Student Astronaut Challenge

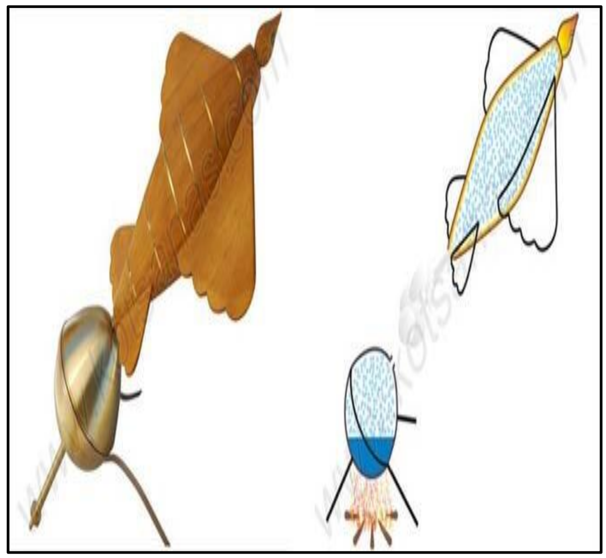
2023-2024 Student Textbook

Chapter 1 Early Rocketry

Roots of Rocketry

Historians believe that armies began hurling combustible weapons toward one another as early as 1,000 B.C. At the time, fire pots were used to set fires. Fire pots were simply pots containing flammable materials like naphtha that were ignited and hurled by various mechanical devices. The concept was simple, yet effective as fire pots were able to be easily deployed and could set fires over large areas however they were not rocketing in the traditional sense.

Archytas and Hero



Although the exact date remains a mystery, it is believed that the reaction principle, the physical law of rocket motion, was first demonstrated about 360 B.C. by a Greek named Archytas. Archytas simply filled a hollow clay pigeon with water. He then suspended the clay pigeon by string over a fire. The heating of the water produced steam, and the clay pigeon could move under its own power as steam escaped through strategically placed holes. Archytas could hardly have imagined that the same basic principle would one day carry men to the Moon.

About three hundred years after the pigeon, another Greek, Hero of Alexandria, invented a similar rocket-like device called an aeolipile. It, too, used steam as a propulsive gas. Hero mounted a sphere on top of a water kettle. A fire below the kettle turned the water into steam, and the gas traveled through pipes to the sphere. Two L-shaped tubes on opposite sides of the sphere allowed the gas to escape, and in doing so gave a thrust to the sphere that caused it to rotate.

Black Powder

By about 200 B.C. it is believed that the Chinese mastered the mixing and use of gunpowder. Known as black powder until the invention of guns, gunpowder would prove to be the primary ingredient of the first true ballistic rockets. The Chinese created the first gunpowder through the traditional mixing of charcoal, saltpeter, and sulfur. While rocketry was still a long way away, the explosive nature of gunpowder was well demonstrated by the Chinese through the loading and detonation of firecrackers.

Black powder technically should not be called gunpowder because its use in rockets preceded that in guns. The ingredients are charcoal, sulfur, and saltpeter (potassium nitrate). These three ingredients were known in China for many centuries before they were combined into black powder. Charcoal was known from the earliest times, and sulfur and saltpeter at least since the sixth century AD, and probably as far back as the first century BC. That the saltpeter is of Chinese origin is indicated by the names given to this material by the Arabs, who called it "Chinese snow", and the Persians, who called it "salt from China".

About 1280 AD, Arab military men, referring to the propulsive ability of black powder, suggested improvements over the simple Chinese skyrocket. One interesting innovation was what might be best described as an air squid or traveling land mine; it could scurry across land in the manner of a squid through water.

Chinese Rockets

Chinese soldier launches fire-arrow

By about 600 A.D. it is believed that the Chinese had adapted the use of gunpowder from firecrackers to fireworks. Certain writings of the era indicate that the Chinese used small explosive charges to send other explosive charges into the air for entertainment.

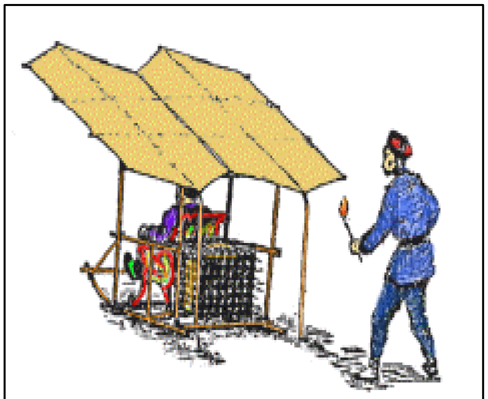
By 900 A.D., the Chinese began experimenting with the gunpowder-filled tubes. At some point, they attached bamboo tubes to arrows and launched them with bows. Soon they discovered that these gunpowder tubes could launch themselves just by the power produced from the escaping gas. The true rocket was born.

The date reporting the first use of true rockets was in 1232. The Chinese and the Mongols were at war with each other. During the battle of Kai-Keng, the Chinese repelled the Mongol invaders by a barrage of "arrows of flying fire." These fire-arrows were a simple form of a solid-propellant rocket. A tube, capped at one end, contained gunpowder. The other end was left open, and the tube was attached to a long stick. When the powder was ignited, the rapid burning of the powder produced fire, smoke, and gas that escaped out the open end and produced a thrust. The stick acted as a simple guidance system that kept the rocket headed in one general direction as it flew.

Chinese Fire-Arrows

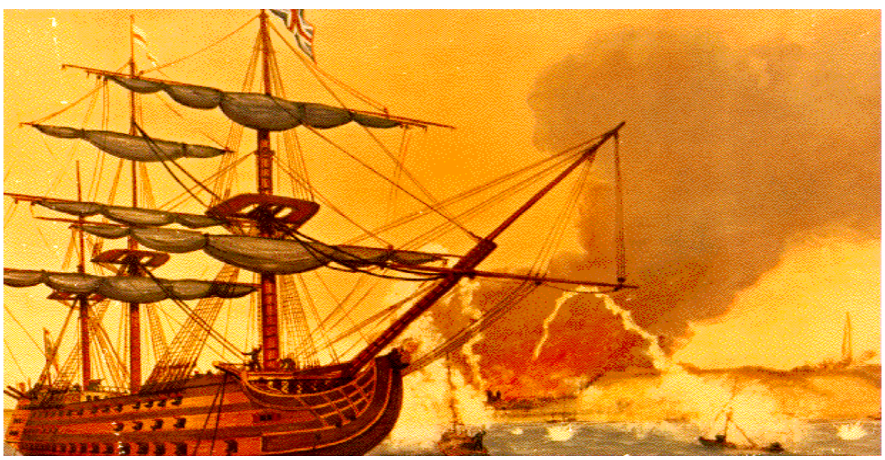
The fire arrows carried flammable materials or sometimes poison-coated heads. In a form more closely resembling modern rockets, the gunpowder tube was lengthened to the tip of the arrow and given a pointed nose, eliminating the need for a traditional arrowhead. Once it was discovered that the fire arrows flew a straight path even after their feathers were burned up by the gunpowder exhaust, the feathers were completely removed. The resulting fire arrow was quite similar in appearance to fireworks used today. The Chinese typically launched these fire arrows in salvos from arrays of cylinders or boxes which could hold as many as 1,000 fire arrows each. The fire arrows propelled by gunpowder may have had a range of up to 1,000 feet. It is not clear how effective these arrows of flying fire were as weapons of destruction, but their psychological effects on the Mongols must have been formidable.

According to Chinese folk tale, a man named Wan-Hoo made the first attempt to carry a man in a rocket propelled vehicle in around 1500. He reportedly took two large horizontal stakes and tied a seat between them. Under the primitive device were placed 47 rockets set to be lit all at the same time. When the rockets were ignited, they burned erratically and could not provide effective thrust to move the contraption. Wan-Hoo is said to have burned to death in the resulting fire.


Legendary Chinese official Wan Hu braces himself for "liftoff"

Rockets in Europe

By the end of the 13th century, armies of Japan, Java, Korea and India are believed to have acquired sufficient knowledge of gunpowder and fire arrows to begin using them against the Mongols. Use of the weapons quickly spread throughout Asia and Eastern Europe. Military writings of al-Hasan al-Rammah indicate that in 1285, Arabs began using gunpowder propelled fire arrows in combat. It is believed that gunpowder propelled fire arrows were subsequently used by Arabs against French troops of Louis IX during the 7th Crusade.



In 1379, an Italian named Muratori used the word "rochetta" when he described types of gunpowder propelled fire arrows used in medieval times. This is believed to be the first use of the word later translated in English as "rocket". The French are reported to have made extensive use of war rockets throughout the 15th century. In 1429, French troops led by Joan of Arc reportedly used rockets in their successful defense of the city of Orleans.

The French also are reported to have used rockets in their sieges of Pont-Andemer in 1449, Bordeaux in 1452 and Gand in 1453. German field artillery colonel Christoph Friedrich is reported to have begun experimenting with war rockets weighing 55 to 120 pounds as early as 1668. In 1680, Peter the Great established the first rocket factory in Russia. Originally located in Moscow, the rocket factory provided the Russian Army with battlefield illumination rockets.

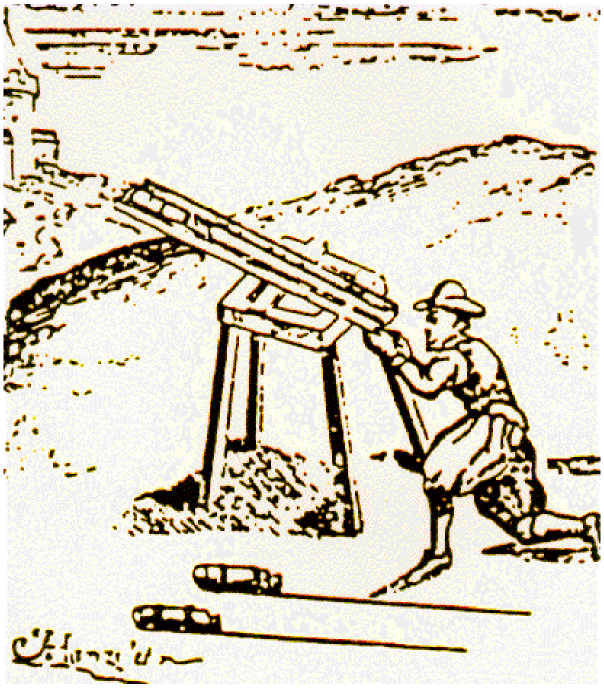
British Congreve Rockets

By 1804, Colonel (later Sir) William Congreve had begun studying and refining captured Indian rockets at the Royal Laboratory, Woolwich Arsenal in Kent. His first product was an elongated, larger version of Indian rockets specifically designed to be launched from ships for the purpose of setting fires on an enemy shoreline. A variety of rockets, which quickly became known as Congreve rockets after their designer, were introduced.

