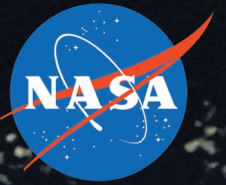


National Aeronautics and Space Administration



Educator Guide

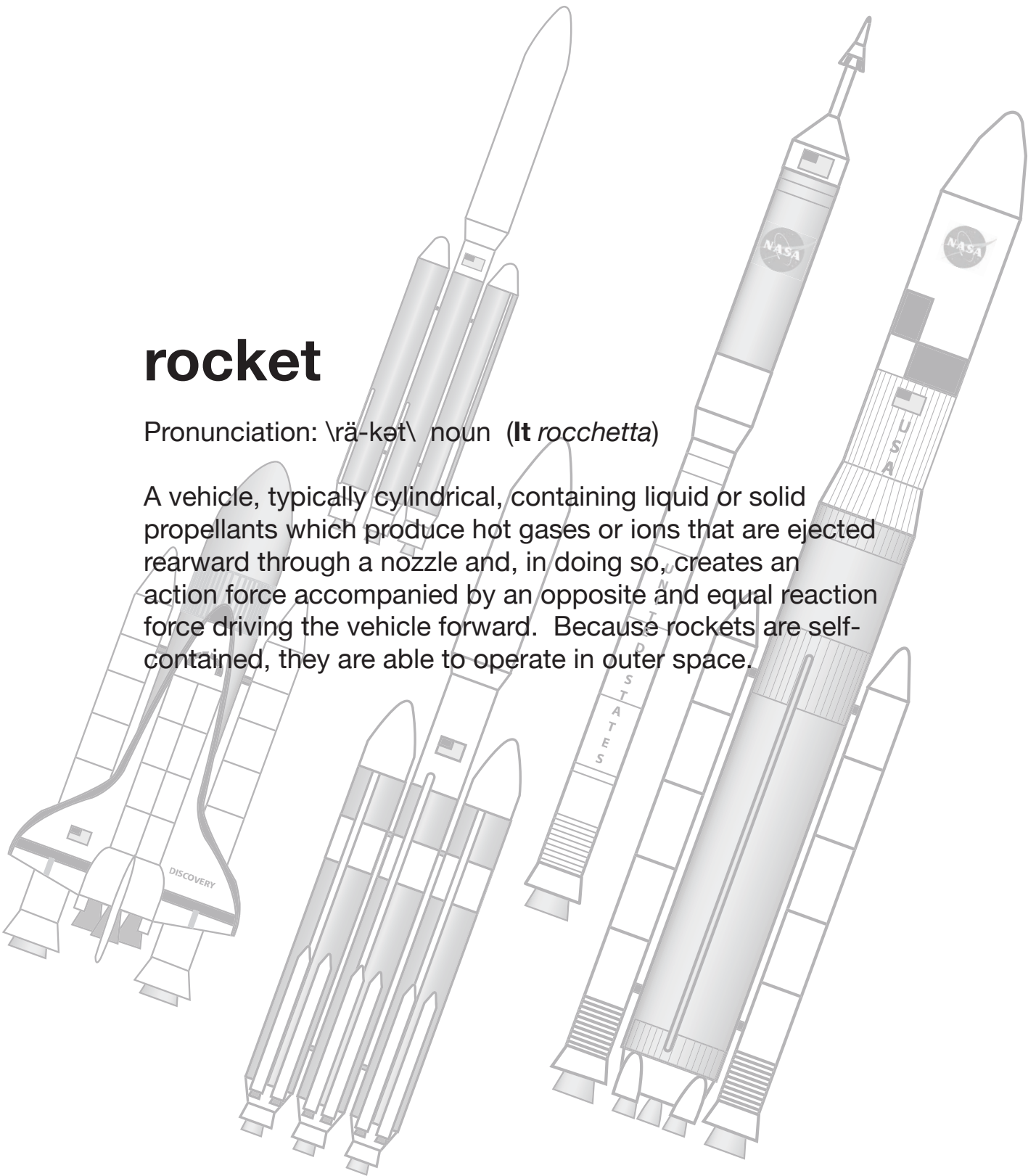
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rockets

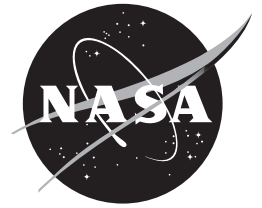
rocket

Pronunciation: \ră-kət\ noun (**It** *rocchetta*)

A vehicle, typically cylindrical, containing liquid or solid propellants which produce hot gases or ions that are ejected rearward through a nozzle and, in doing so, creates an action force accompanied by an opposite and equal reaction force driving the vehicle forward. Because rockets are self-contained, they are able to operate in outer space.



National Aeronautics and Space Administration



ROCKETS

**Educator's Guide with Activities in
Science, Technology, Engineering and Mathematics**

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Acknowledgements

The original *Rockets Teacher Guide* was published by NASA's Education Division in the mid-1990s. It has found widespread use in both formal and informal educational settings because of the exciting nature of the topic and because of its dynamic classroom activities that match and support both national and state education standards for science, mathematics, and technology.

This revision of the guide, by the original authors, updates educators on NASA's 21st Century Space Exploration Policy and the vehicles that will make this vision possible. It builds on classroom experience with the original guide and presents a suite of improved and new activities that prepare students for the future of space exploration.

Many educators and scientists have contributed ideas and content directly and indirectly to this revision. Their assistance is gratefully appreciated.

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Dear Educators:

NASA has embarked on a 21st Century Space Exploration Policy that will establish a permanent human presence on the Moon and carry astronauts to Mars and beyond. The best ideas of our space exploring past are being merged with dreams for the future. It is a wonderful time for you and your students to learn about science, technology, engineering, and mathematics. Rockets will be your vehicle for learning.

The *Rockets Educator Guide* provides you and your students many opportunities. Together, you will examine early rockets and meet thinkers and dreamers. You will learn about rocket science and mathematics and what rocket scientists do. You will see pictures of events and technologies that many of us grew up with - *Sputnik*, *Apollo* and the Moon, and the space shuttle to name a few. You will see what the future of space transportation will look like. You will learn why rockets are the only vehicles we can use to “go where no one has gone before.”

Will your students be a part of this future in space? Will they be the scientists, technicians, engineers, and mathematicians that make dreams of exploring space possible? Yes! This guide will help you prepare them for the wonders that are coming.

Chapters within the guide present the history of rocketry, NASA’s 21st Century Space Exploration Policy, rocketry principles, and practical rocketry. These topics lay the foundation for what follows - a wealth of dynamic rocket science classroom activities that work. The activities focus on Sir Isaac Newton’s laws of motion and how they apply to rockets. They incorporate cooperative learning, problem solving, critical thinking, and hands-on involvement. They support national and state standards for science, mathematics, and technology across many grade levels.

All of the activities are designed with the classroom in mind. They include clear descriptions, background information for the teacher and student, detailed procedures and tips, lists of readily available materials, assessments, questions for discussion, and extensions. The activities are designed to foster excitement and a passion for learning.

The guide is versatile. It has been created as a two to six week classroom unit depending upon the grade level of the students but individual activities can be extracted and used as stand-alone classroom experiences. You will find activity objectives and principles clearly stated along with the vocabulary terms necessary for understanding the principles involved.

The goal of the *Rockets Educator Guide* is to excite young minds. Among your students are future leaders, planners, builders, explorers, settlers, and interplanetary pilots! This guide will help you lay the groundwork for their future in space.

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A Pictorial History of Rockets

The mighty space rockets of today are the result of more than 2,000 years of invention, experimentation, and discovery. First by observation and inspiration and then by methodical research, the foundations for modern rocketry were laid. Humans have traveled into space and walked on the Moon. Soon, we will travel to the Moon to establish a permanent base and later expand the human presence to Mars and beyond. Already, travel to the stars is possible. Robot spacecraft are on their way into interstellar space as you read this. Someday, they will be followed by human explorers.

Often lost in the shadows of time, early rocket pioneers “pushed the envelope” by creating rocket-propelled devices for land, sea, air, and space. When the scientific principles governing motion were discovered, rockets graduated from toys and novelties to serious devices for commerce, war, travel, and research. This work led to many of the most amazing discoveries of our time.

The vignettes that follow provide a small sampling of stories from the history of rockets. They form a rocket time line that includes critical developments and interesting sidelines. In some cases, one story leads to another, and in others, the stories are interesting diversions from the path. They portray the inspirations that ultimately led to us taking our first steps into outer space. The new *Ares* rockets and the rockets that follow owe much of their success to the accomplishments presented here.

Steam, Sparks, Explosions, and Flight

Archytas, 428 to 347 B.C.

Archytas, a Greek philosopher, mathematician, and astronomer was said to have constructed and flown a small bird-shaped device that was propelled by a jet of steam or compressed air. The 'bird' may have been suspended by a wire or mounted at the end of a bar that revolved around some sort of pivot. This was the first reported device to use rocket propulsion.



