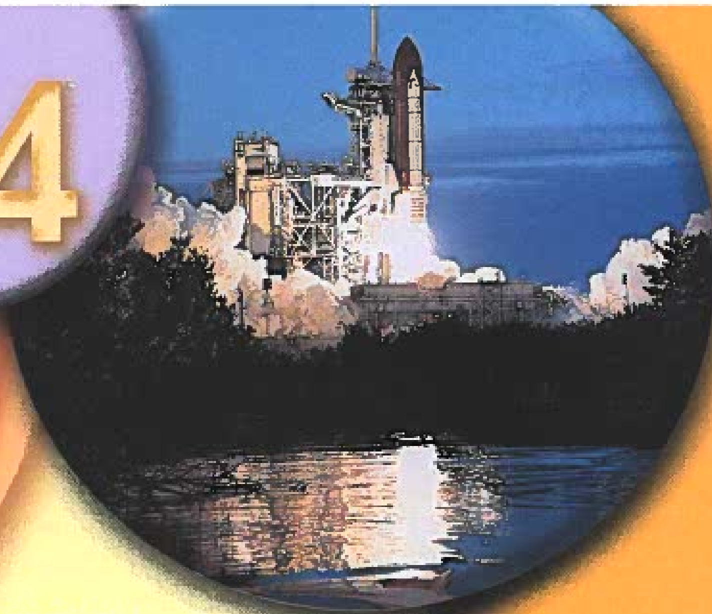
24

Space Vehicular Systems



Basic Concepts

- State the function of a rocket engine.
- Identify the ways navigation information is collected.
- State how manned and unmanned spacecraft are controlled.
- Name the functions of orbiter suspension systems.
- Identify the structures of various types of spacecraft.
- List several support systems for space vehicles.

Intermediate Concepts

- Describe how thrusters operate in the vacuum of space.
- Explain how the Mission Control Center (MCC) operates.

Advanced Concepts

- Relate how an ion engine operates.
- Discuss the aerodynamics of a delta wing.

The goal of spacecraft is to transport people and cargo into space. In order for that to occur, space vehicles must be designed to include several vehicular systems. Propulsion systems, typically rocket engines, are used to propel the craft into space. Guidance systems are used to locate the vehicles in space. Once the location is known, the control systems are used to guide and steer the craft. Suspension systems of spacecraft are used while in the earth's atmosphere, but once the spacecraft are in space, these systems are not of much use because of the lack of gravity. A vehicle's structural system is used to contain and protect the astronauts and payload. Personnel at several support facilities supervise and control the entire process of space transportation.

Propulsion Systems

In order for a spacecraft to operate in the environment it is designed for, space, it must first leave the earth's atmosphere. This, however, is easier said than done. In order for all 4.5 million pounds of a space shuttle to reach orbit, it must be propelled 200 miles above the earth. See **Figure 24-1.** It takes quite an engine to provide this amount of thrust.

Rocket Engines

Currently, the only type of engine able to develop this amount of thrust is the rocket engine. Rocket engines are a type of reaction engine that, as described in Chapter 23, works according to the principle of Newton's third law of motion. This law states that for every action, there is an opposite and equal reaction.

There are two main types of reaction engines: the air stream reaction engine and the rocket engine. Rocket engines are, by far, the more powerful type of reaction engine. The air stream reaction engine, or jet engine, requires an external source of air to operate. Space vehicles, however, operate in an environment without air. For this reason, the jet engine would be useless on a spacecraft. Rocket engines do not require an external source of air to operate, which makes them the perfect choice for space travel. They carry their own fuel and oxygen, known as an oxidizer. An ***oxidizer*** is a chemical substance that mixes with fuel to allow combustion. Rocket engines are classified by the type of propellant they use. ***Propellants*** are mixtures of fuel and oxidizers. There are two types of rocket engine propellants: solid fuel and liquid fuel.

Oxidizer: A chemical substance that mixes with fuel to allow combustion.

Propellant: A mixture of fuel and an oxidizer.

GREEN TECH
One of the most dangerous by-products of rocket fuel is ammonium perchlorate, which is a composite that can be emitted in the exhaust. It has been known to poison water and is associated with hydrochloric acid.

Figure 24-1. Tremendous power is needed to lift a space shuttle into orbit. In this view of a shuttle launch, the two solid rocket boosters (SRBs) and the three main engines on the shuttle itself are all operating, generating 7 million pounds of thrust. (National Aeronautics and Space Administration)

STEM Connection

Science: Newton's Laws of Motion

Sir Isaac Newton presented three natural laws of motion in 1686. The first law states that an object will either remain at rest or in a state of perpetual motion in a straight line until an external force acts upon it. In other words, objects at rest stay at rest, and objects in motion stay in motion. This law is evident in outer space. Once a spacecraft is put into motion, it continues because there are no external forces. If the spacecraft were inside the earth's atmosphere, forces such as gravity and drag would slow it down.

The second law states that a force acting on an object gives the object acceleration in the same direction as the force. The magnitude is also inversely proportional to the mass of the object. This law can be written as the formula "Force = Mass x Acceleration ($F = m \times a$)." The second law of motion is used to calculate the motion of spacecraft and aircraft.

The third law states that for every action, there is an equal and opposite reaction. For example, when you are swimming, as you move your arm through the water, the water pushes you in the opposite direction. This law is observed in both the lift and thrust of spacecraft and aircraft.

Solid-fuel rocket engines

Of the two types of rocket engines, solid-fuel is the simpler one. It is so simple, in fact, it is used in model rockets. See **Figure 24-2.** The ***solid-fuel rocket*** engines contain solid propellant, a combination of fuel and oxidizers, packed into a cylindrical container. The propellant is typically placed inside the cylinder with a channel down the center. This channel serves as the combustion chamber. In the design stage of a solid-fuel rocket engine, the engineer selects the types of chemicals and the proportion of fuel and oxidizer to create a rocket engine with a specific amount of thrust. There is usually more oxidizer than fuel in the propellant mixture. When ready for use, the propellant is ignited at the bottom. As the fuel burns, thrust is produced from the bottom of the engine. See **Figure 24-3.**

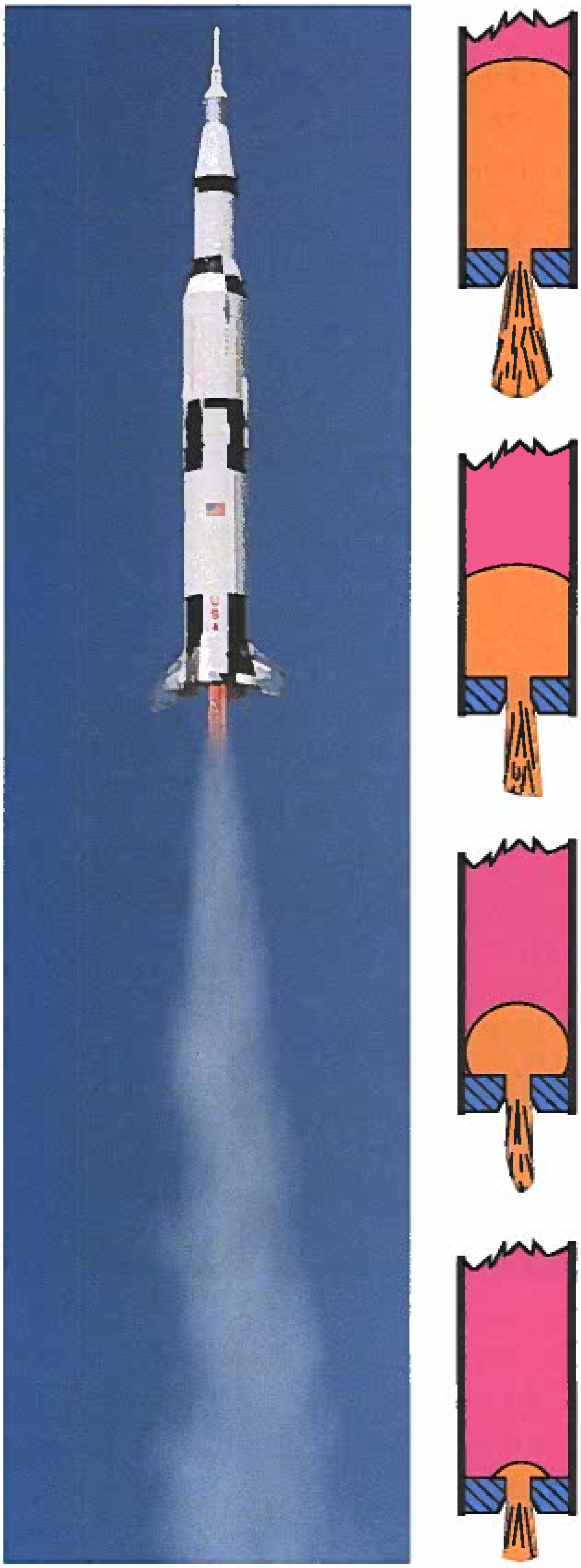
Figure 24-2. Model rockets use solid-fuel engines that are miniature versions of those that power full-size launch vehicles. This rocket is being launched during a high school technology education activity. (Estes)

Solid-fuel rocket: A rocket engine that contains solid propellant packed into a cylindrical container.

