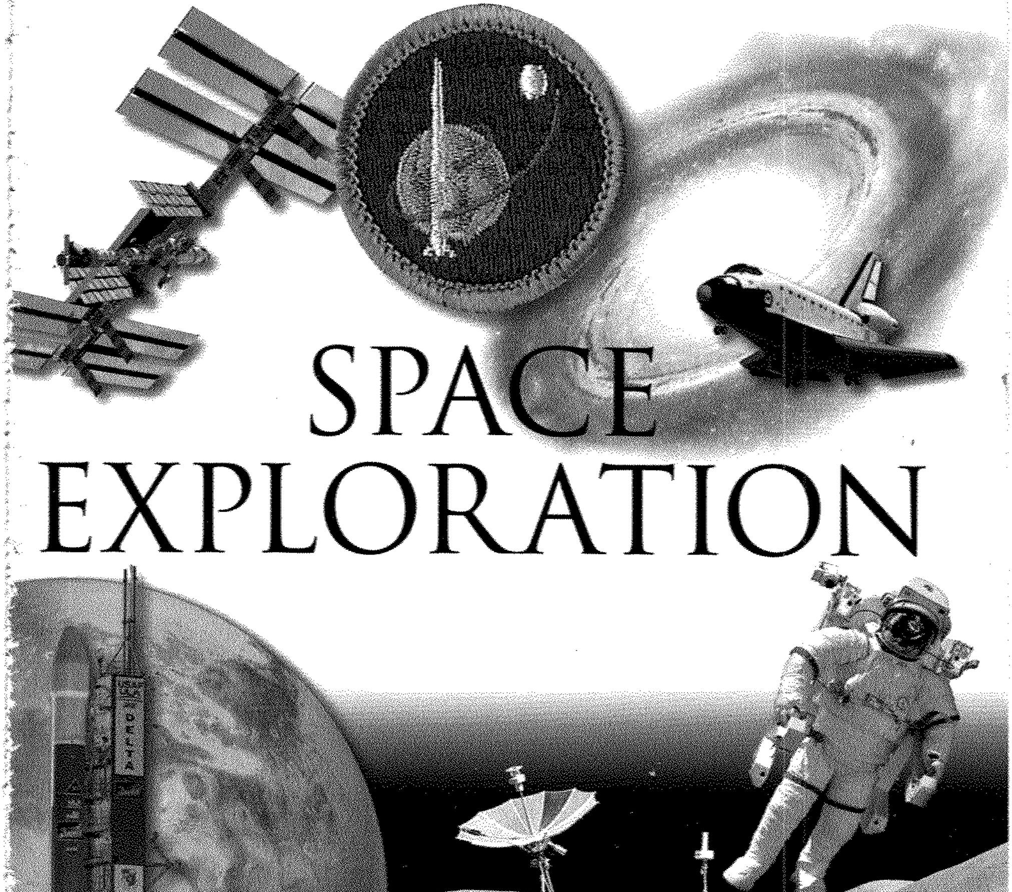
MERIT BADGE SERIES

SPACE EXPLORATION



BOY SCOUTS OF AMERICA®

STEM-Based

How to Use This Pamphlet

The secret to successfully earning a merit badge is for you to use both the pamphlet and the suggestions of your counselor.

Your counselor can be as important to you as a coach is to an athlete. Use all of the resources your counselor can make available to you. This may be the best chance you will have to learn about this particular subject. Make it count.

If you or your counselor feels that any information in this pamphlet is incorrect, please let us know. Please state your source of information.

Merit badge pamphlets are reprinted annually and requirements updated regularly. Your suggestions for improvement are welcome.

Who Pays for This Pamphlet?

This merit badge pamphlet is one in a series of more than 100 covering all kinds of hobby and career subjects. It is made available for you to buy as a service of the national and local councils, Boy Scouts of America. The costs of the development, writing, and editing of the merit badge pamphlets are paid for by the Boy Scouts of America in order to bring you the best book at a reasonable price.

Send comments along with a brief statement about yourself to
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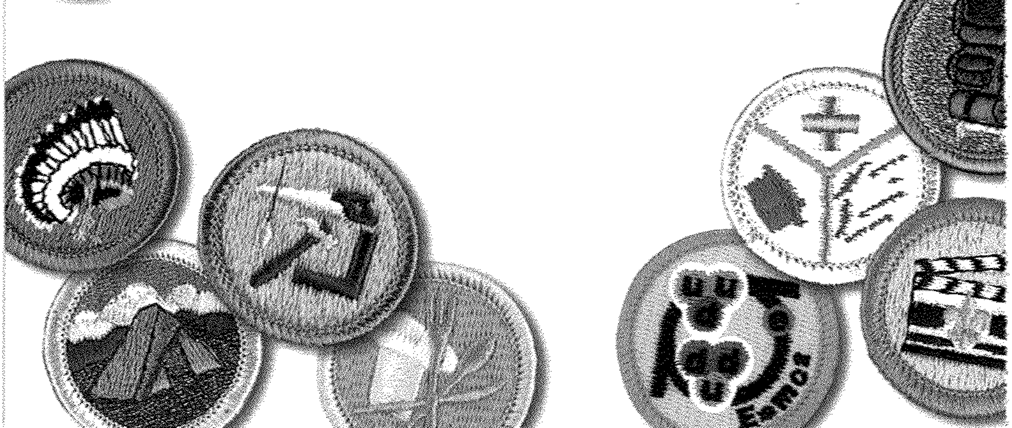

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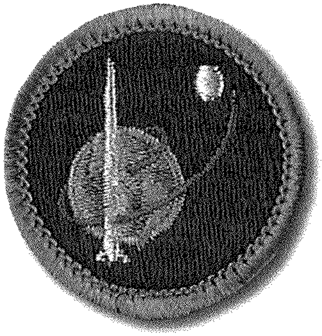
SPACE EXPLORATION



"Enhancing our youths' competitive edge through merit badges"

BOY SCOUTS OF AMERICA®

Requirements

1. Tell the purpose of space exploration and include the following:
   a. Historical reasons
   b. Immediate goals in terms of specific knowledge
   c. Benefits related to Earth resources, technology, and new products
   d. International relations and cooperation

2. Design a collector's card, with a picture on the front and information on the back, about your favorite space pioneer. Share your card and discuss four other space pioneers with your counselor.

3. Build, launch, and recover a model rocket.* Make a second launch to accomplish a specific objective. (Rocket must be built to meet the safety code of the National Association of Rocketry. See the "Model Rocketry" chapter.) Identify and explain the following rocket parts.
   a. Body tube
   b. Engine mount
   c. Fins
   d. Igniter
   e. Launch lug
   f. Nose cone
   g. Payload
   h. Recovery system
   i. Rocket engine

*If local laws prohibit launching model rockets, do the following activity: Make a model of a NASA rocket. Explain the functions of the parts. Give the history of the rocket.

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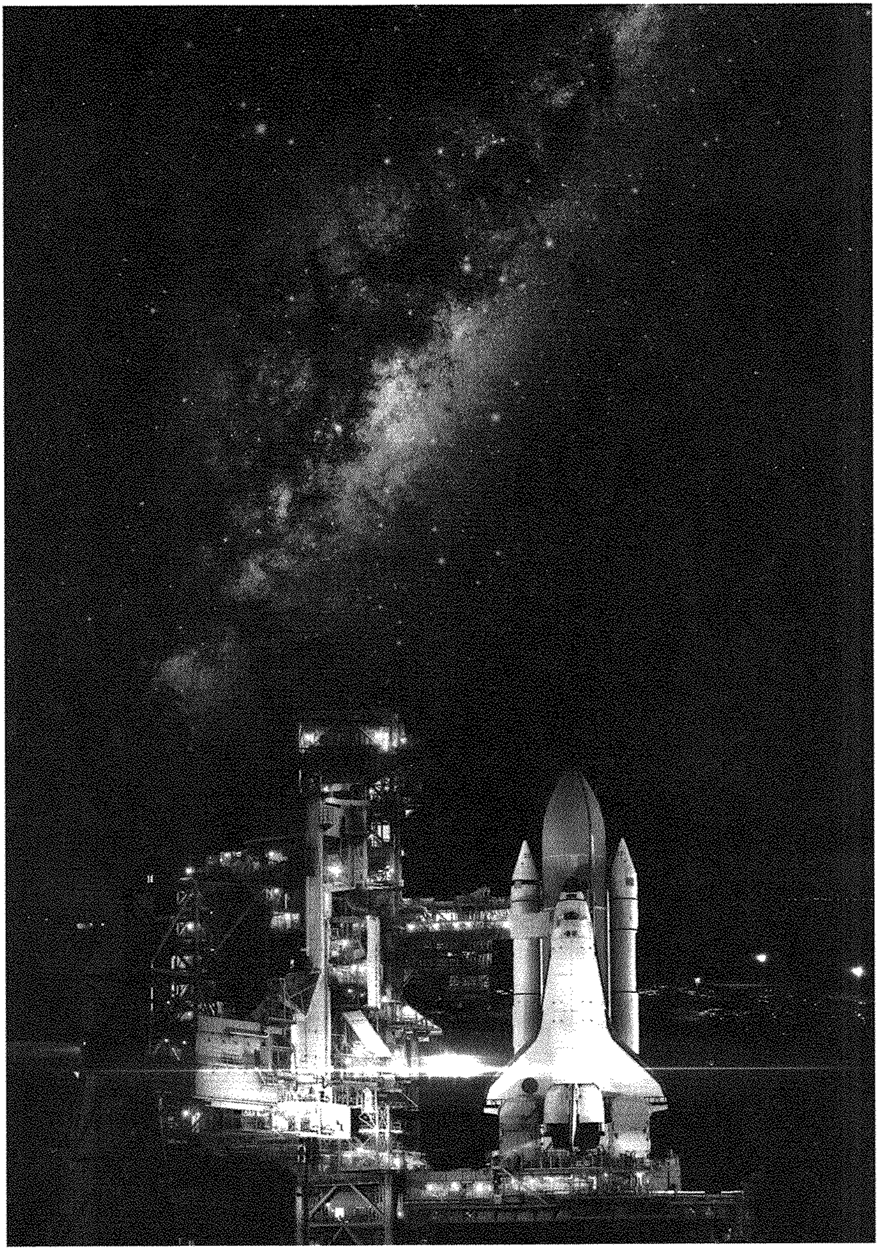
4. Discuss and demonstrate each of the following:
   a. The law of action-reaction
   b. How rocket engines work
   c. How satellites stay in orbit
   d. How satellite pictures of Earth and pictures of other planets are made and transmitted
5. Do TWO of the following:
   a. Discuss with your counselor a robotic space exploration mission and a historic crewed mission. Tell about each mission's major discoveries, its importance, and what was learned from it about the planets, moons, or regions of space explored.
   b. Using magazine photographs, news clippings, and electronic articles (such as from the internet), make a scrapbook about a current planetary mission.
   c. Design a robotic mission to another planet, moon, comet, or asteroid that will return samples of its surface to Earth. Name the planet, moon, comet, or asteroid your spacecraft will visit. Show how your design will cope with the conditions of the environments of the planet, moon, comet, or asteroid.
6. Describe the purpose, operation, and components of ONE of the following:
   a. Space shuttle or any other crewed orbital vehicle, whether government-owned (U.S. or foreign) or commercial
   b. International Space Station
7. Design an inhabited base located within our solar system, such as Titan, asteroids, or other locations that humans might want to explore in person. Make drawings or a model of your base. In your design, consider and plan for the following:
   a. Source of energy
   b. How it will be constructed
   c. Life-support system
   d. Purpose and function
8. Discuss with your counselor two possible careers in space exploration that interest you. Find out the qualifications, education, and preparation required and discuss the major responsibilities of those positions.



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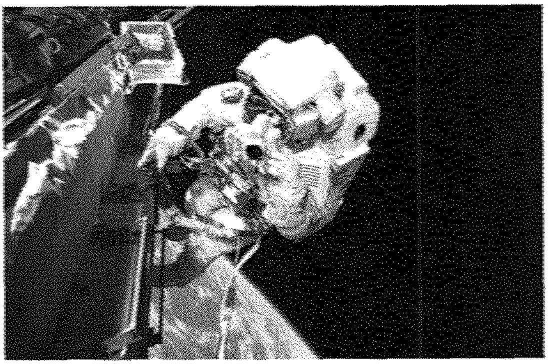
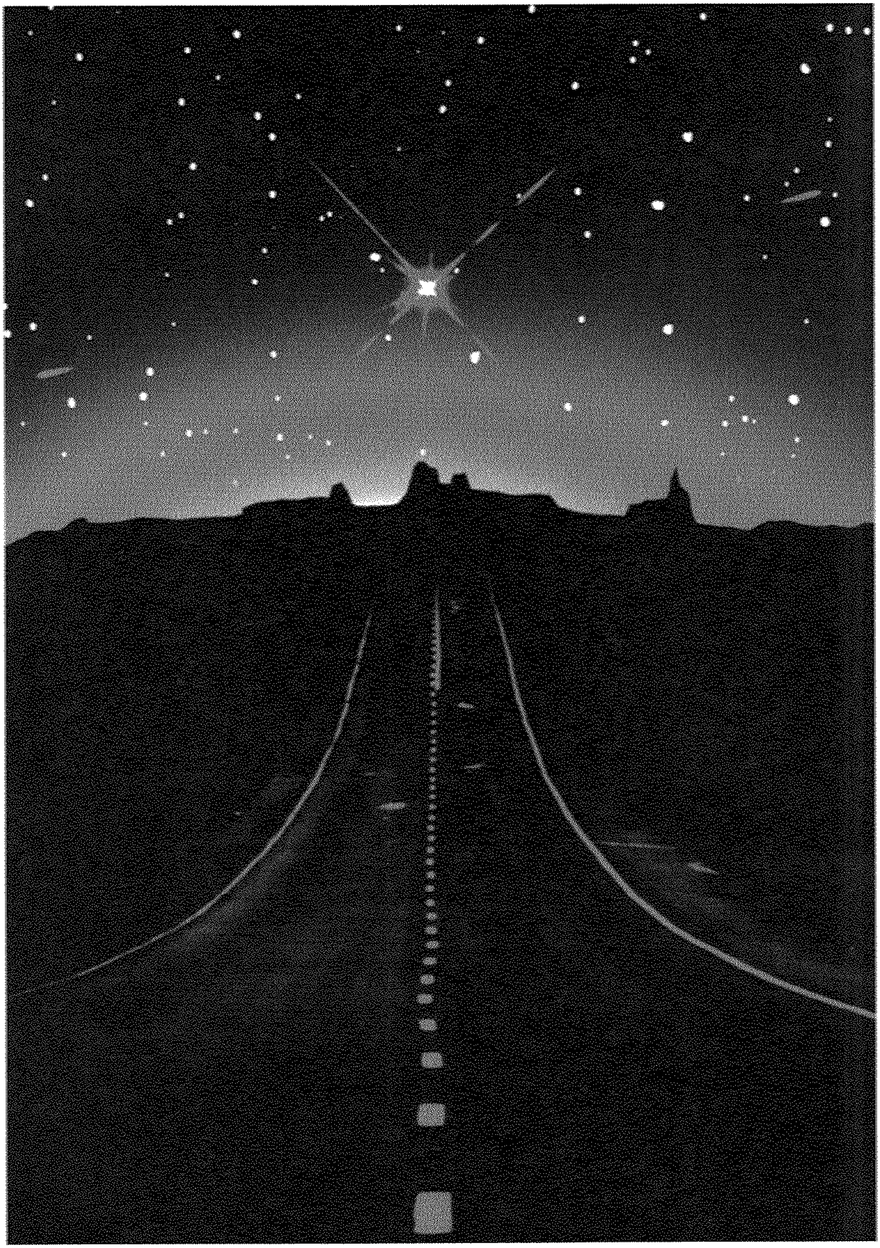


An astronaut uses a camera while working on the International Space Station.



Why Explore Space?

Space is mysterious. We explore space for many reasons, not least because we don't know what is out there, it is vast, and humans are full of curiosity. Each time we send explorers into space, we learn something we didn't know before. We discover a little more of what is there.

When you are on a hike, have you ever wondered what lies around the next bend in the trail, or beyond the next ridge, or down in the valley below? If so, then you will understand the thrill of sending a spacecraft to a world no human has ever seen.

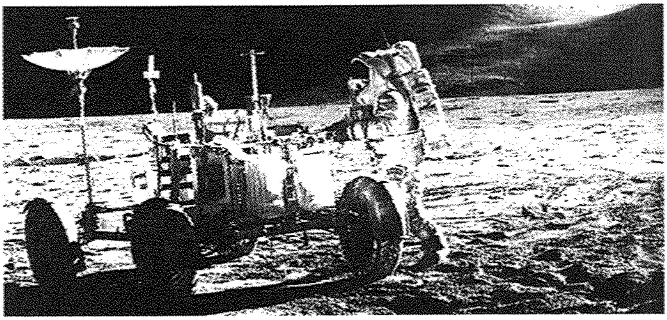
Scientists found in 2013 that a rock sample collected by Curiosity contained sulfur, nitrogen, hydrogen, oxygen, phosphorus, and carbon—elements that mean ancient Mars could have supported life.

Historical Reasons

Space has beckoned us, from early observers such as the Aztecs, Greeks, and Chinese; to 15th-century seafarers like Christopher Columbus and 17th-century astronomers including Galileo Galilei; to today's Scouts. The stars and planets in the sky have helped us shape our beliefs, tell time, guide our sailing ships, make discoveries, invent devices, and learn about our world.

When electricity, airplanes, rockets, and computers came on the scene, some people realized it would be possible to put machines and people into space. No longer would we be limited to observing the wonders of space from the ground. Now we could enter and explore this curious environment. The "final frontier" could be opened.

However, it proved complicated and expensive to build a rocket to put objects into orbit around the Earth. In the mid-20th century, only two countries had the knowledge, workforce, and money to do it—the Soviet Union and the United States. The Soviet Union showed its might by launching a small sphere into orbit. The Soviets' success with *Sputnik 1* on Oct. 4, 1957, began the "space race" between the two countries and launched the Space Age.



***Apollo 15* astronaut Jim Irwin sets up the first Lunar Roving Vehicle on the Moon.**

For more than 10 years, the United States and the Soviet Union competed by launching vehicles, animals, and people into space. The United States achieved its goal of landing men on the Moon by the end of the 1960s. Meanwhile, the Soviet Union built space stations to have a permanent presence in space. (See the chart called "Historic Crewed Spaceflight Programs" for more details about these early missions.)

We learned many new things from space missions focusing on science and education. Astronauts collected rocks from the Moon and did medical and scientific experiments above Earth's atmosphere. Robotic spacecraft visited other planets. People watched on television as an astronaut hit a golf ball on the Moon and when a rover sniffed at a Martian rock. Space looked like fun!

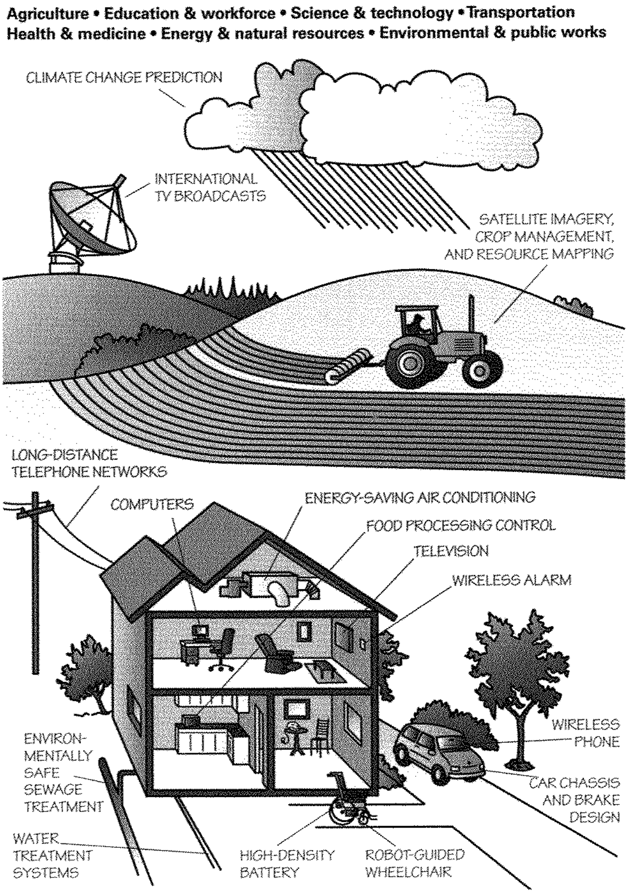
Current Benefits

Some business people looked beyond the fun and adventure of space exploration. They saw space as a chance to make money and satisfy society's needs. The commercial satellite industry blossomed in the 1980s and into the 1990s, when constellations of satellites began to provide increasingly affordable global coverage.

Today, our ability to place satellites in orbit gives us many benefits. Seeing Earth's atmosphere from space, meteorologists can forecast weather and warn people of dangerous storms more accurately than ever before. Looking down on the land and the ocean from space, we have found natural resources and seen disturbing evidence of their careless destruction. Communication satellites help tie the world's population together, carrying video, telephone, computer, and internet data for individuals, schools, governments, and businesses.

Historic Crewed Spaceflight Programs

Program	Country	Years	Major Accomplishments
Vostok	USSR	1961–63	First manned spaceflight (Yuri Gagarin in *Vostok 1,* 1961); first woman in space (Valentina Tereshkova in *Vostok 6,* 1963)
Mercury	U.S.	1961–63	First U.S. manned suborbital flight (Alan Shepard in *Freedom 7,* 1961); first U.S. manned orbital flight (John Glenn in *Friendship 7,* 1962)
Voskhod	USSR	1964–65	First "spacewalk" or extravehicular activity (Alexei Leonov in *Voskhod 2,* March 1965)
Gemini	U.S.	1965–66	First U.S. extravehicular activity (Edward White in *Gemini 4,* June 1965); first docking of two space-craft in orbit (Neil Armstrong and David Scott in *Gemini 8* with unmanned Agena rocket, 1966)
Soyuz	USSR	1967– (Russia continues to use the Soyuz rocket)	First extravehicular transfer of crew members from one spacecraft to another (Yevgeny Khrunov and Aleksei Yeliseyev from *Soyuz 5* to *Soyuz 4,* 1969)
Apollo	U.S.	1968–72	First manned orbit of the Moon (Frank Borman, James Lovell, and William Anders in *Apollo 8,* 1968); first manned lunar landing (Neil Armstrong and Buzz Aldrin in *Apollo 11,* 1969); five other successful manned lunar landings (*Apollos 12* and *14–17,* 1969–72)
Salyut	USSR	1971–86	First space station; first extensive photography of Earth from space; record-breaking endurance flight of 237 days (aboard *Salyut 7,* 1984–1985)
Skylab	U.S.	1973–74	First U.S. space station; three American crews stayed for 28, 59, and 84 days, the last setting a U.S. space-endurance record; first pictures of solar activity taken above Earth's atmosphere (175,000 pictures of the Sun made from Skylab)
Apollo-Soyuz	U.S.-USSR	1975	First international docking in space (Thomas Stafford, Deke Slayton, and Vance Brand in *Apollo 18;* Alexei Leonov and Valery Kubasov in *Soyuz 19,* July 1975)
Space Transportation System (Space Shuttle)	U.S.	1981–2011	First reusable vehicle; first U.S. woman in space (Sally Ride, *STS-7*); first untethered spacewalk (Bruce McCandless, *STS-41B*)



New materials, products, and technologies coming from the space program are called "spinoffs." Spinoffs from the space exploits of the National Aeronautics and Space Administration (NASA) include portable coolers, scratch-resistant lenses, self-righting life rafts, water treatment systems, virtual reality simulators, smoke detectors, cordless tools, firefighter suits made of flame-retardant materials, "cool suits" to lower a patient's body temperature, programmable pacemakers, and voice-controlled wheelchairs. For more on NASA's spinoffs, visit spinoffs.nasa.gov (with your parent's permission).

Military satellites provide intelligence of vital interest to our armed forces and national security. The global positioning system (GPS) operated by the U.S. Department of Defense is an example of a military application of a space technology that has benefited people the world over. The next time you see an automobile's GPS unit giving precise directions to a destination, think of the global network of technology underlying those directions.

We have new medicines and medical devices thanks to the astronauts' experiences and experiments in space. With the construction of the International Space Station (see "Near-Earth Space Habitats"), we are learning how to build structures in the vacuum of space. In the future, such structures could serve as manufacturing facilities for "out of this world" products or as hotels for thrill-seeking tourists.