Hero Engine, c. A.D. 10 to 70

Though not a rocket, the main principle behind rocket (and jet) propulsion was employed in a steam engine invented by Hero of Alexandria. The exact appearance of Hero's engine is not known, but it consisted of some sort of copper vessel heated by a fire beneath. Water in the vessel turned into steam and traveled up two tubes to a hollow sphere that was free to rotate. Two L-shaped tubes from the sphere allowed the steam to escape in jets of gas. The sphere rotated rapidly in the opposite direction of the jets. The Hero engine was seen as an amusing toy, and its potential was not realized for a thousand years.



Chinese Fire Arrows, A.D. 1232

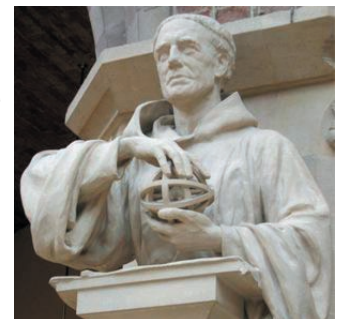
The origins of gunpowder are not clear, but the Chinese reportedly had a rudimentary form of it in the first century, A.D. A mixture of saltpeter, sulfur, and charcoal dust produced colorful sparks and smoke when ignited. The powder was used to make fireworks. Tubes of bamboo and leather, closed off at one end, were packed with gunpowder. Depending upon how the powder was packed and the size of the opening, a fountain of sparks or a bang would result when the powder was ignited. It is likely that some fireworks skittered about because of the thrust produced from the gases escaping the open end. Thus the rocket was born. By 1232, these primitive rockets were attached to arrows and used to repel Mongol invaders in the battle of Kai-keng.



Roger Bacon, c. 1214 to c. 1292

A monk, Bacon wrote about gunpowder in his *The Epistola Fratris R. Baconis, de secretis operibus artis et naturae et nullitate magiae*: "We can, with saltpeter and other substances, compose artificially a fire that can be launched over long distances....By only using a very small quantity of this material much light can be created accompanied by a horrible fracas. It is possible with it to destroy a town or an army...."

Bacon is thought to have developed improved gunpowder formulas that greatly increased the mixture's power.



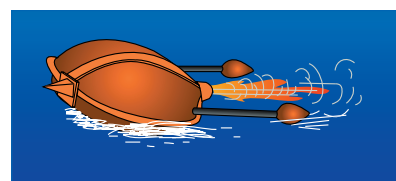
Wan Hu, Sixteenth Century

According to legend Wan Hu, a Chinese stargazer and local official living sometime around the middle of the Ming dynasty, dreamed of spaceflight. He constructed a chair and attached 47 gunpowder rockets to its base. In some versions of the story, his chair also had kite wings. On launch day, 47 assistants rushed up and simultaneously lit the fuses of all the rockets. A huge explosion followed. When the smoke cleared, Wan Hu was gone. Some have suggested Wan Hu actually made it into space, and you can see him as the “Man in the Moon.” Regardless of the actual end, Wan Hu had the right idea—use rockets to travel into space.



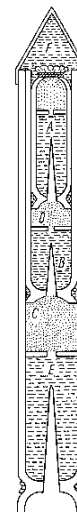
Rockets Go to War

For centuries to come, rockets competed with cannons as the weapon of choice for war. Each technological development moved one or the other system into or out of favor. Cannons were more accurate. Rockets could be fired more quickly. Breech-loading cannons speeded up the firing. Rocket fins increased accuracy. Cannons had greater range. Rockets had greater range. And so on. Invention abounded. Invented by Joanes de Fontana of Italy (1420), a surface-running rocket torpedo was supposed to set enemy ships on fire.



Kazimierz Siemienowicz, c. 1600 to c. 1651

Kazimierz Siemienowicz, a Polish-Lithuanian commander in the Polish Royal Artillery, was an expert in the fields of artillery and rocketry. He wrote a manuscript on rocketry that was partially published before his death. In *Artis Magnae Artilleriae pars prima*, he published a design for multistage rockets that was to become fundamental rocket technology for rockets heading for outer space. Siemienowicz also proposed batteries for military rocket launching and delta-wing stabilizers to replace the guiding rods currently in use with military rockets. It was rumored that Siemienowicz was killed by members of guilds that were opposed to him publishing their secrets, and they hid or destroyed the remaining parts of his manuscript.



The Birth of Rocket Science

Galileo Galilei, 1564 to 1642

In addition to his many other accomplishments, this Italian astronomer and mathematician rekindled the spirit of scientific experimentation and challenged old beliefs relating to mass and gravity. He proved that an object in motion does not need the continuous application of force to keep moving. He called this property of matter, which causes it to resist changes in velocity, “inertia.” Inertia is one of the fundamental properties that Isaac Newton would later incorporate into his laws of motion.



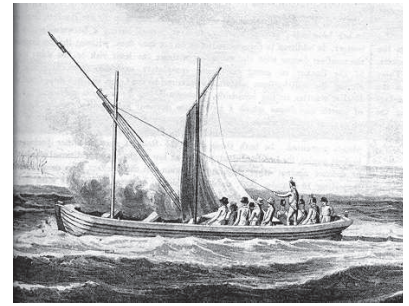
Newton's Laws of Motion, 1642 to 1727

English scientist Sir Isaac Newton condensed all rocket science into three elegant scientific laws. Published in *Philosophiae Naturalis Principia Mathematica* his laws, previously understood intuitively by early rocketeers, provided the foundation for all modern rocket science. (The "Rocket Principles" chapter focuses on these laws and the "Practical Rocketry" chapter demonstrates the applications of these laws.)



Colonel William Congreve, 1772 to 1828

Following stunning rocket barrages against the British by the forces of Tippoo Sultaun of India, William Congreve took charge of British military rocket companies. Some of his designs had operational ranges of 6,000 yards. He created both case-shot rockets that sprayed the enemy with carbine balls and incendiary rockets for burning ships and buildings. He invented launching rockets from ships. The phrase "by the rocket's red glare," coined by Francis Scott Key during the War of 1812, referred to British-launched Congreve rockets.



Jules Verne, 1828 to 1905

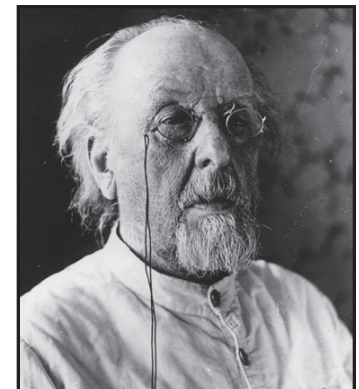
The dream of traveling through space was brought to life by French science fiction writer Jules Verne. In his *De la Terre à la Lune*, Verne used a giant cannon to fire a manned projectile at the Moon. Although not a rocket, the projectile had some interesting parallels with the future Apollo Moon program. It was called the Columbiad and contained a crew of three. It was fired at the Moon from Florida. The *Apollo 11* capsule was named *Columbia*, contained a crew of three, and was launched from Florida. Verne correctly described how the crew would feel "weightless" on their voyage. Of course, the crew would not have survived the initial acceleration of the cannon firing. Nevertheless, Verne, an early space exploration visionary, fired the imaginations of many would-be rocketeers and future astronauts.



Modern Rocket Pioneers

Konstantin E. Tsiolkovski, 1857 to 1935

Konstantin Tsiolkovski was a teacher, theorist, and astronautics pioneer. Son of a Polish forester who emigrated to Russia, he wrote and taught extensively about human space travel and is considered the father of cosmonautics and human spaceflight. Tsiolkovski advocated liquid propellant rocket engines, orbital space stations, solar energy, and colonization of the Solar System. His most famous work, "Research into Interplanetary Space by Means of Rocket Power," was published in 1903, the same year the Wright brothers achieved powered and controlled airplane flight. His rocket equation, based on Newton's second law of motion, relates rocket engine exhaust velocity to the change in velocity of the vehicle itself.



Robert H. Goddard, 1882 to 1945

American college professor and scientist Robert Goddard built and flew the world's first liquid propellant rocket on March 16, 1926. Its flight, though unimpressive (it climbed only 12.5 meters), was the forerunner of the Saturn V Moon rocket 43 years later. At the request of local townsfolk, Goddard moved his experiments from Auburn, Massachusetts, to the deserts around Roswell, New Mexico. There he continued his experiments and developed a gyroscope system to control his rockets in flight, instrumentation payload compartments, and parachute recovery systems. He is often referred to as the "father of modern rocketry."



Hermann Oberth, 1894 to 1989

Hermann Oberth, a Romanian by birth and a naturalized German citizen, became fascinated by the works of Jules Verne and devoted his life to promoting space travel. His dissertation for the University of Heidelberg, rejected for being too speculative, became the basis for his book *Die Rakete zu den Planetenraumen* (By Rocket to Space). The book explained the mathematics of spaceflight and proposed practical rocket designs and space stations. This and other books inspired a generation of rocketeers. Rocket societies sprang up around the world, including the German Verein für Raumschiffahrt (Society for Space Travel) that led to the development of the V2 rocket.