Liquid-fuel rocket engines

Liquid-fuel rockets are much more complex than solid-fuel rockets. They are also safer and offer control over the amount of thrust produced. See **Figure 24-4.** These engines use two separate liquids, which are ignited in a combustion chamber. The two propellants are kept in separate tanks inside the vehicle. They are pumped into a combustion chamber, where

Figure 24-3. A model rocket in flight. The drawings on the right show the burning of the solid fuel as the flight continues. The process takes place very rapidly and continues until the fuel supply is exhausted. (Estes)



they are mixed and burned. Valves are used to control the amount of flow of each liquid fuel. See **Figure 24-5.** As propellant is burned in the combustion chamber, it leaves the bottom of the engine as thrust.

Launch Vehicle Propulsion

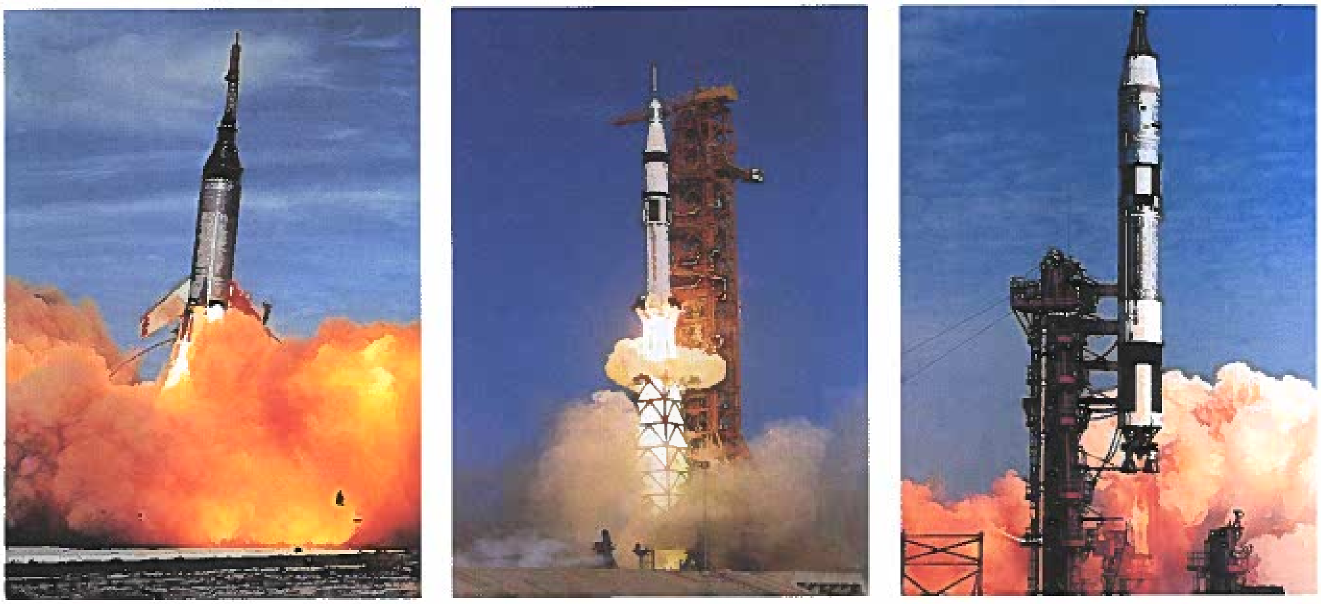
Launch vehicles are used to take spacecraft and satellites into orbit and outer space. They are configured in a number of ways, depending on the payload they are carrying. The launch of a small satellite, for example, may only require a single liquid-fuel rocket. If the vehicle launches a spacecraft on a mission to another planet, it requires more thrust. For example, in 2003, the ***National Aeronautics and Space Administration (NASA)***, the U.S. agency set up for research and development of space exploration, launched the *Mars Rover* onboard the *Delta II* launch vehicle. The vehicle was comprised of a liquid-fuel engine that used kerosene and liquid oxygen as the propellant and produced 200,000 pounds of thrust. This would not be enough, however, to propel the craft into outer space. So, nine solid-fuel rockets were fastened to the *Delta II*. The solid-fuel boosters, as they are called, added over 1 million pounds of thrust to the launch vehicle.

Early manned space vehicles, such as the Saturn V launch vehicle that carried the Apollo mission, relied on ***staging***. This technique places several propulsion systems on top of each other. As the first stage burns out, it is released from the vehicle. This exposes the second stage of propulsion systems. Stages are burned and released until the vehicle reaches its final orbit altitude. By using the staging method, the vehicle can get rid of unneeded mass during its flight. See **Figure 24-6.** Launch vehicles still use staging today.

Space Shuttle Propulsion

Like many launch vehicles, the space shuttle uses both solid- and liquid-fuel rockets. The shuttle has three main propulsion components: the main engines, the solid rocket boosters (SRBs), and the external tank (ET). The ***Space Shuttle Main Engines (SSMEs)*** are

Figure 24-4. Liquid-fuel rockets are more controllable and safer than solid-fuel rockets. (National Aeronautics and Space Administration)



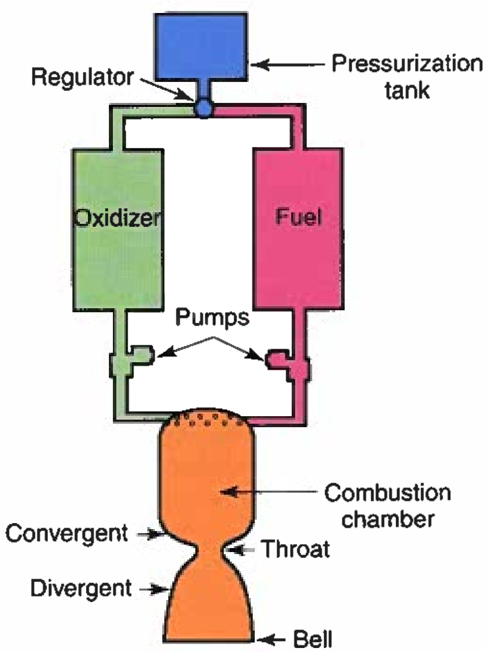


Figure 24-5. A simple liquid-propellant system for a model rocket. One liquid is the fuel burned in the combustion chamber. Fuels often used include liquid hydrogen and kerosene. The second liquid is the oxidizer, which allows the combustion to take place. The oxidizer is often in the form of liquid oxygen. The fuel and oxidizer are sprayed into the combustion chamber to ensure a good mix and efficient combustion. Most combustion chambers also have an igniter to begin the combustion process. Some fuels and oxidizers are so volatile, however, that they ignite on contact and do not require a spark. For this reason, propellants are put into the rocket shortly before they are to be used and are not stored in the rockets. (Estes)

located at the rear of the orbiter. See **Figure 24-7.** There are three engines that make up the SSME system and produce nearly 400,000 lbs. of thrust. During takeoff, the engines receive the needed fuel from the ET. When the ET is released, it burns up and breaks apart over the ocean.

The ***solid rocket boosters (SRBs)***, on the other hand, are recovered and reused. The shuttle is equipped with two SRBs, one on each side of the ET. The SRBs supply the majority of the power at takeoff—3.3 million pounds of thrust each. The propellant used in the SRBs is a combination of ammonium perchlorate, aluminum, iron oxide, and mixture of chemicals used to

Liquid-fuel rocket: A rocket engine that uses two separate liquids, which are ignited in a combustion chamber.

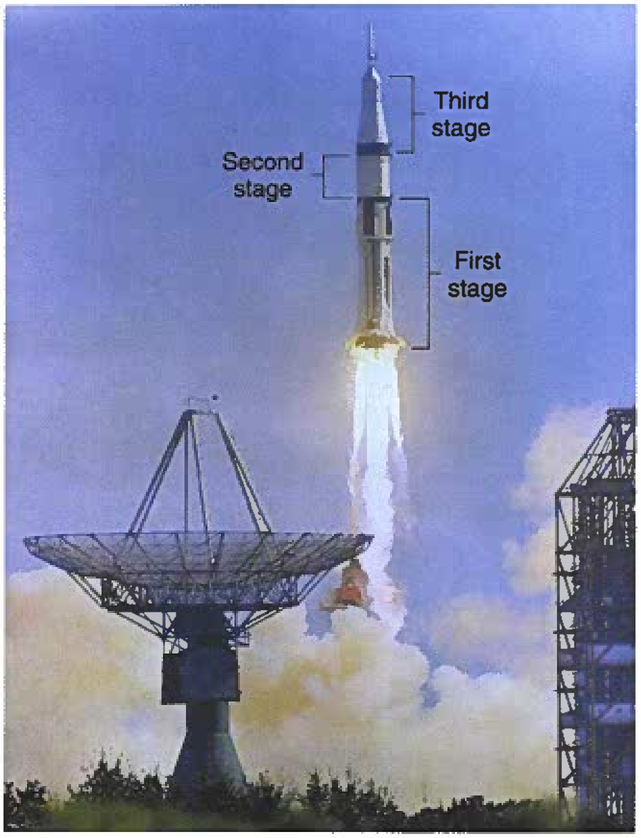


Figure 24-6. The Saturn V launch vehicle used in the early years of the U.S. manned space-flight program consisted of three stages. The vehicle's first stage consisted of five liquid-fuel rocket engines and their fuel supply. It was able to produce about 7.5 million foot-pounds (10.2 million Joules) of thrust. The second stage consisted of five smaller engines capable of producing over 1 million pounds of thrust. The third stage consisted of one engine and its fuel supply. It carried the *Apollo* spacecraft to its final orbit altitude. As the fuel in each stage was exhausted, it separated and dropped away. (National Aeronautics and Space Administration)