The rocket most widely used in battle weighed 32 pounds, with a gunpowder charge housed in a casing 3 feet, 6 inches long by 4 inches wide. Each 32-pound rocket was typically mounted on a stick measuring 15 feet long by 1.5 inches wide. Thus, they became known as stick rockets. Stick rockets could be produced inexpensively and in large numbers. Many stick rockets employed a conical, metal warhead that embedded itself in its target before oozing a slow-burning incendiary mixture.

On September 13 and 14, 1814 a 25-hour barrage of Congreve rockets was fired from the British ship Erebus against Fort McHenry in Baltimore. The Erebus carried about 20 Congreve rocket batteries consisting of a box housing multiple metal firing tubes. Each of the rockets fired against Fort McHenry weighed about 30 pounds and carried an incendiary charge. Although several American ships were destroyed by Congreve rockets during the War of 1812, just four deaths and minimal damage was reported at Fort McHenry during the siege.

However, the battle was witnessed by a young lawyer named Francis Scott Key, who mentioned the Congreve "rockets' red glare" in his song "The Star-Spangled Banner”. The song later became the U.S. National Anthem, paying tribute to the tenacity of the American forces under siege. One of the first peaceful uses of a Congreve-type rocket was introduced by Englishman Henry Trengrouse who fastening a light cord to a small rocket, then launching the rocket over a ship in distress. Sailors then hauled in the cord, fastened a sturdier rope to it and could either pull themselves or be pulled to safety. Under certain rescue conditions, a similar practice is still in use today.



Hale Rockets

By the middle of the 19th century, improved British rockets eclipsed long-lived Congreve rockets. Separate studies conducted in France and the United States suggested that rockets would be more accurate if they were spun, like the way a bullet is spun after it leaves a gun barrel. An Englishman named William Hale was the first rocket designer to take advantage of this principle. He adopted a combination of tail fins and secondary nozzles through which exhaust could pass. Hale rockets became the first spin-stabilized rockets, and quickly became standard equipment for both the British and United States armies.

Although Hale rockets were more accurate than Congreve rockets, they could not travel as far, and typically had a maximum range of 2,000 yards. A version with a 2.25-inch diameter weighed 6 pounds, while a version with a 3.25-inch diameter weighed 16 pounds. The United States made their first use of Hale rockets during the Mexican War of 1846-1848. Since the United States and Great Britain were allies by this time, Hale rockets were made readily available to U.S. troops. Thus, Hale rockets were the first rockets used by United States armed forces in battle.

The use of war rockets diminished as the latter half of the 19th century dawned, primarily due to significant advances in conventional artillery. Perhaps prophetically, the British adapted many military rockets as fireworks to light up the Thames River during the Peace of Aix-la-Chapelle celebration of 1849.

First Multi-Stage Rocket

The year 1855 saw the introduction of the first two-stage rocket, and it was developed for peaceful purposes. The ship rescue line concept pioneered by Henry Trengrouse was improved to increase the range of the rockets and allow for the transport of heavier cord. What became known as the Boxer rocket was developed by British Lt. Colonel E.M. Boxer at the Royal Laboratory. The rocket weighed just six pounds but incorporated two gunpowder charges separated by a small charge of quick-burning powder.

As the first gunpowder charge "stage" burned itself out in an upward direction, it ignited the quick-burning powder charge and fell away. The quick-burning powder charge then ignited the second gunpowder charge "stage" which continued toward its target. Boxer rockets were able to carry a durable half-inch hemp line about 1,000 feet. The rockets were used in rescue line applications until shortly after World War I.

In the latter half of the 19th century, rockets were also used in an interesting, if now considered inhumane, manner. Whaling rockets, also known as whaling harpoons, had a barbed pointed head carrying an explosive charge designed to detonate after entering the whale. A line was spliced to the rocket to aid in recovering the whale. Whaling rockets are perhaps most worthy of interest because they were launched from small hand-held tubes resembling the modern bazooka.

Civil War Rockets

By the start of the Civil War in 1860, military rockets had all but disappeared. Rockets declined in importance due to the deadly accuracy of conventional artillery, most notably weapons with rifled barrels and breech loading. However, both sides in the Civil War remembered how well rockets served armed forces during the Mexican War two decades earlier. But it was quickly discovered that Hale, and even Congreve, rockets that had been stored for long periods of time were rendered useless because their gunpowder charges failed to remain properly bonded to their casings.

This forced both sides to develop new rockets if rockets were to be used at all. The resulting rockets were considered primitive, even by the standards of the day, due to their inaccuracy and unreliability. But a variety of rockets were used during the Civil War by both sides. On July 3, 1862 Confederate forces under the command of Jeb Stuart fired rockets at Union troops during the Battle of Harrison's Landing. Colonel James T. Kirk of the 10th Pennsylvania Reserves later wrote that one of his men was wounded by a projectile carried on a rocket fired from "a sort of gun carriage". Rocket batteries of this type were most often used by Confederate forces in Texas during campaigns in 1863 and 1864. These rockets and their launchers were first manufactured in Galveston, and later in Houston. The New York Rocket Battalion was the first Union force to be issued rockets. The group was organized by British officer Major Thomas W. Lion and was made up of 160 men. Rockets employed ranged in size from 12 to 20 inches long by 2 to 3 inches wide.

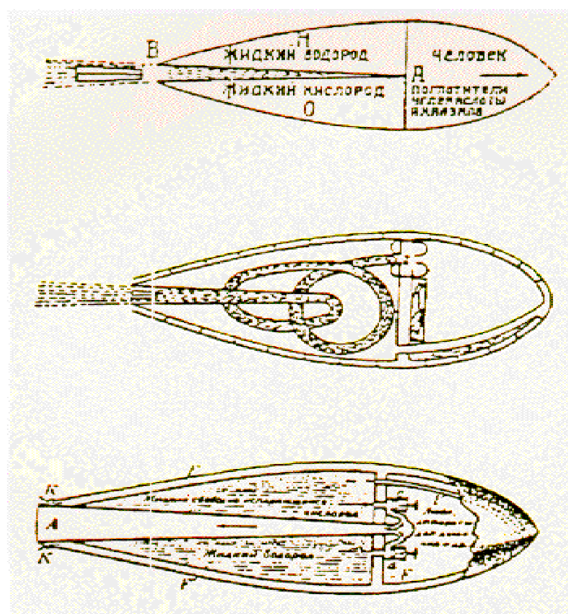
The rockets could be launched from light carriages carrying four wrought iron tubes, each of which was about 8 feet long. They could also be launched from 3.25-inch diameter guiding rods bound together in an open framework, or from individual 3-inch diameter sheet-iron tubes. Each rocket was primarily designed to deliver flammable compounds but could carry musket balls placed in a hollow shell and exploded by a timed fuse. Although the New York Battalion rockets could fly a remarkable maximum distance of 3 miles, they were extremely erratic and were never used in combat. Interest in war rockets continued to decline sharply following the Civil War, again due to advances in the pinpoint accuracy and increased range of conventional artillery. Rockets did, however, continue to be used for years to come in signaling and rescue applications.

Chapter 2 Modern Rocketry

The Rocket Pioneers

Authors Jules Verne and H. G. Wells wrote about the use of rockets and space travel and serious scientists soon turned their attention to rocket theory. It was, of course, the 20th century that witnessed an explosion in the field of rocketry. By the end of the 19th century, the three men considered to be the primary pioneers of modern rocketry had been born and begun their studies, Konstantin Tsiolkovsky (Russian), Hermann Oberth (German) and Robert Goddard (American).

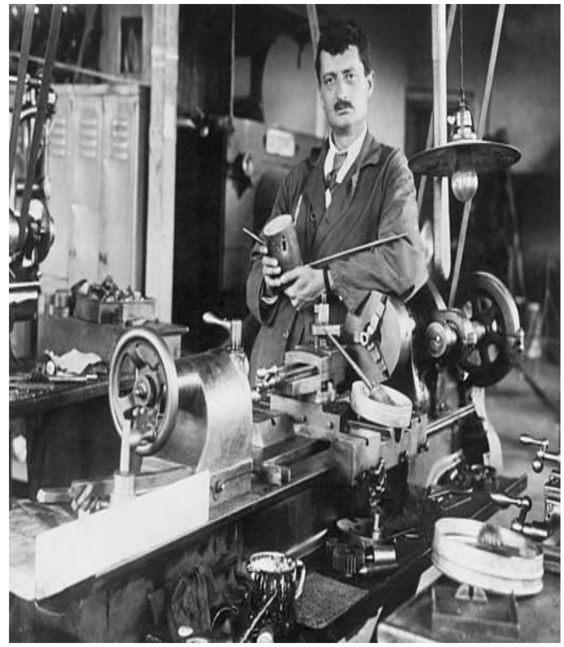
Konstantin Tsiolkovsky



Tsiolkovsky Rocket Designs

In 1898, a Russian schoolteacher, Konstantin Tsiolkovsky (1857-1935), proposed the idea of space exploration by rocket. In a report he published in 1903, Tsiolkovsky suggested the use of liquid propellants for rockets to achieve greater range. Tsiolkovsky stated that the speed and range of a rocket were limited only by the exhaust velocity of escaping gases. For his ideas, careful research, and great vision, Tsiolkovsky has been called the father of modern astronautics.

Hermann Oberth

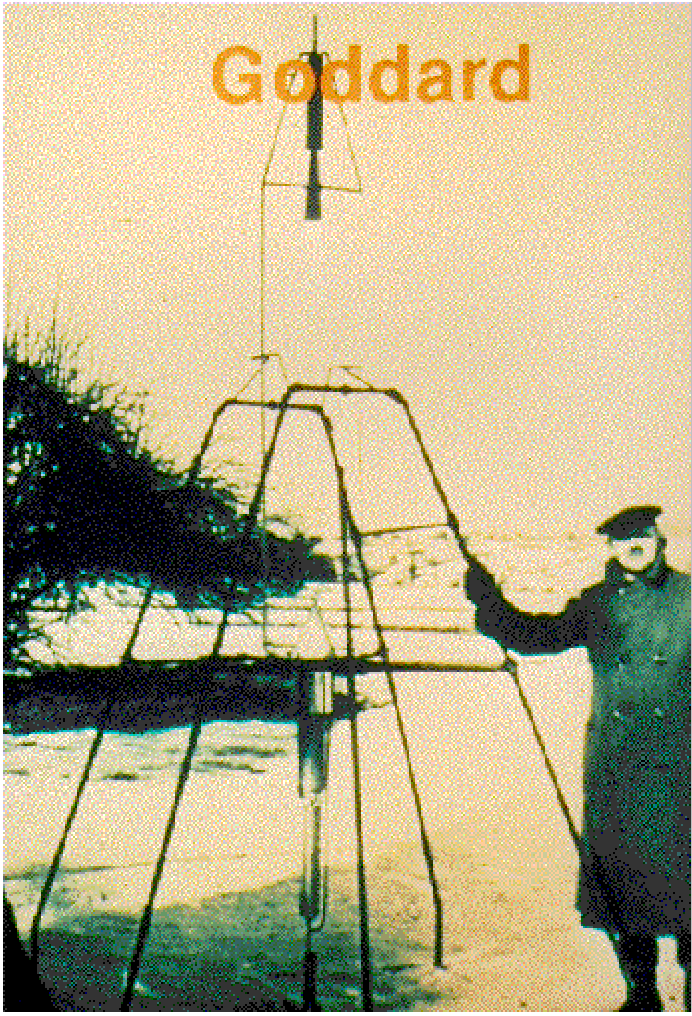


Hermann Oberth, a German scientist, also contributed to the theory and design of rockets. In 1923 he published a work in which he proved flight beyond the atmosphere is possible. In a 1929 book called "The Road to Space Travel" Oberth proposed liquid-propelled rockets, multistage rockets, space navigation, and guided and re-entry systems. He also advanced the idea of a transatlantic postal rocket for quick mail delivery. It was taken seriously at the time but never attempted.