NASA's Technology Transfer and Commercialization Office identifies those technologies developed by NASA or through NASA-sponsored research and works with businesses to bring products based on those technologies to the marketplace.

Any small nickel-iron asteroid contains trillions of dollars' worth of valuable metals. For more about asteroids, see the *Astronomy* merit badge pamphlet.

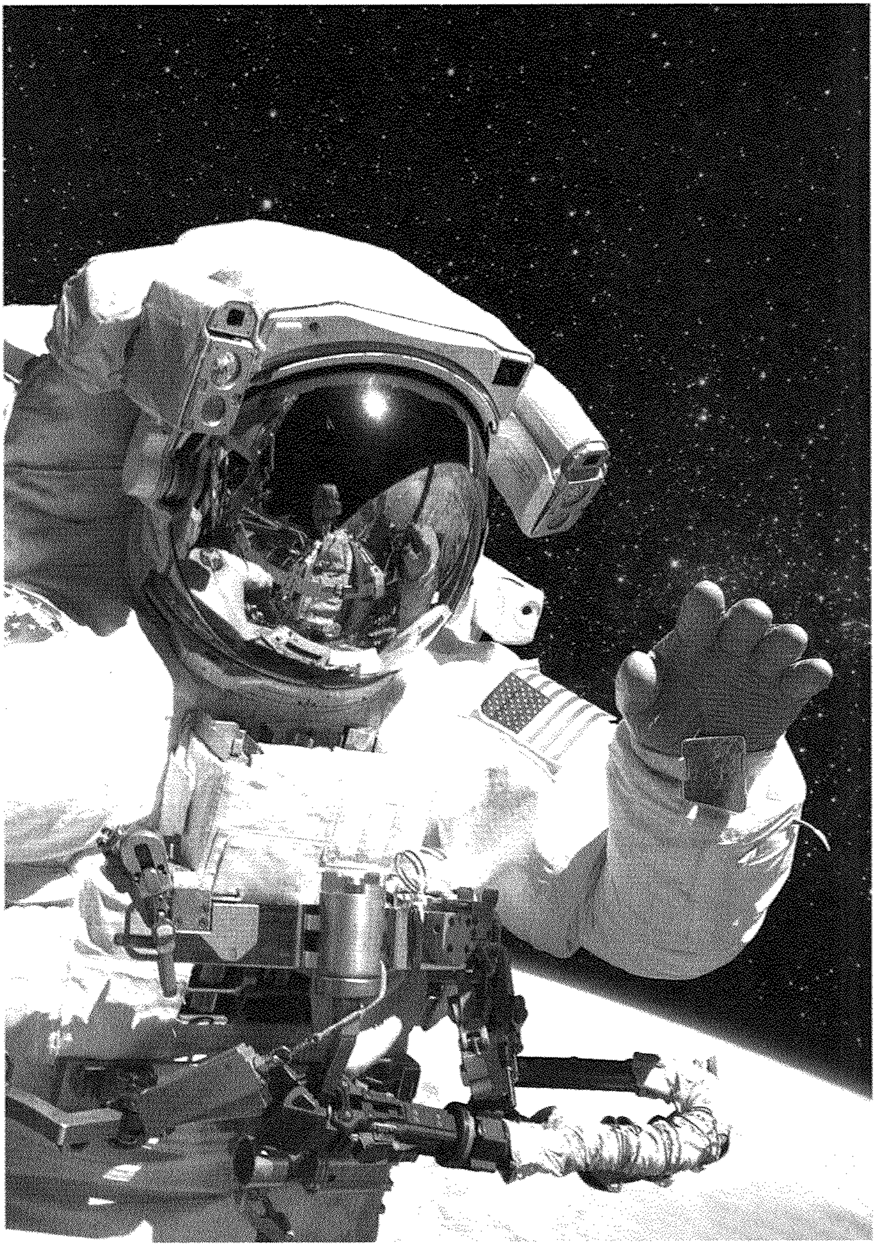
Humanity's Future

Space is about the future. The people who work in space-related projects—engineers and scientists, doctors and teachers, corporations and entrepreneurs—are seeking to improve the future of humanity.

Once we are able to carry people and cargo cheaply into space, we could establish communities in space stations and on the Moon and Mars. We could harness the Sun's energy by using solar-powered satellites to provide clean, reliable electricity to everyone on Earth, eventually replacing polluting carbon-based fuel sources. We could mine the Moon and asteroids for valuable minerals and metals rarely found on Earth.

The far side of the Moon would be an excellent site for astronomical observatories. Communities of people living and working in space would cultivate new cultural activities and arts. Micro- and low-gravity sports could provide exciting new thrills for spectators. Having a growing and vibrant presence in space also increases our ability to better address the threat of asteroid impact.

Earth is only so big and it has only so many resources—resources that our ever-growing population is using up. Spreading humanity among the stars is a magnificent dream. After you read this pamphlet and earn the Space Exploration merit badge, perhaps you will do or discover something that could lead the way to the stars.

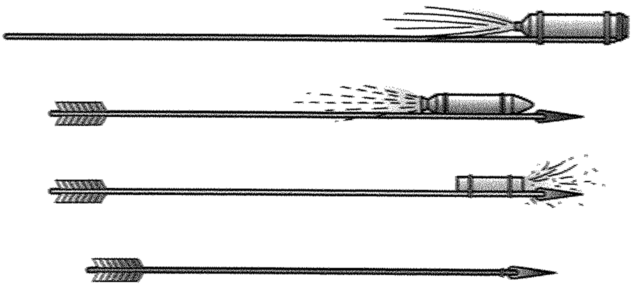


Our Steps Into Space

In 11th-century China, inventors and scholars developed gunpowder. One Chinese scholar packed a tube with gunpowder and sealed off one end. When the gunpowder was ignited, the tube shot forward and sometimes it would explode. People were hurt and property was destroyed during these experiments. Then someone realized this "fire work" could become a weapon, and the fire arrow was invented.

The first recorded use of rockets in war was in the year 1232 when the Mongols laid siege to the Chinese City of Kaifeng. The Chinese chased off the Mongols with a barrage of fire arrows. After the battle, the Mongols developed their own rockets. Some historians believe the Mongols introduced gunpowder and rockets to Europe.

From the 15th through the 17th centuries, cannons replaced rockets as military weapons. During the 18th century, rockets made a comeback thanks to William Congreve, an English inventor. His rockets helped the English win battles against Denmark, France, and Prussia. Francis Scott Key immortalized Congreve's weapons when he wrote of "the rockets' red glare" during the British attack on Fort McHenry in Baltimore Harbor during the War of 1812.



From bottom to top: **The development of the Chinese "fire arrow"**

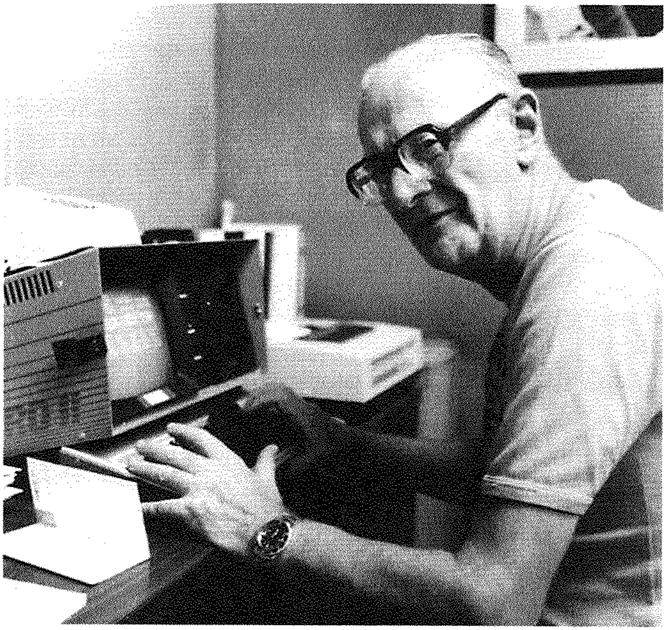
The Visionaries

Although the rocket became an instrument of war, a few dreamers of the 19th and 20th centuries saw it as a method of transportation. *Could* people fly into space on a rocket? As the Industrial Revolution introduced new technology to the public, these dreamers used a new form of fiction—*science fiction*—to express their ideas of traveling beyond Earth in ways that might actually be achievable.

Jules Verne (1828–1905) was born in Nantes, France. He went to Paris to study law. Instead, inspired by balloons, airships, and other new inventions, he began to write science fiction stories. He wrote *From the Earth to the Moon* (1865), *Around the Moon* (1870), and *Around the World in Eighty Days* (1873). In his novel *From the Earth to the Moon*, a giant cannon in Florida launches the space capsule. The astronauts, initially on an incorrect trajectory, execute a propulsive maneuver that puts them on a free-return trajectory. This allows them to circle the Moon and then land in the Pacific Ocean, where an American naval vessel recovers the crew and capsule. Verne told this story 100 years before the Apollo missions. Jules Verne is considered the father of modern science fiction.

Konstantin Tsiolkovsky (1857–1935) was a Russian teacher and scientist who wrote science fiction stories of interplanetary travel that featured real-world technical and scientific issues. He wrote about using liquid propellant to power rocket ships and about the need for spacesuits to protect people in the vacuum of space. He is credited with being the first to work through the mathematics of the "rocket equation" that serves as the foundation of spaceflight, and even considered a tower from Earth to geostationary orbit, which would be called a space elevator today. He is most noted for his quote "Earth is the cradle of mankind, but one does not stay in the cradle forever."

Robert A. Heinlein (1907–1988) served as a U.S. naval officer aboard the first modern aircraft carrier, the USS Lexington. Due to health reasons, he retired from the Navy in 1934 and focused on science fiction writing, becoming widely regarded as the "dean of science fiction writers." His novel *The Moon Is a Harsh Mistress* describes a subsurface lunar colony and electromagnetic launchers 40 years before any similar system existed. Many of his young people's novels were first published as series, such as "Farmer in the Sky," which was published as "Satellite Scout" in *Boys' Life* magazine. A large number of space program supporters credit Heinlein with introducing them to the topic.



Arthur C. Clarke

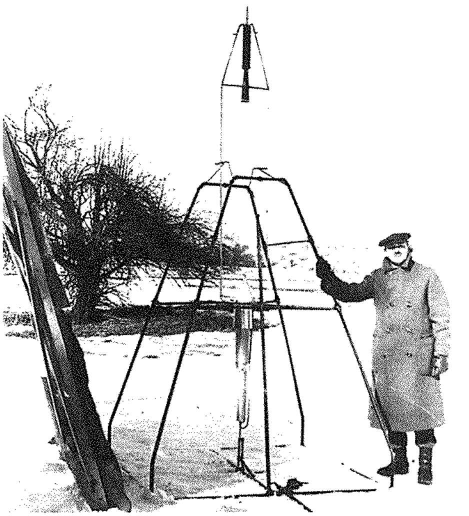
Arthur C. Clarke (1917–2008) wrote fiction and nonfiction for more than 60 years. In 1936, he joined the British Interplanetary Society, where he published their journal and began to write science fiction stories. He served in the Royal Air Force during World War II and tested radar systems. After the war, he returned to school and received degrees in physics and mathematics. In 1945, he published a paper titled "Extraterrestrial Relays" that laid down the principles of modern communications satellites in geostationary orbit, which is sometimes referred to as the Clarke Orbit in his honor. Clarke's space-related works of fiction include the short story "The Sentinel," which was turned into the movie *2001: A Space Odyssey* (1968). His novels include *Earthlight, Islands in the Sky, The Sands of Mars,* and *The Fountains of Paradise.*

Dr. Gerard K. O'Neill (1927–1992) was born in Brooklyn, New York. He served in the Navy during World War II and earned a doctorate in physics at Columbia University. In 1954, he joined the faculty of Princeton University as a physics professor, where his work led to the invention of the colliding-beam storage ring for particle accelerators. Dr. O'Neill envisioned the development of space colonies constructed mainly of materials from the Moon and asteroids—one of the earliest ideas for space industrialization. His book *The High Frontier* (1977) popularized the idea of a giant space colony at the Earth-Moon L5 point and led to the creation of the L5 Society, which was devoted to making space colonization a reality. Dr. O'Neill contributed to the mass driver, which would magnetically levitate and accelerate supplies from the Moon and asteroids to the construction site he envisioned at L5. The L5 Society merged with Wernher Von Braun's National Space Institute in 1987 to form the National Space Society.

The Makers

After the Wright brothers ushered in the age of flight, several rocket scientists laid the foundations for the Space Age.

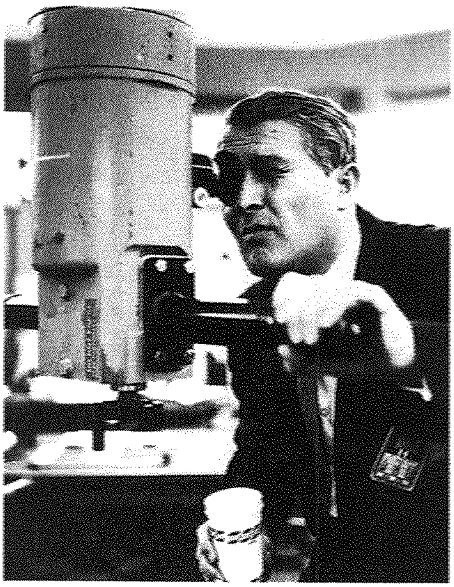
Dr. Robert H. Goddard (1882–1945), born in Worcester, Massachusetts, is considered the "father of modern rocketry." In 1907, while a student at Worcester Polytechnic Institute, he fired a rocket engine in the basement of the physics building, getting the attention of school officials. Seven years later, he patented his rocket inventions. In 1920, he published "A Method of Reaching Extreme Altitudes," in which he suggested using rockets to carry weather instruments aloft. Dr. Goddard developed a rocket using liquid fuel and launched a liquid-fueled rocket that went faster than the speed of sound. He developed the first practical automatic steering device for rockets.



Dr. Robert H. Goddard standing next to the rocket that would make the world's first liquid propellant rocket flight on March 16, 1926.

Sergei Korolev (1907–1966) was born in Zhitomir, Russia. He joined the developing field of aviation as a teenager and later studied engineering. After reading the works of Tsiolkovsky, he formed the Moscow Group for Study of Reactive Motion in 1931 and helped form the Rocket Research Institute in 1932. He was sent to a gulag in 1938 as part of Joseph Stalin's great purges. By 1942, many technically adept prisoners were recruited to contribute to the war effort, including Korolev. At the end of World War II, Russian leaders realized the importance of developing rocket technology, and Korolev became a valuable member of the Soviet space program. During his top-secret career, he directed the launching of the first rockets into orbit, the Vostok, Voskhod, Molniya (now Soyuz), and Zond spacecraft, and probes to the Moon, Mars, and Venus. His death in 1966 was a crucial blow to the Soviet's Moon program.

Dr. Wernher von Braun (1912–1977) was born in Wirsitz, Germany. Inspired by a race car driver when he was 12, von Braun attached six rockets to a coaster wagon and lit the fuses. The wagon careened around his backyard, emitting a fountain of sparks. The commotion attracted the police, who took him into custody. Von Braun became interested in space exploration by reading the science fiction of Verne and H.G. Wells and received his doctorate in aerospace engineering in the early 1930s. Familiar with Dr. Goddard's work, von Braun designed and built Germany's V-2 missile during World War II. At the end of the war, the U.S. Army realized the importance of Dr. von Braun's work. He was brought to the United States with more than 500 fellow scientists and with many V-2 missiles and components under Operation Paperclip. He led the Army missile development program and launched the first U.S. satellite, *Explorer 1*, in 1958. His crowning achievement was the development of the Saturn class of rockets that carried the Apollo astronauts to the Moon.



Dr. Wernher von Braun

Steve Squyres (1956–) was raised in Wenonah, New Jersey. He is a professor of astronomy at Cornell University, focusing on large solid bodies in the solar system. He served on the Voyager imaging science team and was on the teams for Magellan, Mars Observer, and the Russian Mars '96 mission. He is currently principal investigator for the long-serving Mars Exploration Rovers mission, as well as on the teams of Mars Express, Mars Reconnaissance Orbiter, and Odyssey and the imaging team for Cassini. He published *Roving Mars: Spirit, Opportunity, and the Exploration of the Red Planet* in 2006.

The Doers

The "doers" were pilots who became astronauts. Among them were those who walked on the Moon and piloted the space shuttle.

U.S. Sen. John Glenn (1921–2016), an Eagle Scout, was born in Cambridge, Ohio. He received his aerospace engineering degree, joined the Navy during World War II, and earned his

"The urge to explore the unknown is part of human nature. . . . It enriches our spirits and reminds us of the great potential for achievement within us all. The drive to develop the next frontier also has been a fundamental part of the heritage of the people of the United States."

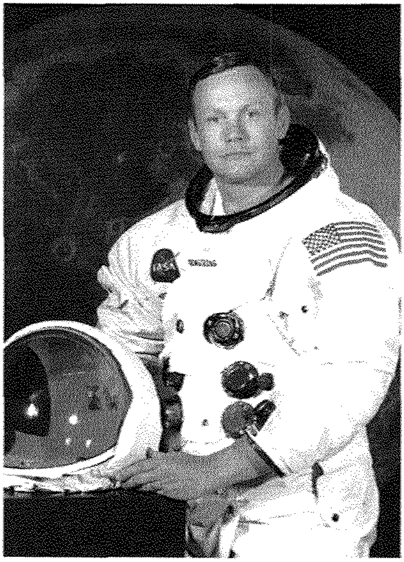
—John Glenn

wings as a Marine aviator. Glenn flew combat missions in World War II and Korea. He attended Navy test-pilot school and became one of the original Mercury astronauts. He was the first American to orbit Earth, in the *Friendship 7* Mercury capsule on Feb. 20, 1962. He served as senator from Ohio for 24 years. Glenn returned to space on a space shuttle mission in 1998, becoming (at age 77) the oldest person to fly in space.

Alan Shepard (1923–1998) was born in East Derry, New Hampshire, and graduated from the Naval Academy. He flew aircraft carriers during World War II. Shepard later attended test-pilot school and was selected as one of the original *Mercury 7* astronauts in 1959. He was the first American to fly in space, on a Mercury *suborbital* mission in May 1961. Shortly after his flight, an inner-ear problem grounded him. An operation corrected the problem, allowing Shepard to lead the *Apollo 14* lunar-landing mission. He hit a golf ball on the Moon that traveled 900 yards—a record that still stands.

Suborbital means "not completing a full orbit."

Neil Armstrong (1930–2012) was born in Wapakoneta, Ohio, and earned his aerospace engineering degree from Purdue University. After serving as a naval aviator, he went to work for the government as an engineer, a test pilot, and then as an astronaut. Armstrong was selected as a Gemini astronaut and commanded the *Gemini 8* mission. Then he went into the Apollo program. On July 20, 1969, as commander of *Apollo 11*, Armstrong became the first man to set foot on the Moon.



Neil Armstrong

John W. Young (1930–2018) holds the distinction of being the only astronaut to fly Gemini, Apollo, and space shuttle missions. Born in San Francisco, he earned his degree in aeronautical engineering from Georgia Tech in 1952, joined the Navy, and became a test pilot. He flew on the first Gemini flight in 1965, commanded *Gemini 10* in 1966, and was the command module pilot of *Apollo 10*, orbiting the Moon alone while his crewmates tested the lunar module. In 1972, he landed on the Moon and drove the *Apollo 16* rover. Young commanded the first space shuttle flight in 1981.

The Entrepreneurs

With space development moving to the private sector, the entrepreneurs are moving into prominence.

Robert Bigelow (1945–), a real estate developer, adapted NASA's technology relating to inflatable habitats, which was part of the development of the International Space Station, and applied it to the concept of orbital facilities that could be leased by private interests. Bigelow Aerospace launched its first spacecraft, Genesis I, in 2006, followed by a larger Genesis II in 2007. Since then, they have provided invaluable data on how the inflatable spacecraft will behave in orbit. NASA is scheduled to test an inflatable module at the International Space Station in 2015.

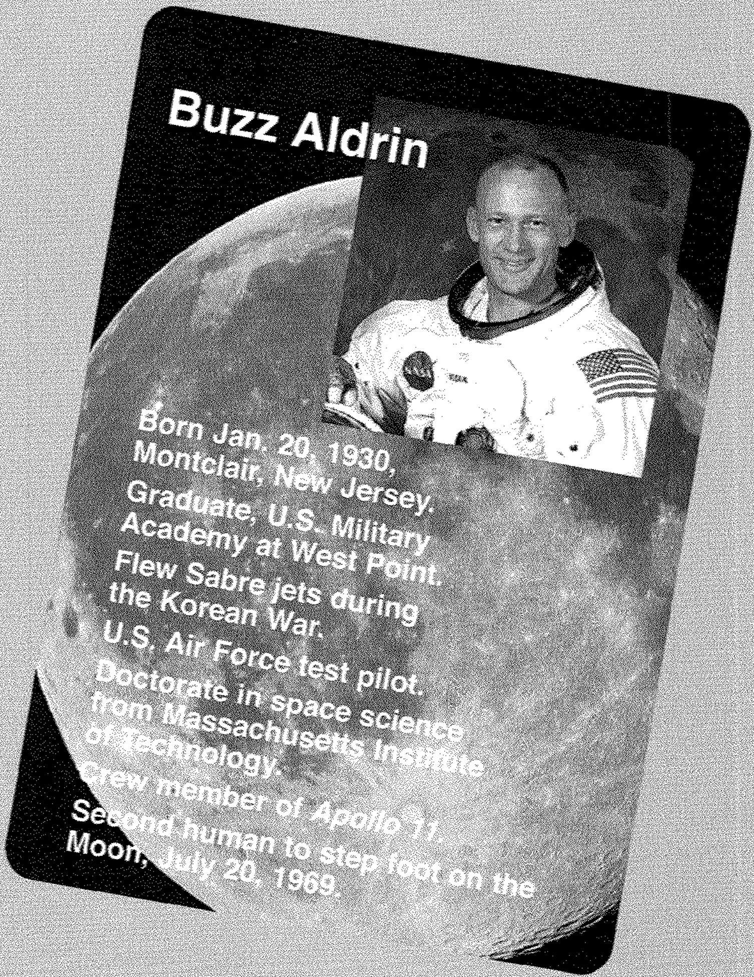
Peter Diamandis (1961–) is a serial entrepreneur who has been involved in the creation of a number of important elements in the broader space community, including the International Space University, Students for the Exploration and Development of Space, and Zero-G Corp., which provides micro-, lunar, and Martian gravity parabolas to customers. He established the X Prize Foundation, which offers monetary awards designed to spur innovation in space exploration and a number of other fields.

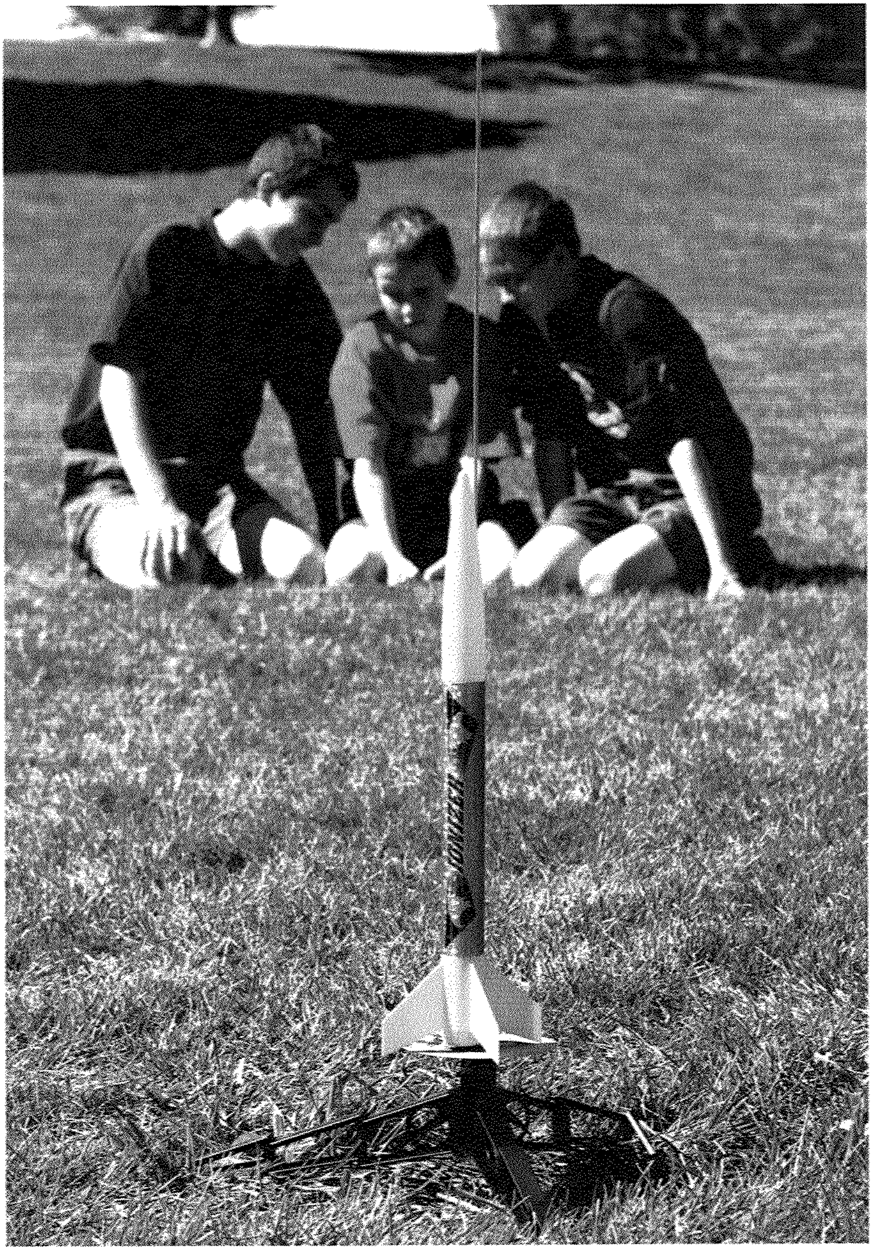
Elon Musk (1971–), the cofounder of internet transaction company PayPal, formed Space Exploration Technologies (SpaceX) in 2002 to build rockets that could inexpensively carry payloads to low Earth orbit and geosynchronous orbit. After years of successful rocket launches, the company began transporting cargo to the International Space Station in October 2012 in its Dragon spacecraft.