Rocket Experimenters, Early Twentieth Century

In the 1920s and 1930s, leading up to World War II, amateur rocketeers and scientists worldwide attempted to use rockets on airplanes, racing cars, boats, bicycles with wings, throw lines for rescuing sailors from sinking ships, mail delivery vehicles for off-shore islands, and anything else they could dream up. Though there were many failures, experience taught the experimenters how to make their rockets more powerful and more reliable.



World War II

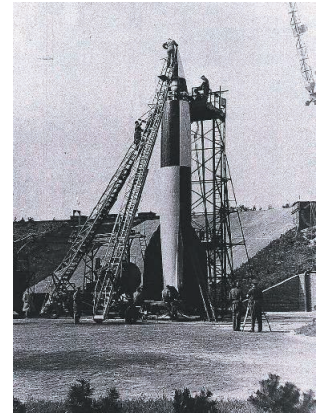
Flying Bombs

The necessities of war led to massive technological improvements in aeronautics and rocketry. Almost overnight, rockets graduated from novelties and dream flying machines to sophisticated weapons of destruction. Rockets propelled nearly unstoppable German fighter planes and Japanese Kamikaze pilots with bombs into ships. War would never be the same again.



Vergeltungswaffe 2 - V2

In the late 1930s, the German Verein für Raumschiffahrt Society for Space Travel evolved into the team that built and flew the most advanced rocket for the time, the V2. On the shores of the Baltic Sea, the team, under the directorship of Wernher von Braun, created a rocket powered by alcohol and liquid oxygen. With a range of 320 kilometers (200 miles) and a maximum altitude of 88 kilometers (55 miles), the V2 could deliver a 1-ton explosive warhead to the heart of London without warning. Thousands of V2s were built, but they entered the war too late to affect the outcome.



The Space Age Begins

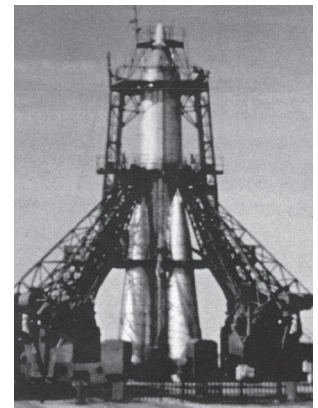
Bumper Project

At the conclusion of the war in Europe, 300 trainloads of V2 rockets and parts were captured and shipped to the United States along with the majority of the principal designers, who decided beforehand to surrender to American troops. The V2 became the basis of the intercontinental ballistic missile development program and led directly to the manned space program. Employing one of the captured V2 rockets with a WAC Corporal rocket (named for the Women's Army Corps) at its top, the initial launch of a "Bumper-WAC" took place on May 13, 1948. During six flights, the largest two-stage rocket launched to date in the United States eventually reached an altitude of almost 400 kilometers (250 miles).



The World's First Artificial Satellite

At the conclusion of World War II, the United States and the Soviet Union engaged in a race for space. The Soviet Union won the first round by launching its *Sputnik I* satellite on October 4, 1957. The satellite had a spherical design with four antenna. It weighed 83.6 kilograms (184.3 pounds). Two months later, the 508.3-kilogram (1,118.26-pound) *Sputnik II* reached space with a living passenger. Laika, a small dog, orbited Earth for a few hours. Although she died in space, she led the way for all humans that followed.



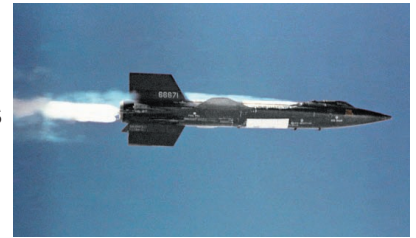
Explorer 1

The United States entered the satellite-launching business on January 31, 1958 with the successful launch of *Explorer 1*. The satellite was launched atop the Juno 1, a modified Jupiter-C booster. Though much smaller than the *Sputniks*, only 13.93 kilograms (30.66 pounds)—*Explorer 1*'s Geiger counter made the first important discovery about the space environment. *Explorer 1* detected around Earth what would later be called the Van Allen Radiation Belts.



X-15

Between 1959 and 1968, the X-15 experimental aircraft flew to the edge of space. In 199 flights, the air-launched rocket plane broke many flight records, including speed (7,274 kph or 4,520 mph) and altitude records (108 kilometers or 67 miles). Test flights established important parameters for attitude control in space and reentry angles. Neil Armstrong, the first American to step on the Moon, was one of twelve X-15 pilots.



Yuri Gagarin Goes Into Orbit

On April 12, 1961, space became the domain of humans with the launch of cosmonaut Yuri Gagarin. His spaceflight lasted 1 hour and 48 minutes. During that time, Gagarin orbited Earth one time inside his *Vostok 1* space capsule, reaching a maximum altitude of 315 kilometers (196 miles). Upon reentry, Gagarin ejected himself from the capsule at an altitude of 6,100 meters (20,000 feet) and parachuted safely to the ground.



Freedom 7

On May 5, 1961, American astronaut Alan Shepherd, Jr., lifted off from Cape Canaveral, Florida, inside his *Freedom 7* Mercury space capsule, which sat atop a Redstone rocket. The rocket did not have enough power to send the craft into orbit, and Shepherd made a suborbital flight reaching 187 kilometers (116 miles) before his capsule returned to Earth in an ocean splashdown 15 minutes 22 seconds later.



Moon Rocket

Just days after Alan Shepard's flight, President John F. Kennedy addressed a joint session of Congress and challenged America to send an American to the Moon and return him safely before the end of the decade. Although it was a shockingly bold announcement, some of the steps to accomplish this mission were already underway. NASA had begun work on components of a rocket capable of a round trip lunar flight. By the next year, the rocket was named the Saturn V. It would be 110.6 meters or 363 feet tall, dwarfing all previous rockets. The Saturn V would consist of three stages, a capsule with a small propulsion unit for the return trip, and a two-stage lunar lander.



Glenn Orbits Earth

On February 20, 1962, riding on a more powerful missile, the Atlas, astronaut John H. Glenn, Jr., became the first American to go into orbit. Glenn's flight achieved parity with the Soviet program. Glenn orbited Earth three times for a total of 4 hours and 55 minutes in space. A sensor switch led to an early return. The sensor indicated that the Mercury capsule heat shield was loose, but the shield was later determined to be firmly in place during flight. The sensor was faulty. The last of the six Mercury flights took place on May 15, 1963, with astronaut Gordon Cooper remaining in space for nearly a day and a half.



Preparing for the Moon

Project Gemini followed the Mercury missions. The *Gemini* space capsule, riding on top of a Titan missile, contained two astronauts. During missions lasting up to 14 days, *Gemini* astronauts pioneered spacewalking, spacecraft rendezvous, and docking procedures. Important spacecraft systems, needed for the coming Moon flights, were evaluated. Ten *Gemini* missions were flown during 1965 and 1966. The Titan rocket, initially created as an intercontinental ballistic missile, went on to carry the *Viking* spacecraft to Mars and the *Voyager* spacecraft to the outer solar system in the 1970s.



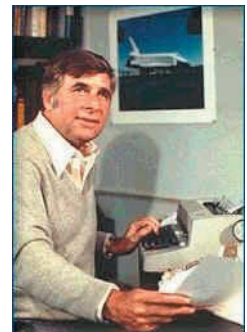
Dr. Wernher von Braun

One of the leading figures in the development of pre-war Germany's rocket program and the development of the V2 missile, von Braun (1912-1977) became a leading proponent of America's space program. He entered the United States after the war and became a naturalized citizen. He worked on the development of intercontinental ballistic missiles and led the development team that launched *Explorer 1*. Dr. von Braun was the chief architect and engineer of the Saturn V Moon rocket. His popular writings and collaboration with Disney on a "Tomorrowland" TV series did much to inspire the next generation of rocket scientists and astronauts.



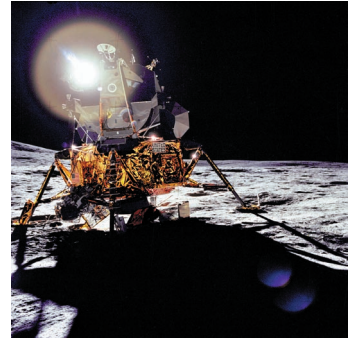
Gene Roddenberry

Gene Roddenberry (1921-1991), a distinguished World War II bomber pilot and commercial pilot, began his writing career penning stories about flying. He began writing for television and developed a concept for a "western" series set among the stars. For three years (1966-1968), the *Star Trek* series explored a wide range of scientific and social issues as humans traveled across the galaxy. The series became so popular that the first space shuttle orbiter test vehicle was named *Enterprise* after the star ship *Enterprise*. The original show spawned several companion series and a string of movies. Roddenberry, a visionary, inspired a generation of space travelers.