Although rockets were used during World War I, they were of limited value. As was the case during the U.S. Civil War, rockets were simply not as effective as artillery weapons of the day. Rockets sometimes were employed both on land and at sea to lay smoke screens. Allied forces also used rockets as a method of illuminating battlefields. Rockets were exploded in a brilliant flash that could illuminate a battlefield for several seconds. Some rockets carried a parachute with a flare attached. As the parachute and flare dropped toward the ground, a battlefield could be illuminated for about 30 seconds.

Robert Goddard

Robert Hutchings Goddard was born on October 5, 1882 in Worcester, Massachusetts. Early in his life, Goddard was inspired by works of science fiction, primarily "War of The Worlds" by H.G. Wells and "From the Earth to The Moon" by Jules Verne. Completely independent of Tsiolkovsky, Goddard realized that the reaction principle would provide a foundation for space travel. But rather than focus entirely on theory, Goddard set out at an early age to become equipped to build and test the hardware he believed was necessary to best demonstrate the reaction principle.



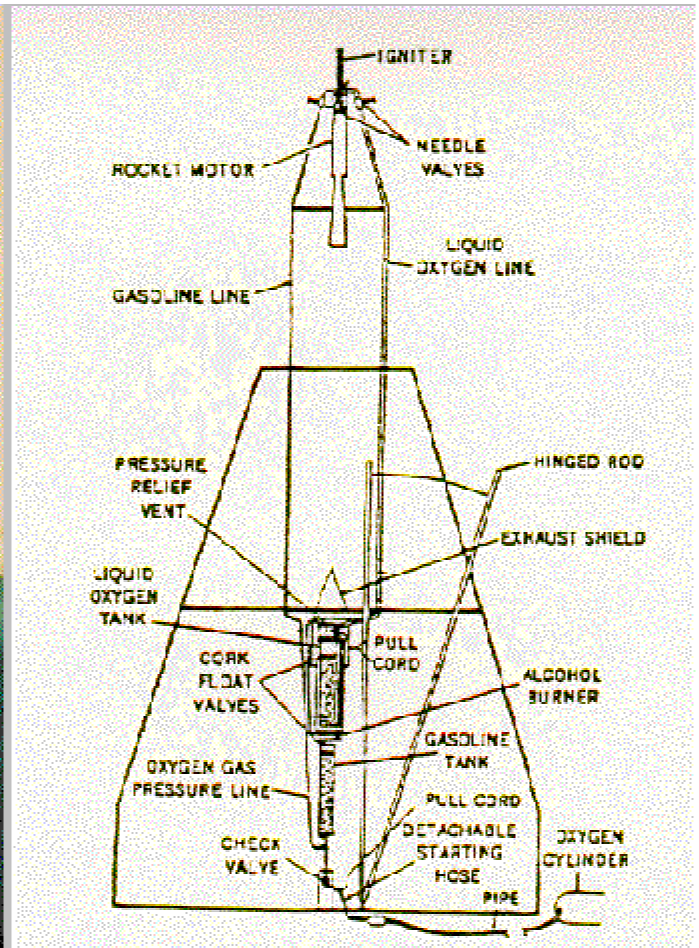
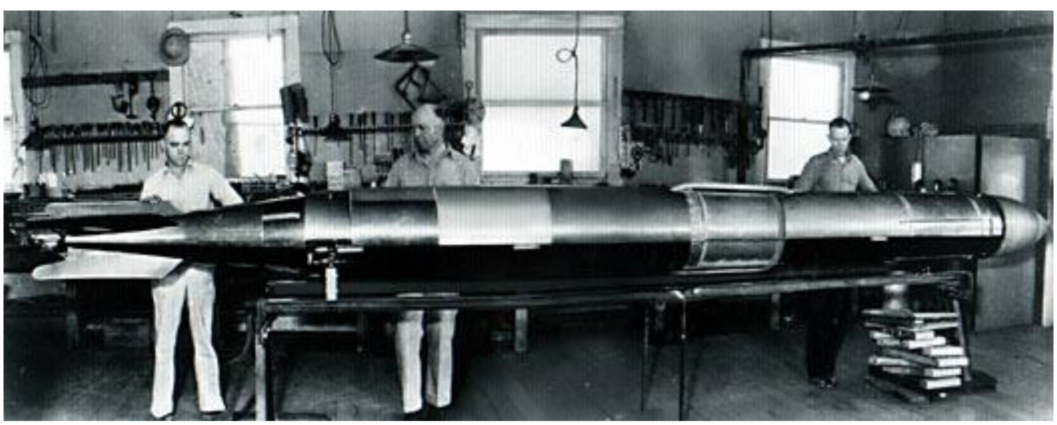


Figure 1
Dr. Goddard's 1926 Rocket

On March 16, 1926 Goddard launched a 10-foot-long rocket from a 7-foot-long frame. The rocket reached a maximum altitude of 41 feet at an average velocity of 60 m.p.h. The rocket remained in the air for 2.5 seconds and flew 184 feet. While this flight did not even come close to matching the performance of gunpowder propelled rockets of years past, it remains one of the most significant events in the history of rocketry. Powered by a combination of liquid oxygen and gasoline, the rocket launched by Goddard on March 16, 1926 was the first to ever be launched using liquid fuel.

The fourth launch of a liquid-fueled rocket occurred on July 17, 1929. Considered much more elaborate than the first three, Goddard equipped the rocket with a barometer, thermometer, and a camera to record their readings during flight. The rocket achieved a maximum altitude of 90 feet in an 18.5-second flight covering 171 feet. The scientific payload was recovered safely via parachute.



Goddard then set up shop at the Mescalero Ranch near Roswell, New Mexico in July 1930. The first Roswell launch occurred on December 30, 1930 using a rocket 11 feet long by 12 inches wide and weighing 33.5 pounds empty. The test was impressive as the rocket reached a maximum altitude of 2,000 feet and maximum speed of 500 m.p.h. The rocket employed a new gas pressure tank to force the liquid oxygen and gasoline into the combustion chamber.

In the years approaching World War II, Goddard had agreed to allow military officials to review his research. On May 28, 1940 Goddard and Harry F. Guggenheim had met with a joint committee of Army and Navy officials in Washington, D.C. A complete report was given to these officials by Goddard which outlined his advances in both solid-fueled and liquid-fueled rockets. The Army rejected the prospect of long-range rockets altogether.

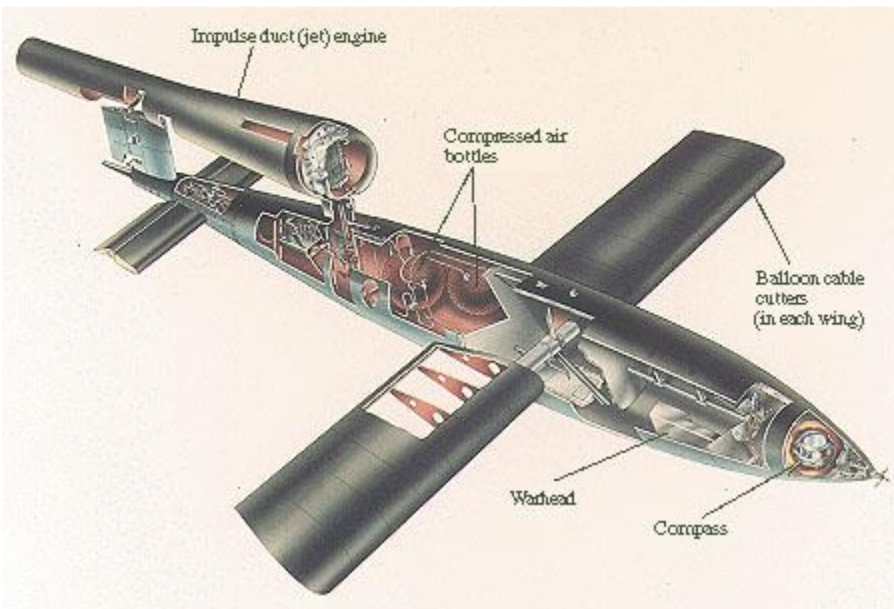
Wernher von Braun

In 1927, an eager 17-year-old scientist named Wernher von Braun joined the Society for Space Travel, which had been formed in June 1927. This group of mainly young scientists immediately began designing and building a variety of rockets. In 1930, the Society for Space Travel set up permanent offices in Berlin and began testing rockets which would ultimately change the nature of warfare and propel the world into the space age.

Wernher von Braun, went to work officially for the German Army at Kummersdorf. There, the Army Ordnance Research and Development Department established a testing site for ballistic missile weapons. By 1938, Germany had begun invading huge portions of Eastern Europe, and Adolph Hitler began recognizing the need for an effective ballistic missile weapon. The German Ordnance Department requested that the team to develop a ballistic weapon that had a range of 150 to 200 miles and could carry a one-ton explosive warhead. The A-4, later renamed V-2, would go on to lay the cornerstone of modern rocketry.