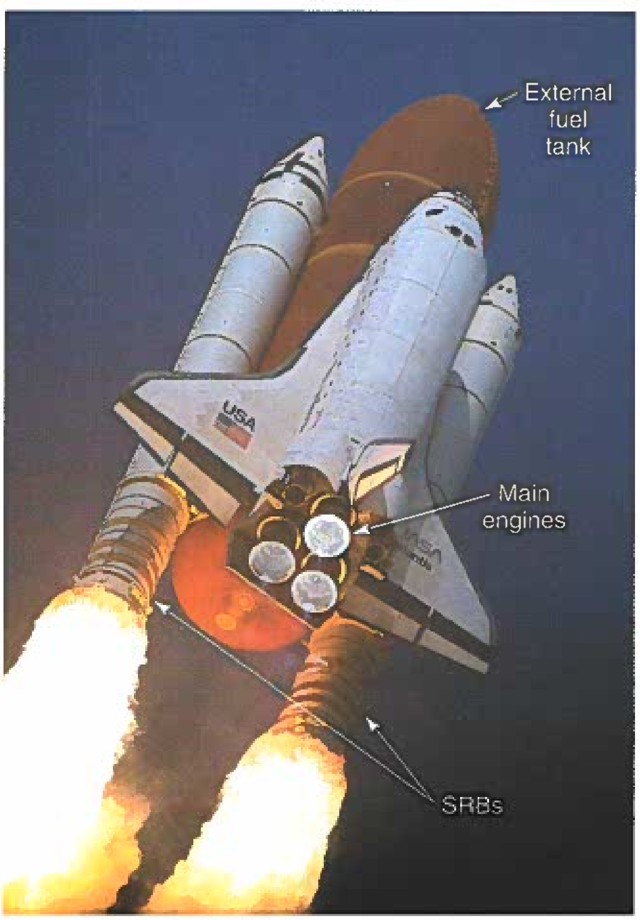


Figure 24-7. The shuttle main engines can be stopped and started as needed. During launch, they burn at full thrust, along with the solid rocket boosters (SRBs). Launch fuel for the main engines is contained in the external fuel tank. The tank is situated on the underside of the orbiter and is the largest part of the space shuttle. The top of the tank holds liquid oxygen, while liquid hydrogen is stored in the bottom. The liquid oxygen and hydrogen are used so quickly that the tanks are empty within 8 minutes after takeoff. The hydrogen is used the quickest, at a rate of over 40,000 gallons per minute (GPM). (A garden hose flows at a rate near 8–10 GPM.) The tank's contents are exhausted during launch, and the tank drops away and burns up during reentry. (National Aeronautics and Space Administration)

Career Connection

Astronautical Engineers

Science, Technology, Engineering & Mathematics

All technology depends on the development of new products. In air and space transportation, aerospace engineers develop new vehicles. There are two main types of aerospace engineers, aeronautical and astronautical. Aeronautical engineers design aircraft, and astronautical engineers design spacecraft. Aerospace engineers often specialize in one area of design, such as aerodynamics, control, structure, or propulsion.

Astronautical engineers not only design spacecraft, such as the shuttle and space station, but they also design satellites, space communication systems, and ballistic missiles. Research and development companies, such as Boeing, Lockheed Martin, and Raytheon, typically employ astronautical engineers. These companies provide products to the federal government and the National Aeronautics and Space Administration (NASA). Some astronautical engineers, however, work directly for NASA and the federal government.

At the very least, astronautical engineers are required to have bachelor's degrees in aerospace or astronautical engineering. Many, however, obtain master's and doctorate degrees. The average salary for an aerospace engineer is slightly over $76,000.

hold everything together. Two minutes after launch, the boosters are empty and released from the shuttle. Several small thrusters at the top and bottom of the SRB are used to ensure the boosters do not come in contact with the rest of the shuttle.

New Propulsion Technologies

Ion propulsion is a type of propulsion much different from liquid- or solid-fuel rockets. Traditional rockets use chemical reactions to accelerate gases that move the spacecraft. Ion propulsion uses the electrical charge of atoms to move vehicles. As you might remember, electrons move between atoms to balance their charges. Ion propulsion uses this movement of electrons to propel a vehicle through space. See **Figure 24-8.** Ion propulsion is not powerful enough to launch spacecraft, but it may eventually be the best method of propelling spacecraft once they are in space.

Guidance Systems

The guidance systems of spacecraft are responsible for two functions—navigation and guidance. Navigation is being able to establish the spacecraft's location in space. Guidance is determining if the vehicle is in the correct place and figuring how to change its location if it is not correct.

In order to determine if a spacecraft is in the correct location and traveling on the correct path, there first must be a flight plan. A flight plan is a detailed account of the path the spacecraft is supposed to travel. Because objects in space are always in motion, the flight must be well planned. See **Figure 24-9.**

National Aeronautics and Space Administration (NASA): The U.S. agency set up for research and development of space exploration.

Staging: A technique that places several propulsion systems on top of each other. Stages are burned and released until the vehicle reaches its final orbit altitude.

Space Shuttle Main Engine (SSME): An engine that can be stopped and started as needed. It is located at the rear of the orbiter.

Solid rocket booster (SRB): A shuttle propulsion component that is recovered and reused. It supplies the majority of the power at takeoff.

Ion propulsion: A type of propulsion that uses the electrical charge of atoms to move vehicles.

Figure 24-8. An ion propulsion engine powered *Deep Space 1*, a spacecraft launched in 1998 to visit a comet far outside our solar system. The spacecraft was retired in 2001, after surpassing all expectations. Currently, ion propulsion is slower than traditional methods, but it can last much longer. The ion engine set a new endurance record—3.5 years of continuous work. *Deep Space 1* approaches the comet 19P/Borrelly in this artist's view. (National Aeronautics and Space Administration's Jet Propulsion Laboratory)

Deep Space Network (DSN): A system with three radio antennas located on three continents. Two of the antennas determine the distance of the spacecraft from themselves. The antennas then determine the distance of a known object in space. All these distances are computed, and the location of the spacecraft in space is determined.

Navigation

Determining a spacecraft's position in space is the role of navigation systems. This is more complex than might be imagined because the entire solar system is constantly moving. Even if a spacecraft remains in one place, its position relative to everything else continues to change. In order to accurately determine the position of spacecraft, navigation systems have to determine three pieces of information: location, velocity, and attitude.

Location

In order to determine the location of a spacecraft, the distance and angle from earth must be known. The distance from earth is most often figured by bouncing a radio signal from earth off the spacecraft. The time it takes for the signal to be returned can be calculated to find the spacecraft's distance from earth. To calculate the angle of the spacecraft to the earth, a process of triangulation is used. NASA's ***Deep Space Network (DSN)***, a system with three radio antennas located on three continents around the earth, takes the necessary measurements. See **Figure 24-10.**

Figure 24-9. The *Stardust* spacecraft was launched in 1999, with the intention to collect samples from the comet Wild 2 in 2004. The flight plan had to take into account where the comet would be five years after the launch. It also had to include two revolutions around the sun prior to meeting the comet, in order to gain enough speed. The flight was successfully planned, and on January 2, 2004, *Stardust* encountered the comet Wild 2. (National Aeronautics and Space Administration)