“One Small Step...”

At 10:56 p.m. EDT, July 20, 1969, American astronaut Neil Armstrong set foot on the Moon. It was the first time in history that humans had touched another world. He was followed to the surface by Edwin “Buzz” Aldrin, Jr. A third astronaut, Michael Collins, remained in lunar orbit in the *Apollo* capsule. The *Apollo 11* mission was the first of six Moon landings extending to the end of 1972. The astronauts’ spacecraft, the lunar module, consisted of a descent and an ascent stage. The descent stage had four legs and a powerful rocket engine to slow the craft for landing on the Moon. After surface explorations, the upper part of the lander lifted off, using its own rocket engine, and rendezvoused with the *Apollo* capsule for the return to Earth.



Skylab

Using a modified third stage of the Saturn V rocket, the United States finally launched its first space station, called *Skylab*, into Earth orbit in 1973. Rather than engines and fuel tanks, the interior of the third stage was fitted with living quarters and laboratories for three astronauts on extended stays in space. Solar panels provided electric power. Due to a problem during launch, one of the large panels was lost. Nevertheless, three crews of astronauts called *Skylab* home until 1974. The last crew remained in space 84 days.



Smaller Saturn

The Saturn V rocket was capable of launching 117,900 kilograms (260,000 pounds) into low Earth orbit and 40,800 kilograms (90,000 pounds) to the Moon. For some *Apollo* missions, though, a smaller Saturn was called for. The Saturn IB was 68 meters (224 feet) tall and required a scaffold platform nicknamed the “milk stool” to be placed on the pad designed for Saturn V rockets. This enabled the Saturn IB to match up with swing arms from the launch structure. The Saturn IB carried some of the early *Apollo* test missions, the three crews for *Skylab*, and the American crew for the 1975 historic *Apollo-Soyuz* mission, linking astronauts and cosmonauts in orbit.



Orbits and Probes

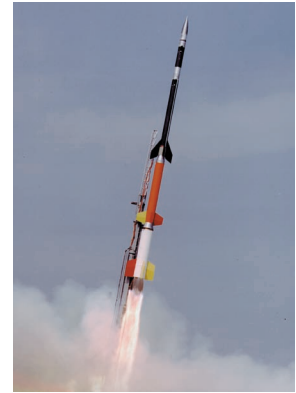
Deep Space

The Titan rockets (1959–2005), used for launching the *Gemini* missions, found wide use in launching unmanned payloads. Upgraded versions of Titans lofted heavy satellites into Earth orbit and propelled important spacecraft to other planets. The *Viking* missions to Mars and the *Voyager* missions to the outer planets and interstellar space are among its credits.



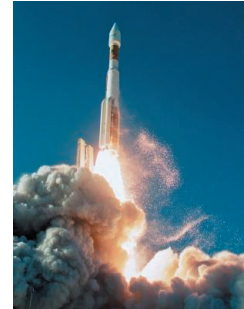
Sounding Rockets

Although rockets have generally gotten larger and more powerful, there are many reasons for flying smaller rockets. The Canadian-designed Black Brant sounding rocket has been flying since 1961 and has successfully completed over 800 flights carrying small payloads such as cameras, instruments, and microgravity experiments. The Black Brant's reliability and low cost has made it a favorite of researchers. The biggest multistage Black Brants have payload capacities of about 100 kilograms (220 pounds) and can reach altitudes of up to 900 kilometers (560 miles).



Ariane

Beginning service in 1979 and continuing today with upgraded versions, the European Space Agency's Ariane rocket has specialized in launching communications satellites to high geostationary orbits. Ariane is launched from French Guiana on the eastern coast of South America to take maximum advantage of Earth's rotational velocity in boosting the rocket into orbit.



Delta Family

With roots going back to the early 1960s, the American Delta rocket is one of the most versatile of the commercial and military payload launch rockets. Delta has many configurations, including multiple stages and heavy-lift strap-on boosters that increase payload capacity to high orbits. The Delta family has logged more than 325 launches, with a success rate exceeding 95 percent.



Atlas

Like the Delta rocket, the Atlas has deep roots. Now in its fifth major configuration, the Atlas was created as a missile in the 1950s. It was adapted to carry John Glenn and three other Mercury astronauts to space and has since been used for many commercial, scientific, and military satellite launches and interplanetary missions. The Atlas V rocket (shown) is the latest in the series.



Pegasus

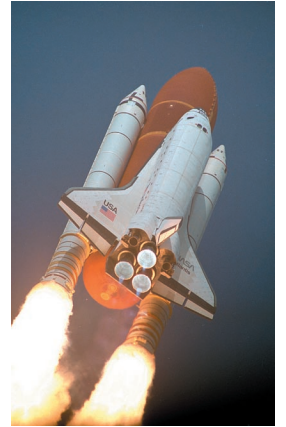
Like the mythological creature, the Pegasus launch vehicle is winged. Lifted to about 12,000 meters it is then air-launched from under the wing of a carrier aircraft. This arrangement keeps launch costs low for small orbital payloads.



The Space Shuttle and International Space Station (ISS) Era

A New Kind of Launch Vehicle

At the completion of the Apollo program, American rocket scientists began building a new system for carrying crews and payloads into low Earth orbit, the space shuttle transportation system. A four-part vehicle arranged around a central external tank, the shuttle system contains liquid hydrogen and oxygen that feeds the main engines of the airplane-like orbiter. On the sides of the tank are two solid rocket boosters. Partway into orbit, the spent boosters separate for return to Earth by parachute for ocean recovery and reuse. The orbiter and tank continue towards orbit. When exhausted, the tank drops and disintegrates on reentry. The orbiter continues on the power of its orbital maneuvering system engines. Once in orbit, payload bay doors open to expose the payload — science laboratories, space probes, telescopes, or Earth-sensing systems. At the end of the mission, the orbiter reenters Earth's atmosphere and glides to an unpowered landing on a runway. The first space shuttle flight took place on April 20, 1981.



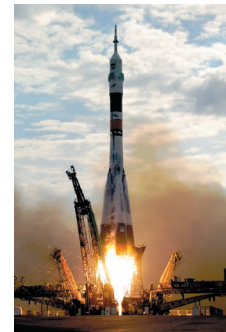
Serving the ISS

The first flight of the space shuttle took place in 1981. More than 120 missions have been completed. Since 1998, the principal mission of the space shuttle has been to ferry components for construction, crews, supplies, and experiments to the ISS. When the station is completed, the space shuttle will be retired.



International Partnerships

In addition to the United States, fifteen other nations support the ISS in a variety of ways. Russia, a major participant, uses its *Soyuz* rocket to launch crews of three to the station and to launch its *Progress* robotic supply spacecraft. Other partners include Canada, Belgium, Denmark, France, Germany, Italy, The Netherlands, Norway, Spain, Sweden, Switzerland, The United Kingdom, Japan, and Brazil.