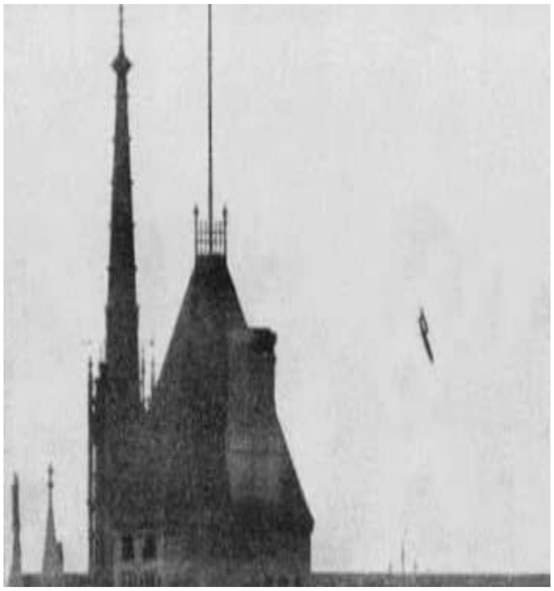
V-1 Buzz Bomb

Although Germany produced and deployed several rocket and missile weapons during World War II, the potency of their weapons was based on the so-called "V" weapons. The "V" was short for "Vergeltungswaffen", roughly translated "weapons of retaliation", "weapons of reprisal" or "weapons of vengeance". The V-1 was the first of the numbered V-weapons. The V-1 was a pilotless bomber that employed a gasoline-powered pulse-jet engine and weighed about 4,900 pounds. V-1 attacks aimed at targets in England began in June 1944. Each V-1 was launched from a ramp and was unguided. After it was launched, the V-1 flew a preset course until a switch cut off its engine, causing the V-1 to simply fall on whatever was under it.



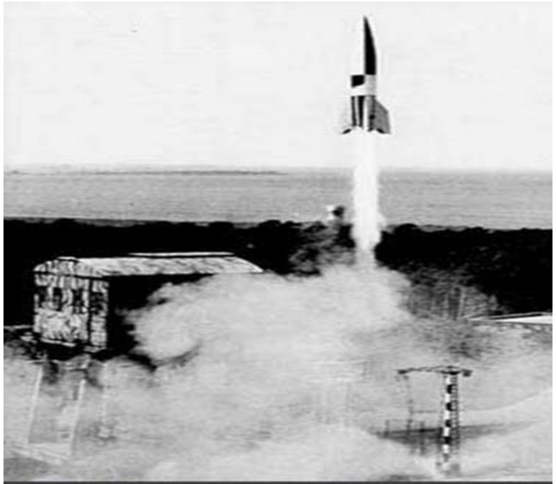
The distinctive sound of the V-1 engine resulted in the vehicle being nicknamed the "buzz bomb" by Allied forces. People on the ground knew they were relatively safe if the buzzing sound came and then faded as the weapon passed out of range. However, if the buzzing sound stopped abruptly, it was quickly understood that a powerful explosion could occur nearby.

Each V-1 carried about 2,000 pounds of explosives and could cause great damage. But, since the V-1 was unguided, the weapon rarely hit a specific target. The V-1 had a top speed of about 390 m.p.h. so could be intercepted by fighter aircraft or destroyed by anti-aircraft artillery. The British reported that 6,139 people were killed as a direct result of V-1 attacks, about three times the number that were killed by the V-2.



German V-2

The V-2 rocket is believed to be one of the most significant scientific advances of World War II, second only to the development of the atomic bomb. Through 1942, development of the V-2 was conducted 24 hours per day under the supervision of Wernher von Braun. The first models of the V-2 were ready for firing by the spring of 1942, by the close of the war 900 V-2 missiles per month were being produced.

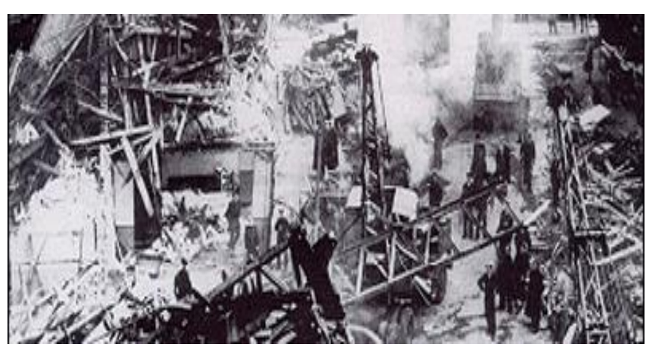


A V-2 blasts off from its launching pad on a predetermined trajectory that will carry it 170 miles over the Baltic.

Each V-2 was 46 feet long, had a diameter of 5 feet, 6 inches and fin span of 12 feet. The entire rocket weighed about 27,000 pounds at launch. The V-2 contained two fuel tanks. One contained liquid oxygen, while the second contained a combination of 75% alcohol and 25% water. These were the fuels that powered the V-2 engine.

The launching platform was a 10-foot rotatable ring housed in a square, angle-iron framework supported at its corners by jacks. The launching platform was very simple in design and could be readily moved from launch site to launch site. Each launch site was supported by about 30 vehicles, including transport trucks and trailers, propellant storage trucks, command and control trucks, personnel carriers and military support vehicles. The operation was very efficient, and a V-2 could typically be launched from four to six hours after a suitable launch site was selected. The actual launch was controlled from a remote location some 200 to 300 yards away from the rocket. An armored vehicle of some type was typically used as a "firing room".

The first hostile V-2 missiles were launched on September 6, 1944. On that day, two V-2 missiles were launched toward Paris but failed to inflict any damage. V-2 attacks on England began on September 8, 1944. V-2 missiles



were typically launched toward London and Antwerp, Belgium. Allied forces also reported that eleven V-2 rockets impacted near Remagen, Germany on March 9 and

10, 1945 as the Germans made an unsuccessful attempt to prevent engineers from completing a pontoon bridge across the Rhine River and hinder an Allied advance there.

Specific numbers vary from source to source, but it is generally believed that about 1,100 V-2 missiles reached England until V-2 attacks ceased on March 27, 1945. About 2,800 people are believed to have been killed and another 6,500 injured as a direct result of V-2 attacks. It is generally believed that about 5,000 V-2 missiles were manufactured by the Germans prior to the close of World War II. About 600 were used for test launches and troop training, with the remainder launched toward targets. Given these numbers, the V-2 failure rate was quite large. The V-2 failure rate was due to several factors. In many instances, the missiles failed to be successfully launched. In other instances, the guidance system failed, causing the missile to miss its target. The missile often exploded or broke up due to the stress of supersonic flight, and in many cases the V-2 explosive warhead failed to detonate after impacting a target.

Both the V-1 and V-2 proved themselves to be potent weapons, but they suffered from basic weaknesses that did not allow the weapons to turn the tide for Germany at the close of World War II. The weapons were rushed into deployment before they could be completely tested and refined. As a result, they lacked accuracy and the ability to carry explosive payloads large enough to compensate for this lack of accuracy. While barrages of huge numbers of V-1 and V-2 missiles might have compensated for the basic weaknesses of the weapons, the Germans were unable to introduce enough to overwhelm Allied advances.

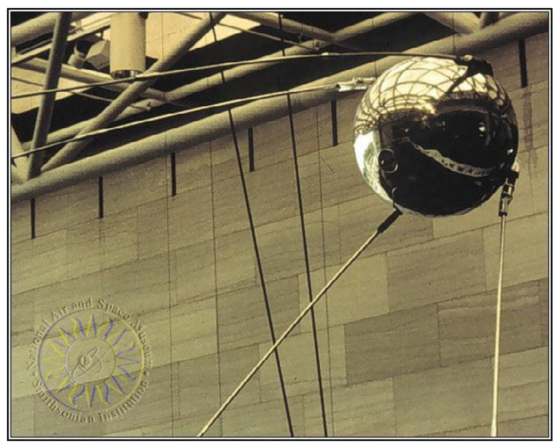
Chapter 3 Early Space Exploration

Introduction

During the 1940's and 50's rockets were achieving higher and higher altitudes with each test. Thus, the question was raised, where does outer space begin? Answering this question depends upon with whom you are discussing the subject. A doctor would state that outer space begins when the human body can no longer survive in the atmosphere. A propulsion engineer might say that space begins when a jet engine, which needs air from the atmosphere to function, can no longer operate. An aerodynamic engineer might say that space begins when there is not enough of an atmosphere for an aircraft's control surfaces to operate the craft. International law states that there is no definitive point where the atmosphere ends and space begin. The major space powers accept the following definition that “Space begins at the lowest point to the Earth that a space vehicle can attain and maintain an orbit” and that “Outer Space is international territory”.

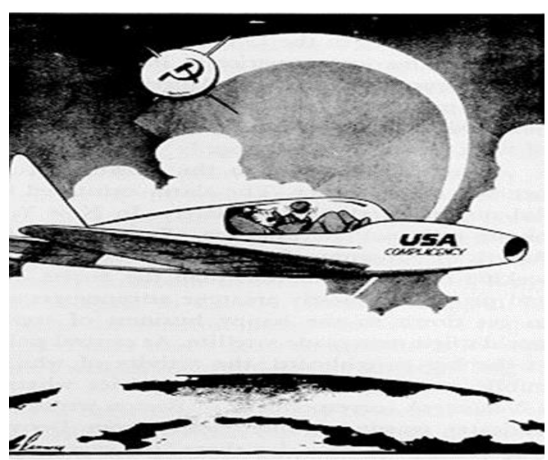
Sputnik

As the result of a large and dedicated effort by Russian scientists and the military, the world's first artificial satellite of the Earth "Sputnik" (the Russians' word for "traveling companion") was created and launched on October 4th, 1957. The satellite was a pressurized sphere 23 inches in diameter and made of an aluminum alloy. The sphere held three silver-zinc batteries, two radio-transmitters, a communications system and temperature and pressure transmitters.



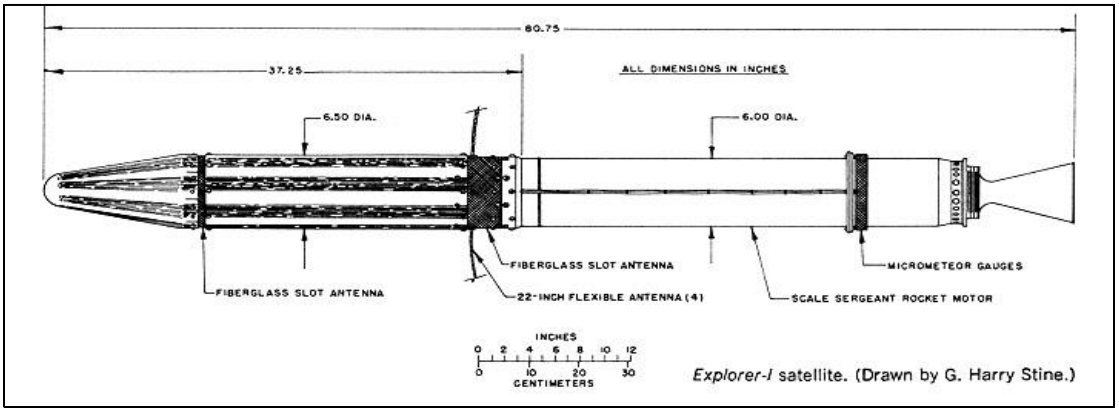
U.S. Space Program

People the world over speak of the `Space Age' as beginning with the launching of the Russian Sputnik. Newspaper proclaimed the birth of the "Space Age" in huge headlines." Gone forever in this country was the myth of American superiority in all things technical and scientific. The Russian success alerted the American



public to deficiencies in their school system, to the need for providing their young people with an educational base wide enough to permit them to cope with the multiplying problems of swift technological change.