Elon Musk

Create a Collector's Card

For requirement 2, create a collector's card of your favorite space pioneer. You can copy or draw the person's face. Include appropriate biographical information. Give details of the person's contribution to spaceflight, including dates, missions, and other accomplishments.





Model Rocketry

Model rocketry is a great way to learn about space exploration. The rocket you build won't reach space, but the science and technology that goes into your rocket is the same as NASA uses in launching giant rockets.

Model rockets are made of paper, balsa wood, plastic, glue, and paint. You build them with simple tools such as a modeling knife, sandpaper, scissors, rulers, and paintbrushes. Model rockets are powered by solid propellant rocket engines. Depending on the size and design of the rocket and the power of the engine, model rockets may fly only 50 feet high or up to a half mile in altitude.

You can purchase model rocket kits and engines online, through mail-order catalogs, and in toy and hobby shops. If you can borrow a rocket launcher, you can buy everything you need to complete requirement 3 for less than $20. If you buy or build your own launcher, the total cost for this requirement could be about $35 to $40.

Though some toy stores sell model rocket kits, model rockets are anything but toys. They are powerful, and through misuse could harm animals, people, or property. By following the commonsense rules found later in this section, you can launch your rockets in complete safety over and over.

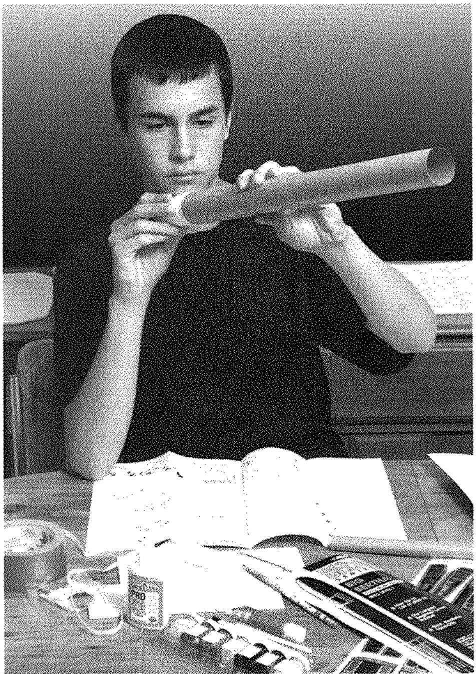
Building Your Rocket

If you have never built a model rocket before, it is best to start with a simple kit. The kit will consist of a body tube, nose cone, fins, engine mount, and parachute or some other recovery system that will gently lower your rocket to the ground at the end of its flight.

Engines must be purchased separately from the rocket. Be sure to buy the recommended engines for your kit. If you use engines that are too powerful, you may lose your rocket on its first flight.

Unless your rocket kit comes with preformed plastic fins, you will need to cut fins from sheets of balsa wood included in the kit. The instructions will tell you to sand the leading and trailing edges of the fins to look like the edge of a knife. Sharp edges on the fins help the rocket slice cleanly through the air as it flies upward, so you will want to do a good job on this step. Blunt fin edges cause *turbulence* (rough air) that robs your rocket of altitude.

Also do a good job painting the fins, and sanding and painting the nose cone if it, too, is made of balsa wood. Very smooth surfaces reduce friction with the air.



Although you may be tempted to tear open the kit and begin slapping together the parts, take time to read all of the instructions twice before starting. Reading all of the instructions first will help you gather the tools and supplies needed for building your rocket.

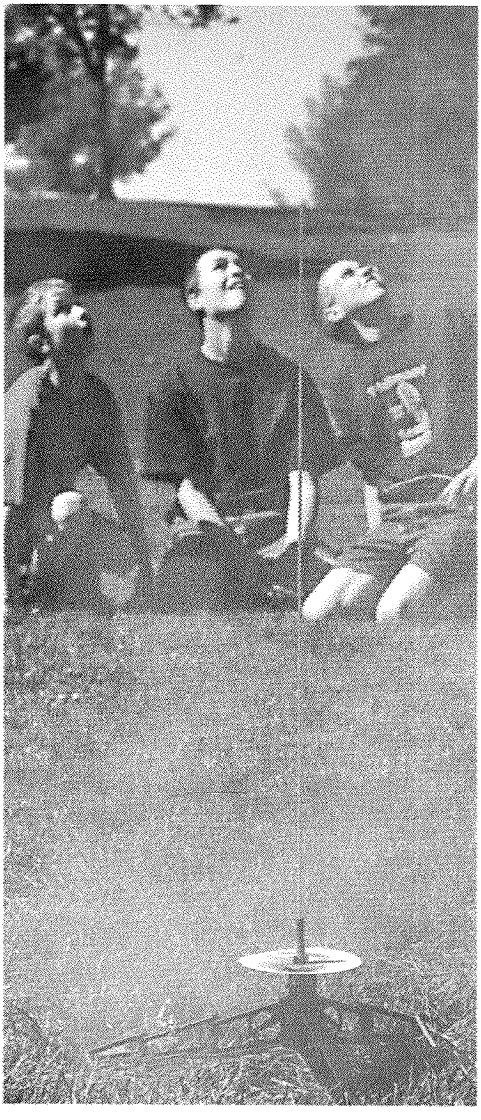
Stability-Checking Your Rocket

Check every rocket for stability before flying it. Stability checks before launch assure you that your rocket will fly properly. Unstable rockets tumble in the air and may head back toward the launchpad at high speed.

Stability checks are simple and require only a long piece of string, a piece of tape, and a few minutes of your time. To check a new model rocket, prepare the rocket for flight and insert a live engine. Tie a slipknot around the body of the rocket and slide it to the point where the rocket is perfectly balanced on the string.

Hold the string in one hand over your head, and begin to twirl your rocket as though you were spinning a lariat. As the rocket picks up speed, gradually play out the string until the rocket is about 6 to 8 feet away. If you are not tall, you may want to stand on a chair at this point.

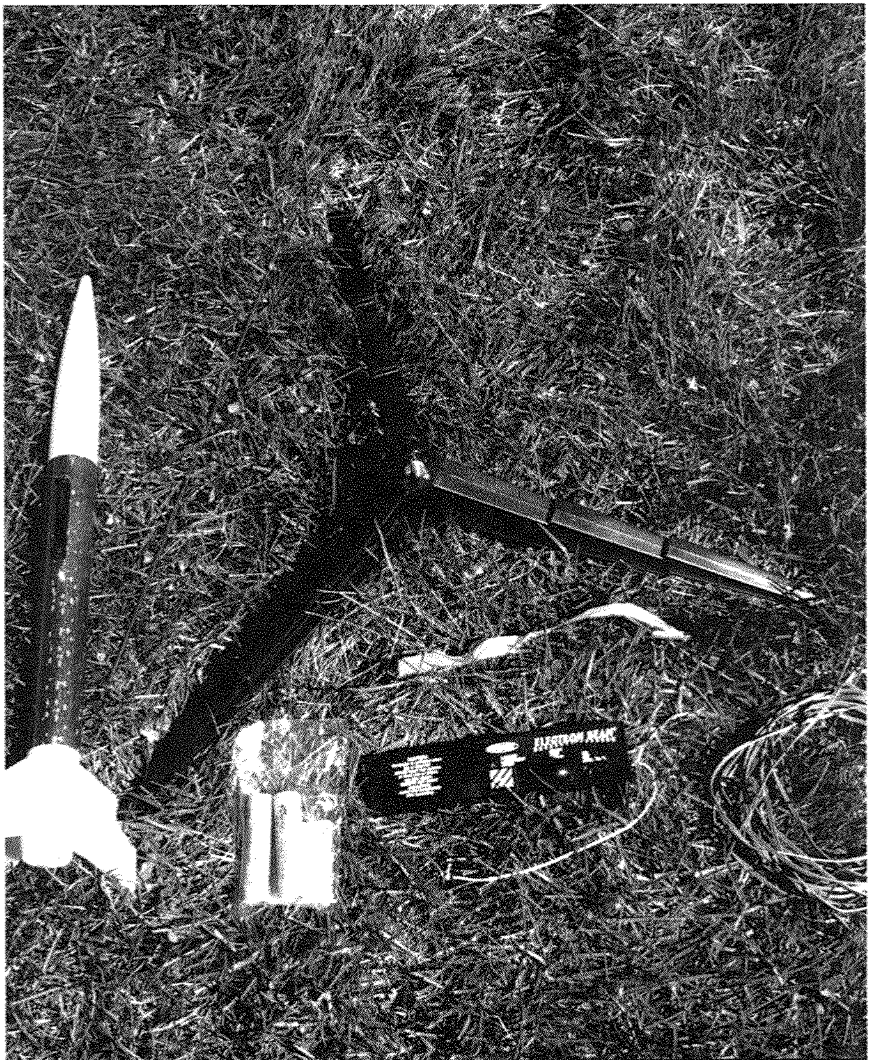
If your rocket is stable, it will travel around you without tumbling. The nose cone will point into the air and the tail end will follow. If the tail end goes first or if the rocket tumbles, your rocket may be dangerous to fly. You can correct this situation by putting on larger fins or adding weight to the rocket's nose with a lump of clay.



Launching Your Rocket

When your rocket is ready for its first flight, you must choose a proper launching site. Your launching site should be a large field that is free of power and telephone lines, trees, buildings, or any other structures that might snag a returning rocket. Choose a field away from airports.

You will need a launchpad. Perhaps you can borrow a launchpad from a local model-rocket club, or join the members on a day when they are launching rockets (To find a local club, see the National Association of Rocketry listing in the resources section.) If not, you can either buy a launchpad kit or build your own. A simple launchpad can be built from a block of wood, a blast deflector made from a flattened metal can, and a straight rod. Rods made specifically for rocket launchers are best and inexpensive. Buy one where you get your rocket supplies.



Instructions for safe launching of your rocket will come with your rocket kit. Follow these instructions carefully.

Not all cities and towns permit model rocket launches. Check with your local fire department or police to find out about local regulations governing model rocket launches. You may have to travel to a rural area to find a launch site. Or you may choose to complete the alternate to requirement 3.

Your launch system should be electric. It must have a switch that closes only when you press it and then opens again automatically. It also should have a master switch, or you should be able to disconnect the batteries while you set up your next flight. The wires from your batteries (about 6 volts) should extend about 15 feet to small "alligator" clips at the ends. These clips will be attached to the wires of the igniter. *Never use fuses or matches to ignite your rocket.*

Some kits may come with payload sections for carrying cargo. **Never send up animals in your rockets.** Mammals and other animals with backbones will possibly die from the experience. Instead, use a hard-boiled egg.

Accomplishing a Launch Objective

After you have made your first launch, make a second launch with a specific objective in mind. You might try to spot-land the rocket within a 50-foot circle. That isn't as easy as it sounds. You must make allowances for wind drift and aim your rocket accordingly.

Another objective might be to carry a payload aloft and recover it safely. Several rocket kits come with payload sections for carrying hard-boiled eggs or other cargo.

Still another objective would be to launch a small camera on your rocket to take a picture of the launch site from high altitude. Specially designed cameras are available for model rockets.

Model Rocket Safety Code*

1. **Materials.** I will use only lightweight, nonmetal parts for the nose, body, and fins of my rocket.
2. **Motors.** I will use only certified, commercially made model rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer.
3. **Ignition System.** I will launch my rockets with an electrical launch system and electrical motor igniters. My launch system will have a safety interlock in series with the launch switch, and will use a launch switch that returns to the "off" position when released.
4. **Misfires.** If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.
5. **Launch Safety.** I will use a countdown before launch, and will ensure that everyone is paying attention and is a safe distance of at least 15 feet away when I launch rockets with D motors or smaller, and 30 feet when I launch larger rockets. If I am uncertain about the safety or stability of an untested rocket, I will check the stability before flight and will fly it only after warning spectators and clearing them away to a safe distance. When conducting a simultaneous launch of more than 10 rockets I will observe a safe distance of 1.5 times the maximum expected altitude of any launched rocket.
6. **Launcher.** I will launch my rocket from a launch rod, tower, or rail that is pointed to within 30 degrees of the vertical to ensure that the rocket flies nearly straight up, and I will use a blast deflector to prevent the motor's exhaust from hitting the ground. To prevent accidental eye injury, I will place launchers so that the end of the launch rod is above eye level or will cap the end of the rod when it is not in use.
7. **Size.** My model rocket will not weigh more than 1,500 grams (53 ounces) at liftoff and will not contain more than 125 grams (4.4 ounces) of propellant or 320 N-sec (71.9 pound-seconds) of total impulse.

8. **Flight Safety.** I will not launch my rocket at targets, into clouds, or near airplanes, and will not put any flammable or explosive payload in my rocket.
9. **Launch Site.** I will launch my rocket outdoors, in an open area at least as large as shown in the accompanying table, and in safe weather conditions with wind speeds no greater than 20 miles per hour. I will ensure that there is no dry grass close to the launch pad, and that the launch site does not present risk of grass fires.
10. **Recovery System.** I will use a recovery system such as a streamer or parachute in my rocket so that it returns safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.
11. **Recovery Safety.** I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places.

Launch Site Dimensions

Installed Total Impulse (N-sec)	Equivalent Motor Type	Minimum Site Dimensions (ft.)
0.00–1.25	1/4A, 1/2A	50
1.26–2.50	A	100
2.51–5.00	B	200
5.01–10.00	C	400
10.01–20.00	D	500
20.01–40.00	E	1,000
40.01–80.00	F	1,000
80.01–160.00	G	1,000
160.01–320.00	Two Gs	1,500

Revision of August 2012

*Approved by the National Association of Rocketry (NAR)

Rocket Parts

The **body tube** is the barrel of the rocket. It holds the engine, the recovery device, and the payload. The rocket's fins and launch lug are mounted to the body tube.

The **engine mount** is a small tube that is glued to the inside of the body tube. The engine mount provides a sturdy place for inserting the rocket engine.

Rocket **fins** are the main stability device of the rocket. Their function is similar to that of feathers on an arrow.

Igniters are small wires that are inserted into the nozzle of a rocket engine. When electricity is passed through the wire, the wire heats, and chemicals coating the wire ignite. This, in turn, ignites the rocket engine. The igniter wires are blasted out the nozzle when the engine propellants start burning.

Before fins can stabilize a rocket, the rocket must be moving through the air. The **launch lug** is a small straw mounted to the side of the body tube. The lug slides over the rod on the launchpad, and the rod stabilizes the rocket until the fins are able to take over (which happens in a fraction of a second).

The **nose cone** is fitted at the upper end of the rocket. Its purpose is to divide the air smoothly so the rocket can travel through the air with little turbulence. Nose cones are usually tapered to a point.

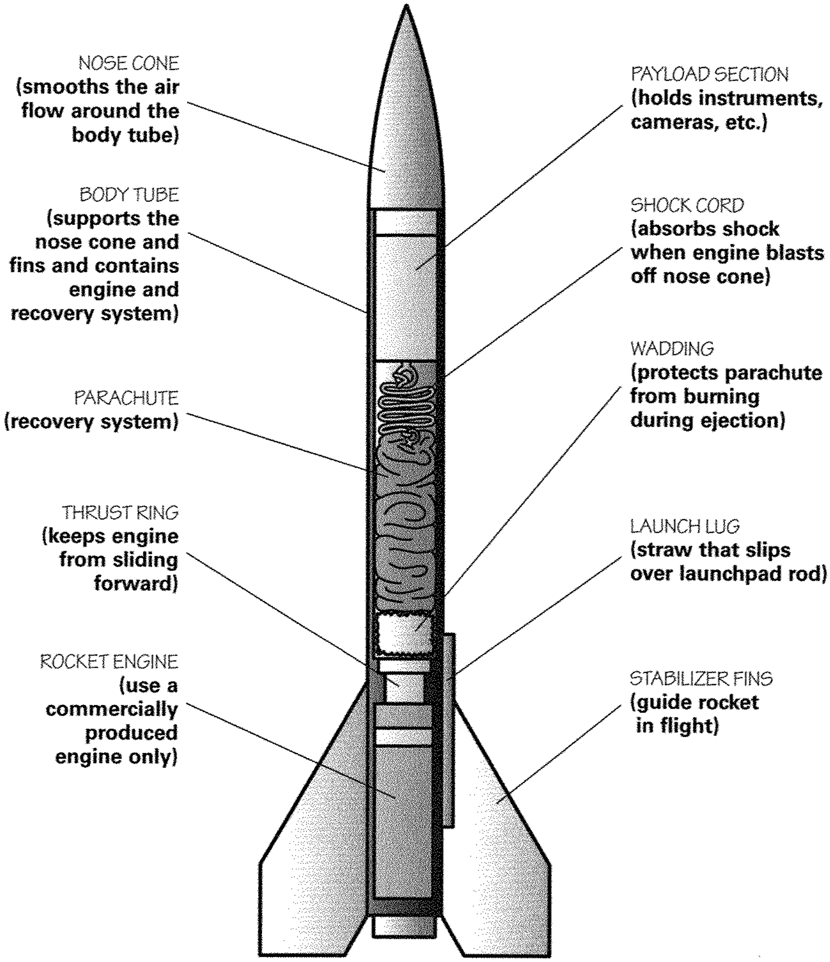
Payloads that can be carried on model-rocket flights include small cameras, radio transmitters, and raw eggs. Payloads carried on space rockets include satellites, spacecraft bound for other planets, scientific experiments, and astronauts.

Model rockets can be recovered in many ways. **Recovery systems** may be parachutes that are stored inside the body tube and ejected automatically by the rocket engine near the time the rocket reaches its maximum altitude. Streamers also are used for recovery. They slow the rocket as it falls back to Earth. Other recovery systems are helicopter-type rotors or wings for gliding landings.

The **rocket engine** is the power plant of your model rocket. An engine consists of a cylinder, called the *casing*, that holds the solid propellant. The upper end of the casing usually has a *plug* and the lower end has a *nozzle*. The nozzle is a small opening through which the burning gases escape. The nozzle makes the gases travel at high speeds when they exit, much the same way the nozzle on a garden hose makes water squirt farther when the hole is smaller.

Inside the engine are the solid propellants. The propellants have oxygen built into their chemistry. This enables them to burn even in outer space, where there is no outside oxygen. (Rocket engines are different from jet engines. Jet engines must take in air from the atmosphere to burn their fuel.)

Model rocket parts



A rocket must accelerate to more than 25,000 miles per hour to completely escape Earth's gravity and fly off into space.

The Way Things Work

Space exploration has been a reality since the late 1950s. Space-age words such as *rocket, satellite,* and *orbit* have become part of nearly everyone's vocabulary. While many people use these words, few really understand the important concepts behind them, such as how a rocket works, how a satellite stays in orbit, or how pictures taken of other planets arrive on Earth.

Physical Laws of Space Flight

In the 17th century, a great English mathematician and scientist named Sir Isaac Newton developed the basics of modern physics. He formed the theories of gravitation when he was only 23 years old. Some 20 years later, he presented his three laws of motion. These three laws explain how a rocket is able to work and how satellites and spacecraft are able to get into orbit and stay there.

Newton's Three Laws of Motion

1. An object in motion tends to stay in motion, and an object at rest tends to stay at rest, unless the object is acted upon by an outside unbalanced force.
2. Force equals mass times acceleration.
3. For every action there is an equal and opposite reaction.

These three laws of motion help make it easier to understand how rockets, satellites, and spacecraft work.

The First Law

Newton's first law is a simple statement of fact. To make an object move, an unbalanced force must be exerted on that object. An unbalanced force is important because forces that are balanced cancel each other out. Imagine two football players pushing against each other. If they exert equal force, they stay in the same place. If one player exerts more force than the other, the weaker player is pushed backward.

It is the same with a rocket. When a rocket is sitting on the launchpad, gravity tries to pull the rocket downward. The structure around the rocket holds the rocket up. Each exerts a force that balances the other, and the rocket stays at rest on the launchpad. When the rocket engine fires, the rocket exerts a greater force than the pull of Earth's gravity. It begins to climb slowly upward. As the rocket gets higher and farther from Earth's surface, the atmospheric pressure thins out and the rocket's mass gets lighter as fuel is expended, changing the balance of forces and allowing it to climb faster and faster.

Once in outer space, the rocket goes into orbit around Earth and the engine stops firing. The rocket continues to move because forces have again become balanced. Its forward motion balances the pull of gravity. (See the section "How Satellites Stay in Orbit.") To bring the rocket back to Earth, those balanced forces must again be unbalanced to allow gravity to take over. This time, the rocket engine fires in the direction of motion to start slowing the rocket. When this happens, gravity brings the rocket back down into the atmosphere.

Conventional rockets carry propellant, which consists of both fuel and *oxidizer.* For a rocket to work in space, it must carry oxygen or a chemical that contains the oxygen necessary for chemical combustion.

The Second Law

Newton's second law states that the force on a body is equal to the time rate of change of momentum of that body, more commonly understood as "force equals mass times acceleration." It determines the amount of force *(thrust)* a rocket engine must produce to leave the launchpad. Burning rocket propellants produce flames, smoke, and gas, which shoot out of the engine as exhaust to produce the thrust.

The amount of thrust depends on two things—mass and acceleration. *Mass* is the total amount of matter contained in the fire, smoke, and gas. The more matter flowing from the engine, the greater the thrust produced. *Acceleration* refers to how fast the exhaust is expelled from the rocket engine. The greater the acceleration, the greater the thrust. A rocket motor achieves this with the "throat" of the nozzle, which constricts the flow of mass and forces it to move faster. The higher the

Multiplying mass by velocity gives a quantity called *momentum.*

exhaust velocity, the more thrust a given quantity of propellant can provide.

Putting mass and acceleration together gives the simple formula $F = ma$. Keeping this formula in mind, a rocket designer should try to make both the burned mass *(m)* and the acceleration *(a)* as large as possible to get the maximum thrust (force, *F*). This is complicated by the fact that as the engine burns fuel, the vehicle gets lighter. If the thrust from the engine remains the same, the acceleration continuously increases.

The Third Law

Newton's third law is the most familiar to people. It is sometimes called the *law of action-reaction*. Imagine you are a firefighter holding a fire hose. When the water is turned on, it explodes out of the hose and douses the fire. The motion of the water is an *action*. At the same time the water is thrown from the hose, the hose produces a strong recoil (kick) on your body, pushing you backward. This is a *reaction*. The reaction is in the opposite direction from the action and is equal in its force.

The movement of a balloon when air is released from it also demonstrates the third law of motion. In the case of the balloon, what is the action? What is the reaction?

How Rockets Are Propelled

Rockets are driven by engines that obey Newton's three laws of motion. While a rocket sits on the launchpad, it is in a state of rest because all forces are balanced. When the rocket engine fires, forces become unbalanced (first law). As exhaust rushes downward out of the engine, an upward thrust is produced because of action-reaction (third law). The strength of that thrust is determined by the amount of matter expelled by the engine and how fast the matter is expelled (second law).