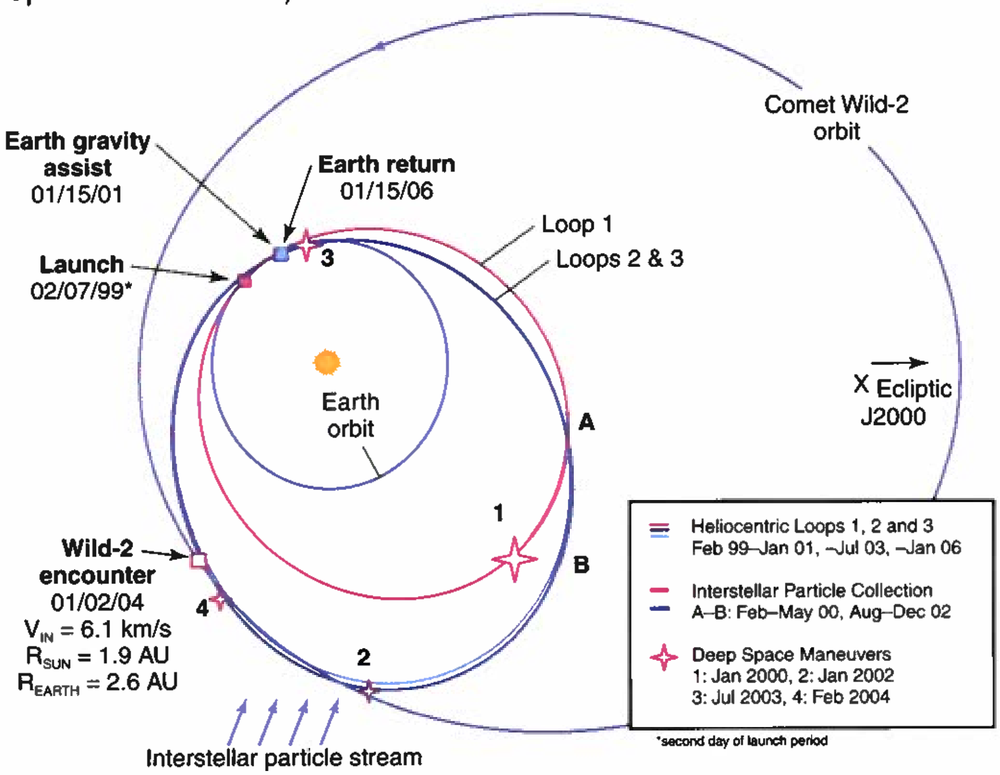
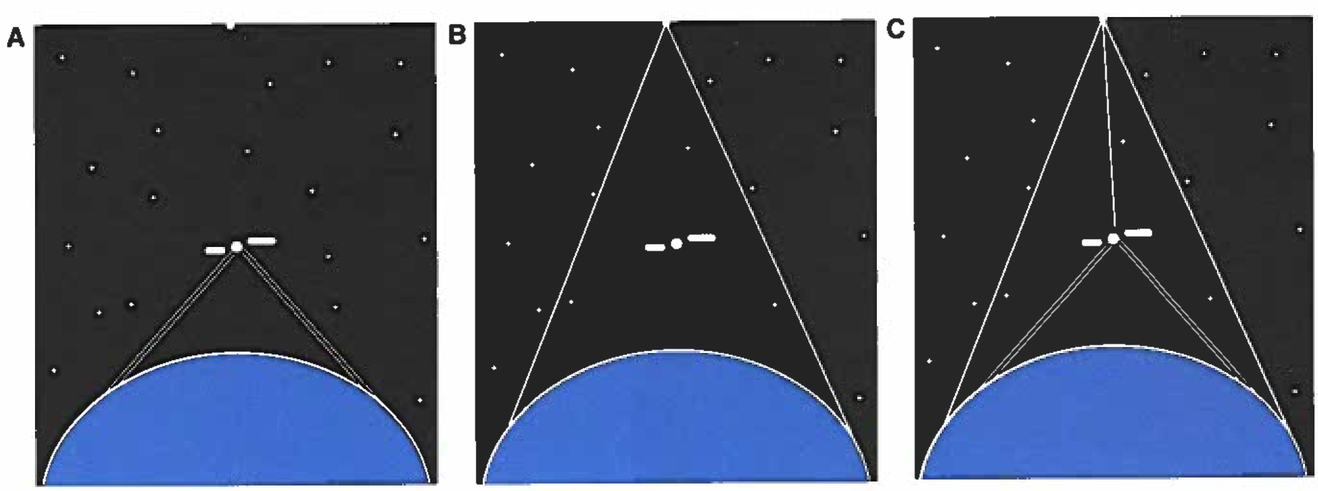


Figure 24-10. Triangulation is used to compute the location of a spacecraft or other object in space. A—The Deep Space Network (DSN) uses two of its antennas to determine the distance of the spacecraft from themselves. B—The antennas then determine the distance of a known object in space, such as a star. C—All these distances are computed, and the location of the spacecraft in space is determined. (National Aeronautics and Space Administration)



Velocity

The velocity, or speed, of spacecraft is often also computed by NASA's DSN. See **Figure 24-11.** The DSN is able to determine the speed a spacecraft is traveling by measuring the Doppler shift. This shift is based on the Doppler effect, which is the change in pitch that occurs as an object moves past an observer. For example, if you are sitting at a racetrack, the pitch of the engine gets higher as the car approaches you and decreases as the car passes. This same effect occurs in space. The radio antennas at the DSN are able to detect the change in pitch and calculate the velocity of the moving spacecraft.

Attitude

Celestial reference device: A device that uses the locations of objects in space to figure the rotation of a spacecraft.

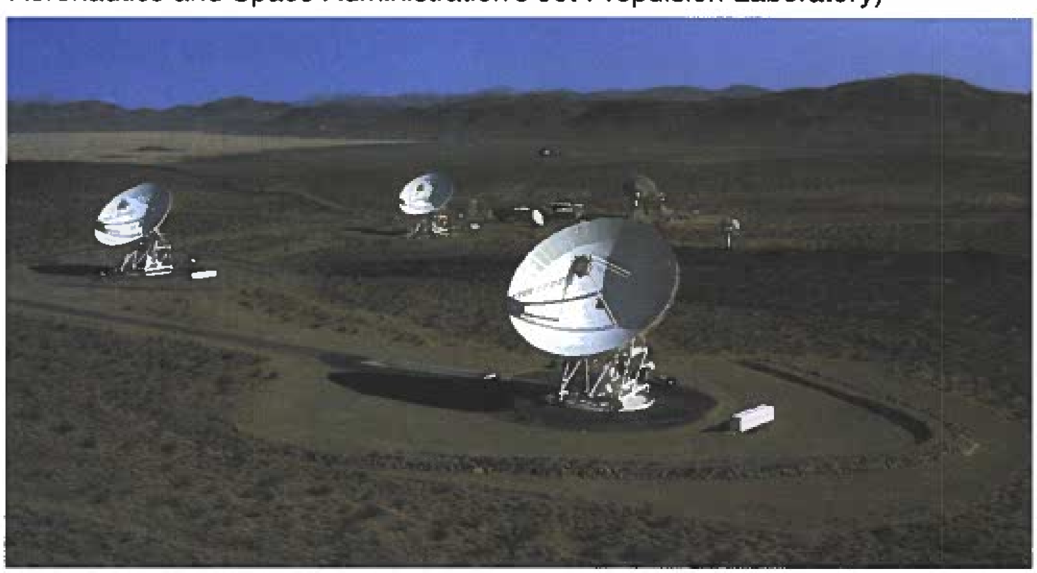
Inertial reference system: A system that uses gyroscopes to determine the attitude of a spacecraft.

The attitude, or rotation, of a spacecraft can be determined in two ways: celestial reference and inertial reference. ***Celestial reference devices*** use the location of objects in space to figure the rotation of the spacecraft. ***Inertial reference systems*** use gyroscopes to determine the attitude of the spacecraft. Gyroscopes are spinning devices that can measure the amount of rotation from an initial setting.

Complete systems

Systems have been designed that combine the measurements of location, velocity, and attitude into integrated functions. These systems are known as Space Integrated Global Positioning System and Inertial Navigation Systems (SIGIs). A SIGI uses both a global positioning system (GPS) and inertial navigation systems (INSs) to navigate. This system is used on the International Space Station (ISS) and may be used in the future on space shuttles. A GPS is already used on shuttles and other orbiting spacecraft to quickly determine location and attitude.

Figure 24-11. Deep Space Network (DSN) antennas at the Goldstone site in California's Mojave Desert are used for communication and to measure the Doppler shift when determining the velocity of a spacecraft. (National Aeronautics and Space Administration's Jet Propulsion Laboratory)



Guidance

Knowing the location, velocity, and attitude of the spacecraft is only one piece of guiding the vehicle. The other part is determining if the spacecraft is in the right place. This is the job of guidance systems. Guidance systems, usually computers, examine the navigation information and flight plan to determine if the spacecraft is on the proper trajectory. A ***trajectory*** is the course or route of the craft. If the trajectory is incorrect, the guidance computers or personnel from ground control centers can use the spacecraft's control system to change its course. Periodic trajectory changes are usually built into a flight plan because there are many variables in space that can cause a spacecraft to fly off course.

Trajectory: The course or route of a spacecraft.

Control Systems

Having enough power to propel the spacecraft into space is only one part of space travel and exploration. The space vehicle must also be able to be controlled. A spacecraft is controlled in several different ways, depending on the type of vehicle.

Unmanned Spacecraft

Satellites and space probes are controlled much differently from space shuttles. Both are unmanned and must be completely controlled from ground control centers. The rotation, or attitude, of both of these spacecraft is extremely important. For example, imagine if a television satellite was at the wrong attitude and, instead of transmitting television programming to the earth, it sent the transmission into outer space. There would be a lot of unhappy customers. The same is true for a space probe. Imagine if millions of dollars were spent to build a probe to explore Mars and instead it headed to the moon and crashed.

To avoid those types of situations, the control systems of unmanned spacecraft are designed to be highly accurate and have many backups in place. The guidance systems are used to determine the position in which the spacecraft should be. The job of the control system is to rotate the vehicle into that position. Three types of systems are used to maneuver a satellite or space probe. The first is the use of thrusters. There are typically several thrusters pointed at 90° from one another. By using these thrusters, the satellite can rotate itself into position. Another method of rotating is using reaction wheels. ***Reaction wheels*** are large rotating wheels that can generate momentum and spin the spacecraft. Three or four wheels are typically placed at different angles to ensure the vehicle can be rotated into any position. The last type of control is known as spin stabilization. This works because if the satellite or a part of the satellite remains spinning, it will be naturally stable. This system also uses small thrusters to make any minor corrections that may be needed.

Reaction wheel: A large rotating wheel that can generate momentum and spin an unmanned spacecraft.

Manned Spacecraft

The pilots onboard manned spacecraft are able to control the vehicles. The two main types of manned spacecraft include space shuttles and manned maneuvering units (MMUs). Each vehicle uses different systems to control the direction of the vehicle.

Space shuttle orbiters

Elevon: A flap located at the rear of a shuttle orbiter's wing. It is used to control pitch and roll.

Gimbal: To rotate the nozzle surrounding each of the three main engines.