Space Tourism

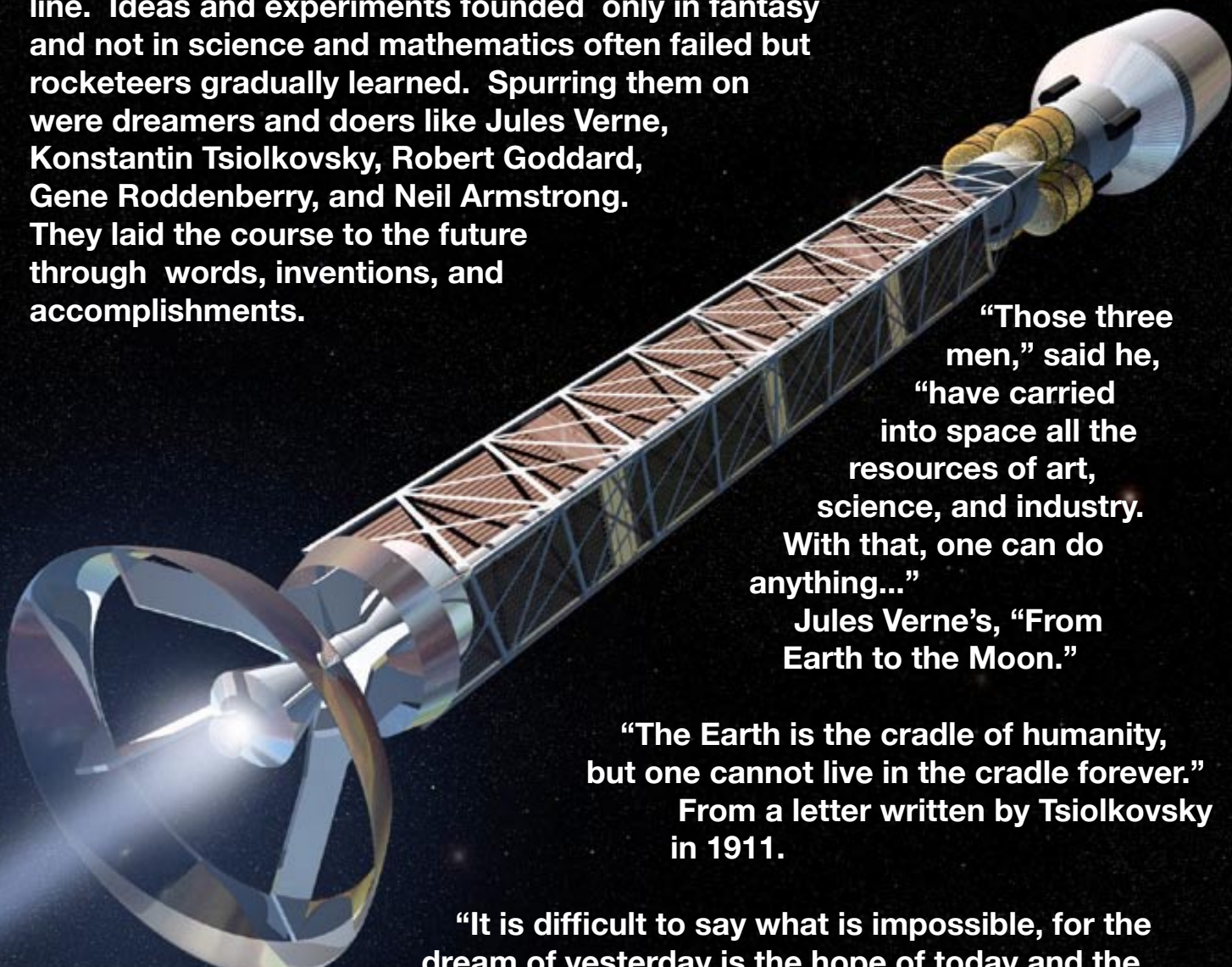
SpaceShipOne

Private companies worldwide are entering the rocket business. They envision a demand for suborbital and orbital space tourism. Many designs are being tested. Some have actually flown. On October 4, 2004, SpaceShipOne, built by Scaled Composites of California, became the first private space vehicle to climb above an altitude of 100 kilometers (62 miles) twice in a fourteen-day period. SpaceShipOne, air launched by a mother ship, crossed the acknowledged boundary of Earth's atmosphere and space.



And Beyond?

Beginning more than 2,000 years ago, rockets evolved from toys into complex machines capable of amazing flights. Rockets are still the only means of travel to and through space. Their evolution depended upon discovery, necessity, and experimentation. The development of rockets did not move in a straight line. Ideas and experiments founded only in fantasy and not in science and mathematics often failed but rocketeers gradually learned. Spurring them on were dreamers and doers like Jules Verne, Konstantin Tsiolkovsky, Robert Goddard, Gene Roddenberry, and Neil Armstrong. They laid the course to the future through words, inventions, and accomplishments.



“Those three men,” said he, “have carried into space all the resources of art, science, and industry. With that, one can do anything...”
Jules Verne’s, “From Earth to the Moon.”

“The Earth is the cradle of humanity, but one cannot live in the cradle forever.”
From a letter written by Tsiolkovsky in 1911.

“It is difficult to say what is impossible, for the dream of yesterday is the hope of today and the reality of tomorrow.”

Goddard’s high school graduation oration, “On Taking Things for Granted”, June 1904

“...to seek out new life, new civilizations. To boldly go where no man has gone before.”

Star Trek television series opening theme.

“ That’s one step for (a) man; one giant leap for mankind.”
Neil Armstrong

What Comes Next

An entire generation has grown up with the space shuttle. Under development for most of the 1970s, the space shuttle *Columbia* made its maiden flight on April 12, 1981. Since then, the shuttle has flown more than 120 missions and carried more astronauts into space than all other rockets combined. It has deployed satellites, sent space probes throughout the solar system, and lofted science laboratories and many of the major components of the ISS.

The space shuttle is a complex and versatile space launch system, but its flights will end when the ISS is fully assembled. What comes next?

In the decades of exploration that followed its creation in 1958, NASA expanded our perspective of the universe and humanity's place within it. Many important lessons have been learned, some of them the hard way. As we move into the second century of human flight, it is time to improve our ability to travel and live in space. For its second 50 years, NASA will pursue a new era of space exploration.



Ares I and V, to Earth orbit, the Moon, and Mars.

Human Space Flight Objectives for the Second Fifty Years:

- Implement a sustainable and affordable human and robotic exploration program throughout the solar system and beyond.
- Build a permanent outpost on the Moon and prepare for human exploration of Mars.
- Develop the innovative technologies, knowledge base, and infrastructure needed to support and sustain human exploration.
- Promote international and commercial participation leading to furthering U. S. scientific, security, and economic interests.

Essential to NASA's plans is a new and versatile space launch system to replace the space shuttle. Capitalizing on NASA's multi-decade experience, the new system will combine the best of the past with the best of the present and future. It is called the Constellation program and will consist of two launch vehicles, each with different configurations to meet varying mission and cost requirements.

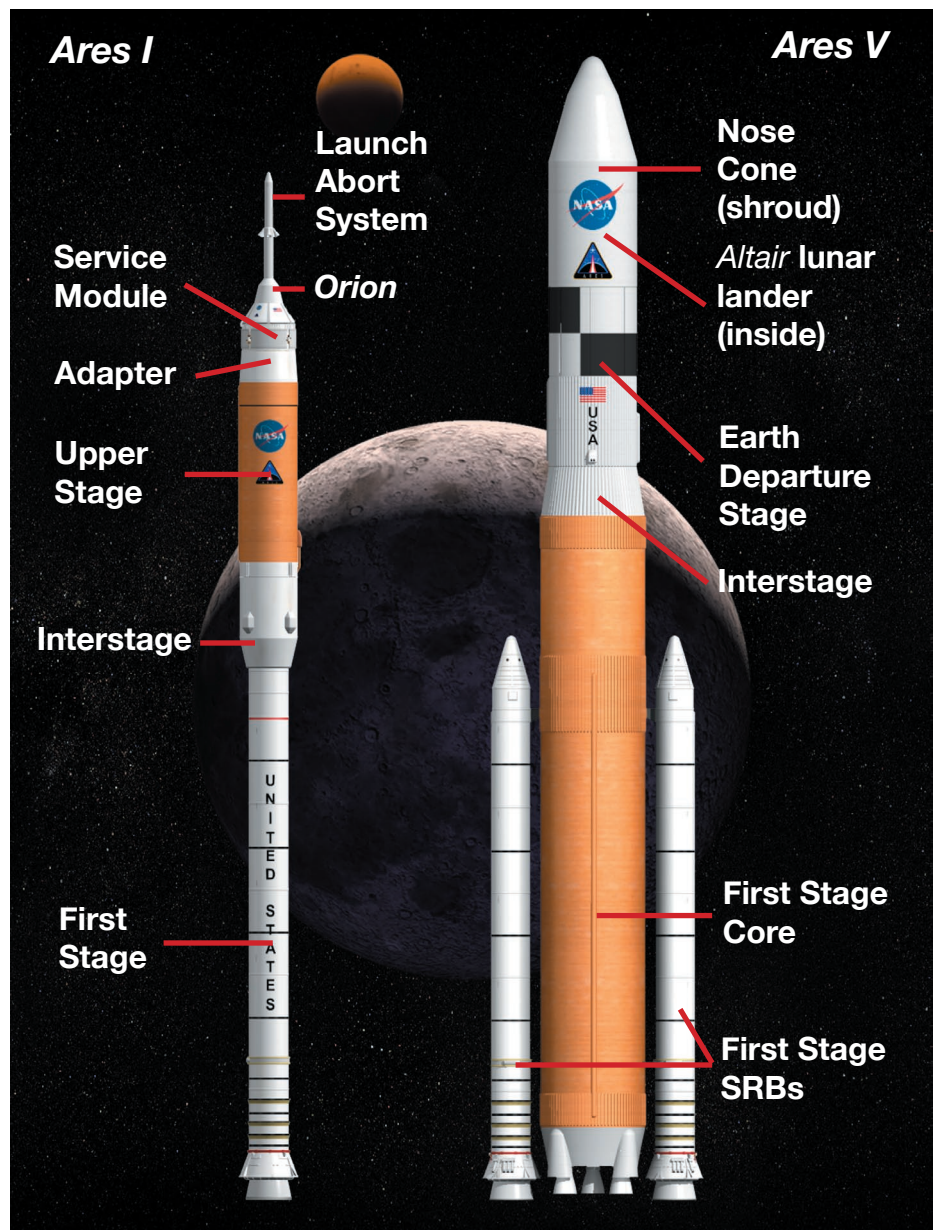
For maximum crew safety, the Constellation program separates human crews and payloads. The crew launch vehicle is called the *Ares I* and it is capped with the *Orion* crew exploration vehicle. The heavy-lift unmanned payload vehicle is the *Ares V*.