In response, on February 1st, 1958 the U.S. responded with the launch of its own satellite. The challenge of the Russian Sputniks had been met with the successful launch of America's first artificial satellite, Explorer I. The science instruments on Explorer I consisted of a cosmic ray detector, internal and external temperature sensors, and a micrometeorite impact detector. The cosmic ray detector was designed to measure the radiation environment in Earth orbit. Once in space this experiment, provided by Dr. James Van Allen of the State University of Iowa, revealed the existence of a radiation belt surrounding the earth. This was confirmed by another U.S. satellite two months later, and this belt became known as the Van Allen belt.



Explorer-I satellite. (Drawn by G. Harry Stine.)

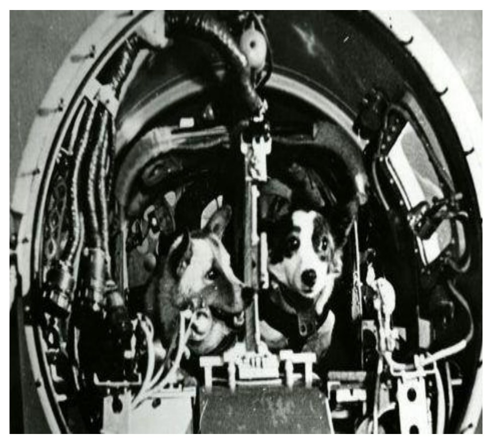
Sputnik 2

On November 3rd ,1957 the Russians sent their second satellite, Sputnik II, into orbit. Unlike its predecessor it carried an 11-pound test dog, Laika (barker in Russian), in a sealed compartment, along with instrumentation for measuring cosmic rays, solar ultraviolet and x-radiation, temperature, and pressures. Although its transmitters functioned only seven days, they supplied the world scientific community with disclosures concerning the effect of space travel on animal life, solar influence on upper atmosphere densities, and the shape of the earth. There was

no safe re-entry possible at the time, so Laika was put to sleep. The satellite itself remained in orbit 162 days before returning to earth and burning up in the atmosphere.

Vostok

In the spring of 1957, the Soviets organized a project to design a new spacecraft. This spacecraft called the Vostok would hold one cosmonaut, in a spacesuit, equipped with an ejection seat for launch aborts and for landing on the earth. The spacecraft had two windows: one above the cosmonaut's head in the entry hatch, one at his feet. A single parachute allowed recovery of the capsule. There was no soft-landing system, so the pilot ejected for a separate landing under his own parachute. The Russians used a spherical design and had no maneuvering engines to orient it. Since it was shaped like a ball, with the heavy weight concentrated at one end, it automatically swung around with the heavy end downward.



The Soviet Union launched many unmanned test flights of the Vostok spacecraft. The spacecraft was used to carry two dogs, Strelka and Belka. Electrodes attached to the dogs and linked with the spacecraft communications system, which included a television camera, enabled Soviet scientists to check the animals' hearts, blood pressure, breathing, and actions during the trip. After the spacecraft reentered and landed safely the next day, the animals were reported to be in good condition.

First Man in Space

The Soviet Union accomplished the feat of placing the first human in space with the launch of Yuri Gagarin on April 13, 1961 in the Vostok 1 spacecraft. Three press releases were prepared, one for success, two for failures. The payload included life-support equipment and radio and television to relay information on the condition of the pilot. Gagarin's 1-orbit flight was the first of six Vostok missions that gave the Soviets a commanding lead in the new frontier of space exploration. While the United States' Mercury program was limited to orbital flights of less than one day, Vostok flights lasted five days. Also, on two occasions the Soviets were able to launch two Vostok spacecraft within days of each other, achieving another space first of having two men in space simultaneously. As with the American Mercury program, Vostok was used by the Soviet Union to learn about the space environment and man's ability to work in weightlessness.

The US Space Program

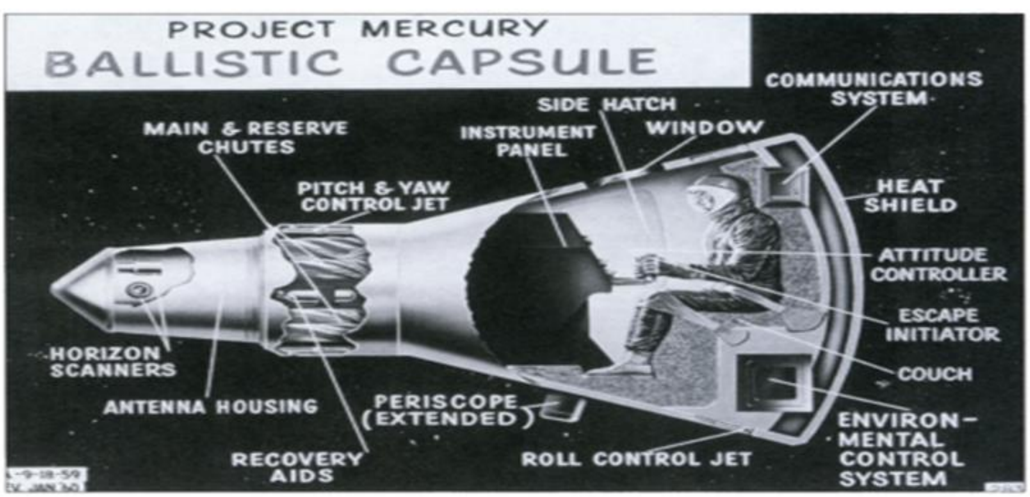
After the Soviet space program's launch of Sputnik 1 the United States re-evaluated its own efforts. The U.S. Congress, alarmed by the perceived threat to national security and technological leadership (known as the "Sputnik crisis"), urged immediate and swift action. President Dwight D. Eisenhower organized a Special Committee on Space Technology which recommended the formation of a new federal agency that would be responsible for all non-military space exploration.

The National Aeronautics and Space Administration (NASA) opened for business on Oct. 1, 1958. It was responsible for all science and technology related to air and space and would oversee all future space exploration and aeronautics research. The NASA administrator would be nominated by the president and confirmed by a vote in the Senate, overall supervision of the agency was under the direction of the Vice-President of the United States.

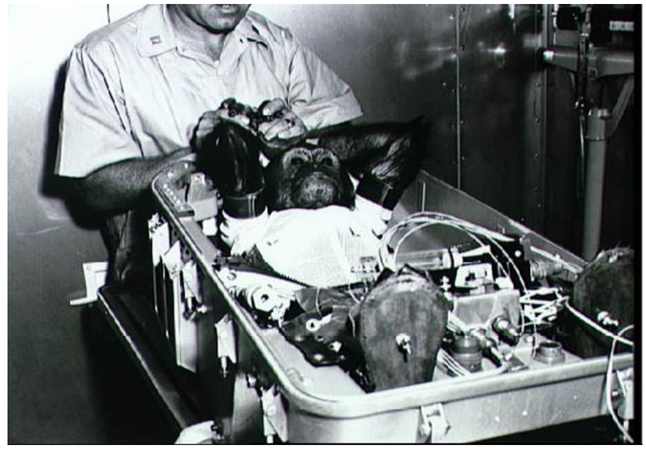
In a 25 May 1961 address to joint session of the U.S. Congress, President John F. Kennedy establishes the goal "of landing a man on the moon and returning him safely to earth" before the decade is out. Specific studies and tests conducted by government and industry culminating in 1958 indicated the manned space flight was possible. The Americans establish a national manned space-flight project, later named Project Mercury, on October 7, 1958.

The Mercury Project

The Mercury spacecraft were cone shaped, with a neck at the narrow end. It had a convex base, which carried a heat shield consisting of an aluminum honeycomb covered with multiple layers of fiberglass. Strapped to it was a retropack consisting of three rockets deployed to brake the spacecraft during reentry. Next to the heat shield was the pressurized crew compartment where an astronaut would be strapped to a form-fitting seat with instruments in front of him and with his back to the heat shield. The spacecraft contained three parachutes: A launch escape system was mounted to the narrow end of the spacecraft containing three small solid-fueled rockets which could be fired briefly in a launch failure to separate the capsule safely from its booster. The Mercury Capsule was designed to land in the water for recovery which was an important improvement in design as comared to Russian Vostok spacecraft.



The first The Mercury mission was accomplished on January 31, 1961 from the Cape Canaveral test site with a chimpanzee as a passenger. The mission was successful, and most of the test objectives were met. The chimpanzee was recovered in good condition, even though the flight had been more severe than planned.

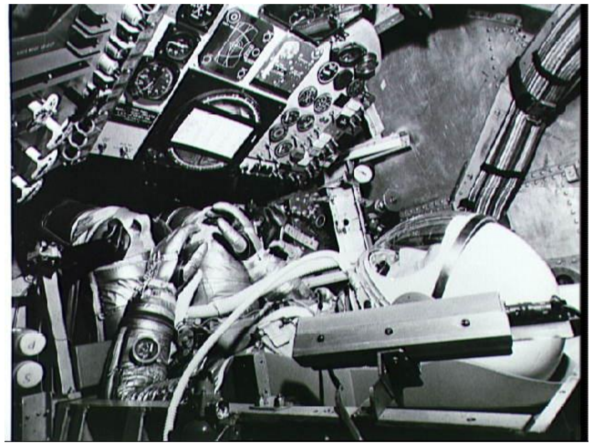


Mercury 7 Astronauts

Astronauts were selected for Project Mercury after a series of the most rigorous physical and mental tests ever given to U.S. test pilots. Chosen from a field of 110 candidates, the finalists were all qualified test pilots. They were called the Mercury Seven as they were the group of seven astronauts selected to fly spacecraft for Project Mercury. They are also referred to as the Original Seven and Astronaut Group 1. Their names were publicly announced by NASA on April 9, 1959. All seven would eventually fly in space.

Front row, left to right: Walter M. Schirra, Jr., Deke Slayton, John H. Glenn, Jr., and M. Scott Carpenter; back row, Alan B. Shepard, Jr., Gus Grissom, and L. Gordon Cooper, Jr.

The first manned space flight by the United States, was successfully accomplished on May 5, 1961, from the Cape Canaveral launch site piloted by Astronaut Alan Shepard. Both the pilot and the spacecraft performed as planned. The spacecraft achieved an altitude of about 101 nautical miles and Astronaut Shepard was in weightless flight for slightly over 5 minutes. On July 21,1961, from the Cape Canaveral launch site, Astronaut Virgil Grissom was the pilot. The spacecraft on this mission was somewhat different, the spacecraft achieved a maximum altitude of about 103 nautical miles, with a period of weightlessness of about 5 minutes. The flight was successful, however, after landing the spacecraft explosive hatch activated which led to the loss of the spacecraft but however the pilot was rescued from the surface of the water.