There are two different control systems used on the space shuttle orbiter. The first type of control system is the use of control surfaces. Control surfaces, as you may remember from Chapter 22, are used on aircraft. They are used on space shuttles for the same purposes as in aircraft, to control the pitch, roll, and yaw. See **Figure 24-12.** Flaps at the rear of the wing, known as ***elevons***, control pitch and roll. See **Figure 24-13.** The use of a body flap located along the bottom rear of the shuttle, under the main engines, also controls the pitch. A rudder positioned on the tail fin of the orbiter controls the yaw. Switches on the instrument panel and foot pedals at both the commander's seat and the pilot's seat activate the control surfaces. These surfaces operate by deflecting air in the opposite direction of the desired movement. Therefore, once the shuttle leaves the atmosphere, the surfaces are not useful because there is no air to deflect.

Once outside the earth's atmosphere, the second control system must be used. This system uses three sets of small and large rocket engines to control the movement of the orbiter. The first set of engines used for control is the SSME. While these engines are mainly used to propel the craft into space, they can also help control direction. The nozzle surrounding each of the three main engines can be rotated, which is known as ***gimbaling***. By directing the flow of the escaping gas, the engines are able to aid in steering the space shuttle.

GREEN TECH

One of the more recent attempts to make rocket fuel better for the environment has been by private space agencies. Their goal is not only to send regular people into space, but also to do that in a more environmentally friendly way, such as using non-toxic fuels and hybrid rocket motors.

Figure 24-12. The space shuttle's control surfaces are used to control pitch, roll, and yaw. Pitch is movement around the X axis, roll is movement around the Y axis, and yaw is movement around the Z axis.

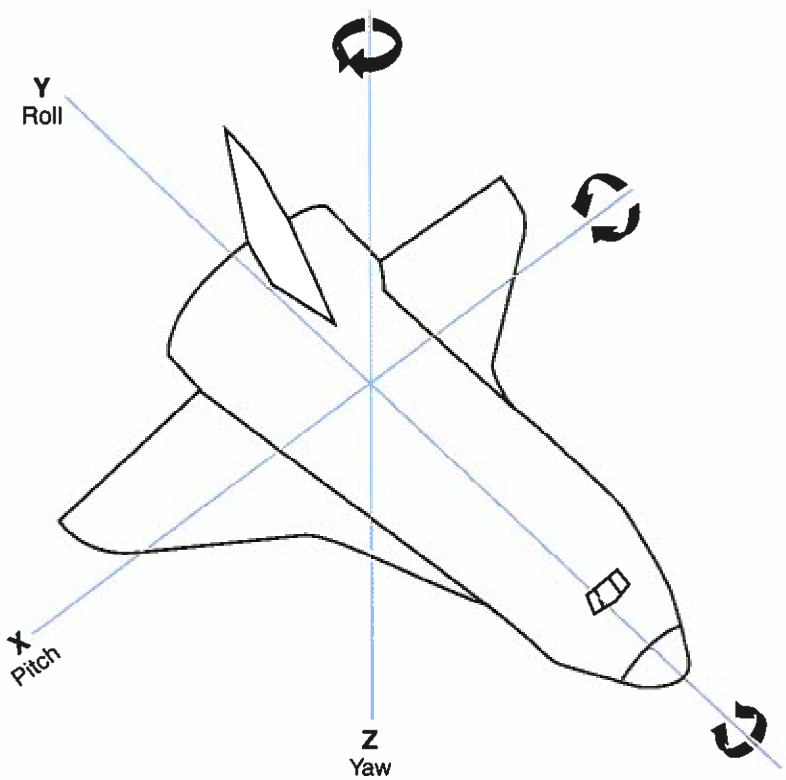


Figure 24-13. Elevons are flaps at the rear of the shuttle's wings that serve the same purposes as ailerons and elevators in a conventional aircraft. The rudder performs the same function—yaw control—on both conventional aircraft and the shuttle. (National Aeronautics and Space Administration)

The second set of engines is used to control the rotation, or attitude, of the orbiter. These are the ***orbital maneuvering system (OMS) engines***, located at the rear of the orbiter above the main engines, one on each side of the tail fin. They are used primarily to maneuver the shuttle into orbit and to slow and deorbit the craft prior to reentry. In most missions, engines are fired twice to place the shuttle into orbit and once to remove it from orbit. These engines use two propellants that ignite on contact, nitrogen tetroxide and hydrazine. Therefore, an igniter is not needed. This type of rocket is known as a ***hypergolic engine***.

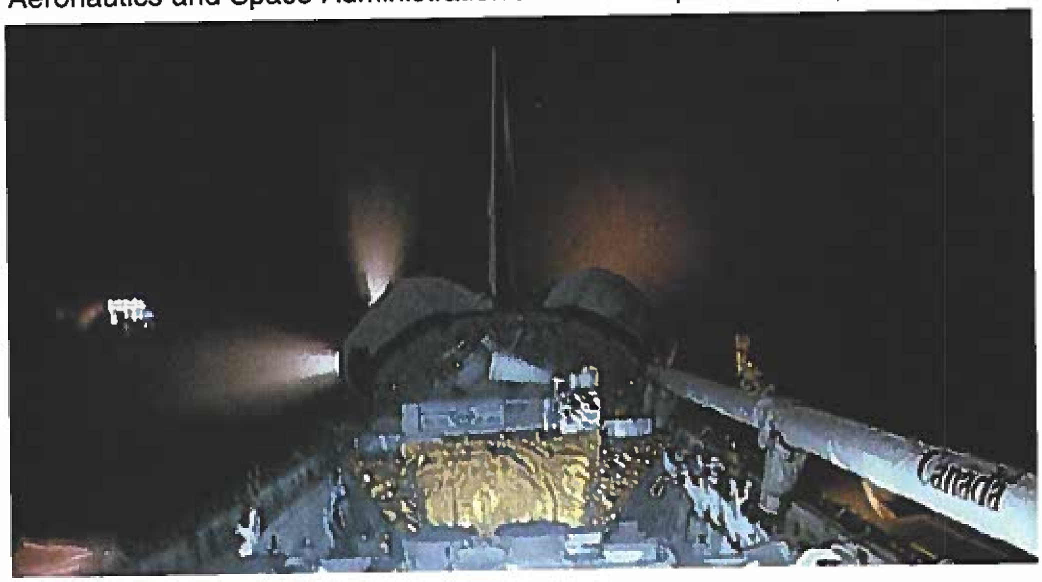
The third collection of engines is known as the ***reaction control system (RCS) engines***. See **Figure 24-14.** These engines serve as thrusters that enable the shuttle to maneuver in space. The crew of the shuttle can operate the RCS engines using two types of controllers. The first is known as a rotational hand controller. This controller resembles a video game joystick. It is used to change the pitch, roll, and yaw of the shuttle. To change the pitch, the stick is pushed forward or backward, and the nose of the shuttle lowers and rises. If the controller is moved to the right or left, the shuttle banks left or right, changing the roll. To change the yaw, the controller is turned clockwise or counterclockwise to rotate the shuttle. When the controller is pushed in any direction, a signal is sent to a computer, which then turns on the required thrusters and moves the shuttle in the desired direction. The other type of controller is the translational hand controller. This resembles a knob that can be moved up and down, right and left, and in and out. The movement is sent to a computer, and thrusters are activated to move the shuttle in the desired direction. The translational hand controller only produces movements along the X, Y, or Z plane. This is helpful when the shuttle is docking with a space station or another spacecraft.

Orbital maneuvering system (OMS) engine: An engine located at the rear of the orbiter above the main engines. It is used primarily to maneuver the shuttle into orbit and to slow and deorbit the craft prior to reentry.

Hypergolic engine: A type of rocket in which the engines use two propellants that ignite on contact, nitrogen tetroxide and hydrazine. Therefore, it does not require an igniter.

Reaction control system (RCS) engine: An engine located in a cluster in either the front or rear of a shuttle. It serves as a thruster that enables the shuttle to maneuver in space.

Figure 24-14. Reaction control system (RCS) engines are located in clusters in the front and rear of the shuttle. There is a total of 14 primary and 2 secondary RCS engines in the front and 12 primary and 2 secondary RCS engines on each side of the tail fin in the rear. The primary thrusters are used for most movements, and the secondary engines are used to hold a position or for small movements. In this view, taken during a mission of the shuttle *Discovery*, the RCS engines are firing upward and to the left. (National Aeronautics and Space Administration's Johnson Space Center)



Manned maneuvering units (MMUs)

Some specialized space vehicles use inert gas jets to propel them while they are in space. ***Manned maneuvering units (MMUs)***, developed by NASA, are one example. See **Figure 24-15.** These use small jets that emit nitrogen gas. The escaping gas provides the action that causes a reaction in the opposite direction.