Forcing the exhaust through a small opening called a nozzle increases the speed of the exhaust, producing more thrust. Imagine using a garden hose with a nozzle attachment. With the nozzle wide open, the water streams out and lands a few feet away. By shrinking the nozzle opening, you force the water to move faster and it lands farther away. The greater the velocity, the greater the thrust. You can feel the thrust of the garden hose if you hold it.

The same principle applies to rocket engines, which come in many varieties based on the type of fuel used. Some types of engines used on today's spacecraft include solid propellant engines, liquid propellant engines, hybrid engines, and ion engines. Nuclear engines, solar sails, mass drivers, and other kinds of "futuristic" engines are being studied or developed.

Chemical Rocket: Solid Propellant

The first rocket engines, invented in China hundreds of years ago, used solid propellant. A solid propellant is a chemical compound in powder form that will burn but not explode. The powder is burned inside an enclosed tube, with the exhaust forced out a nozzle at one end.

Solid propellant engines have three advantages: simplicity, low cost, and safety. However, they have two disadvantages: the engine can't be stopped or restarted after the fuel begins to burn, and thrust cannot be actively controlled during the burn. Solid fuel rockets are used for short tasks, like shooting missiles or boosting spacecraft off the launchpad. To have more control over a rocket, liquid propellant engines must be used.

For more about atoms, electrons, and ions, see the *Electricity* merit badge pamphlet.

Chemical Rocket: Liquid Propellant

In this engine type, the fuel and oxidizer are liquids carried in separate tanks. The fuel and oxidizer are pumped into a combustion chamber where the fuel is burned. The exhaust is forced out of the combustion chamber through a nozzle and produces thrust. The nozzle can be tilted *(gimbaled)* to point the thrust in different directions, creating an effective way to steer the rocket.

Liquid hydrogen (fuel) and liquid oxygen (oxidizer) are the most efficient liquid propellants for rockets. They must be kept very, very cold, so the fuel tanks are carefully insulated. These super-cold fluids also are used to cool the super-heated parts of the engine, like the combustion chamber and the nozzle, allowing them to be made of thin metal. Using the liquids as a coolant system allows the weight of the rocket to be reduced.

When you try to push the same poles of two magnets together, the magnets will push each other away—action and reaction. An ion engine uses this effect to accelerate ions and produce thrust.

Chemical Rocket: Hybrid Propellant

Hybrid engines combine a solid fuel with a liquid oxidizer. The solid fuel is contained within the combustion chamber. The oxidizer is fed into the combustion chamber from an oxidizer tank. The exhaust is forced through a nozzle, creating thrust. Because the liquid oxidizer cannot mix with the solid fuel by accident, such a rocket is very unlikely to explode.

Ion Rocket Engines

Ion rocket engines accelerate ions to produce thrust. Ions are created by stripping electrons from atoms. The propellant, usually xenon gas, is heated to extremely high temperature, which causes the xenon atom to give up an electron.

The positively charged ion is passed over a positively charged plate that repels and accelerates the ion from the thrust chamber at extremely high speeds.

Ion engines are the most efficient rocket engines in use today. They produce a low thrust, but they operate for a long time. This means they have a high thrust for the amount of fuel used. An ion engine proved itself on the probe *Deep Space 1*, launched in 1998 and powered by a first-of-its-kind ion engine. The European Space Agency's SMART-1 probe to the Moon and NASA's *Dawn* mission to the asteroid belt also used ion engines. (See "Planetary Exploration" in the next section.)

Currently, the most advanced plasma engine is the Variable Specific Impulse Magnetoplasma Rocket (VASIMR), first conceived in 1977 by astronaut Franklin Chang Diaz. The system uses radio waves to create a plasma of helium ions and electrons generated by a helicon plasma injector and confined and shaped by high-temperature superconducting magnets, which create a magnetic field that guides and accelerates the plasma through the rocket chamber, where it is further heated by radio frequency waves to 1 million degrees. Small amounts of fuel can create significant thrust, and a VASIMR motor has been proposed as a means to continually reboost the orbit of the International Space Station so that Proton rockets don't have to be sent periodically to do so.

How Satellites Stay in Orbit

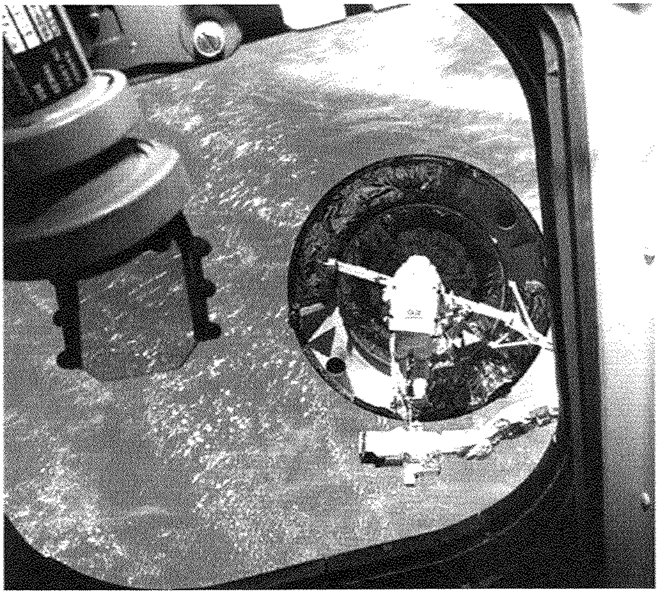
Isaac Newton reasoned that it was the force of gravity—not its absence—that kept the Moon in orbit around Earth. Artificial satellites also operate under the same Newtonian laws.

To explain Newton's reasoning, think about what happens when you throw a ball. Imagine you are standing in a big field and throw a baseball as hard as you can. The ball might travel 100 feet before gravity pulls the ball down to the ground.

Now imagine you are standing on Mount Everest. You throw the baseball and it travels parallel to Earth for some distance before it falls to Earth. Each time you throw the ball, you increase the thrust and the ball travels farther. If you could throw the ball fast enough (and if you ignore friction from the atmosphere), the ball would fall at exactly the same rate that the curve of Earth falls away from the ball. This situation is called *free fall*. The ball would continue traveling parallel to Earth's surface, achieving orbit. This is the basis for how satellites stay in orbit.

At higher altitudes, where the vacuum of space is nearly complete, there is almost no drag and a satellite can stay in orbit for centuries, up to 100,000 years at geosynchronous orbits.

Knowing where satellites and space stations are going to be in their orbit has helped to popularize the pastime of satellite spotting. See the resources section for positioning information.



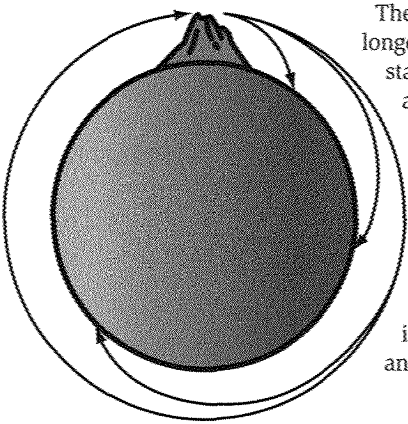
This photo, taken from the shuttle's aft (rear) flight deck windows, shows an astronaut from the space shuttle *Endeavour* trying to capture the Intelsat VI communications satellite.

All satellites ride on rockets to get into orbit. Satellites as large as several tons make it safely into orbit on a regular basis.

Rockets travel straight up at first. This is the quickest way to get the rocket through the thickest part of Earth's atmosphere. Once above the atmosphere, the rocket control mechanism brings the rocket to a course that is parallel to Earth's surface while the rocket accelerates to the velocity needed for that satellite to remain in orbit. This velocity is determined by the weight of the satellite and the altitude of the orbit to be achieved.

Orbital velocity is the speed needed to reach a balance between gravity's pull on the satellite and the satellite's inertial tendency to keep going. If too much velocity is imparted to the satellite, it will escape from Earth and enter into a Sun-centered (heliocentric) orbit. If too little velocity is imparted to the satellite, gravity will pull it back to Earth. At the correct speed, the satellite will be in perpetual free fall.

Because of this constant state of everything falling together at the same speed, the satellite and everything aboard seems weightless. That is why astronauts can float inside the International Space Station.

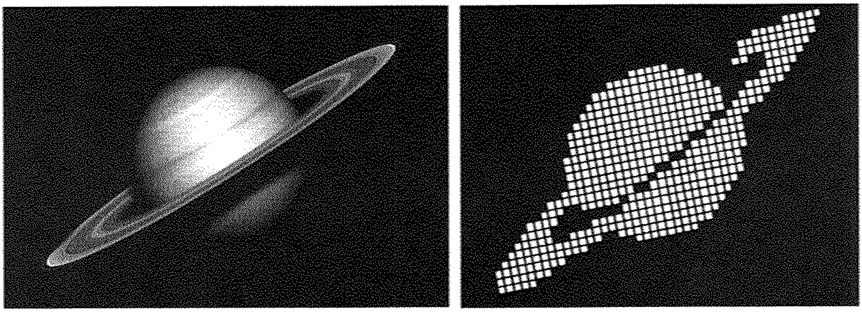


The higher the orbit, the longer the satellite can stay in orbit. At lower altitudes, a satellite runs into traces of Earth's atmosphere, which creates drag. The drag causes the orbit to decay, or decrease, until the satellite falls back into the atmosphere and burns up.

The arrows represent baseballs thrown at different velocities.

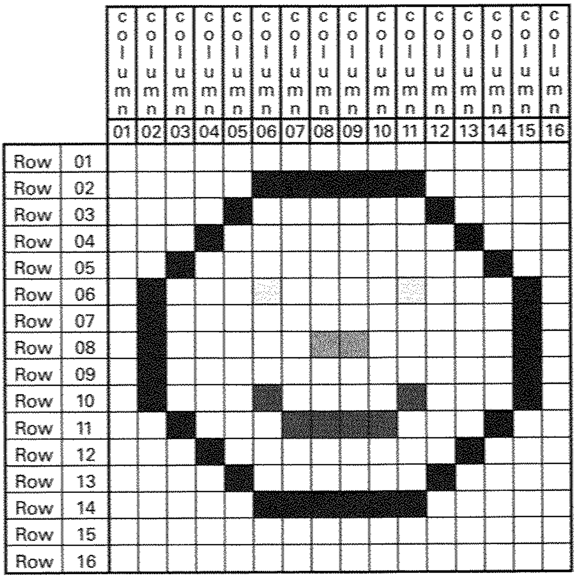
Space Pictures

Space pictures have evolved along with the digital technology of the computer, internet, and cell phone. Early space pictures were made on film, which had to be returned to Earth and processed. Today, scientists use CCDs, or charge-coupled devices, to gather the information digitally. Early video was grainy and barely usable.



Images taken by spacecraft consist of many tiny squares called *pixels.* The picture of Saturn, *left,* is made of hundreds of thousands of pixels, shown (greatly exaggerated) at *right.*

As space probes ventured farther into space, scientists needed better ways to record, store, and transmit pictures. Information scientists developed a coding system that treats each picture frame as a grid with numbered squares. Each square is a picture element—*pixel,* for short. Every pixel has its own address of numbers in the grid that gives the pixel's row and column. For example, the address of the pixel in row 01, column 01, is 01-01. The address of the pixel in row 16, column 10, is 16-10. (See the illustration.)



Tone Scale

01		White
02		Light Gray
03		Medium Gray
04		Dark Gray
05		Black

In this "smiley face" example, pixel 01-01 is white, and therefore is coded as 01-01-01. Pixel 06-02 is black. It is coded as 06-02-05. Pixel 06-06 is light gray. It is coded as 06-06-02.

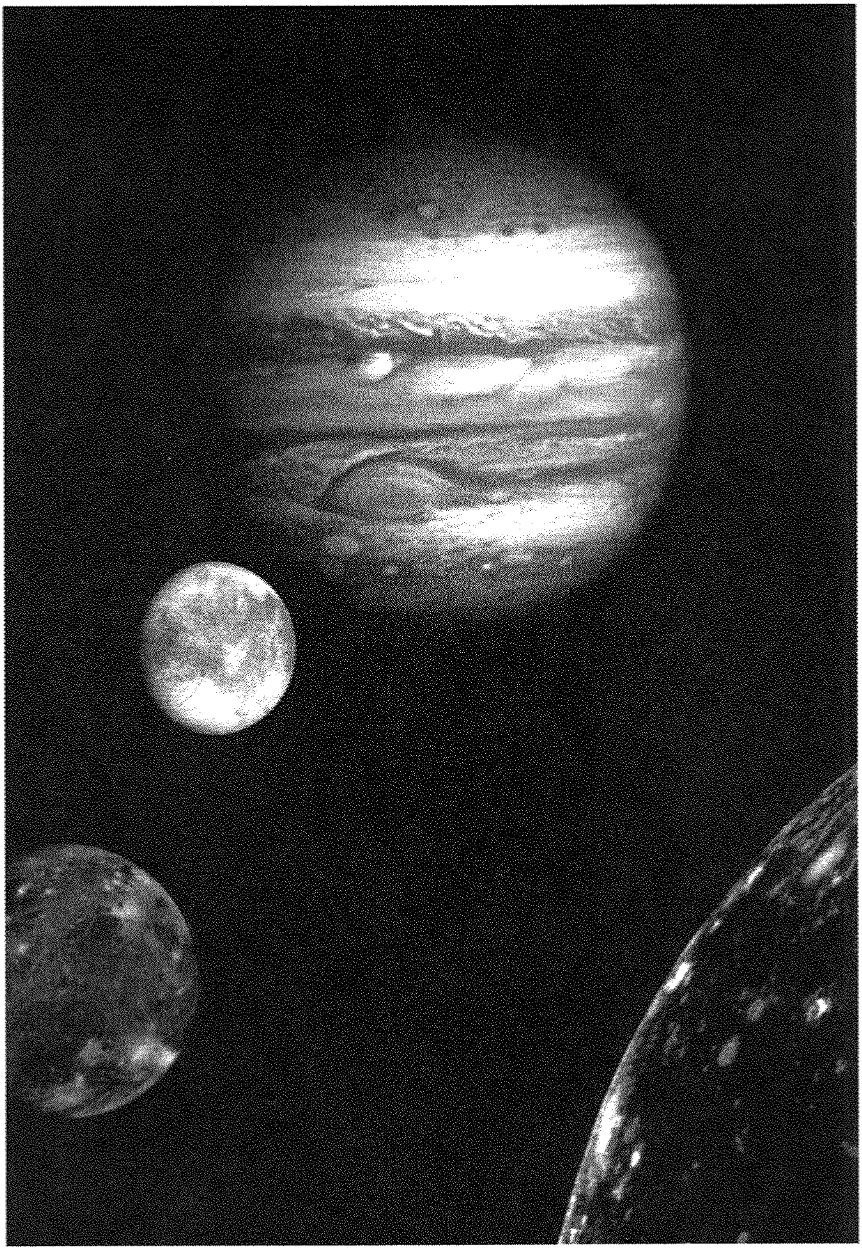
When a space probe's sensor views an object, it senses the brightness or shade of each pixel in the scene. Shades are measured on a *gray scale,* which is a gauge of the shades of gray from pure white to pure black.

Let's assume we have a simple gray scale with only five shades. Each shade is numbered. White is 01, light gray is 02, and so on to solid black, 05. The sensor assigns each pixel the number that corresponds to the shade sensed.

These numbers are stored in a computer memory and then transmitted to the waiting scientists. The receiving computer is programmed to arrange the pixels into a grid, show the correct shade of gray for each picture element, and reconstruct the picture row by row.

In early missions where the data transmission rate was slow and computer memory limited, it might take several minutes to display one picture frame. *Mariner 4,* when it photographed Mars in 1965, made images 200 x 200 pixels in size. Each complete image took nearly 9 hours to reach Earth. In contrast, the *Clementine* lunar mission in 1994 returned 2 million images in $2^1/2$ months, averaging more than 1,000 images an hour. (These robot spacecraft are described in the next section, "Planetary Exploration.")

A farmer in Kansas takes part in a program that gives him satellite imagery of his farm. He can see moisture content and decide when to plow and seed his crops. As the crops grow, he can tell if insecticides or fertilizers are required. The farmer can tell when his wheat is ripe and can be harvested. This is just one of many examples of how space pictures can improve everyday life.



Planetary Exploration

Long ago, the Greeks noticed bright, starlike objects moving among the stars. These "wanderers" included the Sun, Moon, Mercury, Venus, Mars, Jupiter, and Saturn. People thought all these objects circled Earth, which was thought to be at the center of the universe.

In the 16th century, Nicolaus Copernicus determined that Earth was a planet, too, and that the six known planets went around (orbited) the Sun while the Moon circled Earth. Then, in 1610, Galileo Galilei turned a newly invented instrument—the telescope—toward the heavens. He looked at Jupiter, and what he saw astounded him.

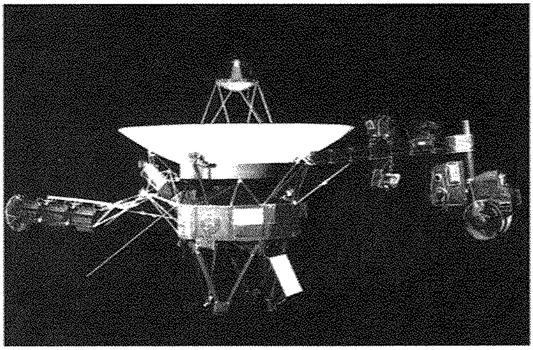
Through the telescope, Jupiter was not a wandering point of light, but a round disk with four small starlets (moons) circling it. Earth's Moon was not a smooth shadowy ball, but a sphere pockmarked with craters and laced with cracks and ridges. Venus went through phases like the Moon, Saturn had bumps on its sides (the rings), and the Sun had spots on its surface. The worlds of outer space were more exciting than anyone had imagined.

Almost 350 years later, when people learned how to send objects—spacecraft—into space, a new era of exploration began. Scientific instruments and cameras could now be carried above the filtering effects of Earth's atmosphere, providing clearer views of outer space than ever before. Spacecraft could go to those faraway places Copernicus and Galileo barely knew.

For more about planets, moons, and stars, see the *Astronomy* merit badge pamphlet.

Space Probes: Tools of the Space Age

A *spacecraft* is any vehicle that flies in outer space, whether or not it carries people. An unmanned spacecraft is technically known as a space *probe.* Such probes have been used since the late 1950s to explore other worlds, large and small, in our solar system.



The space probe *Voyager 2*

A space probe is a clever arrangement of mechanical and electronic parts packed together inside a sturdy, compact box or shell that is launched aboard a rocket. Once in space, the box opens and the various parts (components) begin to operate. Each group of components plays an important role toward accomplishing the mission—controlling the spacecraft, taking measurements of its surroundings, or communicating with people on Earth, thousands or millions of miles away.

Scientific instruments aboard a spacecraft detect and measure what's out there. Almost every probe carries one or more cameras to capture images of the object it visits. Some probes may have devices to measure radiation, temperature, and magnetic fields. Those that land on an alien surface may carry a miniature weather station and a scoop to sample the soil. Other devices may be designed to detect certain chemical elements or compounds, such as water.

More recently it has become possible for landers to relay their communications through an orbiter around the same planet that then sends the data to Earth at a later time.

A computer system stores commands that direct the other components to function and to control the craft. The computer also collects the information gathered by the instruments and gets it ready for transmission to Earth. When it is time to send the data to Earth, an antenna aims radio signals in the right direction. Another antenna receives signals from Earth.

To do all these things, a spacecraft needs a power supply. The probe may have solar cells to convert sunlight into electricity. Or it may have a nuclear-powered generator to provide electricity, especially if it is visiting a planet far from the Sun. Because outer space is extremely cold, some power goes to a heater that keeps the spacecraft at the right temperature for the computer, instruments, and other components to operate.

After the probe has been launched into space, altering its direction becomes necessary during millions of miles of travel. A set of small rockets (thrusters) is used to adjust the probe's course or "put on the brakes" if the probe must go into orbit around a planet or land on an alien surface.

Another means of changing direction or speed takes advantage of a large planet's gravity—a "slingshot" effect, known as *gravity assist*. With careful aim, a probe can be pulled toward the planet, whipped around, and then accelerated away in the desired direction. Spacecraft use the gravity-assist method to travel quickly to their destination while conserving precious fuel.

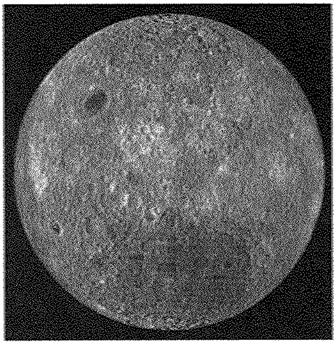
The Soviet Union's *Zond 5* was the only spacecraft to carry living creatures other than humans as far as the Moon. A payload of turtles, mealworms, plants, and other life-forms survived the trip and splashed down in the Indian Ocean in September 1968.

Robotic Missions to the Moon

Many attempts were made before the first probe flew past the Moon. On Jan. 4, 1959, the Soviet *Luna 1* impactor flew within 6,000 km of the Moon before entering an orbit around the Sun. Two months later, *Pioneer 4* became the first U.S. probe to pass by the Moon, at a distance of 60,000 km, before also entering a heliocentric orbit. The Soviets achieved additional lunar firsts with the first hard lander, *Luna 2*, which landed in Palus Putredinis in September of the same year, and *Luna 3* a month later, which provided the first images of the lunar far side. As a consequence, all of the most easily photographed features bear Russian names.

After a number of failures on both sides over the next five years, the *Ranger 7, 8,* and *9* missions returned more than 17,000 increasingly close-up images on their way to impacting the Moon's surface in 1964 and 1965. In mid-1966, NASA achieved the first controlled landing on the Moon with *Surveyor 1*. Four more Surveyor missions followed to research the lunar surface in anticipation of the Apollo landings. Five Lunar Orbiter spacecraft also mapped the lunar surface to provide greater detail on potential landing sites.

The Soviet Union continued to explore the Moon into the mid-1970s. Zond spacecraft flew around the Moon, took photographs, and returned to Earth with their payload. The Soviet Moon program also included several successful sample return missions and a pair of remote-driven rovers called *Lunokhod* ("moon walker"), which covered 10.5 km and 37 km of the lunar surface over a period of more than a year.



This mosaic of the far side of the Moon is composed of more than 15,000 images taken by the Lunar Reconnaissance Orbiter Camera between November 2009 and February 2011.

NASA scientists increasingly turned their attention to other destinations in the solar system, while lunar scientists worked through the enormous amount of data returned by Apollo. This led to a long dearth of lunar missions.

The Japanese space agency conducted its first lunar mission in 1990 with the *Hiten* (meaning "celestial maiden" or "flying angel") probe, which achieved limited success in conjunction with the deployed *Hagoromo* orbiter.

In 1994, the U.S. Department of Defense launched an experimental spacecraft named *Clementine* that orbited the Moon for 70 days, mapping its surface. It detected the possible presence of frozen water at the Moon's south pole with an experiment that demonstrated the presence of hydrogen. In 1998, *Lunar Prospector* mapped the lunar surface in more detail, measured magnetic and gravity fields, and studied geological events. It also showed the presence of hydrogen near the poles. After one year, it was intentionally crashed near the south pole in the hope of revealing water ice.

The European Space Agency (ESA) launched its first mission to the Moon, *SMART-1*, in 2003. This probe used an ion thruster, slowly spiraling the probe up out of Earth's gravity well until it could be captured into the Moon's gravitational sphere of influence. It arrived in late 2004 and began surveying to identify chemical elements in the lunar surface. It too was crashed into the Moon in hopes of excavating a debris plume with evidence of water.

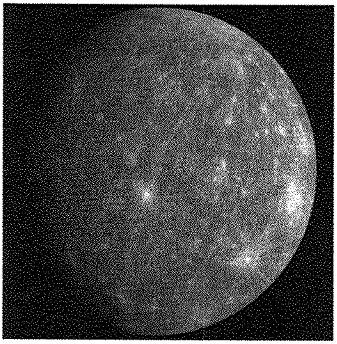
In late 2007, Japan launched its *Kaguya* ("Moon maiden") probe and China joined the roster of lunar visitors with its *Chang'e-1* ("Moon princess") probe. Both were designed to map the surface and identify the chemicals found there. A year later, India launched its first Moon probe, *Chandrayaan-1* ("Moon vehicle"), which carried an international suite of scientific instruments. Then came NASA's Lunar Reconnaissance Orbiter (LRO) and Lunar CRater Observation and Sensing Satellite (LCROSS), which slammed a school bus–sized probe into the lunar south pole region to try to excavate a plume that was observed from Earth, and revealed a rich variety of chemicals, including water. In 2010, China launched *Chang'e-2*.