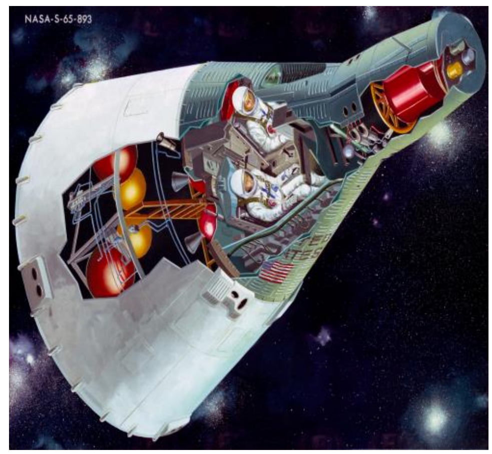


First American in Space

On February 20, 1962 from Cape Canaveral, Florida, John Herschel Glenn Jr. was successfully launched into space aboard the Friendship 7 spacecraft on the first orbital flight by an American astronaut. Toward the end of Glenn's third and last orbit, mission control received a mechanical signal from the spacecraft indicating that the heat shield on the base of the capsule was possibly loose. Traveling at its immense speed, the capsule would be incinerated if the shield failed to absorb and dissipate the extremely high reentry temperatures. It was decided that the craft's retrorockets, usually jettisoned before reentry, would be left on to better secure the heat shield. Less than a minute later, Friendship 7 slammed into Earth's atmosphere. During Glenn's fiery descent back

to Earth, the straps holding the retrorockets gave way and flapped violently by his window, in addition, during reentry Glenn lost radio contact with mission control. As mission control anxiously waited for the resumption of radio transmissions that would indicate Glenn's survival. After four minutes of radio silence, Glenn's voice crackled through loudspeakers at mission control, and Friendship 7 splashed down safely in the Atlantic Ocean. He had spent nearly five hours in space. Astronaut Glenn was hailed as a national hero and was given a ticker-tape parade in New York City.

Project Gemini



The next big step in space exploration was the Gemini project. The Gemini capsule on the outside looked much like the capsule used for the Mercury missions, but it was much bigger. It could hold two people instead of one, but each astronaut did not have much room. The Gemini capsule improved on the Mercury spacecraft; the Mercury spacecraft could change only the way it was facing in its orbit while the Gemini could change what orbit it was in. NASA named the Gemini spacecraft and program after the constellation Gemini. The name is Latin for "twins." NASA used this name because the Gemini capsule would carry two people. Astronauts accomplished many things on the Gemini missions. The Gemini missions included the first U.S. spacewalk, prolonged orbits (Gemini 5 stayed in orbit for more than a week), two ships meeting in space and the docking of a crewed spacecraft with another un-crewed spacecraft in orbit. The goal of the Gemini missions was to develop the skills that would be necessary to eventually go to the moon. Before people could land on the moon, NASA had to learn many things. It had to learn what happened when astronauts spent many days in space. It had to learn how astronauts could go outside a spacecraft in a spacesuit. It had to learn how to connect two spacecraft together in space. Going to the moon would require doing all these things and Gemini proved NASA could do them all.

Chapter 4 Modern Space Exploration

The Apollo Program

The Apollo program included many un-crewed test missions and 12 crewed missions: three Earth orbiting missions (Apollo 7, 9 and Apollo-Soyuz), two lunar orbiting missions (Apollo 8 and 10), a lunar swing by (Apollo 13), and six Moon landing missions (Apollo 11, 12, 14, 15, 16, and 17). Two astronauts from each of these six missions walked on the Moon (Neil Armstrong, Edwin Aldrin, Charles Conrad, Alan Bean, Alan Shepard, Edgar Mitchell, David Scott, James Irwin, John Young, Charles Duke, Gene Cernan, and Harrison Schmitt), the only humans to have set foot on another solar system body. Total cost for the Apollo program was approximately $20,443,600,000.

The Saturn V

When the United States made the decision in 1961 to have a human set foot on the moon there was no rocket in the country that could get the astronauts there. The Saturn V was the first rocket in the U.S. space program to be developed for that specific purpose and would be the biggest rocket effort undertaken at that time.

The Saturn V, including the Apollo spacecraft, was 364 feet tall and fully loaded, the vehicle weighed 6.1 million pounds. The Apollo space craft that sat on top of the rocket consisted of the lunar module. the

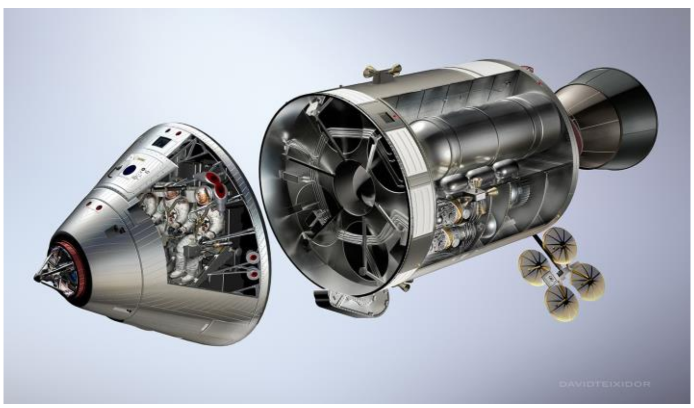
service module and the command module. The jumping-off place for the trip to the moon was NASA's Launch Complex 39 at the Kennedy Space Center.

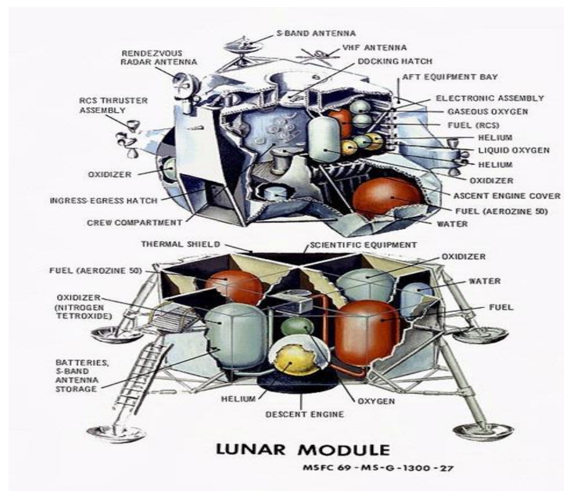
The Spacecraft

The Apollo spacecraft consisted of a combined command and service module (CSM) and an Apollo Lunar Module (LM) pictured below.

The design was based on the lunar orbit rendezvous approach: two docked spacecraft were sent to the Moon and went into lunar orbit. While the LM separated and landed, the CSM remained in orbit. After the lunar excursion, the two craft rendezvoused and docked in lunar orbit, and the CSM returned the crew to Earth. The command module was the only part of the space vehicle that returned with the crew to the Earth's surface.

The Command Module (below) housed the crew, spacecraft operations systems, and earth re-entry equipment. The Service Module carried most of the consumables (oxygen, water, helium, fuel cells, and fuel) and the main propulsion system. The Lunar Module (below) is the part of the space vehicle that would land on the moon and had an upper and lower stage. It would serve as an operations center by the astronauts during their lunar stay. The upper stage housed two astronauts and was the command center that controlled the lunar landing, lunar launch, and rendezvous and docking with the Command and Service Module. The lower or Descent Stage contained equipment essential for landing and working on the lunar surface and was left behind to serve as a platform for launching the upper Stage after completion of the lunar mission.

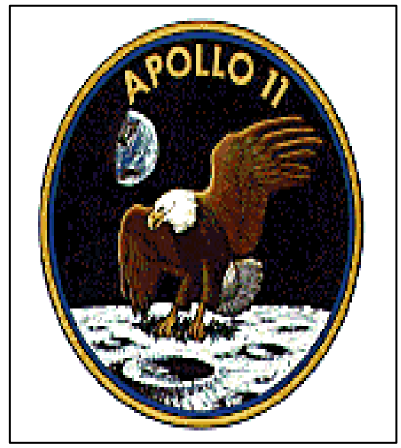




The Apollo Missions

Apollo 1

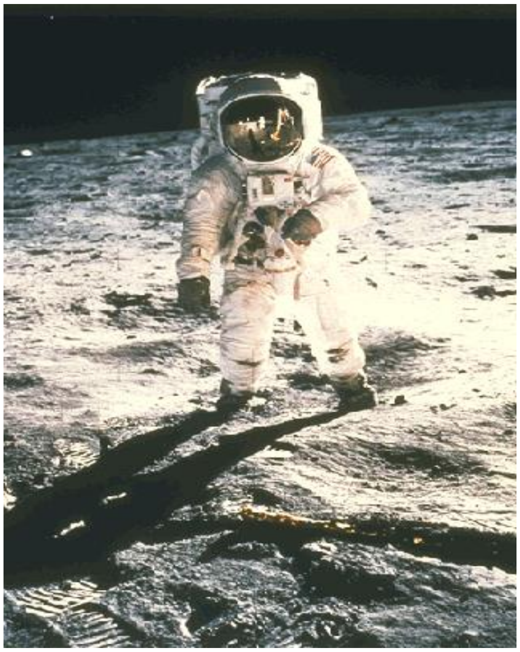
In 1967 NASA declared the Apollo-Saturn rocket was ready for its first crewed mission. On January 27th, however, a flash fire in the capsule during a launch countdown practice test killed astronauts Virgil “Gus” Grissom, Edward White, and Roger Chaffee. The disaster halted crewed Apollo flights for 21 months and the rocket did not fly again until January 22nd, 1968, when it carried an unmanned Apollo capsule into orbit.