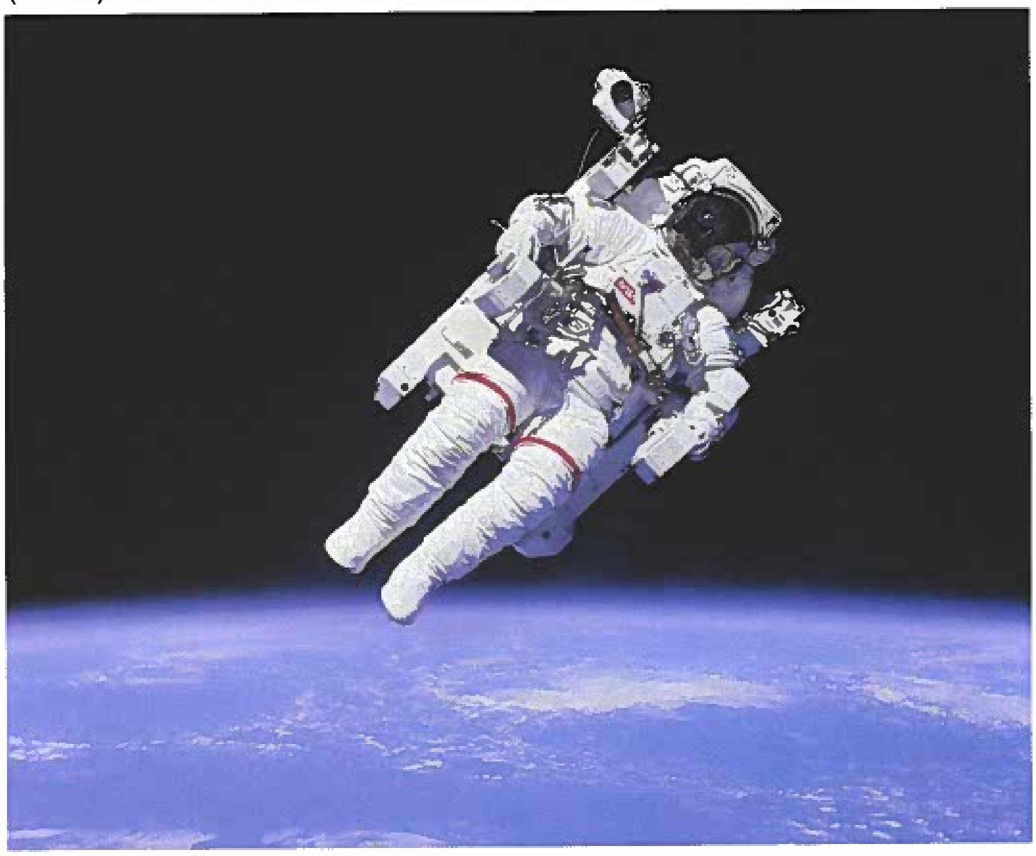
Manned maneuvering unit (MMU): A specialized space vehicle developed early in the shuttle program to allow astronauts to maneuver outside the vehicle.

Suspension Systems

Vehicular suspension systems are the components of a vehicle supporting it in its environment. In land transportation, the suspension system is the wheel. In air transportation, it is the wings, and in water transportation, the hull works to support the ship. In space transportation, the suspension system is a little different. Some spacecraft do not even need suspension systems. Spacecraft that travel in outer space have no need for suspension systems to keep them in the air because space is a vacuum. Anything will float in space. There is also very little, if any, friction, so aerodynamics are of minor concern.

Spacecraft that orbit the earth, such as satellites and space stations, do not require sophisticated suspension systems. Once they are placed in orbit, the centrifugal force and gravitational pull keep the craft suspended. As long as a spacecraft can keep the proper speed and distance from earth, it will continue to be suspended. This is the same reason space debris remains in orbit for years, until it finally loses speed and falls to earth.

Figure 24-15. Early in the shuttle program, the National Aeronautics and Space Administration (NASA) developed the manned maneuvering unit (MMU) to allow astronauts to maneuver outside the vehicle. When the operator wants to move in a certain direction, he activates the jet nozzle, which will produce movement in that direction. In this 1984 view, astronaut Bruce McCandless performed the first spacewalk without a tether. In recent years, the more efficient Extravehicular Mobility Units (EMUs) have replaced MMUs. (NASA)



The only time a space vehicle uses a suspension system is when it exits and reenters the earth's atmosphere. This is especially important for a space shuttle, since the shuttle carries passengers. The suspension system used on space shuttles is the orbiter wings. The wings are a unique design, known as a ***delta wing***. See **Figure 24-16.** Delta wings are triangular and relatively flat. This style of wing is not commonly used on aircraft because it is ineffective and hard to control at speeds under the speed of sound, or subsonic speeds. The two most common vehicles that have used the delta wing, Concordes and space shuttles, travel at supersonic speeds. Supersonic speeds are between Mach 1 and 5, or between the speed of sound and five times the speed of sound. On reentry, space shuttles even reach ***hypersonic speeds***, which are speeds over Mach 5. Travel at these speeds makes the delta wing a good choice for space shuttles.

The wing of the orbiter serves two purposes. The first is to suspend the shuttle in the air as it is guided back to earth during reentry. The orbiter begins reentry at over 16,000 miles per hour (mph) and has 25 minutes to decrease its speed to 200 mph, so it can land safely. The

Delta wing: An orbiter wing used as the suspension system on space shuttles. It is triangular and relatively flat.

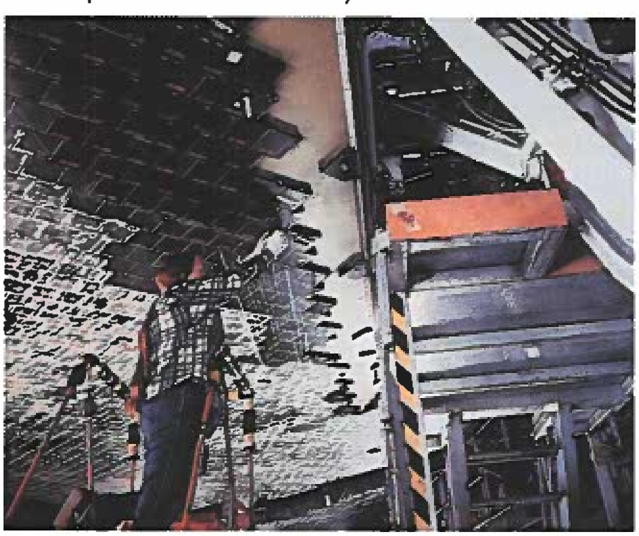
Hypersonic speed: Speed over Mach 5 (five times the speed of sound).

Reinforced carbon-carbon panel: The covering for the leading edge of an orbiter wing. It is made of a material that has several layers of carbon and can withstand extreme temperatures.

Figure 24-16. The space shuttle uses a triangular wing design known as the delta wing. This wing shape is most effective at supersonic speeds. (National Aeronautics and Space Administration)

shuttle is flown at a high angle of attack, where the nose is elevated at an angle between 25° and 40°. Flying at such an angle causes a large amount of drag, which slows the orbiter down. The orbiter also goes through a series of *S* turns to help it decrease speed. The entire reentry is computer controlled. The process of controlling an object going this fast would be very hard for a person to handle. In fact, a pilot has controlled the process only once. The landing process also requires a high amount of accuracy. The orbiter, as part of the deorbiting process, burns all the remaining fuel and is left with no functioning engines. So, it actually works like a glider and would be in trouble if it decreased its speed too quickly or not quickly enough because it has no engines to retry the landing.

Figure 24-17. A technician installs high-temperature reusable surface insulation tiles on the wing of a space shuttle. Most of the tiles are 6 × 6 in and range in thickness from 1″ to 5″. When heated, the tiles glow red, but they cool so quickly that within seconds, they are cool enough to touch. (National Aeronautics and Space Administration)



The second function of the wing is to serve as a thermal protection system. The underside and leading edge of the wings are exposed to temperatures over 2000°F on reentry. To protect the shuttle, the wings are covered with two different materials. The leading edge of the wing is covered with ***reinforced carbon-carbon panels***. These panels begin as pieces of rayon cloth and are subjected to several chemical processes. The result is a material that has several layers of carbon and can withstand extreme temperatures. The underside and nose of the shuttle are covered with tiles of a different material. See **Figure 24-17.** These tiles are known as ***high-temperature reusable surface insulation tiles*** and are made of nearly pure silica fibers. The specially designed tiles rapidly dissipate heat and can withstand temperatures from below –200°F to over 2000°F.

The final space shuttle suspension device is the landing gear. See **Figure 24-18.** The pilot completes the landing of the shuttle with the use of an electronic landing system, much like the one commercial aircraft use.

High-temperature reusable surface insulation tile: A specially designed tile, made of nearly pure silica fibers, that rapidly dissipates heat and can withstand temperatures from below –200°F to over 2000°F. These tiles cover the underside and nose of shuttles.

Structural Systems

The builders of most space vehicles use construction techniques similar to those used on aircraft. Variations of truss and monocoque construction are relied on. Designs for spacecraft depend on many things and vary greatly. Some considerations include the vehicle's destination, whether it is to be manned or unmanned, the tasks to be performed on the mission, and conditions the vehicle will have to endure.

Unmanned Spacecraft

Unmanned spacecraft all have similar components based around a main structure. The main structure, also known as the ***bus***, can come in different shapes, sizes, and materials. Rectangular, cylindrical, and polygonal buses are all common. The size of the structure often ranges from several feet to slightly over 10′ in width. The vehicle used to launch the spacecraft constrains the size. If it is to be deployed from a space shuttle, the satellite or probe can be larger than if it is to be launched from the nose of a rocket. The bus material is most often an aluminum alloy, a

Bus: The main structure of an unmanned spacecraft.

Figure 24-18. The space shuttle uses tricycle-style landing gear, with one set of tires in the front and two sets farther back, under the fuselage. The front set can be steered, while the two in back have brakes. The shuttle tires are safe to use up to 225 miles per hour (mph) and are replaced after each flight.

titanium alloy, or a magnesium alloy. Composite materials, such as Kevlar® resins, are becoming more popular, but they are often used in combination with an alloy.