NASA launched the Gravity Recovery and Interior Laboratory (GRAIL) mission in 2011 to study the Moon's gravity fields and internal mass distribution. Under development for future launch are *LADEE, Luna-Glob, Chang'e-3, Chandrayaan-2,* and the first node of NASA's International Lunar Network (ILN).

Unveiling Venus and Mercury

Mysterious Venus, whose surface hides from Earth-based telescopes under a shroud of clouds, was the first planet after Earth to be examined by a robotic spacecraft. The United States had *Mariner 2,* after orbiting the Sun for almost a year, approach and fly by Venus in December 1962. The spacecraft reported the planet was over 900 degrees Fahrenheit, hotter than Mercury.

The Soviet Union was bolder with its Venera program, whose 16 probes intensively explored Venus between 1961 and 1983. Venera was the first spacecraft to probe the planet's atmosphere, the first to land there, the first to photograph its surface, the first to analyze the soil, and the first to map the terrain. Starting with *Venera 4* (1967), the spacecraft was two probes: a carrier that stayed up high and a lander that dropped toward the surface. But the dense Venusian atmosphere crushed each lander before it could land. Eventually, *Venera 7* was built strong enough to safely descend. It lasted for 23 minutes on the surface of Venus in 1970.

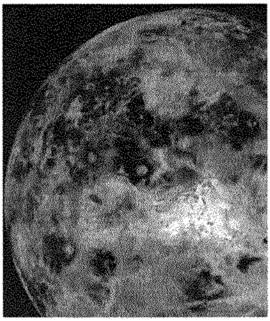


Mercury photographed by *MESSENGER* in October 2008 as the spacecraft left the planet.

The United States then sent *Mariner 10,* which achieved two goals. Three months after launch in November 1973, the probe flew by Venus and took many measurements of the atmosphere. With assistance from Venus' gravity (like a slingshot), it sped onward to Mercury, the Sun's closest planet. *Mariner 10,* which photographed about 40 percent of Mercury's surface, has been the only probe to visit there until the *MESSENGER* probe began flybys in 2008 and started orbiting the planet in 2011.

In the 1980s, *Vega 1, Vega 2,* and *Magellan* visited Earth's "sister" planet. The Vegas, identical 36-foot-long probes from the Soviet Union, reached Venus in June 1985. They dropped a landing capsule onto the surface, released a balloon into the atmosphere, and then got slingshot by the planet to intercept

Magellan revealed the presence of large volcanoes, lava plains, and extremely long lava channels. It also discovered deformed, flattened mountains. We finally knew what lurked under Venus' clouds: a barren world.


***Magellan's* view of Venus**

Halley's Comet. The balloon carried instruments that measured atmospheric temperature, pressure, and wind speed. The lander took similar measurements and photographs, and analyzed the chemical makeup of the air and soil.

Magellan was the first planetary spacecraft to be launched from the space shuttle (in May 1989). After entering a polar orbit around Venus in August 1990, *Magellan* spent more than four years mapping 98 percent of the hidden terrain using radar.

Scientists returned to Venus in 2006, when the ESA's *Venus Express* probe entered into a polar orbit around the planet. The probe revealed a thinner atmosphere than expected as well as evidence that the planet may still be geologically active.

NASA's *MESSENGER* probe has made several close approaches to Mercury, providing imagery to fill in the gaps left by *Mariner 10*. In March 2011, it became the first spacecraft ever to orbit Mercury, where it has been studying the composition and structure of the crust, among other things. The ESA has the *BepiColumbo* probe under development for launch in 2015 with arrival at Mercury in 2022.

Missions to the Red Planet

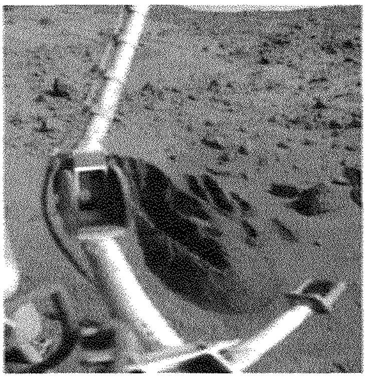
At the end of the 19th century, astronomer Percival Lowell focused a large telescope on Mars and reported seeing canals on its surface. People's imaginations soared, but scientists had to wait until 1965 before a spacecraft flew to the Red Planet. Pictures from *Mariner 4* revealed a surface covered with craters, similar to the Moon. The probe's instruments found Mars had a thin atmosphere of mostly carbon dioxide. Not a single canal or other sign of life was spotted.

Mariner 9 was the first U.S. spacecraft to orbit another planet, arriving at Mars in November 1971 to find a dust storm enveloping the planet. The probe delayed taking pictures of the surface for several months until the dust settled. After 349 days in orbit, *Mariner 9* had transmitted more than 7,000 images, covering over 80 percent of the Martian surface. Notable features were river beds, massive extinct volcanoes, and a series of canyons that stretched more than 2,500 miles long. The probe found evidence of wind erosion, water erosion, weather fronts, clouds, and fog—but no life.

The Soviet Union turned its attention to Mars in the 1970s, beginning with the *Mars 2* probe, which successfully arrived in November 1971, a few weeks after *Mariner 9*. The *Mars 2* spacecraft released a lander that descended into the raging dust storm and crashed. However, the orbiter took photographs and studied the atmosphere and surface. *Mars 3*, which was identical to *Mars 2*, had better luck. The vehicle landed safely and transmitted the first television pictures of the Martian surface for 20 seconds, then communication from the lander was lost.

Americans were excited when two Viking missions reached Mars in 1976. Each craft had two parts, an orbiter and a lander. *Viking 1* landed on July 20, 1976, while *Viking 2* settled on the other side of the planet six weeks later. While each orbiter took detailed photos and communicated with Earth, each lander stood on three legs with large circular footpads and performed its duties. A camera took the first close-up image of the Martian surface—a footpad and a bunch of rocks. People were awestruck by Mars—its red boulders, red soil, and pinkish sky.

Each Viking lander extended a long arm into the soil, scooped up samples, and dropped them into three chemical laboratories. The labs tested the soil to find chemicals that might come from a microscopic organism. The results of all these experiments were inconclusive, the scientists decided, meaning there was still much to learn about Mars.



The *Viking 1* lander dug these trenches on Mars.

Mars Pathfinder was the next spacecraft to arrive safely, landing on July 4, 1997. The craft bounced onto the Martian surface, its fall from space cushioned by inflated airbags. The craft was shaped as a tetrahedron—four triangular sides—so that when it stopped bouncing, the three sides standing up would fall open like a flower.

Mars' giant canyon was named Valles Marineris in honor of the Mariner spacecraft. The canyon is three times as deep as the Grand Canyon. One of Mars' extinct volcanoes, Olympus Mons, is 15 miles high, the largest in the solar system.

The redness of the rocks and soil on Mars is due to the presence of iron oxide, which we know as rust. The sky looks pink because of the dust blown about by the wind.

Aboard was a small rover (two feet long and one foot high) named *Sojourner.* Powered by a solar panel on its back, the rover rolled down a ramp and traveled close enough to the nearest rock for one of its instruments to touch the rock and determine its composition. Then the rover visited other rocks, large and small, around the lander. The rover was designed to last for seven days and the lander for 30 days; each operated for 83 days.

A Mars probe was launched in 1996, arriving in September 1997. After establishing a nearly polar orbit, the *Mars Global Surveyor* began mapping the terrain in early 1999. Its original two-year mission lasted until 2006.

Missions to Mars show how difficult space exploration can be and, in particular, what a challenge it is to send spacecraft to Mars. Several missions to the Red Planet have failed. The Soviet Union had trouble with every one of its Mars-bound probes—*Mars 2–7, Phobos 1–2,* and *Mars '96.* The United States experienced a huge loss when its *Mars Observer* craft, carrying many science instruments, vanished in space in 1993. To prepare for orbit, the craft turned off its transmitter while pressurizing its fuel tanks. Something went wrong, and the spacecraft was never recovered.

After the success of *Mars Pathfinder,* NASA launched *Mars Climate Orbiter* in December 1998 and *Mars Polar Lander* in January 1999. As *Climate Orbiter* tried to orbit the planet, an earlier miscommunication between NASA and a contractor that did not specify English or metric units triggered an error in the probe's trajectory that plunged it too low into the atmosphere during its aerobraking maneuver, causing it to burn up. Months later, on Dec. 3, 1999, planetary scientists and space enthusiasts waited anxiously as *Polar Lander* began its descent into the Martian atmosphere. Since there had been no communication, there was no way to know what went wrong.

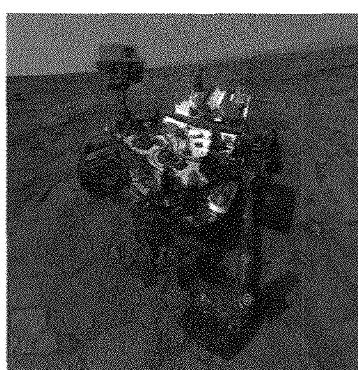
After 2000, scientists began to explore the Red Planet in a more robust and comprehensive manner. NASA's *Mars Odyssey,* which arrived in late 2001, mapped the global distribution of near-surface ice on Mars, finding ice-rich ground extending far toward the equator from the visible polar caps. It was still returning data in 2016. ESA's *Mars Express,* which arrived in late 2003, provided critical radar scans of the subsurface of Mars and studies of the atmosphere and space environment around the planet and its moons. It also carried the *Beagle 2* lander to study the surface, but contact was lost with the lander after it separated from *Mars Express*.

In early 2004, the Mars Exploration Rovers (MER) *Spirit* and *Opportunity* arrived at Mars for a three-month mission to "follow the water," looking for environments that had water in the past and might have been able to support life. *Spirit* proved that some of the planet's rocks were formed in the presence of water in ancient Mars, and both rovers found nickel-iron meteorites there. Communication was lost with *Spirit* in 2010, but *Opportunity* continued to return data for several more years.

Spacecraft have made a number of discoveries about Mars:

- The entire north polar area of Mars may be a gigantic impact basin.
- Mars has climate cycles similar to Earth's.
- Mars has methane in the atmosphere, which could be produced by underground bacteria or geological events.
- Mars has millions of cubic miles of water frozen in its polar caps and in its crust near the poles. Early Mars probably had a huge ocean filled with icebergs and pack ice that covered its north polar area. Liquid water on the surface became rare as the planet lost atmosphere and got colder and drier.
- Mars has a very weak magnetic field, which allows some of its air to leak into space more easily.

Mars exploration continued in 2006 with the *Mars Reconnaissance Orbiter* and in 2008 with the *Phoenix Mars Lander*. The Mars Science Laboratory named *Curiosity* was launched in August 2012. Its mission is to provide an intensive study of its landing zone as well as serve as a weather station with a suite of climate and meteorology instruments to provide a richer knowledge of how Mars' atmosphere and climate works now, so we can better predict how it worked in the recent and distant past.



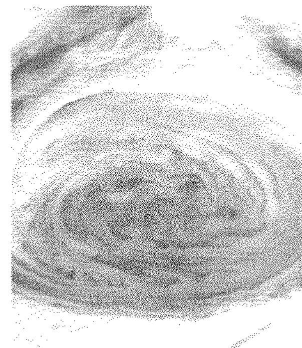
The Mars rover *Curiosity*

While *Pioneer 10* headed into interstellar space (leaving the solar system in 1983), *Pioneer 11* flew by Saturn in 1979, the first probe to do so. It photographed and took measurements of the planet, its rings, and some of its moons, too. The spacecraft lost power in 1995.

The Grand Tour: Exploring the Outer Planets

Jupiter and Saturn have mystified people for centuries. What is that Great Red Spot? Why does Saturn have rings? How many moons circle each planet? The Pioneer and Voyager missions revealed those worlds to be more fascinating than expected.

Pioneer 10 was the first spacecraft to travel through the asteroid belt. Some scientists feared the craft might hit an asteroid, but it reached Jupiter safely in December 1973. *Pioneer 10* took the first up-close photographs of Jupiter, which showed the planet had colorful swirling bands. Photos revealed smaller white spots besides the Great Red Spot, which is a hurricane large enough to cover at least two Earths. The craft also measured Jupiter's strong magnetic field and radiation belts. *Pioneer 11* did the same, one year later.



Jupiter's Great Red Spot

The United States launched two Voyager probes in 1977. *Voyager 1* reached Jupiter in March 1979. *Voyager 2* arrived four months later. Each probe photographed the planet and its four largest moons—Io, Europa, Ganymede, and Callisto—in detail. Io has volcanoes and resembles a "pizza ball." Europa has a cracked, icy surface (and possibly a liquid ocean beneath the ice). The probes discovered that lightning crackles in Jupiter's cloud tops, a thin ring surrounds the planet, and it has many more moons than had been observed from Earth.

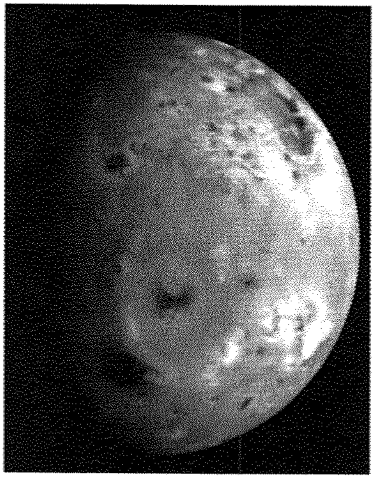
At Saturn in 1981, Voyager revealed the rings to be more complex and grand than expected. Dark spokes could be seen, and small moons were found that guided the ring material. Saturn's largest moon, Titan, was also studied, though its atmosphere was too thick for cameras to see the surface.

While *Voyager 1* headed out of the solar system, *Voyager 2* took advantage of a rare alignment of the outer planets. The spacecraft continued on to Uranus (1986) and then Neptune (1989), achieving the "Grand Tour." The craft detected faint rings around both gas giants and discovered new moons.

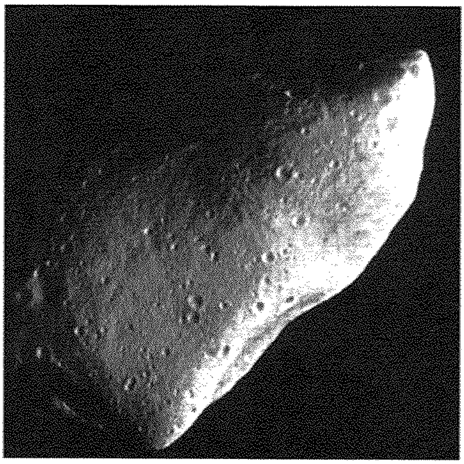
A spacecraft named *Galileo*, launched from the space shuttle in 1989, visited Jupiter in 1995, using gravity assist from

Venus and Earth. It released a small probe that plunged into Jupiter's cloud layers and measured temperature, pressure, chemical composition, and other characteristics before the planet's dense atmosphere crushed it. Its orbiter flew around Jupiter often and visited the major moons, collecting much data. *Galileo* survived for eight years in the Jovian system despite the harsh radiation.

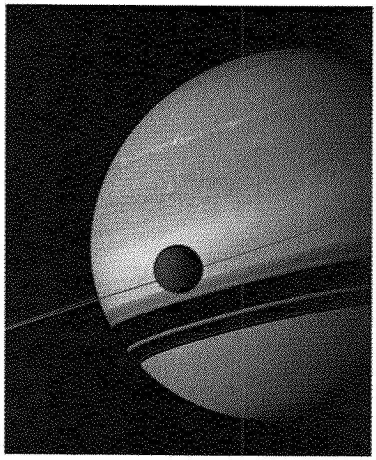
The *Cassini* mission to Saturn was launched in 1997, carrying ESA's *Huygens* probe along for the long journey. After gravity-assist visits to Venus, Earth, and Jupiter, the robotic probe arrived at Saturn in June 2004. Six months later it released the *Huygens* probe for its descent to Titan. The *Cassini* orbiter spent the next four years studying Titan and Saturn's rings and other moons. Its operations were later extended, first as the Cassini Equinox Mission and then as the Solstice Mission through 2017.



Jupiter's moon Io is one of the most volcanically active bodies in the solar system.



***Galileo* was the first spacecraft to photograph an asteroid (Gaspra) up close. It also discovered a tiny moon named Dactyl orbiting the asteroid Ida, *above*.**



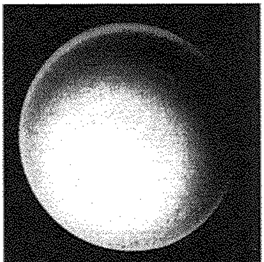
***Cassini*'s view of Saturn and Titan, Saturn's largest moon**

Wandering Through Space

Giotto found that the nucleus of Halley's Comet was about 9 miles long and 6 miles wide. Although the comet lost about 35 tons of matter every hour as it neared the Sun, it still has enough material to survive a few hundred trips through the solar system.

Not every robot space probe visits a planet. Some head to much smaller objects—comets and asteroids. When Halley's Comet approached the Sun in 1986, some countries and space agencies launched probes to meet it. From the Soviet Union, two Vega spacecraft flew by the comet in March 1986 and took measurements on their way to Venus. A few days later, Japan's *Sakigake* probe briefly passed by. Last and most daring was *Giotto*, a probe sent by the European Space Agency.

Giotto traveled into the fuzzy white "head" of Halley's Comet, a cloud of gas and dust surrounding the nucleus. More than 200 dust particles per second struck the craft. One dust grain (about a third of an ounce) knocked out communications with Earth for a short while, but the 9-foot-long cylinder-shaped probe survived its passage through the comet. Giotto found that the nucleus of the comet was about 9 miles long and 6 miles wide.


Uranus

NASA launched *NEAR Shoemaker* in February 1996. The craft's name explained its objective: Near Earth Asteroid Rendezvous. It reached the small, potato-shaped asteroid Eros in February 2000 and became the first probe to orbit and land on an asteroid.

NEAR Shoemaker was named for Dr. Eugene Shoemaker, a famous geologist and astronomer who studied how asteroids and comets may have shaped the planets. He was co-discoverer of a comet (Shoemaker-Levy No. 9) that smashed spectacularly into Jupiter in 1994.

The spacecraft *Deep Space 1* had no destination when it launched in October 1998. Its purpose was high-tech testing in outer space. One device tested was an ion engine, first of its kind, that performed better and longer than expected. *Deep Space 1*'s mission was extended to encounter a near-Earth asteroid in 1999 and Comet Borrelly in 2001.

The *Stardust* probe's primary mission for its was to collect comet samples and return them to Earth for study. It flew by the comet Wild 2 (pronounced Vilt) in 2004, and in 2006 returned a canister of aerogel containing bits of comet dust, which included small amounts of stardust grains. The robotic probe visited comet Tempel 1 in 2011 to build on the *Deep Impact* dataset.

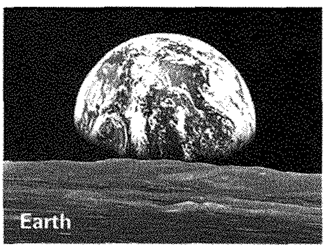
For *Stardust* to collect the comet particles without damaging them, NASA made use of a unique high-tech material called *aerogel* which is 99 percent air. Aerogels are now put to a variety of uses, from hyperefficient winter coats to thermal insulation in the construction trade.

NASA's *Deep Impact* probe was designed to look inside a comet. In mid-2005 it did so by hitting comet Tempel 1 with a copper impactor and then examining the plume of debris from that collision (including 250,000 tons of water). The probe visited comets Hartley 2, Garradd, and ISON before communication was lost in September 2013.

ESA's *Rosetta* probe is designed to provide long-term data collection of a comet, 67P/Churyumov-Gerasimenko. Launched in 2004, the probe arrived in 2014 after a series of gravity boost planetary flybys of Earth and Mars. It then delivered a lander to study the comet surface in detail.

Japan's *Hayabusa* ("peregrine falcon") probe was launched in 2003 to rendezvous with and collect samples from asteroid Itokawa, an asteroid so small that other objects tend to just settle up against it without creating a crater. Using an ion engine, it was able to catch up with and touch down on the asteroid to collect samples from the surface. These samples were returned to Earth by the spacecraft in mid-2010.

NASA's *Dawn* mission is tasked with visiting the two largest occupants of the asteroid belt: Vesta and Ceres. The mission, launched in 2007, reached the asteroid Vesta in 2011 where it orbited for one

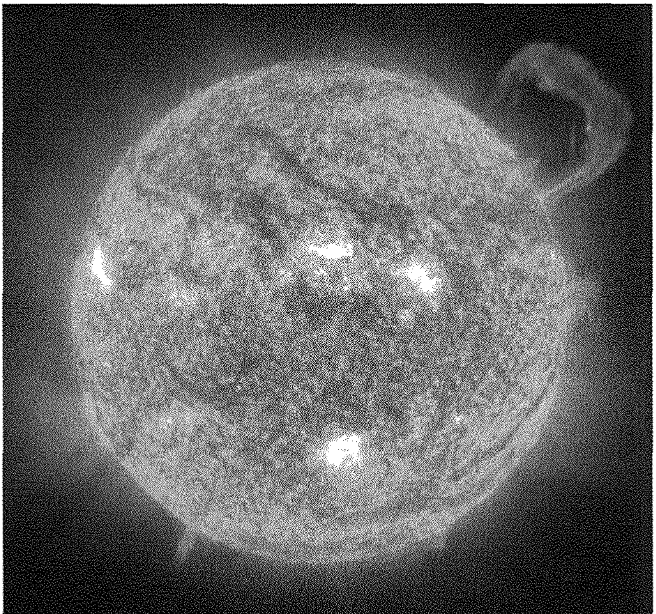


The **ecliptic plane** is the two-dimensional plane traced out by the Earth's orbit around the Sun, its orbital plane. Eclipses can only happen when the Moon is in this plane, hence the name. The other planets in the solar system have orbital planes whose inclinations are very close to Earth's orbital plane.

year while studying the size, shape, mass, gravitational fields, surface and subsurface composition, interior structure, and the nature and role of water in the asteroid. *Dawn* rendezvoused with Ceres in 2015.

What About Our Sun?

Let's not forget the largest and most important member of the solar system. Several space probes have been sent into orbit to study our Sun. Some of the Pioneer series did so in the 1960s. Two Helios probes measured the solar wind in the mid-1970s. The Solar Maximum Mission observed solar flares in the 1980s and was repaired in space when a shuttle crew captured, repaired, and released it in 1984.



The **corona** is the outermost and thinnest part of the Sun's atmosphere. It is sometimes visible during a solar eclipse. The **solar wind** is a stream of charged particles coming from the corona.

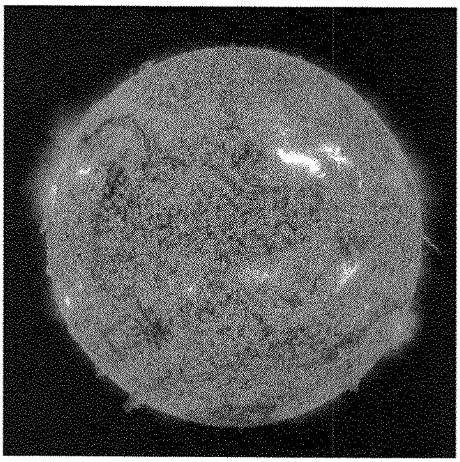
Ulysses, launched in October 1990, was the first spacecraft to travel in an orbit nearly perpendicular (vertical) to the *ecliptic plane*. No human-made vehicle could produce the power to break out of the ecliptic plane on its own, so *Ulysses* relied on mighty Jupiter's gravity to hurl it above that level. During its 18-year mission, it was able to fly over the Sun's north and south poles, which had never been observed or measured in scientific detail before.

SOHO is the *So*lar and *H*eliospheric *O*bservatory. Launched in December 1995, *SOHO* was sent to study the nature of the Sun's *corona* and inner structure, as well as detect the *solar wind*. During its mission, *SOHO* discovered more than 50 Sun-grazing comets and made movies of *coronal mass ejections*, which produce dangerous radiation that can cause communication blackouts on Earth. *SOHO* continues to operate and is still returning data after more than 20 years in space.