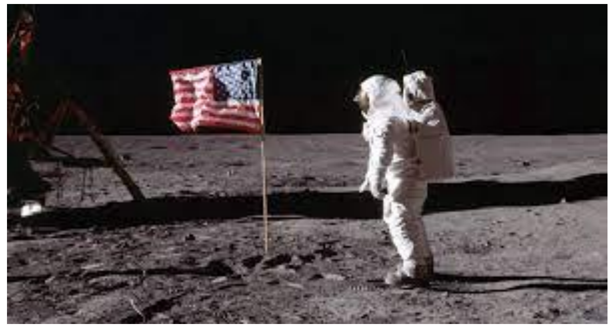


Apollo 11

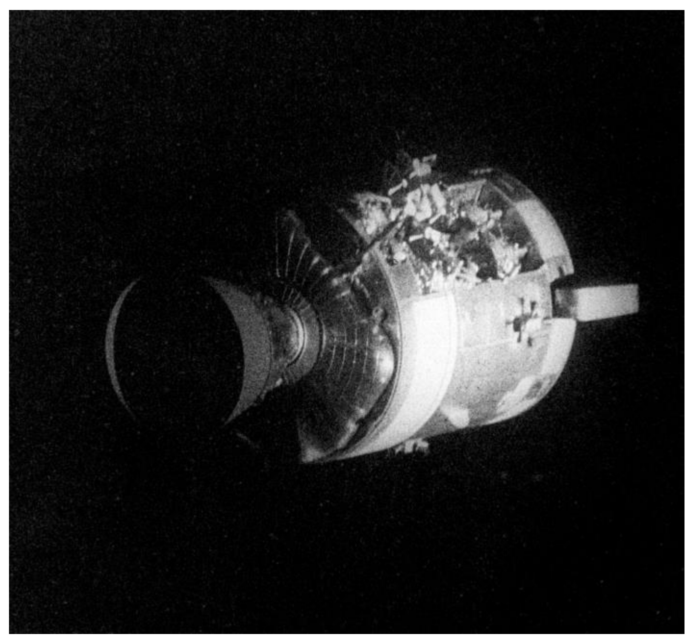
After four successful practice missions, that demonstrated Apollo could perform as required**,** Apollo 11 was designated to be the first mission in which humans would land and walk on the lunar surface and returned to Earth. On July 20^{th}, 1969 two astronauts (Apollo 11 Commander Neil A. Armstrong and LM pilot Edwin E. "Buzz" Aldrin Jr.) landed in Mare Tranquilitatis (the Sea of Tranquility) on the Moon in the Lunar Module (LM) while the Command and Service Module (CSM) (with CM pilot Michael Collins) continued in lunar orbit.

During their stay on the Moon, the astronauts set up scientific experiments, took photographs, and collected lunar samples. The LM took off from the Moon on July 21^{st} and the astronauts returned to Earth on July 24^{th}. The Lunar Module landed at Mare Tranquilitatis (the Sea of Tranquility) at 4:17 PM with Armstrong reporting, "Houston, Tranquility Base here - the Eagle has landed." Armstrong stepped onto the lunar surface at 10:56:15 PM on July 21^{st} stating, "That's one small step for (a) man, one giant leap for mankind". Buzz Aldrin followed 19 minutes later becoming the second human to step foot on the moon. The primary mission goal of landing astronauts on the Moon and return them to Earth was finally achieved.





<u>Apollo 13</u>



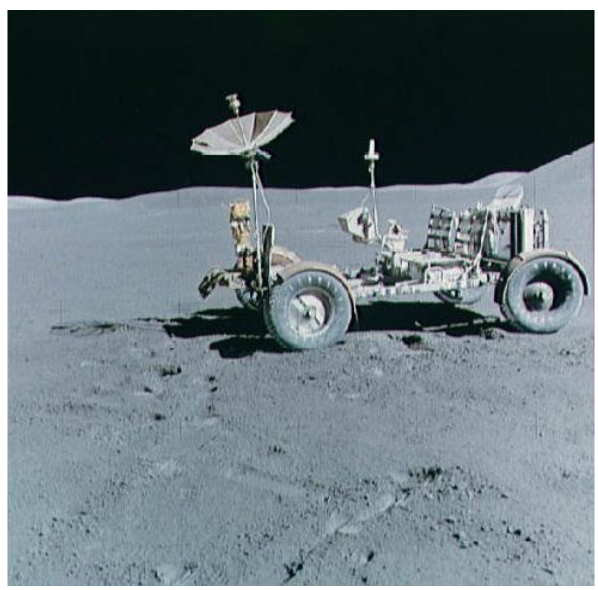
This was the seventh crewed mission in the Apollo space program and the third meant to land on the Moon. The craft was launched from Kennedy Space Center on April 11, 1970, but the lunar landing was aborted after an oxygen tank in the service module exploded two days into the mission. The crew instead looped around the Moon and returned safely to Earth on April 17. The mission was commanded by Jim Lovell with Jack Swigert as command module pilot and Fred Haise as Apollo Lunar Module pilot. Swigert was a late replacement for Ken Mattingly, who was grounded after exposure to rubella.

A damaged wire inside an oxygen tank caused an explosion. Without oxygen, needed for breathing and for generating electric power, the propulsion and life support systems could not operate. The CM's systems had to be shut down to conserve the ships battery for reentry, forcing the crew to transfer to the LM as a lifeboat. With the lunar landing canceled, mission controllers worked to bring the crew home alive.

Although the LM was designed to support two men on the lunar surface for two days, Mission Control in Houston improvised new procedures so it could support three men for four days. The crew experienced great hardship caused by limited power, a chilly and wet cabin, and a shortage of potable water. There was a critical need to adapt the CM's cartridges for the carbon dioxide scrubber system to work in the LM; the crew and mission controllers were successful in improvising a solution. The danger the astronauts' faced briefly renewed public interest in the Apollo program; tens of millions watched the splashdown in the South Pacific Ocean on television.

Lunar Rover

The Lunar Roving Vehicle was an electric vehicle designed to operate in the low-gravity vacuum of the Moon and to be capable of traversing the lunar surface, allowing the Apollo astronauts to extend the range of their surface extravehicular activities. Three vehicles were driven on the Moon, one on Apollo 15 by astronauts David Scott and Jim Irwin, one on Apollo 16 by John Young and Charles Duke, and one on Apollo 17 by Gene Cernan and Harrison Schmitt



Skylab

The Skylab space station was launched May 14, 1973 and was America's first experimental space station. It was designed to prove that humans could live and work in space for extended periods, and to expand our knowledge of solar astronomy well beyond Earth-based observations. The program was successful in all respects despite early mechanical problems. Skylab made extensive use of Saturn and Apollo equipment.

Crews visited Skylab and returned to Earth in Apollo spacecraft. A total of three teams of three-man crews occupied the Skylab workshop for a total of 171 days and 13 hours. It was the site of nearly 300 scientific and technical experiments, including medical experiments on humans' adaptability to zero gravity, solar observations, and detailed Earth resources experiments. The empty Skylab spacecraft returned to Earth on July 11, 1979, scattering debris over the Indian Ocean and the sparsely settled region of Western Australia.

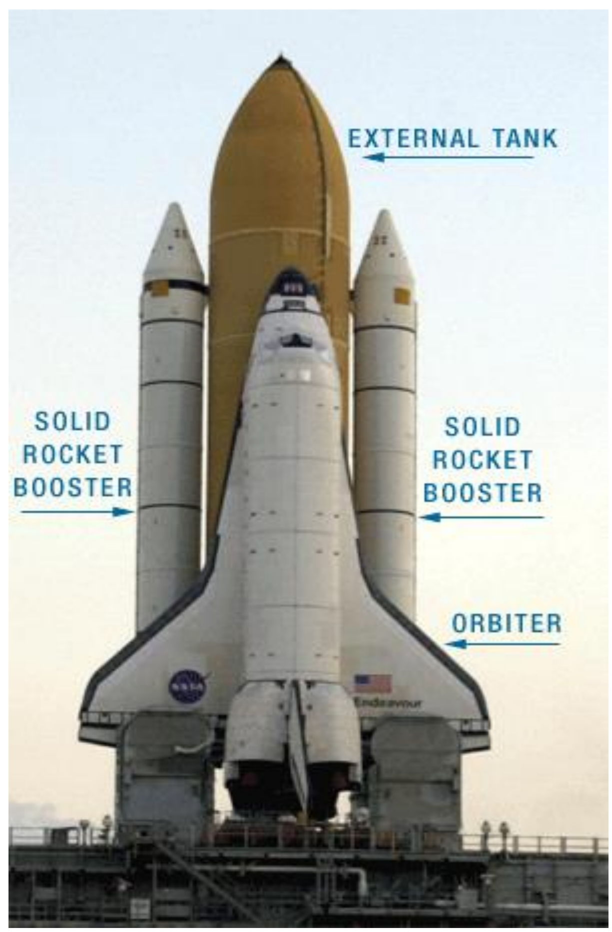
Apollo-Soyuz

The first international partnership in space was the Apollo-Soyuz Test Project, the first international human spaceflight between the United States and Russia. On July 15, 1975, an Apollo spacecraft launched and docked two days later with a Soyuz spacecraft and its crew. Designed to test the compatibility of rendezvous and docking systems and the possibility of an international space rescue, the nine-day Apollo-Soyuz mission brought together two former spaceflight rivals.

The Apollo spacecraft was modified to provide for experiments, extra propellant tanks and the addition of controls and equipment related to the docking module. The Soyuz was the primary Soviet spacecraft used for manned flight since its introduction in 1967. The docking module was designed and constructed by NASA to serve as an airlock and transfer corridor between the two craft. During nearly two days of joint activities, the mission's two Soviet cosmonauts and three U.S. astronauts carried out five joint experiments and exchanged commemorative items. The successful Apollo-Soyuz Test Project paved the way for future international partnerships.

The Space Shuttle

In September 1966, NASA and the Air Force announced that a new vehicle was required to satisfy the future demands for space travel. A partially reusable system would be the most cost-effective solution. The space shuttle was the world's first reusable spacecraft, and the first spacecraft in history that could carry large satellites both to and from orbit. The shuttle launches like a rocket, maneuvered in Earth orbit like a spacecraft and lands like an airplane.



An early space shuttle orbiter, the Enterprise was developed, it never flew in space but was used for approach and landing tests at the Dryden Flight Research Center and several launch pad studies in the late 1970s.

On June 4, 1974, Rockwell Corporation began construction on the first orbiter. Columbia was the first space shuttle to be delivered to NASA's Kennedy Space Center, Fla., in March 1979. Columbia and the STS-107 crew were lost Feb. 1, 2003, during re-entry. The orbiter Challenger was delivered to KSC in July 1982 and was destroyed in an explosion during ascent in January 1986.

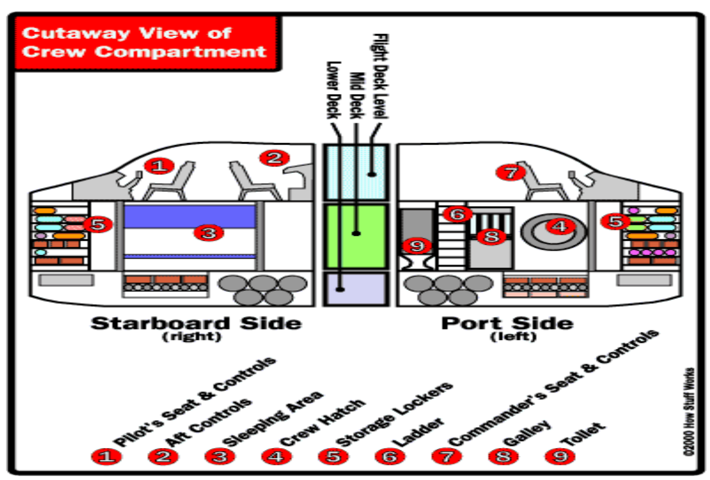
Discovery was delivered in November 1983. Atlantis was delivered in April 1985. Endeavour was built as a replacement following the Challenger accident and was delivered to Florida in May 1991.