The main purpose of the bus is to serve as a structure to which the spacecraft components can be attached. These components include solar panels, antennas, guidance and navigation equipment, measurement instruments, and monitoring devices. The types of components used depend on the type of mission the spacecraft is to complete. A broadcast satellite would have much different components from a space probe traveling to Jupiter.

Manned Spacecraft

Manned spacecraft require additional structural considerations. The structure must be able to hold human astronauts and scientists. The structures of both space stations and space shuttles are designed to contain and protect the human travelers. The structures, however, are still very different.

Space stations

The ISS, when complete, will be the largest space station ever constructed. The entire structure will be over 200′ long and 350′ wide. The station will have several modules in a continuous line that will serve as the living quarters and research area for the crew. See **Figure 24-19.** At the center of the space structure is the *Unity* capsule, which serves as a hub for other capsules.

Figure 24-19. The International Space Station (ISS) is constructed from a series of interconnected modules produced by the United States, Russia, and Japan. Extending from one side of *Unity* are two Russian modules, *Zarya* and *Zvezda*. Each module has solar collectors attached to provide power to the station. *Zarya* serves as the control center, and *Zvezda* is the living quarters. Connected to the other side of *Unity* is the U.S. lab *Destiny*, which serves as a science lab. Other modules will be added to the ISS. (National Aeronautics and Space Administration)

Technology Link

Construction: The International Space Station (ISS)

The International Space Station (ISS) is not only the largest space station ever built and the largest international project ever completed, but it is also a combination of several types of technology. In order for the ISS to be completed, it relies on transportation, manufacturing, and construction technology. The station itself is a transportation vehicle, as it carries astronauts, equipment, and experiments around the earth. It also contains all the vehicular systems present in all vehicles.

The ISS, however, is not a typical mass-produced vehicle. The station contains many components, each of which is custom manufactured. There are several aspects of the manufacturing of the components that make it very challenging. First, the components are manufactured in phases and sent into space at different times. When the components are sent into space, it is the first time they have been connected to each other. The ISS was not built on earth first and then disassembled and sent to space for reassembly. One other challenge is that different companies build the components all over the world. To overcome these challenges, the manufacturers of the components must ensure that they build each component exactly as planned, with very high tolerances.

After the components have been manufactured and are ready to be assembled, they are sent to space. The individual pieces are assembled in what can be viewed as a construction project. The astronauts onboard the ISS serve as construction workers and assemble the components. Several cranes and robotic arms have been designed into the ISS to help the astronauts with the construction. When working on the ISS, the astronauts are tethered to the station, and their tools are tethered to their space suits to make sure the astronauts remain safe and their tools do not drift away. The ISS may seem like strictly a transportation vehicle, however, without both manufacturing and construction technologies, it could never be built.

Running perpendicular to the research modules and centered on the *Unity* module will be a truss system. The aluminum trusses, when completed, will span 300′ and contain the cooling system and solar arrays needed to maintain the ISS. The entire structure will require over 40 spaceflights and 160 space walks to complete.

Space shuttles

When you think of a space shuttle, the first image that may come to mind is a shuttle sitting on the launchpad, ready for takeoff. See **Figure 24-20.** When the shuttle is in this position, it is actually made of three distinctly different parts. It consists of two SRBs, a large ET, and a shuttle orbiter.

The SRBs are the largest solid-fuel rocket engines ever developed. See **Figure 24-21.** These boosters are also the first ones to be used on any manned space vehicle. They are constructed of a series of hardened steel rings. The booster sections are attached with high-strength steel pins. The resulting joints are sealed with rubberlike O-rings and then covered with a

Figure 24-20. A space shuttle being moved to the launchpad at the Kennedy Space Center (KSC) aboard a giant transporter. The shuttle orbiter is attached to a large external fuel tank and two solid rocket boosters (SRBs). The structure of each part is unique to the space program. (National Aeronautics and Space Administration)

Figure 24-21. During launch, the two solid rocket boosters (SRBs) create a huge amount of thrust. The three main engines of the shuttle, as seen on the right, fire at the same time as the SRBs. (National Aeronautics and Space Administration)

fiberglass tape to make a smooth, aerodynamic shape. Inside the nose cone of the SRBs are flight electronics and a parachute. The SRBs are reusable, and once they have been disconnected from the orbiter, they parachute into the ocean, where U.S. Navy vessels recover them.

The large ET is the largest part of the launch vehicle. It holds the liquid fuel the shuttle's main engines will use. There are three parts to the ET. The top section is the liquid oxygen tank. To produce an aerodynamic shape, the top of this tank is tapered to a point. The bottom section is the liquid hydrogen tank. It is the larger of the two tanks. This section also holds the mounting brackets for the SRBs and the shuttle orbiter. A collar joins the two tanks. This is the third part of the ET structure. When the ET is released from the orbiter, it descends to earth and is burned up during reentry into the atmosphere.

The orbiter is the only component of the three that enters orbit. The shuttle orbiter makes use of the construction techniques found in the aircraft industry. The fuselage, or body, of an orbiter can be divided into three sections, much like a ship. The forefuselage is the only pressurized section and contains all the operating and living quarters. It is divided into two decks. The upper deck, or ***flight deck***, contains all the flight controls. One of the latest modifications to space shuttles is in the cockpit area. See **Figure 24-22.** The midfuselage is also known as the ***payload area***. This area holds the cargo the shuttle is carrying on its mission. A robotic arm is housed in the midfuselage to help load and unload the mission cargo. See **Figure 24-23.** When astronauts exit the shuttle to spacewalk, they exit from the forefuselage to the midfuselage, through an ***air lock***. The air lock ensures that the cabin remains pressurized and provides a place for the astronauts to put on their space suits. The rear section of the shuttle is the aftfuselage. This area contains the majority of the propulsion system (the main engines, orbital maneuvering engines, and reaction control thrusters).

Flight deck: The upper deck of a space shuttle's forefuselage, which contains the flight controls.

Payload area: The midfuselage of a space shuttle, which holds the cargo.

Air lock: An area through which astronauts exit the shuttle. It ensures that the cabin remains pressurized and provides a place for the astronauts to put on their space suits.

Support Systems

As you know, space transportation is very specialized and experimental. Governments of various countries support their space exploration efforts by supplying money for research and development. In the United States, NASA is the agency set up to conduct work in this area. NASA extends its arms into all areas of aviation and space travel. It is the primary support system of space transportation.

Figure 24-22. Space shuttles are being upgraded with the installation of a "glass cockpit," in which conventional gauges have been replaced with full-color graphic display screens. These displays improve the safety and flight conditions for the pilot and commander. Similar systems are being used in modern airliners. (National Aeronautics and Space Administration)

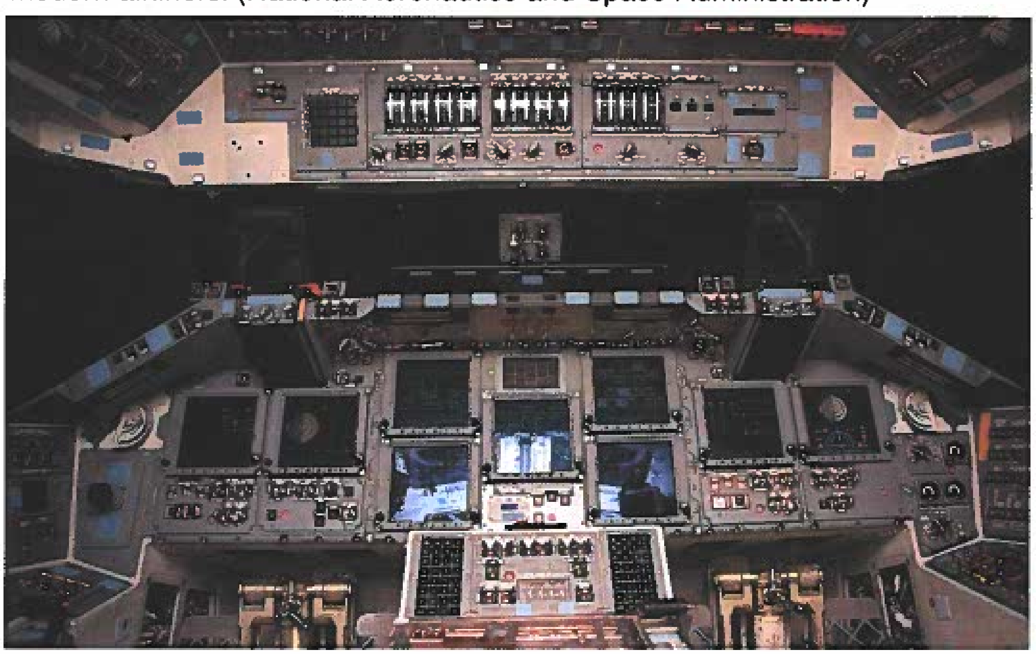


Figure 24-23. A robotic arm aboard the space shuttle is used to unload cargo. Oftentimes, the cargo is either a satellite or a section of the International Space Station (ISS). The robotic arm is helpful in moving the objects and can be operated at the payload control center at the rear of the flight deck. In this view, the Hubble Space Telescope is being lifted out of the cargo bay and redeployed after a servicing mission. (National Aeronautics and Space Administration)

Orbiter Processing Facility (OPF): A facility that houses the orbiter from the time it lands until a week before the next scheduled launch.

Vehicle Assembly Building (VAB): A facility in which the orbiter is stood vertically and the solid rocket boosters (SRBs) and external tank (ET) are attached.