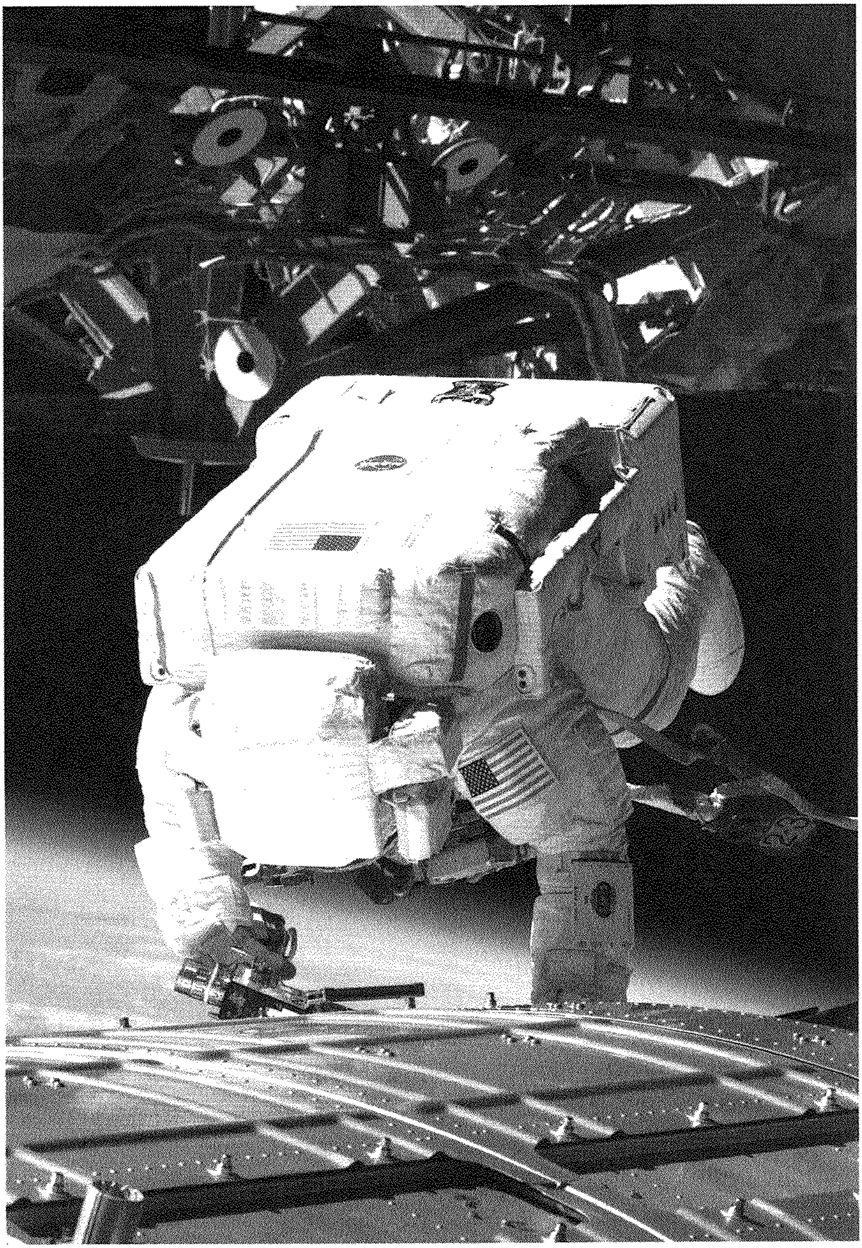
Launched in late 2001, NASA's *Genesis* mission was designed to collect particles of solar wind to return to Earth for study. After taking up station at the Sun-Earth L1 point that same year, it spent the next 28 months in collection mode using collector arrays of different materials as well as a bulk collector. The probe then used its ion engines to maneuver into a low-energy trajectory that swung it by the Moon and back to Earth, where it crashed into the Utah desert in 2004. Scientists were able to recover some of the arrays relatively intact and have been analyzing them since.

STEREO, or Solar *TE*rrestrial *RE*lations *O*bservatory, was launched in October 2006 to study coronal mass ejections. It consists of two observatories, one of which is ahead of Earth in its orbit and the other behind.

NASA launched the Solar Dynamics Observatory (SDO) in early 2010 to geostationary orbit, where it collects data on our Sun with a focus on the magnetic fields and how they affect space weather.



SDO's view of the Sun in 2012



Distinguished Eagle Scout Mike Fossum, STS-124 mission specialist, took a seven-hour space walk during a mission at the International Space Station in 2008.

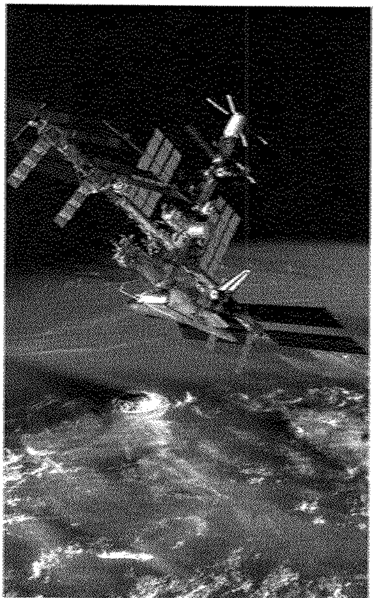
Near-Earth Space Habitats

People need food, water, air, clothing, shelter, waste disposal, and some measure of safety to live. Earth gives us these things, but outer space does not (not even on other planets). There is no air to breathe in space. Space is either too cold or too hot for humans. Radiation from the Sun and cosmic rays can harm a person. There are small and large objects—natural (meteoroids) or artificial (pieces of rockets, paint chips, and other "space junk")—that travel fast enough to make holes in metal sheets or spacesuits.

A habitat built in space must provide everything essential for a comfortable life while shielding people from the dangers of space. There are four kinds of space habitats:

1. Spaceships (such as the space shuttle)
2. Space stations that orbit Earth (near-Earth habitats)
3. Bases and settlements on other worlds (such as the Moon and Mars)
4. Permanent structures in deep space

This section covers the space shuttle and space stations that go (or have gone) around Earth. The next section discusses the possibility of an inhabited base on the Moon or Mars. (The fourth kind of space habitat—deep-space structures—will not be discussed here.)



A spaceship is for travel; a space station is for living. A spaceship carries a person from one habitat (such as Earth) to another (the space station) and provides a comfortable environment for as long as the trip lasts. A space station, on the other hand, must keep people alive for months or years.

Features of a Near-Earth Habitat

Consumables are things that are used up and must continually be replaced. For a near-Earth space habitat, the consumables—food, clothing, water, and air (to start with)—are brought up from the ground.

On a large space station, water and air can be recycled and some food grown to reduce the amount that must be transported. Chemical "scrubbers" remove carbon dioxide and return clean air to the habitat. Water is recycled from the moisture collected from the air and from wastewater (including urine).

Many trips to a space station are necessary to bring enough supplies to keep the occupants alive and well for a long time. This is very expensive.

A space station keeps air at the same pressure as on the ground. This lets the occupants live and work in regular clothes rather than wear spacesuits all the time. The pressurized area also protects occupants from some levels of radiation and tiny meteoroids and space debris. To protect people from high radiation events, such as solar flares, a small heavily shielded area is usually provided.

For people to live in space for long periods, they must have a way to dispose of wastes—solid and liquid body wastes, wastewater from washing and cleaning, water from fuel cells that generate electricity, used food containers, packaging, and other trash. Water can be collected and recycled or discarded into space. Garbage usually is put into a robot craft that burns up in the atmosphere.

Heat is another waste product. People and equipment produce heat as they work. If there is no way to get rid of the excess heat, it will build up. Soon it would be too hot for either people or machines to work. This heat is collected from living and working areas and shed into space by radiators.

Fuel cells use hydrogen and oxygen to make electricity, also producing water. On the space shuttle, wastewater was dumped overboard, while on the International Space Station, water from fuel cells is saved and used for drinking.

Radiator panels that stick out into space work like the radiator in a car. A liquid passes through the hot area and absorbs heat. The hot fluid flows through the panels, where the heat is given off into space. This process cools the liquid, which is then pumped back to the hotter area to pick up more heat.

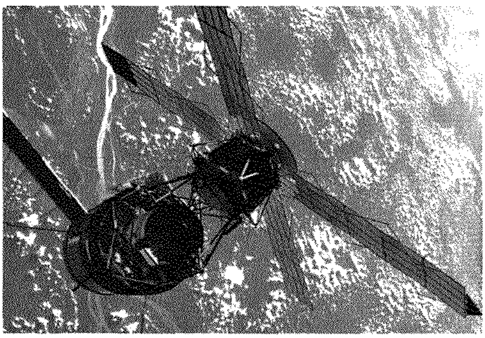
Salyut

The first space station to orbit Earth was named Salyut. The Soviet Union launched seven Salyuts between 1971 and 1982. The earliest Salyut stations were designed only for temporary operations. Crews flew to the stations in Soyuz spacecraft and were resupplied by unmanned Progress vehicles. *Salyut 6* (1977–82) and *Salyut 7* (1982–86) were designed for longer missions. The longest mission was 237 days. The last crew left *Salyut 7* in 1986. The space station re-entered Earth's atmosphere in 1991, burning up over Argentina.

Skylab

The United States launched its first space station, Skylab, in 1973 atop a Saturn V rocket, the same type that sent astronauts to the Moon. The third stage of the rocket was converted to provide living quarters, life support, and scientific instruments for a crew of three. Apollo command modules carried astronauts to and from Skylab.

Eleven days after Skylab was launched, three astronauts docked with it. They noticed one of two large solar panels had torn away. A second solar panel was jammed, and part of the heat shield was missing. The crew installed a cover over the unshielded area to cool the spacecraft. They freed the jammed solar panel and restored power to the craft. These unplanned activities showed how people could repair equipment and structures in space.



Skylab's orbit decayed faster than expected because greater than expected activity on the Sun "puffed up" the top of Earth's atmosphere, slowing the station down. Skylab was destroyed as it burned up in the atmosphere in 1979.

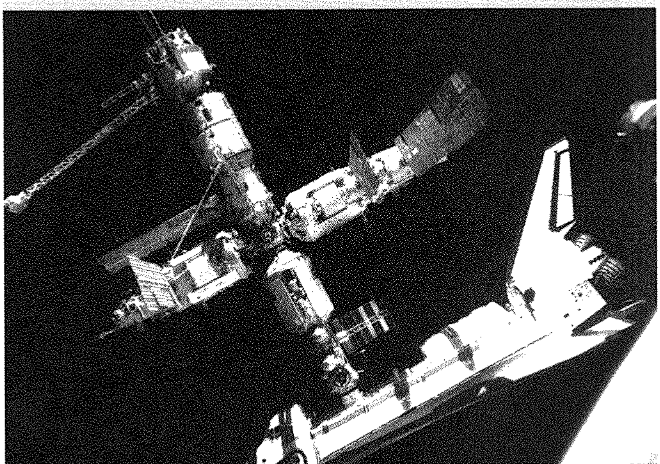
Three different crews lived on Skylab through 1974. They studied the properties of fluids and materials and the medical effects of microgravity (the nearly complete absence of gravity). They also observed the stars, the Sun, and Earth. Their missions proved people could live productively in space over long periods.

Mir

In 1986, the Soviet Union launched the first module of Mir (meaning "peace"), the next generation of space stations. Unlike Salyut, the Mir space station could have modules attached to each other. Eventually, Mir grew to be a set of six modules that totaled 107 feet long and 90 feet wide.

Mir was occupied for more than 12 of its 15 years in orbit. It served as a home in space for 104 people representing 11 countries. One of the cosmonauts (Soviet/Russian astronauts), Dr. Valeri Polyakov, spent 438 days in space before returning to Earth. Three other cosmonauts spent at least one year in space.

The End of Mir. Mir had its share of problems. Once, the crew had to put out a dangerous fire. Another time, a resupply craft collided with the station, seriously damaging one module. Eventually, components designed to last three years began to fail. The space station was brought out of orbit in a controlled manner and crashed into the Pacific Ocean in 2001.



This photo of the space shuttle *Atlantis* docked with Mir was taken by the Mir-19 crew on July 4, 1995, as they undocked the *Soyuz* spacecraft from Mir for a brief fly-around.

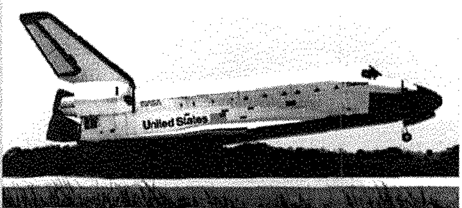
The Space Shuttle

The most ambitious space vehicle to date is certainly the United States' space shuttle, in service from 1981 to 2011. This system used solid-fuel rocket boosters and a large external tank for liquid fuel in combination with an airplane-like vehicle, the orbiter, to lift up to seven crew members and 25 tons of payload into a low Earth orbit and remain there for as long as two weeks. Because the orbiter, which carried the expensive liquid-fuel rocket engines, could be refurbished and flown again repeatedly, the shuttle is regarded as the first reusable space launch system. It was used for launching satellites, repairing them in space, and even returning them to Earth, and served as a kind of temporary space station for performing scientific experiments.

Combining all these capabilities into one vehicle, however, proved problematic. Originally conceived as a low-cost, frequent space transportation system accessible to commercial users, the shuttle proved much more expensive to operate than anticipated. Furthermore, in the course of 130 flights, two orbiters—*Challenger* in 1986 and *Columbia* in 2003—were destroyed with the loss of all crew members. After the loss of *Challenger*, the types of payloads flown on the shuttle were restricted, limiting it primarily to purely scientific missions.

While the space shuttle was intended to be a method of transportation between the ground and low Earth orbit, it became the only space habitat for astronauts from its first launch until the mid-1990s.

Fun Facts About the Space Shuttle



- In 8½ minutes, the space shuttle accelerates at launch from zero to 17,400 miles per hour, almost nine times as fast as a rifle bullet.
- If the main engines pumped water instead of fuel, they would drain an average-sized swimming pool in 25 seconds.
- The solid rocket boosters consume more than 10 tons of fuel each second at launch.
- The orbiter has more than 2½ million parts, including 230 miles of wire.

Metric Matters
The global international standard for measurement in science and engineering is the metric system. To compete in global markets, as the space industry does, you need to learn metric. This can, at first, lead to confusion, as with the case of tons and tonnes. A *ton* in imperial units is 2,000 pounds, with each pound weighing 16 ounces. The metric version of the ounce is the gram, and of the pound is the kilogram (kilo = thousand). One kilogram equals 2.2 pounds, and 1,000 kilograms is a *tonne* (often noted as metric tonne or mT), which works out to 2,200 pounds, or 10 percent more than the ton. For this reason, and as *Mars Climate Orbiter* highlighted, it is very important to be clear on what measurement system you are using.

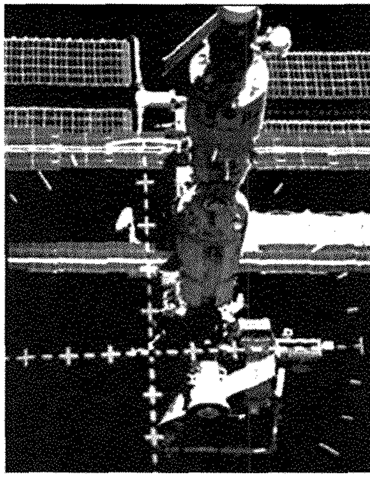
International Space Station

NASA began planning a permanent space station in the late 1960s. In 1984, President Ronald Reagan revealed the plans for Space Station Freedom, a cooperative effort among the United States, Canada, Japan, and some European countries. But the space station was redesigned yet again. In 1993, Russia and Brazil joined the project, and the name was changed to the International Space Station (ISS).

The ISS is an engineering marvel, a challenge to design, construct, test, outfit, assemble, and operate. While it was originally built to last at least 15 years in orbit, it was designed with a safety factor of 2, meaning it could last 30 years. Sixteen countries have contributed to its construction. More than 100 major pieces have been assembled in orbit more than 200 miles above Earth.

In the 1990s, the United States and Russia brought U.S. astronauts and Russian cosmonauts together to operate the Mir space station. Space shuttle *Atlantis* docked with Mir for the first time in 1995. It was one of nine trips to Mir to exchange crew members, bring supplies, and—in this case—deliver a new module to the station. The two countries gained valuable experience working together and laid the foundation for the eventual construction and operation of the International Space Station.

But why build another space station? Mir had gotten too old. The United States, Russia, and other countries wanted a larger, longer-lasting facility to do long-term research in space. The space shuttle had supported some research, but flights had been too few and too short. A bigger space station also would provide better research support services (such as data transmission) than the shuttle could ever provide.



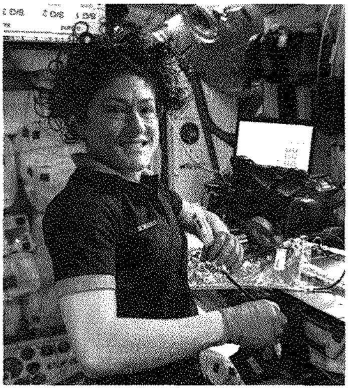
The million-pound ISS is the largest construction project ever attempted in space.

The 16 partner countries providing equipment and support for the International Space Station are the United States, Russia, Canada, Japan, Brazil, Belgium, Denmark, France, Germany, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland, and the United Kingdom.

Purposes of the ISS

The International Space Station has several purposes. One of the most important is that the ISS provides a constant presence in space. Since November 2000, there have been from two to 13 (when the space shuttle orbiter was docked) astronauts and cosmonauts at a time living in space on the ISS. Rather than spend a few weeks in space, astronauts and scientists can stay for three to six months to study the effects of weightlessness on the human body and to do experiments in microgravity.

The research done aboard the ISS may lead to breakthroughs in medicine, engineering, and technology that will have practical uses for humanity on Earth. The research could create jobs and economic opportunities tomorrow and in the decades to come. As an investment in the future, the ISS provides ways to do research that cannot be done on Earth. With its view of 85 percent of Earth's surface, the ISS can help us observe and understand changes in the environment and our impact on the planet. By exposing materials to the harsh environment of space, we can learn how materials are affected in order to better design future spacecraft.



The ISS shows how countries can work together for the peaceful use of space. We can accomplish greater feats (like a crewed mission to Mars) with cooperation rather than competition. Also, the lessons we learn from building and operating the ISS will prepare us for future manned missions in space exploration.

Components of the ISS

The International Space Station is made of cylinder-shaped modules and other large parts that are built on the ground, then assembled and maintained in space. The station was designed to be expanded.

- The first piece, a control module named Zarya ("Sunrise"), came from Russia and was put into orbit by a Russian rocket in November 1998. Zarya has docking ports for additional modules and solar arrays for power.
- The second piece was Unity, which a space shuttle carried into orbit in December 1998. As its name suggests, Unity is a small module that allows six other modules to be connected together.
- The ISS became a working space habitat when the third piece, the service module Zvezda ("Star") from Russia, was attached to the station in July 2000. Zvezda provided living quarters and life-support systems for the first few crews.
- Destiny, a U.S. laboratory, was delivered in February 2001. Scientific research aboard the station could now begin.

More components have been added since, with 15 pressurized modules as well as a number of unpressurized components making up the ISS. The central girder or truss, which is a set of long beams fitted together, connects the modules and the main solar power arrays. The truss provides a rigid framework for the station.

Various countries are providing other pieces of the ISS. The Space Station Remote Manipulator System, provided by Canada, is a 58-foot-long robot arm that helps with assembly and maintenance. The arm travels along the truss on a moving platform. Four solar arrays, which provide electrical power, rotate on the truss to stay facing the Sun. Six large radiators provide cooling in pressurized areas. From Italy and Brazil

Canada's Space Station Remote Manipulator System can creep slowly along the outside of the space station like an inchworm.

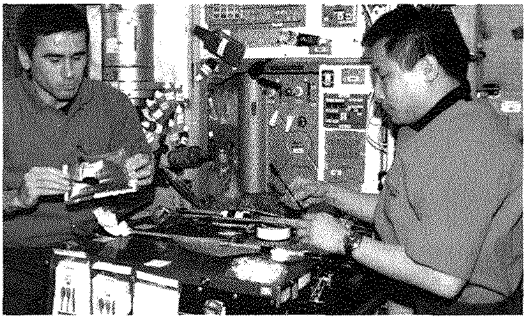
have come cargo containers. The Quest airlock, from the United States, allows crew members to conduct spacewalks.

An emergency crew return vehicle (a Soyuz spacecraft for every three crew members) is always docked at the ISS while it is inhabited. This assures the safe return of all crew members if a hazardous situation (such as a fire or loss of pressure) occurs on the space station and a quick departure must be made.

The construction of the ISS was largely completed in 2010, resulting in about 1 million pounds of hardware in orbit assembled during 33 space missions with more than 150 spacewalks over a period of 13 years. The ISS will be operated through at least 2020 and will be deorbited into the Pacific Ocean when its operational life is complete. The ISS is the largest structure ever built in space and has honed and perfected our skills at assembly, maintenance, logistics, and international cooperation on scientific and technical endeavors. The use of distributed power and cooling systems, the repair of the solar arrays and rotary joints, and the recycling of water and air for life support are good examples of what we've learned that could help us as we explore the solar system and establish homes in space.

The ISS flies over 85 percent of Earth's surface and 95 percent of Earth's population and is as bright as Venus. To find out when the ISS is visible over your location, see the resources section.

An **airlock** is a small room with one door to the pressurized area and another door to the outside (vacuum). A control panel allows a crew member to release the air out to space, after which the door to the outside can be opened and a space-suited crew member can exit the station on a spacewalk. When the space walk is finished, crew members reenter the airlock and another control pumps air back into the airlock until the pressure is equal with the interior of the space station after which they can re-enter the station.



Without gravity, hot air does not rise. Aboard the ISS, an oven has a fan that forces the hot air to move around. Hot metal shelves conduct heat directly to food containers.

Living and Working in Microgravity

It isn't easy to provide for eating, drinking, sleeping, cleaning, and personal hygiene on the space station. Air, water, materials, and the human body act differently in space because of microgravity. Equipment we use on Earth would not work the same way, or not work at all, aboard the space station.

Food for ISS crews is nutritious and compact, and tasty most of the time. The food must come in convenient packages for easy handling in weightlessness. Astronauts select their menus before going to the space station, but their choices are limited. Fresh foods sometimes arrive with new crew members, although they do not last long. Water must be added to most items to make them edible.

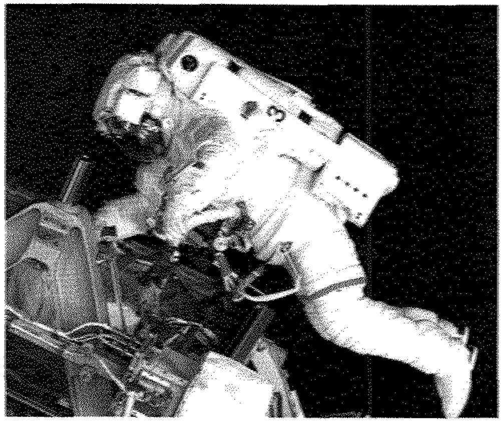
The ISS is designed to be maintained while in orbit. Most parts, inside or outside, can be disconnected, replaced, and reconnected (like a light bulb). This makes it easier for the crew to make repairs.

Personal hygiene is a novel experience on the ISS. A crew member takes a shower using a hand sprayer and a washcloth. Because loose water droplets floating around in weightlessness can be a hazard for electrical equipment, the bather must catch the sprayed water in a sponge or washcloth and then use the wet cloth to clean themselves. In space, toothpaste is swallowed. A special dry shampoo is rubbed into the hair with a towel without needing to be rinsed. When shaving or cutting hair, a vacuum tube is used to collect the hair and keep it out of equipment and air filters.

Every few months, Russia launches a Progress resupply rocket stocked with food, water, personal items, and spare parts. The Progress spacecraft attaches to a Russian-made module. The crew uses supplies from Progress and fills the craft with trash. Eventually, the Progress undocks from the station and burns up in the atmosphere, incinerating the trash it carries.

Robotic spacecraft from the European Space Agency, Japan, and the United States can also be launched by expendable rockets to resupply the ISS. Japan's H-II Transfer Vehicle (HTV) and SpaceX's Dragon cargo ship are reusable crafts that can return scientific samples to Earth.

Crew members can work outside for about eight hours at a time—wearing spacesuits, of course. While they work in space, they have several ways to move around. They can pull themselves hand-over-hand using handholds on the modules. They can ride on a small railcar along the truss of the station. Or they can hitch a ride on a robot arm. Crew members use tether lines to stay attached to the ISS, keeping them from drifting away if they lose their grip.