Ares I Crew Launch Vehicle

The *Ares* rockets take their name from the Greek word for the planet Mars. *Ares I* is an in-line, two-stage rocket with a crew capsule on top. The first stage is derived from the space shuttle's solid rocket boosters. The space shuttle uses two boosters, each consisting of four segments joined end-to-

end. The *Ares I* first stage is a single booster with five segments. Like the space shuttle's boosters, it will be recoverable from the ocean for reuse.

Resting on top of the first stage will be a interstage with mechanisms and small rocket motors used for separating the first and upper stages. The upper stage, resembling the external tank of the space shuttle, is a new vehicle with a liquid hydrogen liquid oxygen J-2X engine at its base. Derived from the Saturn rockets of the *Apollo* era, the J-2X engine is an upgraded version of the J-2 engines used for the second and third stages of the Saturn V. The J-2X will consume liquid hydrogen and liquid oxygen propellants contained in large tanks within the upper stage.

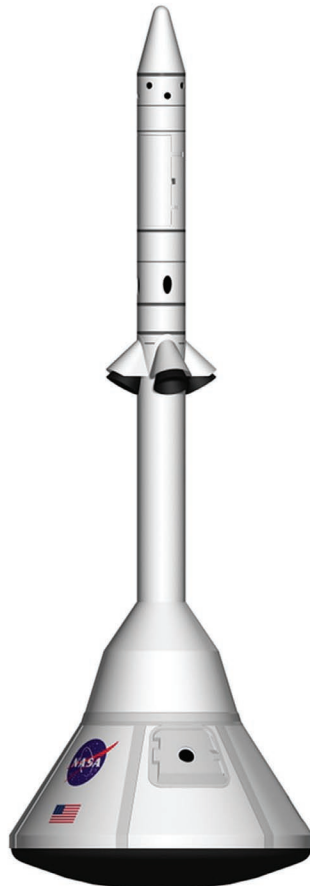


.On top of the second stage will be an instrumented adapter ring that will connect to the *Orion* crew exploration vehicle.

Orion will consist of two modules, similar to but larger than the crew modules used for *Apollo*. A service module, containing propellants for a single rocket engine and power systems for the crew module, will perch directly on top of the upper stage adapter. The crew module, a cone-shaped capsule, will be mounted on top of the service module. It will be large enough to carry six astronauts to the ISS or four astronauts to the Moon. On lunar missions, the crew of *Orion* will rendezvous with a lunar landing craft launched into Earth orbit by Constellation's cargo vehicle, *Ares V*.

Lastly, a thick, pencil-shaped launch abort system attaches directly to the apex of the crew module. The abort system has a cluster of small rocket engines angled outward from the capsule below. The abort system enhances crew safety during the launch phase.

In the event of an emergency, its rockets will pull the *Orion* away from the *Ares I* stack so that the capsule can parachute safely into the ocean. When *Orion* is successfully launched, the launch abort system will be jettisoned. Another significant safety improvement of the *Orion* design is the placement of the capsule above the *Ares I* upper stage. *Orion* will be out of harm's way from colliding with any ice or insulation material that might vibrate loose and fall during launch.



Ares I on the launch pad.

***Ares V* Cargo Launch Vehicle**

Ares V will become NASA's primary heavy-lift cargo launch vehicle. Like *Ares I*, it will be derived from earlier launch systems and will consist of two stages. The first stage will be assembled around a cylindrical core vehicle containing liquid hydrogen and liquid oxygen. The core design is based on proven technology for the Saturn V rocket. At the base of the core stage will be five RS-68 engines upgraded from engines currently used in the Delta IV rocket. Flanking the core will be two five-segment solid rocket boosters.

For lunar missions, an Earth departure stage (EDS) will be mounted on top of the core stage adapter rings. The EDS, propelled by liquid hydrogen and oxygen, will employ a J-2X engine.

Above the EDS and covered by a nose cone shroud will be the *Altair* lunar lander. The shroud will be jettisoned once the lander is in orbit, exposing the lander and its docking adapter to space.



Ares V ready for flight.

ISS Missions

For missions to the ISS, only the *Ares I* rocket will be flown. Up to six astronauts will ride in the *Orion* capsule. The *Ares I* launch will be carefully timed to make sure *Orion* arrives in orbit in a favorable position to rendezvous with the station. Using the engine on the service module, the crew will approach the station. Small clusters of attitude control rockets, along the outside of the service module, will permit minor velocity changes and adjustments in the direction (attitude) *Orion* points. Slowly moving forward, the docking adapter mounted in the apex of the *Orion* cone is pushed onto and locked to the matching adapter on the station. Airlock doors open, and the crew transfers into the station along with supplies.

Orion will have the ability to remain docked to the ISS for six months at a time. It will serve as a “lifeboat” for emergency evacuation of station crews. *Orion* will also be able to deliver large quantities of supplies to the station in an automatic, unpiloted flight mode.



Orion approaching the International Space Station.

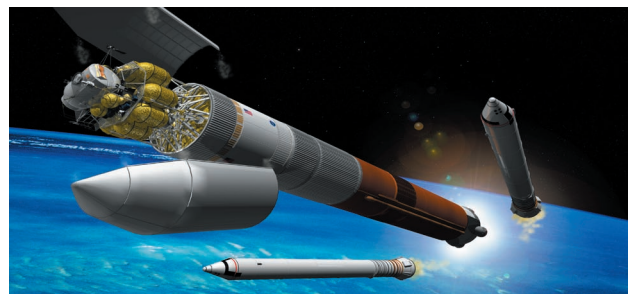
To The Moon

For missions to the Moon, both *Ares I* and *Ares V* will be deployed. In orbit, the crew of *Orion* will begin maneuvers for rendezvous. *Orion* docks with the *Altair* lunar lander mounted on the forward end of the EDS. Once a hard dock is achieved, an interconnecting airlock door is opened, and the crew can pass from *Orion* into the lander and back again.

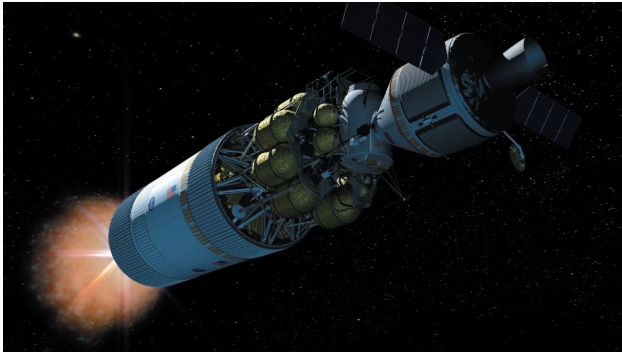
When ready, the EDS fires its engine and sends *Orion* and the lander towards the Moon. At this point, the EDS will have completed its mission. It will leave *Orion* and the lander and propel itself out of the way into a long-period solar orbit.

For the next three days, *Orion* and lander will coast to the Moon. The crew will rotate the combined vehicle so that the engine of the lander is aimed in the direction of the Moon.

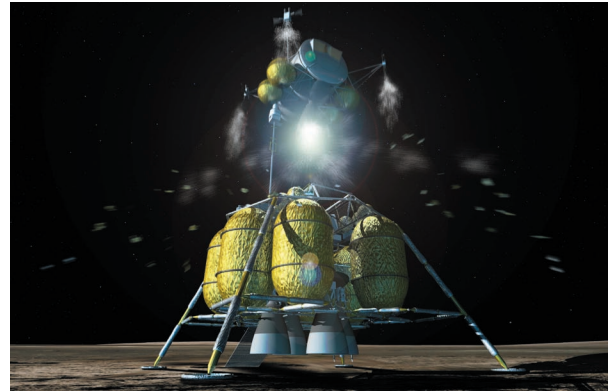
The *Altair* lunar lander will be functionally similar to the landing vehicles used for the Apollo Moon landings. It will consist of two stages. The descent stage has four landing pod legs that will unfold and a large landing



Ares V lifts the Earth departure stage and *Altair* lunar lander to orbit.



The EDS propels *Orion* and the *Altair* lunar lander to the Moon.



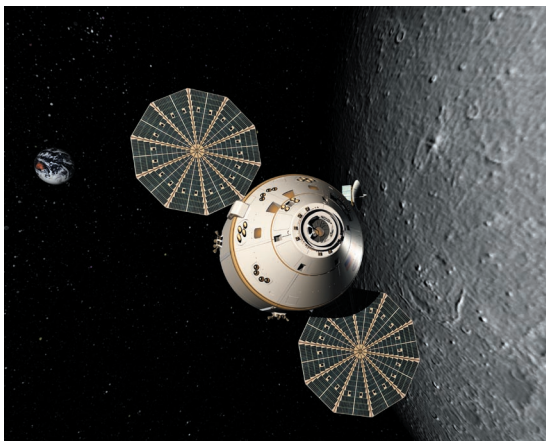
The surface crew returns to orbit in the ascent stage of *Altair*.

engine. The four crew members enter *Altair* for the trip to the lunar surface. *Orion* will remain in orbit, functioning in automatic mode.