NASA has a number of space centers, research centers, and test facilities that conduct research and tests and prepare spacecraft for flight. The most well-known support centers are the Kennedy Space Center (KSC) in Florida and the Johnson Space Center (JSC) in Texas. These centers are the most highly involved with the launching and flight control of space shuttles. The shuttles are prepared and launched from the KSC. The preparation for launch is done in the Orbiter Processing Facility (OPF) and the Vehicle Assembly Building (VAB). The ***Orbiter Processing Facility (OPF)*** houses the orbiter from the time it lands until a week before the next scheduled launch. In the OPF, the orbiter is examined and reconditioned. Any problems are fixed, and needed modifications are made. From the OPF, the orbiter is taken to the ***Vehicle Assembly Building (VAB).*** Here, the orbiter is stood vertically, and the SRBs and ET are attached. See **Figure 24-24.**

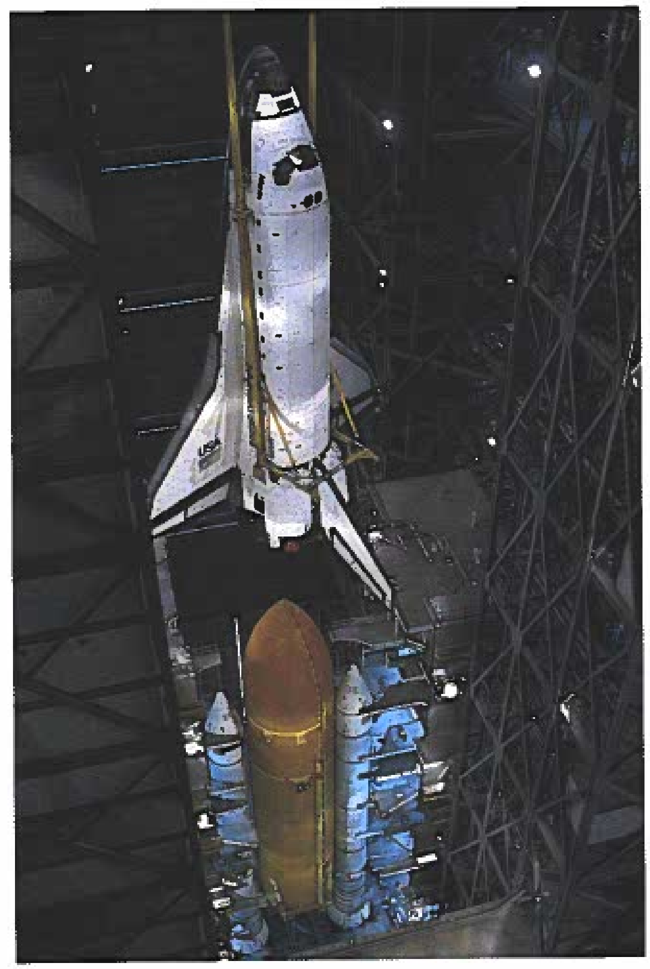
The *Mission Control Center (MCC)* at the JSC directs the actual liftoff of the shuttle, the mission of the orbiter, and the control of the ISS. See **Figure 24-25.** All personnel work facing a large screen in the front of the room displaying the vital information and location of the spacecraft. At each desk, the engineers have equipment monitoring the specific functions of the spacecraft and astronauts. The lead support person is the ***flight director***, who is the team leader. The flight director is in charge of making decisions based on the information each engineer and officer provides. The spacecraft communicator then relays the information to the commander of the spacecraft.

The JSC also contains the space vehicle mock-up facility. This facility serves as one of the main training areas for astronauts. There are full and partial orbiters, as well as replicas of space station components, that serve different training functions. Astronauts are able to perform routine training and prepare for emergencies at this location.

Unmanned spacecraft are supported by NASA's DSN. The DSN is a system of three deep space antennas that are able to track space probes. The antennas are placed across the globe in California, Spain, and Australia so the spacecraft can be "seen" by at least two of the antennas at all times. The DSN is able to monitor and correct trajectories, as well as collect scientific data the spacecraft is sending.

The KSC, JSC, and DSN are only a few of the support facilities used in space transportation. Private companies also provide much support. These companies help to maintain and improve the existing spacecraft and research ways to enhance space travel.

Figure 24-24. In the Vehicle Assembly Building (VAB) at the Kennedy Space Center (KSC), a shuttle orbiter is being mated to the external fuel tank and solid rocket boosters (SRBs). The assembly is completed on a mobile platform, which is later driven to the launchpad. The pad is only about 4 miles away, but the trip takes 6 hours, due to the weight of the shuttle. At the launchpad, the shuttle goes through a number of inspections prior to liftoff. (National Aeronautics and Space Administration)



Mission Control Center (MCC): An area in the Johnson Space Center (JSC) where the liftoff of the shuttle, the mission of the orbiter, and the control of the International Space Station (ISS) is directed.

Flight director: The team leader at the Mission Control Center (MCC).

Figure 24-25. The Mission Control Center (MCC) at the Johnson Space Center (JSC) in Texas controls and monitors all U.S. spaceflights. It has two separate flight control rooms—one for the shuttle operations and the other for the space station. The rooms are laid out with many desks that have specific purposes. This view was taken during a television transmission from the Apollo 13 mission in 1970. During the launch and recovery of a space vehicle, technicians and engineers work at all the consoles. (National Aeronautics and Space Administration)

Career Skills

Joining Organizations

Belonging to a student organization can help you reach your career goal. You will find student organizations focused on almost every career topic. They will help you learn more about career options and meet other students and professionals who can help you establish a career.

You may also belong to professional organizations as a student member while you are still in school. Becoming involved in professional organizations now can help you land a job in your chosen field. Your membership shows employers that you are already involved in the organization and serious about a career in this area. To be a student member of these organizations, you may need to be enrolled in a certain number of courses that will lead to a career in the given area.

Summary

In order for space transportation vehicles to function, they must first get off the ground. This is the job of the propulsion system. All spacecraft are currently propelled into outer space using rocket engines. The rocket engines are either solid or liquid fueled and are the largest engines used in the world. Once in space, thruster or rotational devices control the spacecraft. The spacecraft are controlled in an effort to remain on the planned trajectory. The information gathered from the guidance systems helps to determine if the spacecraft is on the correct path and how much correction is needed.

For most spacecraft, other than space shuttles, suspension systems are unimportant because the spacecraft fly in the vacuum of space. For a shuttle's orbiter, the delta-style wings serve as suspension as the craft reenters the earth's atmosphere. The structure of spacecraft varies, depending on the use of the craft. The components of satellites and space probes are attached to a frame serving as the structural center. A number of space agencies and facilities across the world support space research and transportation. In the United States, the National Aeronautics and Space Administration (NASA) is the supporting agency of space transportation. Its facilities and research centers, along with private companies, research, design, build, and operate space vehicles that orbit the earth and travel to distant planets.

Key Words

All the following words have been used in this chapter. Do you know their meanings?

air lock
bus
celestial reference device
Deep Space Network (DSN)
delta wing
elevon
flight deck
flight director
gimbal
high-temperature reusable surface insulation tile
hypergolic engine
hypersonic speed
inertial reference system
ion propulsion
liquid-fuel rocket
manned maneuvering unit (MMU)
Mission Control Center (MCC)
National Aeronautics and Space Administration (NASA)
orbital maneuvering system (OMS) engine
Orbiter Processing Facility (OPF)
oxidizer
payload area
propellant
reaction control system (RCS) engine
reaction wheel
reinforced carbon-carbon panel
solid-fuel rocket
solid rocket booster (SRB)
Space Shuttle Main Engine (SSME)
staging
trajectory
Vehicle Assembly Building (VAB)

Test Your Knowledge

Write your answers on a separate sheet of paper. Do not write in this book.

1. What is the difference between an air stream reaction engine and a rocket engine?
2. Summarize how thrusters operate in the vacuum of space.
3. *True or False?* An oxidizer is mixed with fuel to create a propellant.
4. *True or False?* Liquid-fuel rockets are simpler and offer less control than solid-fuel rockets.
5. Paraphrase how a liquid-fuel rocket works.
6. What is staging?
7. *True or False?* Ion propulsion was the first type of rocket propulsion used.
8. Write two or three sentences relating how an ion engine operates.
9. How are the distance and angle of a spacecraft from earth figured?
10. Select one type of attitude measurement device and explain how it is used.
11. *True or False?* A global positioning system (GPS) cannot be used in space.
12. *True or False?* Reaction wheels use momentum to maneuver the spacecraft.
13. Rotating the nozzle of an engine to change direction is known as _____.
14. Why are reaction control system (RCS) engines necessary for controlling spacecraft?
15. How are the functions of the rotational hand controller and translational hand controller different?
16. The orbiter wing style is a(n) _____ wing.
17. Analyze the aerodynamics of a delta wing.
18. Speeds of over Mach 5 are known as _____ speeds.
19. *True or False?* The high-temperature tiles used on the orbiter retain heat for a long period of time.
20. Cite the three components that make up a space shuttle.
21. The _____ is the section of the orbiter containing the flight controls.
22. _____ is the major organization supporting space transportation in the United States.
23. Recall and describe two space transportation support facilities.
24. The lead person of flight control is the _____.

STEM Activities

1. If your class has access to a model rocket kit, construct and launch a rocket with your instructor's assistance. This can be a class project or a team project. Prepare a report on what you did and what you observed.
2. Construct a model of a satellite and display it.