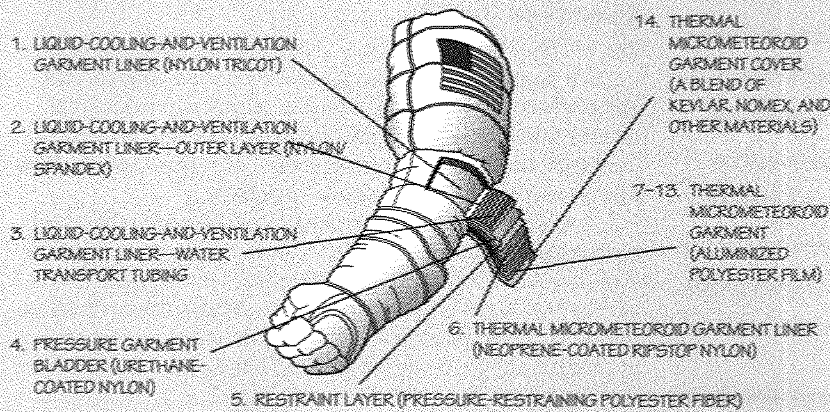


Crew members wear small gas jetpacks that can get them back to the station if they get separated from the spacecraft.

ISS Crews

Astronauts wear spacesuits made with 14 layers of fabric. Going from the inside out, there's nylon tricot, spandex, a lacing of plastic tubes, urethane-coated nylon, polyester fiber, ripstop nylon, seven layers of polyester film, and an outer layer made of fibers that are lighter and tougher than steel.

Those same stronger-than-steel fibers, called *aramid* fibers, are used to make bulletproof vests for police officers and flameproof suits for firefighters. One of the best-known aramids has the trade name Kevlar.



The ISS can hold a crew of three to six people (a group called an expedition) for up to six months. Crew members arrive and depart in either a space shuttle or a Soyuz spacecraft. Most occupants have been American astronauts or Russian cosmonauts, but European and Japanese astronauts have also been part of the crews. A few wealthy "tourists" have paid to visit for a few days to do experiments or educational outreach or just relax but are not considered an official part of the crew. The official language is English, but a lot of Russian gets spoken, too.

The first crew, known as Expedition One, boarded the station in November 2000. American Commander Bill Shepherd and Russians Yuri Gidzenko and Sergei Krikalev stayed for four months. They were replaced by Expedition Two, which had a Russian commander and two Americans, including the first woman on the station, Susan Helms.

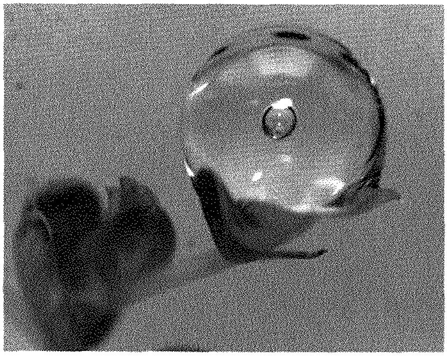
Most crews have a commander, a flight engineer, and a science officer. The commander has the overall responsibility for running the station and managing the crew. The engineer's main duty is to keep the station's mechanical and electrical systems working properly. The science officer supervises the scientific and medical experiments. Additional crew members will work mainly on science experiments. All of the crew take part in medical experiments and station maintenance.

The ISS is about the length and width of a football field including the end zones and has an internal pressurized volume similar in size to the passenger cabin of a 747 jet.

Science on the ISS

The ISS may have as many as six laboratory modules, becoming five times larger and having more research abilities than any previous space station. The United States provided the Destiny laboratory, Japan provided the Kibo module, and the European Space Agency provided the Columbus module. Russia may provide up to three research modules.

Some experiments done aboard the ISS study the effects of microgravity on the human body and research how plants and animals could behave at different levels of gravity, such as one-sixth Earth's gravity (as on the Moon) or one-third (as on Mars). Other experiments investigate various properties of physics and chemistry, while still others may produce new materials that cannot be made on Earth.



This photograph by cosmonaut Nikolai Budarin of the ISS Expedition Six shows how strange space gardening can be. The air bubble trapped in this water drop doesn't rise because in space there is no buoyancy. The droplet rests on the leaf without bending the stalk or falling off because of zero-gravity.

Medical research aboard the ISS may lead to the development of drugs that can stop bone loss. Besides helping space travelers, such drugs would benefit millions of older people. Other studies in space might lead to a treatment for cancer or find ways to make purer forms of medicines. Researchers are also working to develop vaccines for *Salmonella* and *Staphylococcus aureus*, which causes antibiotic-resistant staph infections.

Scientists want to better understand how physical laws and chemical processes work in space. Materials act differently, fluids flow differently, and fire burns differently in a microgravity environment. New materials could be made in orbit from substances that will not stay mixed on Earth due to their different densities. (See "All Mixed Up.") Studies of the process of burning could lead to improvements in firefighting techniques and equipment or help to strengthen pollution controls.

Flames in microgravity look different from those we see. On Earth, a flame is shaped like a teardrop and yellow in color. On the ISS, it would be round and blue.

All Mixed Up. Imagine you are trying to mix molten lead and molten aluminum. The large difference in densities will cause them to separate in Earth's gravity before the metals can cool into solid metal. In weightlessness, however, the two could mix to form a new material (an *alloy*). Perhaps a new material that was similarly made could be used to build future spacecraft.

The knowledge gained from experiments that are not possible on Earth will benefit us all. The International Space Station is the next step to satisfy humanity's ancient yearning to explore, learn, and achieve. From this outpost, we can continue to explore the frontier of space.

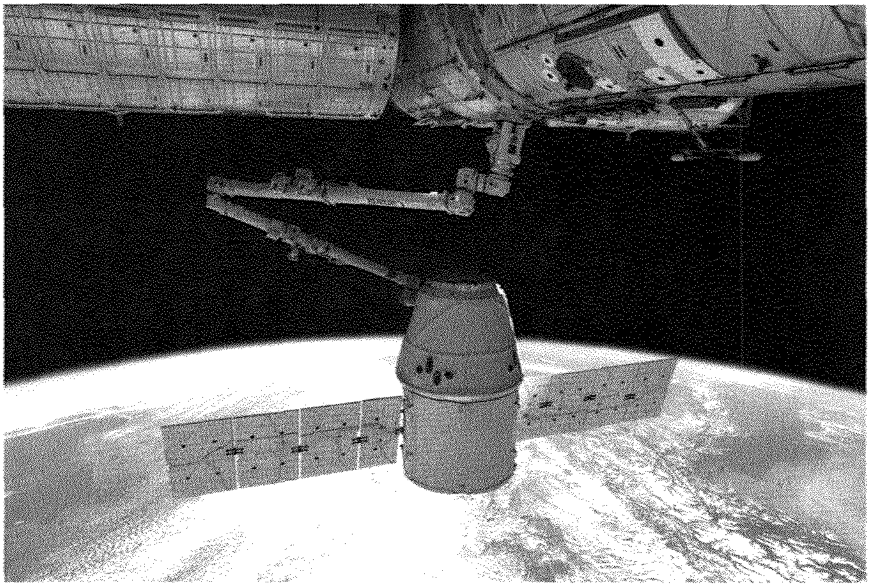
The New Era of Space Transportation

With the retirement of the space shuttle in 2011, the only regular crew transport to the ISS is via the Russian Soyuz crew vehicle. In the United States, a number of companies are working hard to provide the next generation of cargo and crew vehicles. Having multiple launch vehicles available reduces the risk to the space station crew.

The military was concerned about not having the ability to put satellites in orbit after cargo was restricted following the *Challenger* accident. In the mid-1990s, it decided to work with Boeing and Lockheed Martin to develop a pair of launch vehicles, the Delta IV and Atlas V, respectively, that could lift large assets into space. In the late 1990s, Beal Aerospace tried to build inexpensive vehicles to launch commercial satellites to geostationary orbit, and at one point fired the largest liquid rocket motor developed in the United States since Apollo. Government subsidies to commercial competitors drove the company to close in 2001. Shortly thereafter, SpaceX began development of the Merlin rocket motor and Falcon family of launch vehicles, with the larger Falcon 9 rocket having its first successful delivery of payload to orbit in 2010.

The delivery of crew is more complicated. NASA began working with industry in 2004 to provide alternatives to the shuttle program. Many proposals recommended use of the existing Atlas and Delta rockets. NASA later decided to develop its own launch vehicle that used elements of the space shuttle. This became the Ares rocket component of the Constellation program to go to Mars by way of the Moon. Funding was cut in 2010, which left private efforts, already underway, as the only potential near-term solution.

Originally an element of the canceled Constellation program, the Orion Multi-Purpose Crew Vehicle is designed for crewed missions beyond low Earth orbit.



The ISS's robot arm captures the Dragon spacecraft as it approaches on a resupply mission.

SpaceX designed its rocket to launch the company's Dragon capsule, which will also have a crewed version. One design feature of the Dragon capsule is that instead of using "tractor" motors on the nose of the capsule, as with Apollo and Orion, that drag the capsule away from an emergency situation, the Dragon instead uses "pusher" motors in the base to push the capsule away from a blossoming crisis. SpaceX launched Dragon in October 2012 on the first commercial resupply mission to the ISS.

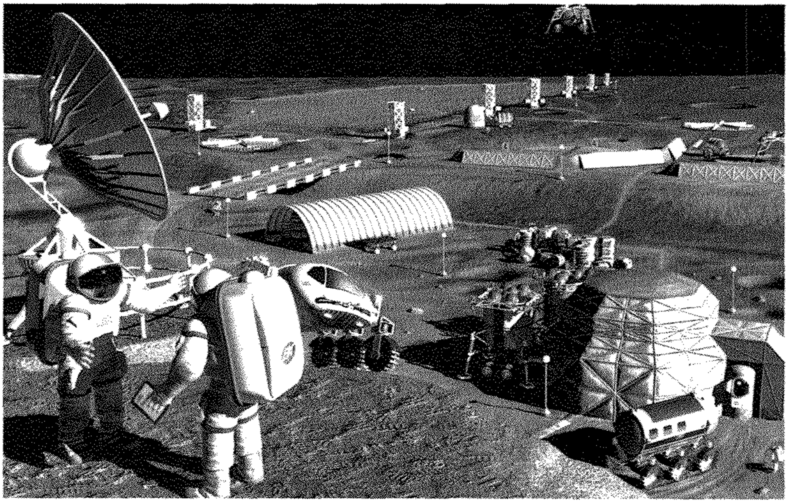
Boeing and Bigelow Aerospace have teamed up to develop and provide the CST-100 capsule, designed to be launched on Delta, Atlas, and Falcon rockets, for launching astronauts into low Earth orbit.

The ISS will be the primary destination for global space activities. As more transport solutions are developed, especially for crew, there will be increasing pressure for spacecraft in other orbital inclinations to transport to those facilities.

Planetary Bases and Settlements in Space

Where would we build space bases and settlements? The Moon and Mars are current candidates. Bases and settlements could also be built on asteroids, on the moons of other planets, and even in space itself (in orbit). At first, these bases would depend on supplies from Earth, but they could eventually become self-sufficient as we learn how to make use of the materials found in space.

A base is normally supported and supplied by a government, while a settlement would need a financial basis to support itself and its inhabitants. By creating self-sufficient settlements away from Earth, our civilization can spread to other worlds, and even bring life to them. Having a space-based civilization in existence would also make it easier to recover from a widespread disaster on Earth.



Free Space Facilities

Also to be considered is what value the facility will create so that people would want to live and work there. Removing scrap satellites from geostationary orbit, for example, would help keep functioning satellites safe so that broadcasts of satellite TV and radio can continue uninterrupted.

Not every location of interest in space is on a planetary surface. One example is the Earth-Moon L1 point (EML-1). Balanced in one direction by the gravity of Earth and in the other by centrifugal force and the gravity of the Moon, the L1 point lies about 86 percent of the way to the Moon on an imaginary line connecting the centers of Earth and the Moon.

A facility in a halo orbit around EML-1 (like the SOHO and Genesis probes at the Sun-Earth L1 point) would benefit from a number of advantages:

- It is accessible from any inclination of low Earth orbit, even from the ISS.
- It has access to any point on the lunar surface.
- It offers a "high-ground" view of space traffic out to geostationary orbit.
- It is the cheapest place, fuel-wise, to launch a mission to an asteroid or to Mars.
- Probes can be sent out on the interplanetary superhighways and brought back periodically to be serviced and upgraded like the Hubble Space Telescope.

Another location of interest is the Earth-Moon L5 point, trailing 60 degrees behind the Moon in its orbit. This was the location proposed by Dr. Gerard O'Neill for large orbital colonies that would provide homes for thousands of individuals in a climate-controlled environment. This type of free space facility requires much more space development; we will need to perfect methods of economically bringing many hundreds of thousands of tons of materials from one space location or object to another before we can build large space colonies.

A facility at EML-1 offers the possibility of considering materials from multiple sources. The core modules might be ISS-style or Bigelow inflatable modules, but radiation shielding might be provided by slag from industrial processes on the Moon. There might be an industrial facility there manufacturing solar cells from asteroid materials to be used for solar-power satellites in geostationary orbit or as a garage for nonfunctioning satellites retrieved from geostationary orbit.

Asteroid Facilities

A natural extension of using asteroids for the natural resources they contain is to create facilities on or in the asteroids. Such a facility located in the asteroid belt would have access to virtually unlimited resources. Locating a facility within an asteroid would allow for great variability in design of interior spaces, and thick layers of rock would mitigate the dangers from cosmic rays and solar flares, as would be the case in lunar lava tubes. In addition, engines could be mounted on the asteroid, allowing it to be directed to destinations of interest in the solar system.

Selection of a particular asteroid would depend on its composition. It is one thing to mine platinum group metals from a large rock; it is another to have the supplies necessary for life, mainly carbon, hydrogen, oxygen, and nitrogen, as well as ample amounts of water. Consequently, any likely target will be extensively examined by robotic probes to determine the resources it would offer for a facility.

Visiting an asteroid would be just the first step.

Moon Bases

The Moon is just a few days of travel from Earth. Earth-Moon communication takes only a few seconds round-trip. We have had experience with crewed operations on the Moon. The gravity is only one-sixth of Earth's, so landing on and lifting off from the Moon's surface does not take much fuel. All of these are advantages.

There are also disadvantages of establishing a lunar base. The Moon does not have an atmosphere. On its surface, people would be unprotected from space radiation and the impacts of micrometeorites. The Moon rotates about once a month, creating a scorching hot day (+250 degrees F) that lasts two weeks, followed by an intensely cold night (-250 degrees F) that also lasts two weeks. No one knows how the low gravity might affect the growth of children or the aging process if families lived at the base. There are unlikely to be any concentrated bodies of mineral ore to mine.

For these reasons, while Moon is not the best place to start a colony, it is suitable for scientific research.

Purposes of a Moon Base

A moon base would allow continued exploration of the Moon. We can search for valuable materials, such as titanium, helium-3, and rare earth elements. Bases near the north or south poles would receive sunlight almost all the time to power a base. Explorers working out of those bases might find polar ice deposits in nearby areas that are always in darkness.

We also might set up an astronomical observatory. A telescope on the Moon's stable surface, looking out through no air, would have a superb view of the universe. A base on the far side of the Moon would be valuable for radio astronomy, because it would be shielded from almost all the radio "noise" generated on Earth and in space by human activity.

Businesses might be able to mine lunar material for a profit. Common metals like iron, aluminum, and titanium could be smelted from moon rocks to make building materials and solar cells. Oxygen, taken out of the rocks, would provide breathable air and rocket propellant. Someday a lunar hotel or resort could be built, followed by a lunar colony.

Living on the Moon

A moon base would have modules for laboratories and living quarters. The modules would be buried in lunar soil, except for their entrances, to shield the inhabitants from space radiation and solar flares. The lunar soil would also insulate the base from extreme temperatures.

The modules would have the same life-support functions as a space station, providing a breathable atmosphere, clean water, food, power, and temperature control. Water would be recycled as much as possible. Most food would be imported from Earth but could eventually be supplemented by a greenhouse module. A crew would either stay at the base or visit regularly to maintain and repair equipment and do scientific work.

At first, all of the modules would be built on Earth and hauled to the Moon. Because this will be expensive, a moon base will grow faster if lunar materials are used to build the modules. Once we develop the technology and capability to mine, process, and transport lunar ore, a settlement on the Moon will be highly desirable.

Mars Bases

Mars has many advantages for a base or settlement. Its atmosphere (almost all carbon dioxide) would protect anyone on the surface from micrometeorites and partly from space radiation. The atmosphere is thick enough to produce wind and clouds, and maybe support an airplane. However, the air lacks oxygen and enough air pressure for a person to survive. Any surface water would boil away very fast. Anyone exploring Mars will need to wear a spacesuit, just like on the Moon. What looks like a raging dust storm would make it difficult to see afar.

The gravity on Mars is about 38 percent as strong as Earth's, so humans and animals might be able to grow and reproduce there normally. A day on Mars is only slightly longer than on Earth, so a person could easily adapt to a Martian day.

Mars has huge quantities of subsurface ice in many places, and on the surface in the polar areas. There may be salt water under the ice, which could be tapped by drilling. Elements, such as sodium and chlorine, dissolved in the salty water could be separated and used. Mars rocks would also contain useful metals. In fact, most of the materials needed to build a base or colony probably exist on Mars, but they must be found. Rocket propellants can be made using the carbon dioxide atmosphere and water on Mars, greatly reducing the cost of missions to Mars and Mars settlements.

But Mars has its disadvantages, too. The planet lacks a notable magnetosphere, which helps protect Earth from solar wind particles. Additionally, Mars is much farther away than the Moon. With current technology, it would take five to six months for a crew to reach Mars' orbit from Earth. With better technology, using nuclear-powered ion rockets, the crew's trip might be cut to two months. Cargo-only vehicles could be sent as "slow boats" to use less energy, taking as long as a year to reach Mars.

Any crew that takes a trip to Mars using a traditional transfer orbit would likely have to stay there for about two years.

Because Mars is far from the Sun, it does not get hot. However, it can get cold enough in winter for dry ice to form directly on the polar caps from the carbon dioxide in the atmosphere.

Building a Mars Base

Before starting to build a base on Mars, we will need to send robot rovers to locate several promising sites. Then humans will survey those sites to find the best location. An orbiting base would be established in a low Mars orbit, complete with a propellant depot and a crew habitat. Vehicles to carry crew and cargo to the surface base site would be sent from Earth to the orbiting base. To make supporting the base more affordable, these vehicles could be reusable, just like airplanes.

What would be a good place for a base? A location near the equator for warmth, if possible. We would also want a site with access to ice or water, and that might be closer to the poles. Resources available from the rocks nearby would be important. If we could use the water on Mars, by digging ice out of the ground, we would not need to bring it from Earth, making it much cheaper to build and maintain a base.

A low-lying location would provide the best protection from space radiation. However, just as on the Moon, all permanent habitats would be buried underground, to reduce radiation exposure. Temporary habitats could be on the surface, but they would have to withstand the raging dust storms on Mars. All habitat modules would be insulated against the cold. Methods would need to be perfected to get rid of Mars dust on space-suited explorers entering the habitats.

Just like on the Moon, the first components to build the base would come from Earth. Bulldozers and backhoes could be used to dig holes and bury the habitat modules. To dig for water or to look for life, heavy drilling equipment would be designed to operate under Mars conditions. All habitat modules would be insulated against the cold.

The base would need energy for heat and to run its equipment. Some power could come from solar panels during the day, but a small nuclear reactor would be ideal for power around the clock. Electricity from the reactor could be used to turn carbon dioxide (from the air) and water or ice (from the crust) into oxygen, hydrogen, and other materials. The oxygen could be used directly to make breathable air. It might also be possible to ship a small smelter and manufacturing plant to Mars, for turning local materials into metal and parts for new habitat modules. The water found there might make it possible to use other kinds of construction materials, such as locally produced concrete.

Living on Mars

The oxygen and hydrogen from Mars' water could be used as rocket propellants for flights back into Mars orbit and to power "over-the-road" vehicles. Vehicles for traveling on the surface of Mars could include rovers large enough for several people, and buggies that space-suited crew members could ride. The crew would stay busy maintaining the base, conducting research, and prospecting for better supplies of water and minerals. They would explore and learn about the topography, geology, and weather of Mars. Recent proof that methane is being produced underground on Mars means that either bacteria or geologic activity is producing it. A major focus of the base may be drilling to find life.

Food for the crew would come from Earth at first. But eventually food could be grown locally. Mars has enough sunlight for plants to grow in pressurized greenhouses, but keeping them warm would take much energy. By the time we are ready to go to Mars, we may know how to make some food synthetically, without using plants at all.

To find out if Mars has (or had) indigenous life, we cannot contaminate it with our own. For this reason, precautions are taken when building space vehicles so they carry as few microbes as possible.

Build a Space Habitat

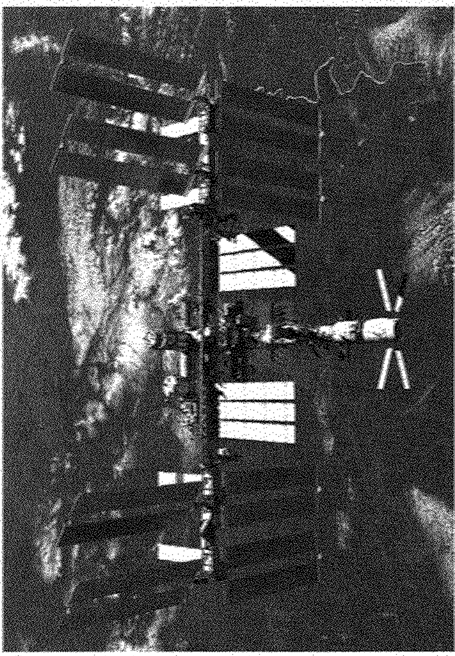
For requirement 7, you are to design a space habitat. You can find material for this project around the house and in your family's recycling bin. A little thought and ingenuity can make a potato-chip tube into a lunar rover. Soda straws become the axles; bottle caps become the wheels. Aluminum foil can be wrapped around the tube, and a glue gun helps put it all together. A three-liter soda bottle and similar imagination can make a habitation module, a colony, or a space base. A cereal box can become a hangar bay for ground and space operations.

As you plan this project, ask yourself: What is the base's intended use? How have you provided for crew quarters, power, breathable air, radiation protection, food, water, and transportation? Your design must satisfy all these needs.

The Future of Space Exploration and Space Development

As this pamphlet points out, "Space is about the future." Because the Space Age is just six decades old, we assume that the history of humankind's adventures in and use of space is only just beginning. There is a lot of future to anticipate!

Space activities in the United States and in other countries are undergoing a major transformation. Because the space station is nearly complete, astronauts can turn more of their attention to scientific investigations. Private rocket vehicles are being developed to take both cargo and passengers for short suborbital (up and down) trips and into low Earth orbit. Robotic probes are being launched by countries other than the United States and are now playing a major role in exploring the solar system.



There is a continuing public debate on what role the U.S. government can and should play in this new era of space exploration. The private decisions by companies and the public ones by governments will determine the future of the space program. While some of these discussions may be technical and complicated, many are practical or about costs and benefits. You can watch the new space program take shape right before your eyes!

Here are some of the issues under discussion:

- What should the next major goal of the U.S. crewed space program be: Go back to the Moon, go to Mars, visit an asteroid, focus on space development projects such as creating space energy resources for use on Earth, focus on research on the space station, focus on reducing launch costs, conduct more robotic missions, or have multiple goals?
- What are the reasons for going to each destination or working on each goal?
- Should the government build another crew-carrying vehicle itself, or rely on one or more private vehicles that can be used without requiring much, if any, development cost from the government?
- Should we build a "heavy lift vehicle" that can place objects larger than 75 tons in low Earth orbit, or try to rely on smaller rockets and assemble larger vehicles in orbit as was done with the space station?
- If we build a "heavy lift vehicle," should it be based on parts from the shuttle or a brand new design, be expendable or reusable, be built and operated by the government or by a private company?
- What is the best way to build reusable space launchers to reduce launch costs?
- How much should the U.S. space program rely on cooperation with other countries?
- How much money can the government spend on the space program each year?
- How much should be spent on robotic exploration, and how much on the crewed program?
- What kind of vehicle should be built for crews to operate in deep space away from low Earth orbit?

Space development represents a step beyond space exploration—which is basically finding out what is there—and the use of the resources in space. Many asteroids have large amounts of very valuable platinum group metals in them, which we may mine someday. The Moon has large amounts of oxygen, silicon, aluminum, and titanium in its soil.