The engine fires in a retrograde direction (reverse to the direction it is moving) to slow for landing. During the descent, clusters of small rocket engines on the ascent module fire as needed for attitude control.

Following surface operations (sample collections, automatic experiment deployment,

be jettisoned, and the blunt heat shield side of the *Orion* capsule will be aimed towards Earth's atmosphere. Following intense heating of the shield, small drogue parachutes will be



Orion in lunar orbit while the landing crew explores the Moon's surface below.



Orion reenters Earth's atmosphere.

exploration, etc.), the surface crew will board the ascent stage and fire its engine to return to lunar orbit. The descent stage will be left behind. Following docking with *Orion* and crew transfer, the ascent stage will be jettisoned to crash on the Moon.

Using the engine of the *Orion* service module, the crew will begin the voyage home. Near Earth, the service module will

deployed from the capsule to stabilize its fall. Three main parachutes will then open, and the capsule will make a water landing.



Orion's main chutes bring the capsule down for a soft landing.



Mars and Beyond

The Constellation program will support NASA's exploration programs for decades to come. The first flights of *Ares I* will take place around 2015, and the first return missions to the Moon will take place after 2020. Later, missions to the planet Mars will be mounted. The *Ares V* will make several flights to bring components of the Martian spacecraft up to orbit for assembly. The Mars crew will ride an *Orion* capsule to rendezvous with the completed spacecraft. Upon return from Mars two years later, an *Orion* capsule will be waiting in orbit to carry the crew back to Earth.

How Rockets Work

Whether flying a small model rocket or launching a giant space shuttle into space, the principles of how rockets work are exactly the same. Understanding and applying these principles means mission success.

In the early days of rocketry, the flight of a fire arrow or other rocket device was largely a matter of chance. It might fly; it might skitter about, shooting sparks and smoke; or it might explode. Through centuries of trial and error, rockets became more reliable. However, real advancements in rocketry depended upon a scientific and mathematical understanding of motion. That came in the seventeenth century with the works of scientists such as Galileo and Isaac Newton.

Galileo conducted a wide range of experiments involving motion. Through studies of inclined planes, Galileo concluded that moving objects did not need the continuous application of force (in the absence of friction and drag) to keep moving. Galileo discovered the principle of *inertia*, that all matter, because of its mass, resists changes in motion. The more mass, the more resistance.

Isaac Newton, born the year Galileo died, advanced Galileo's discoveries and those of others by proposing three basic laws of motion. These laws are the foundation of all rocket science. Understand the laws and you know just about everything you need to build successful rockets. Apply the laws and you become a "rocket scientist."

Newton's Laws of Motion

In his master work entitled *Philosophia Naturalis Principia Mathematica* (usually referred to as *Principia*), Isaac Newton stated his laws of motion. For the most part, the laws were known intuitively by rocketeers, but their statement in clear form elevated rocketry to a science. Practical application of Newton's laws makes the difference between failure and success. The laws relate force and direction to all forms of motion.

In simple language, Newton's Laws of Motion:

First Law

Objects at rest remain at rest and objects in motion remain in motion in a straight line unless acted upon by an unbalanced force.

Second Law

Force equals mass times acceleration (or $f = ma$).

Third Law

For every action there is an equal and opposite reaction.

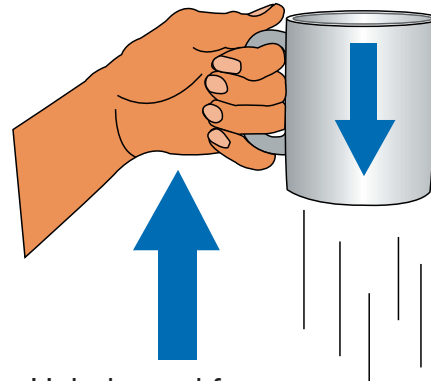
Before looking at each of these laws in detail, a few terms should be explained.

Rest and *Motion*, as they are used in the first law, can be confusing. Both terms are relative. They mean rest or motion in relation to surroundings. You are at rest when sitting in a chair. It doesn't matter if the chair is in the cabin of a jet plane on a cross-country flight. You are still considered to be at rest because the airplane cabin is moving along with you. If you get up from your seat on the airplane and walk down the aisle, you are in relative motion because you are changing your position inside the cabin.

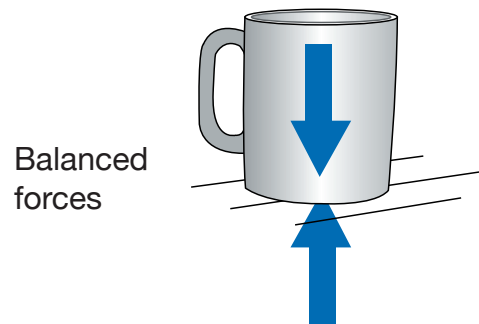
Force is a push or a pull exerted on an object. Force can be exerted in many ways, such as muscle power, movement of air, and electromagnetism, to name a few. In the case of rockets, force is usually exerted by burning rocket propellants that expand explosively.

Unbalanced Force refers to the sum total or net force exerted on an object. The forces on a coffee cup sitting on a desk, for example, are in balance. Gravity is exerting a downward force on the cup. At the same time, the structure of the desk exerts an upward force, preventing the cup from falling. The two forces are in balance.

Reach over and pick up the cup. In doing so, you unbalance the forces on the cup. The weight you feel is the force of gravity acting on the mass of the cup. To move the cup upward, you have to exert a force greater than the force of gravity. If you hold the cup steady, the force of gravity and the muscle force you are exerting are in balance.



Unbalanced force

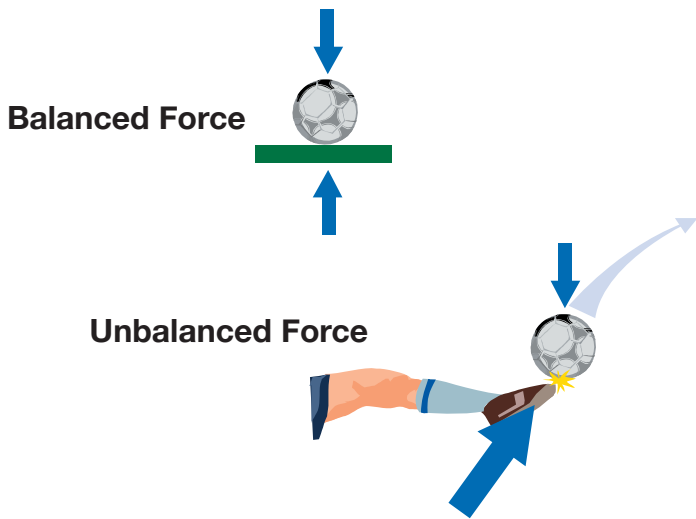


Balanced forces

Unbalanced force also refers to other motions. The forces on a soccer ball at rest on the playing field are balanced. Give the ball a good kick, and the forces become unbalanced. Gradually, air drag (a force) slows the ball, and gravity causes it to bounce on the field. When the ball stops bouncing and rolling, the forces are in balance again.

Take the soccer ball into deep space, far away from any star or other significant gravitational field, and give it a kick. The kick is an unbalanced force exerted on the ball that gets it moving. Once the ball is no longer in contact with the foot, the forces on the ball become balanced again, and the ball will travel in a straight line forever.

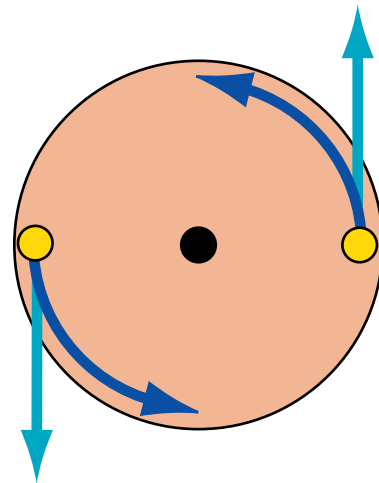
How can you tell if forces are balanced or unbalanced? If the soccer ball is at rest,



the forces are balanced. If the ball is moving at a constant speed and in a straight line, the forces are balanced. If the ball is accelerating or changing its direction, the forces are unbalanced.

Mass is the amount of matter contained in an object. The object does not have to be solid. It could be the amount of air contained in a balloon or the amount of water in a glass. The important thing about mass is that unless you alter it in some way, it remains the same whether the object is on Earth, in Earth orbit, or on the Moon. Mass just refers to the quantity of matter contained in the object. (Mass and weight are often confused. They are not the same thing. Weight is a force and is the product of mass times the acceleration of gravity.)

Acceleration relates to motion. It means a change in motion. Usually, change refers to increasing speed, like what occurs when you step on the accelerator pedal of a car. Acceleration also means changing direction.