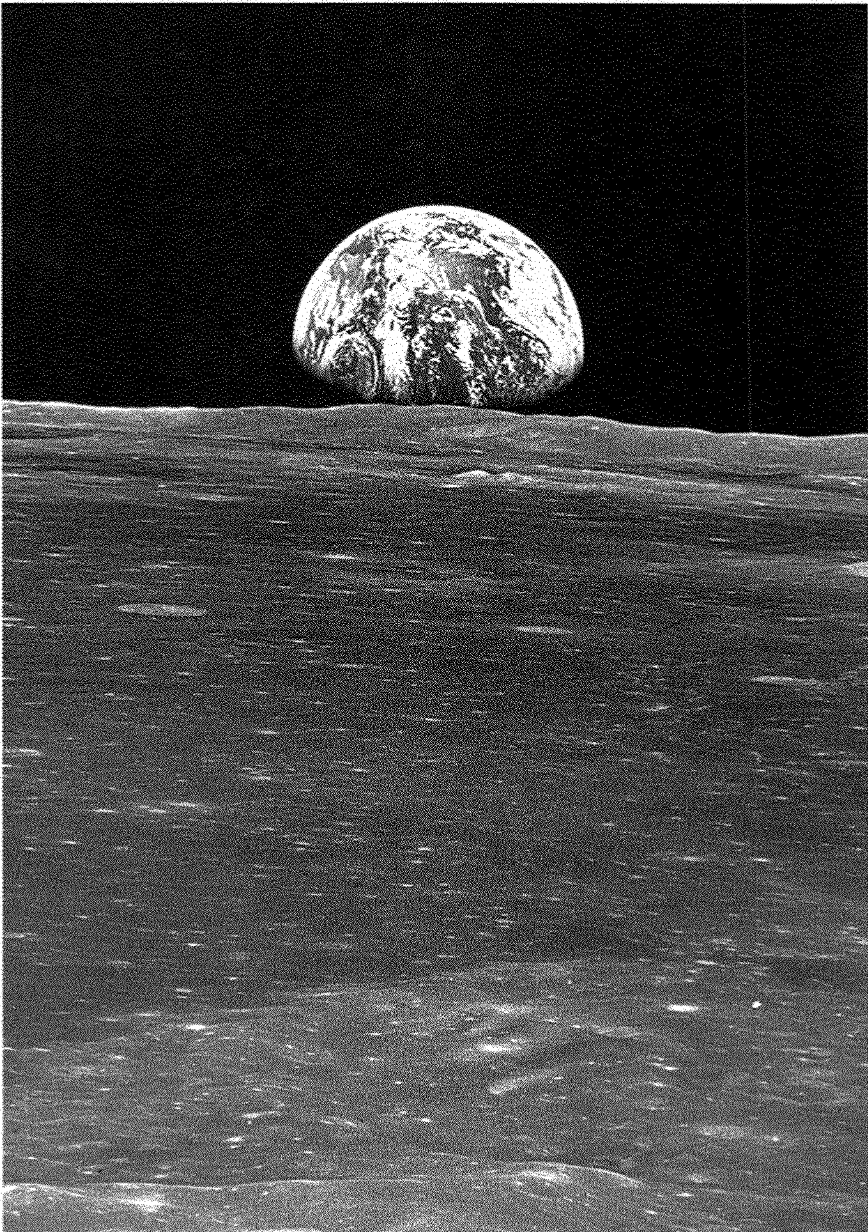
Away from Earth, even as close as in the orbit used by communications satellites, the Sun shines virtually all the time and is 30 percent stronger than on the ground. This makes it a very good location for solar panels, which would get about five to 10 times more energy per day than they would on Earth. This concept is called space solar power, but the energy is used on Earth.

Space development also means building infrastructure in space for humans to use, just like building roads and power stations on Earth. Part of this involves equipment that would make it easier, cheaper, and safer to move people and cargo from Earth to space and to different locations in space. The space station itself is an example of infrastructure. Other examples include propellant depots to accumulate large quantities of propellants for deep space missions and reusable space tugs to move cargo between orbits instead of using expendable rocket stages.

The Greatest Adventure

Earlier we asked: Why explore space? We have covered several possible answers to that question, but they can all be summed up like this: Because it is human to do so. People have always explored the environment around them. As we have observed, experimented, and taken risks, we have learned how to better protect and maintain our environment and improve our way of life.

Exploring space helps us better understand and protect our home planet. As we begin our move into the universe, we look back at our home world and see how small, yet how beautiful, it is. Boundaries of states and nations are invisible. It becomes obvious that Earth itself is a great spaceship on an unending journey and that all of us are astronauts. Space exploration is the greatest adventure of all.



Careers in Space Exploration

A career in space exploration makes you think of being an astronaut. Since 57 percent of the present and former astronauts were Scouts, you have a good head start. But astronautics is only one occupation among the many that will be needed to explore and settle our solar system and beyond. Many positions at NASA, at educational facilities, and in private businesses involve space exploration and research.

The Mercury, Gemini, and Apollo programs in the 1960s harnessed the talents of more than 250,000 employees at NASA, universities, and various companies.

Getting Ready

To prepare for a space career, you must study math and science. Take all the high-school math you can—algebra, geometry, trigonometry, and calculus. Also take biology, chemistry, physics, and computer science.

You must be able to write and speak clearly. Being bilingual and having good people skills are vital in this age of the International Space Station. Study English and at least one foreign language. You will also need social studies including history, geography, international studies, art, drama, and music. All of these will widen your world and make you a better communicator.

To get into college, you will need good grades and high scores on standard exams such as the SAT (Scholastic Aptitude Test) or ACT (American College Test). In college, choose a technical or science major—physics, chemistry, biology, geology, mathematics, engineering, computer science, or premedicine. Round out your education with humanities courses such as languages, history, economics, art, and public speaking.

If you want to be a pilot astronaut, a military background is helpful. If you want to be a mission specialist astronaut, a scientific or medical background is helpful. Most importantly, follow the path where your interests lie.

Where Is the Work?

Other than at NASA, you might work at a university as a principal investigator for an experiment on the International Space Station or on a grant from NASA's Astrobiology Institute to search for life on Mars or under Europa's icy surface. You might be a science teacher or someone who trains astronauts. You might be a medical researcher who studies the effects of spaceflight or a doctor who keeps astronauts healthy.

You might provide independent services to NASA, as Mike Malin did. He developed the camera on the *Mars Global Surveyor,* which has given us the best map, to date, of the surface features on Mars.

Additionally, small private companies are developing new technologies for spaceflight. Some strive to build rockets that will send tourists into space at affordable prices. You might decide to work for a company that is building a spacecraft to fly to another planet. Or you might form your own business to provide access to space for your own reasons. To do any of these occupations, you will need a college degree in engineering or business, or both.

A Sampling of Careers

Requirement 8 asks you to find out the qualifications, education, and preparation required for two possible space careers, and to discuss the major responsibilities of those positions. Here's a closer look at some space careers, and a list of careers you might explore on your own.

Aerospace engineering and operations technicians work with systems used to test, launch, or track aircraft and space vehicles. Like all engineering technicians, those who specialize in aerospace apply science, math, and engineering principles to solve technical problems. They may assist engineers and scientists with research, by building or setting up equipment, preparing and conducting experiments, collecting data, and calculating the results. Engineering technicians need creativity to help with design work, often using computer-aided design (CAD) software or making prototypes of newly designed equipment. They must be able to work with their hands to build and repair small, detailed items without making errors.

Most positions for engineering technicians require at least a two-year associate degree in engineering technology. Training is available at technical institutes, community colleges, and vocational-technical schools and in the armed forces. Engineering technicians often work as part of a team of engineers and other specialists.

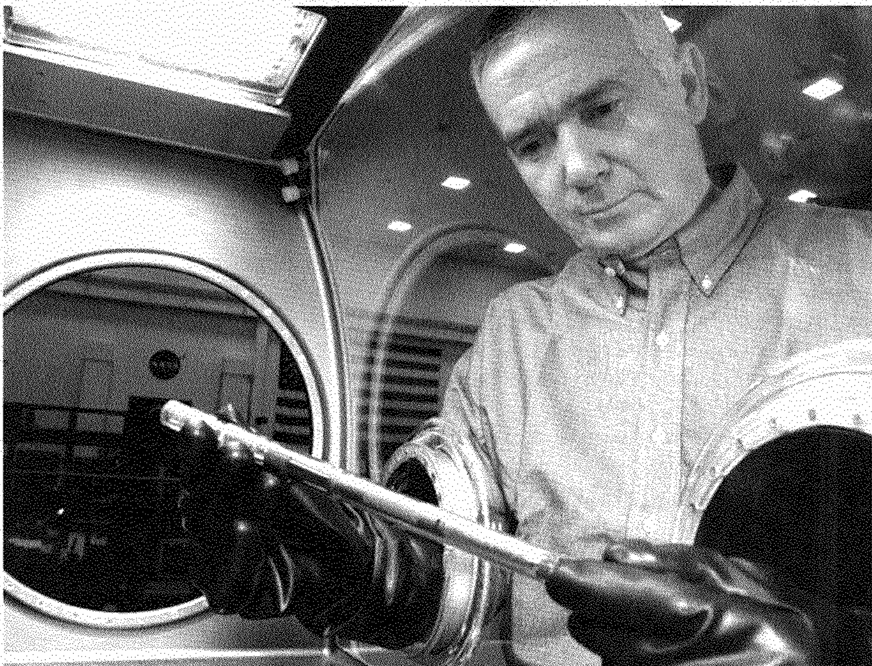
Aerospace engineers design, develop, and test aircraft, spacecraft, and missiles. They develop new technologies for space exploration, often specializing in areas such as structural design, propulsion systems, navigation and control, instrumentation, and communications. Aerospace engineers who work with spacecraft are also called astronautical engineers.

A bachelor's degree in engineering is required for almost all entry-level engineering positions. Most engineers earn their degrees in electrical, electronics, mechanical, or civil engineering. Many aerospace engineers are trained in mechanical engineering. Engineering students typically spend their first two years of college studying math, basic sciences, introductory engineering, humanities, and social sciences. Courses in their last two years are mostly in engineering, usually concentrating in one branch. The last two years of an aerospace program might include courses in fluid mechanics, heat transfer, applied aerodynamics, flight vehicle design, trajectory dynamics, and aerospace propulsion systems.

Research associates may take part in experiments or help analyze data for research projects such as mapping the planets and their moons. This work generally requires a master's degree, which takes two to three years of study beyond a bachelor's degree.

Space scientists must have at least a Ph.D. degree, which usually takes four to six years of study beyond a bachelor's degree. Scientists work with existing projects and are also expected to use their creativity to develop future missions. Space scientists need a broad base of knowledge. A scientist whose major field is chemistry, for instance, also needs a good grounding in physics, mathematics, and engineering.

No matter what your specialty, you must be able to communicate and work well with others as part of a team. You must be good at solving problems.



Space-related careers in the future will be varied and indescribable in today's terms. Some occupations could take you into space; others could help someone else get there. We stand on the shore of a great sea and can only imagine what lies beyond the horizon. Perhaps your career will allow you to find out!

Consider these careers:

- A **systems programmer** who designs, writes, and maintains computer programs for scientific analysis or for controlling a telescope in space
- A **systems analyst** who improves the performance of complex systems, such as making it easier for astronauts to conduct experiments aboard a space station
- An **engineer** in the areas of automation and robotics, materials and structures, propulsion and power systems, flight systems, measurement and instrumentation systems, data systems, experimental facilities and equipment
- A **space scientist** specializing in meteorology, ionospherics, lunar and planetary studies, radiation fields and particles, meteoroid studies
- A **life scientist** specializing in psychology, physiology, microbiology, hematology, neurobiology, botany, exobiology, biochemistry, interactions between human and machine systems

Space Exploration Resources

Information about space exploration changes constantly. Each new mission makes discoveries and shows that some of our old ideas were incorrect. When you look up information about space and humankind's efforts to explore it, always try to find a recently published book or a dependable website.

Scouting Literature

Astronomy, *Aviation*, *Chemistry*, *Digital Technology*, *Electricity*, *Electronics*, *Engineering*, *Geology*, *Inventing*, *Nuclear Science*, *Photography*, *Programming*, *Radio*, and *Robotics* merit badge pamphlets

With your parent's permission, visit the Boy Scouts of America's official retail website, www.scoutshop.org, for a complete listing of all merit badge pamphlets and other helpful Scouting materials and supplies.

Books

Chaikin, Andrew, and James A. Lovell. *Space*. Carlton, 2009.

Dethloff, Henry C., and Ronald A. Schorn. *Voyager's Grand Tour: To the Outer Planets and Beyond*. Konecky & Konecky, 2009.

Dyson, Marianne J. *Home on the Moon: Living on a Space Frontier*. National Geographic, 2003.

———. *Space Station Science: Life in Free Fall*. Windward Publishing, 2004.

Engelhardt, Wolfgang. *The International Space Station: A Journey Into Space*. Tessloff/BSV Publishing USA, 1998.

Furniss, Tim. *The Atlas of Space Exploration*. Friedman, 2002.

Lee, Wayne. *To Rise From Earth: An Easy-to-Understand Guide to Spaceflight*, 2nd ed. Checkmark Books, 2000.

Mullane, R. Mike. *Do Your Ears Pop in Space? And 500 Other Surprising Questions About Space Travel*. John Wiley & Sons, 1997.

Reich, Tony, editor. *Space Shuttle: The First 20 Years—the Astronauts' Experiences in Their Own Words*. DK Publishing, 2002.

Sagan, Carl, and Carol Sagan. *Pale Blue Dot*. Random House, 1997.

Voigt, Gregory, and Alwyn T. Cohall. *Space Exploration Projects for Young Scientists*. Scholastic, 1995.

Organizations and Websites

American Institute of Aeronautics and Astronautics
Telephone: 800-639-2422
Website: www.aiaa.org

European Space Agency
Website: http://www.esa.int

"Europe's gateway to space" has 22 member countries, including France, Germany, and the United Kingdom.

Galileo Legacy Site
Website: http://solarsystem.nasa.gov/galileo

Goddard Space Flight Center
Website: www.nasa.gov/goddard

The center is "home to the nation's largest organization of combined scientists, engineers, and technologists that build spacecraft, instruments, and new technology to study Earth, the Sun, our solar system, and the universe."

NASA Image Galleries
Website: www.nasa.gov/multimedia/imagegallery/

The NASA image galleries boast a collection of more than a thousand images "of significant historical interest."

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109
Telephone: 818-354-4321
Website: www.jpl.nasa.gov

The JPL is considered NASA's leading "center for robotic exploration of the solar system."

Johnson Space Center
Space Center Houston
2101 NASA Parkway
Houston, TX 77058
Telephone: 281-483-5111
JSC website: www.nasa.gov/centers/johnson/home/index.html
SCH website: www.spacecenter.org

Kennedy Space Center
Telephone: 321-867-5000
Website: www.nasa.gov/centers/kennedy/home/index.html

Marshall Space Flight Center
Website: www.nasa.gov/centers/marshall/home/index.html

National Aeronautics and Space Administration
Telephone: 202-358-0001
Website: www.nasa.gov

NASA's website has a bounty of information about space exploration for students of all ages.

Opportunities at NASA: www.nasa.gov/careers

Astronaut Selection Program: http://astronauts.nasa.gov

SkyWatch applet to track satellite sightings including the International Space Station: https://spotthestation.nasa.gov/sightings/

Spinoffs: http://spinoff.nasa.gov

National Association of Rocketry
Toll-free telephone: 800-262-4872
Website: www.nar.org

The world's oldest and largest sport rocketry organization. Visit the website to find the club nearest you.

National Space Society
Telephone: 202-424-2899
Website: https://space.nss.org

Planetary Society
Telephone: 626-793-5100
Website: www.planetary.org

Smithsonian National Air and Space Museum
Independence Avenue at Sixth Street, SW
Washington, DC 20560
Telephone: 202-633-1000
Website: https://airandspace.si.edu

Technology Student Association
Toll-free telephone: 888-860-9010
Website: www.tsaweb.org

TSA provides programs for middle and high school students interested in the technology.

Acknowledgments

The Boy Scouts of America thanks the National Space Society of North Texas and the Austin (Texas) Space Frontier Society for their hard work and diligence in updating the *Space Exploration* merit badge pamphlet. The NSS is a nonprofit, international, educational organization dedicated to the creation of a free spacefaring civilization. We are especially grateful to the following individuals for their involvement with this pamphlet.

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- **Tracy Benninger,** physicist and graduate of the University of Texas at Dallas in space science. She contributed to the chapter called "The Way Things Work."
- **Carol Johnson,** physicist, space advocate, and aerospace systems engineer. She wrote the sections about the space shuttle and the ISS, and contributed to the overall editing and reviewing of the manuscript.
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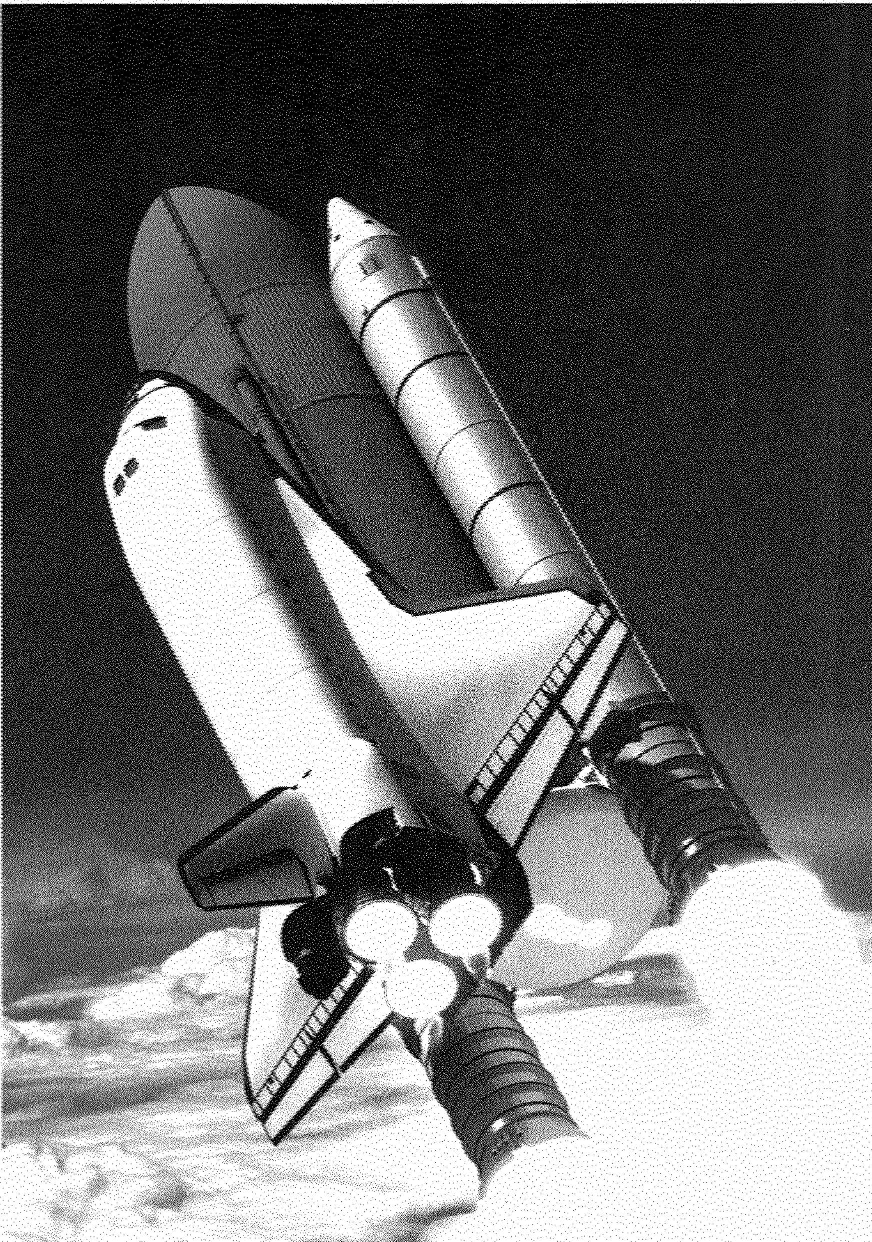

MERIT BADGE LIBRARY

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If a Scout has already started working on a merit badge when a new edition for that pamphlet is introduced, *they may continue to use the same merit badge pamphlet to earn the badge and fulfill the requirements therein.* In other words, the Scout need not start over again with the new pamphlet and possibly revised requirements.

Merit Badge Pamphlet	Year
American Business	2019
American Cultures	2013
American Heritage	2013
American Labor	2018
Animal Science	2014
Animation	2015
Archaeology	2017
Archery	2019
Architecture and Landscape Architecture	2014
Art	2013
Astronomy	2019
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Cycling	2017
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Farm Mechanics	2017
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Medicine	2012
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Personal Fitness	2019
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Reptile and Amphibian Study	2018
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Safety	2016
Salesmanship	2013
Scholarship	2014
Scouting Heritage	2019
Scuba Diving	2009
Sculpture	2019
Search and Rescue	2018
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Snow Sports	2019
Soil and Water Conservation	2019
Space Exploration	2016
Sports	2012
Stamp Collecting	2013
Surveying	2004
Sustainability	2013
Swimming	2019
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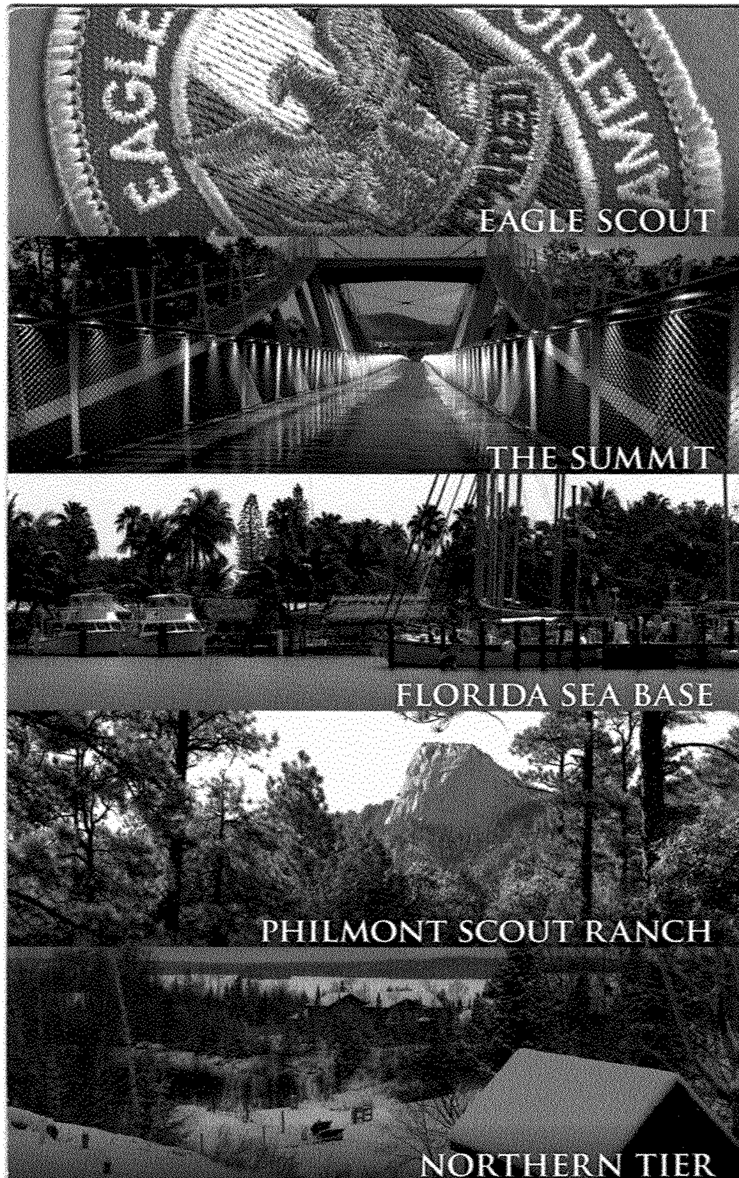
Theater	2019
Traffic Safety	2016
Truck Transportation	2013
Veterinary Medicine	2015
Water Sports	2019
Weather	2019
Welding	2016
Whitewater	2019
Wilderness Survival	2019
Wood Carving	2016
Woodwork	2019



ON THE ROAD TO HIGH ADVENTURE

THE SUPPLY GROUP IS READY TO BE A PARTNE[R] ON YOUR TRAIL TO EAGLE THROUGH HIGH ADVENTURE. THE ADVENTURE IS YOURS, AND WE ARE READY WITH THE GEAR YOU WILL NEED. YOU CAN DEPEND ON THE LATEST IN LIGHTWEIGHT, DURABLE, QUALITY GEAR THAT WILL MEET AND SURPASS YOUR TOUGHEST REQUIREMENTS.

SATISFACTION GUARANTEED — SUPPLY GROUP

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