Top view of two riders on a carousel. The carousel platform exerts unbalanced forces on the riders, preventing them from going in straight lines. Instead, the platform continually accelerates the riders in a counterclockwise direction.

This is what happens on a carousel. Even though the carousel is turning at a constant rate, the continual change in direction of the horses and riders (circular motion) is an acceleration.

Action is the result of a force. A cannon fires, and the cannon ball flies through the air. The movement of the cannon ball is an action. Release air from an inflated balloon. The air shoots out the nozzle. That is also an action. Step off a boat onto a pier. That, too, is an action.

Reaction is related to action. When the cannon fires, and the cannon ball flies through the air, the cannon itself recoils backward. That is a reaction. When the air rushes out of the balloon, the balloon shoots the other way, another reaction. Stepping off a boat onto to a pier causes a reaction. Unless the boat is held in some way, it moves in the opposite direction. (Note: The boat example is a great demonstration of the action/reaction principle, providing you are not the one stepping off the boat!)

Newton's First Law

This law is sometimes referred to as Galileo's law of inertia because Galileo discovered the principle of inertia. This law simply points

out that an object at rest, such as a rocket on a launch pad, needs the exertion of an unbalanced force to cause it to lift off. The amount of the thrust (force) produced by the rocket engines has to be greater than the force of gravity holding it down. As long as the thrust of the engines continues, the rocket accelerates. When the rocket runs out of propellant, the forces become unbalanced again. This time, gravity takes over and causes the rocket to fall back to Earth. Following its “landing,” the rocket is at rest again, and the forces are in balance.

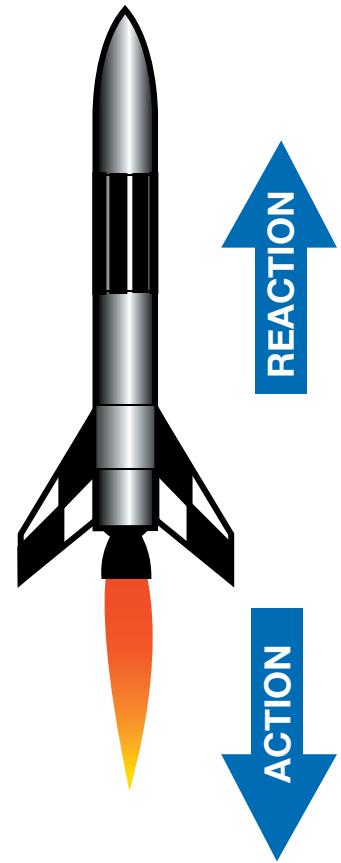
There is one very interesting part of this law that has enormous implications for spaceflight. When a rocket reaches space, atmospheric drag (friction) is greatly reduced or eliminated. Within the atmosphere, drag is an important unbalancing force. That force is virtually absent in space. A rocket traveling away from Earth at a speed greater than 11.186 kilometers per second (6.95 miles per second) or 40,270 kilometers per hour (25,023 mph) will eventually escape Earth’s gravity. It will slow down, but Earth’s gravity will never slow it down enough to cause it to fall back to Earth. Ultimately, the rocket (actually its payload) will travel to the stars. No additional rocket thrust will be needed. Its inertia will cause it to continue to travel outward. Four spacecraft are actually doing that as you read this. *Pioneers 10 and 11* and *Voyagers 1 and 2* are on journeys to the stars!

Newton’s Third Law

(It is useful to jump to the third law and come back to the second law later.) This is the law of motion with which many people are familiar. It is the principle of action and reaction. In the case of rockets, the action is the force produced by the expulsion of gas, smoke, and flames from the nozzle end of a rocket engine. The reaction force propels the rocket in the opposite direction.

When a rocket lifts off, the combustion products from the burning propellants accelerate rapidly out of the engine. The rocket, on the other hand, slowly accelerates

skyward. It would appear that something is wrong here if the action and reaction are supposed to be equal. They are equal, but the mass of the gas, smoke, and flames being propelled by the engine is much less than the mass of the rocket being propelled in the opposite direction. Even though the force is equal on both, the effects are different. Newton’s first law, the law of inertia, explains why. The law states that it takes a force to change the motion of an object. The greater the mass, the greater the force required to move it.



Newton’s Second Law

The second law relates force, acceleration, and mass. The law is often written as the equation:

$$f = m a$$

The force or thrust produced by a rocket engine is directly proportional to the mass of the gas and particles produced by burning rocket propellant times the acceleration of those combustion products out the back of the engine. This law only applies to what is actually traveling out of the engine at the moment and not the mass of the rocket propellant contained in the rocket that will be consumed later.

The implication of this law for rocketry is that the more propellant (m) you consume at any moment and the greater the acceleration (a) of the combustion products out of the nozzle, the greater the thrust (f).

A Taste of Real Rocket Science

Naturally, launching rockets into space is more complicated than Newton's laws of motion imply. Designing rockets that can actually lift off Earth and reach orbital velocities or interplanetary space is an extremely complicated process. Newton's laws are the beginning, but many other things come into play. For example, outside or ambient air pressure plays an important role while the rocket is still in the atmosphere. The internal pressure produced by burning rocket propellants inside the rocket engine combustion chamber has to be greater than the outside pressure to escape through the engine nozzle. In a sense, the outside air is like a cork in the engine. It takes some of the pressure generated inside the engine just to exceed the ambient outside pressure. Consequently, the velocity of combustion products passing through the opening or throat of the nozzle is reduced. The good news is that as the rocket climbs into space, the ambient pressure becomes less and less as the atmosphere thins and the engine thrust increases.

Another important factor is the changing mass of the rocket. As the rocket is gaining thrust as it accelerates upward due to outside pressure changes, it is also getting a boost due to its changing mass. Every bit of rocket propellant burned has mass. As the combustion products are ejected by the engine, the total mass of the vehicle lessens. As it does its inertia, or resistance to change in motion, becomes less. As a result, upward acceleration of the rocket increases.

In practical terms, Newton's second law can be rewritten as this:

$$f = m_{exit} V_{exit} + (p_{exit} - p_{ambient}) A_{exit}$$

("A" refers to the area of the engine throat.)

When the rocket reaches space, and the exit pressure minus the ambient pressure becomes zero, the equation becomes:

$$f = m_{exit} V_{exit}$$

In real rocket science, many other things also come into play.

- Even with a low acceleration, the rocket will gain speed over time because acceleration accumulates.
- Not all rocket propellants are alike. Some produce much greater thrust than others because of their burning rate and mass. It would seem obvious that rocket scientists would always choose the more energetic propellants. Not so. Each choice a rocket scientist makes comes with a cost. Liquid hydrogen and liquid oxygen are very energetic when burned, but they both have to be kept chilled to very low temperatures. Furthermore, their mass is low, and very big tanks are needed to contain enough propellant to do the job.

In Conclusion...

Newton's laws of motion explain just about everything you need to know to become a rocket scientist. However, knowing the laws is not enough. You have to know how to apply them, such as:

- How can you create enough thrust to exceed the weight of the rocket?
- What structural materials and propellant combinations should you use?
- How big will the rocket have to be?
- How can you make the rocket go where you want it to?
- How can you bring it back to Earth safely?

Applying Newton's Laws

The next step in becoming a rocket scientist is to apply rocket science and mathematics to the design and construction of actual rockets. There are many tricks of the trade for maximizing thrust and reducing rocket mass. Each of these tricks is an application of one or more of Newton's laws. Although there are many different kinds of rockets, the same laws apply to all.

Rockets are generally classified as either solid or liquid. They produce thrust by burning propellants and expelling the combustion products out of the engine. Propellants are simply a combination of fuel and oxidizer. The oxidizer for solid propellants is a chemical containing oxygen. For example, gunpowder, used in the engines of model rockets, contains potassium nitrate (KNO_3). Potassium nitrate provides the oxygen needed for the other gunpowder chemicals to burn rapidly. The oxidizer for liquid rockets is usually pure oxygen chilled to 90 K (-183°C or -297.3°F) so that it condenses into liquid oxygen (LOX).

The propellants for rockets are held in tanks or within cases. This is both an advantage and a disadvantage. Because they carry their propellants (oxygen onboard), rockets can work in space. No other presently available vehicle can do that. A jet engine cannot function in space because it is an "air-breather." Although jets and rockets both employ Newton's law of action and reaction, the jet needs to draw in air from the atmosphere to burn its fuel. This limits the altitude of a jet plane.

Solid Propellant Rockets

The first true rockets, "fire arrows" invented by the Chinese, employed solid propellants. An early form of gunpowder was packed into a cylinder closed off at one end. On the other end was an opening. When the gunpowder was ignited, it burned very quickly and created great quantities of gas and other combustion products that rushed out of the hole. This produced thrust. Flight control was accomplished by attaching a long stick to the rocket to create drag as the rocket sailed