The Orbiter

The orbiter was both a rocket and an aircraft. It could launch vertically like a rocket and then land as a glider. It contained a crew compartment, cargo bay and engines. The rear of the orbiter contained the Space Shuttle Main Engines, which provided thrust during launch, as well as the Orbital Maneuvering System which allowed the orbiter to move in space. The orbiter had landing gear allowing it land on a runway.

The crew compartment was made up of three decks and was where the astronauts lived and worked. The flight deck consisted of two seats for the commander and pilot, as well as an additional two to four seats for crew members. The mid-deck was located below the flight deck and was where the galley and crew bunks were set up, as well as three or four crew member seats. It also contained the airlock to allow the Astronauts to work in space. The lower deck stored environmental control and waste management systems.

The payload bay was the largest part of the orbiter and provided the cargo-carrying space for the Space Shuttle's payloads. It was 60 ft long and 15 ft wide allowing the Space shuttle to transport very large objects from Earth into Space.

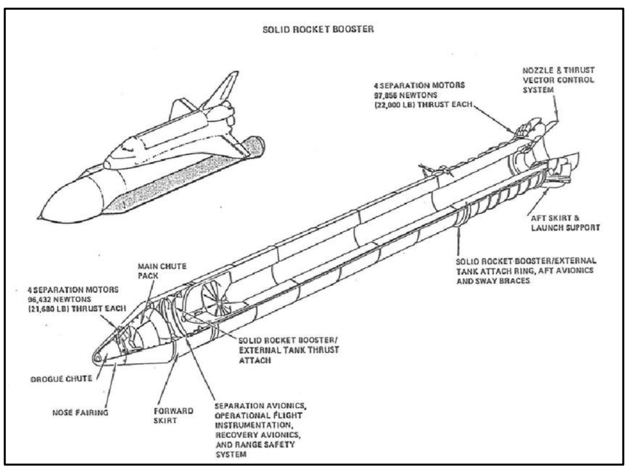


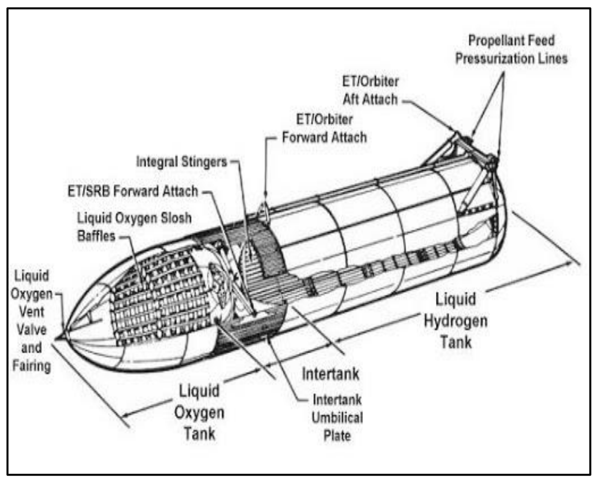
Solid Rocket Boosters

The SRBs are solid rockets that provide most of the main force or thrust needed to lift the space shuttle off the launch pad. In addition, the SRBs support the entire weight of the space shuttle orbiter and fuel tank on the launch pad.

External Fuel Tank

The ET is made of aluminum and aluminum composite materials. It has two separate tanks inside, the forward tank for oxygen and the aft tank for hydrogen, separated by an inter-tank region. Each tank has baffles to dampen the motion of fluid inside. The ET is covered with a 1-inch (2.5 cm) thick layer of spray-on insulation that keeps the fuels cold, protects the fuel from heat that builds up on the ET skin in flight, and minimizes ice formation. When Columbia launched in 2003, pieces of the insulating foam broke off the ET and damaged the left wing of the orbiter, which ultimately caused Columbia to break up upon re-entry.





Shuttle Retirement

The Shuttle was presented to the public in 1972 as a "space truck" that would, among other things, be used to build a United States space station in low Earth orbit. When the concept of the U.S. space station evolved into that of the International Space Station, the service life of the Space Shuttle was extended several times until it completed construction of the ISS. The Space Shuttle Atlantis flew the last mission for the program in July 2011.

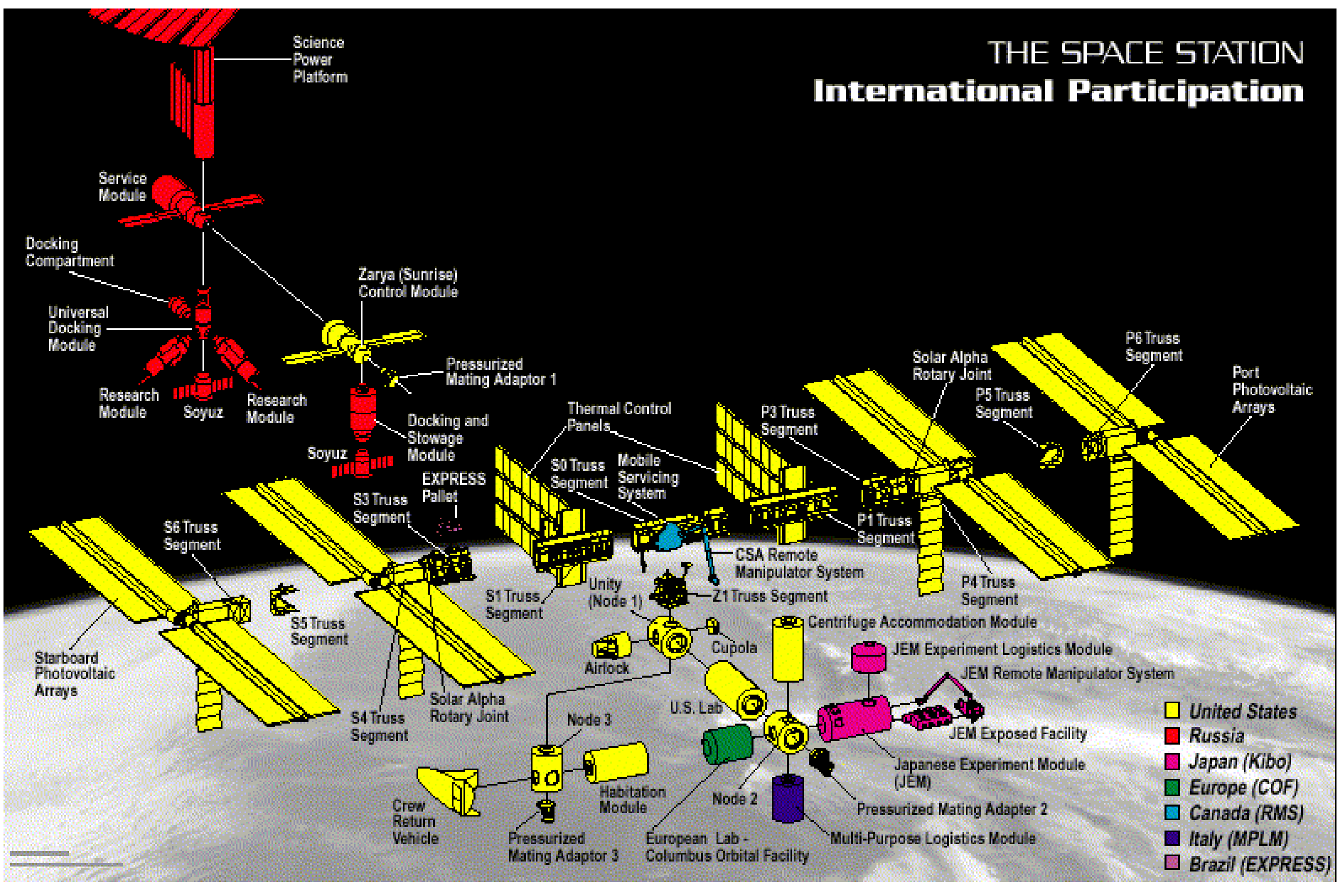
Commercial Crew Program

After retirement of the Space Shuttle**,** the US launched its astronauts aboard Russian Soyuz spacecraft. In 2012 NASA created the Commercial Crew program in response to the end of the space shuttle program and contracted with two private companies SpaceX and Boeing Orbital ATK to deliver supplies to the space station. In 2012, SpaceX's Dragon became the first commercial spacecraft ever to deliver cargo to the space station and on May 30, 2020 their maned launch vehicle Crew Dragon successfully delivered two Astronauts to the ISS. At the present time Blue origin, Boeing, Paragon Space Development Company, Sierra Nevada, Space X, Orbital Science Corporation and United Launch Alliance are all commercial space companies developing vehicles for operations in space.

International Space Station (ISS)

The International Space Station, or ISS, represents a global partnership of 16 nations. This project is an engineering, scientific and technological marvel ushering in a new era of human space exploration. The million-pound space station will include six laboratories and provide more space for research than any spacecraft ever built. Internal volume of the space station will be roughly equal to the passenger cabin volume of a 747-jumbo jet. Its main construction was completed between 1998 and 2011, although the station continually evolves to include new missions and experiments. It has been continuously occupied since Nov. 2, 2000.

Astronaut time and research time on the space station is allocated to space agencies according to how much money or resources (such as modules or robotics) that they contribute. The ISS includes contributions from 15 nations. NASA (United States), Roscosmos (Russia) and the European Space Agency are the major partners of the space station who contribute most of the funding; the other partners are the Japanese Aerospace Exploration Agency and the Canadian Space Agency. Current plans call for the space station to be operated through at least 2024, with the partners discussing a possible extension until 2028. Afterwards, plans for the space station are not clearly laid out.


THE SPACE STATION
International Participation
Science Power Platform
Service Module
Docking Compartment
Zarya (Sunrise) Control Module
Universal Docking Module
Pressurized Mating Adaptor 1
Research Module
Soyuz
Research Module
Docking and Stowage Module
Soyuz
Thermal Control Panels
P3 Truss Segment
Solar Alpha Rotary Joint
P6 Truss Segment
P5 Truss Segment
Port Photovoltaic Arrays
EXPRESS Pallet
S0 Truss Segment
Mobile Servicing System
S3 Truss Segment
P1 Truss Segment
S6 Truss Segment
CSA Remote Manipulator System
Unity (Node 1)
Z1 Truss Segment
P4 Truss Segment
S1 Truss Segment
S5 Truss Segment
Centrifuge Accommodation Module
Cupola
JEM Experiment Logistics Module
Airlock
JEM Remote Manipulator System
Starboard Photovoltaic Arrays
Solar Alpha Rotary Joint
S4 Truss Segment
Node 3
U.S. Lab
JEM Exposed Facility
Japanese Experiment Module (JEM)
Habitation Module
Node 2
Crew Return Vehicle
Pressurized Mating Adapter 2
Pressurized Mating Adaptor 3
European Lab - Columbus Orbital Facility
Multi-Purpose Logistics Module
United States
Russia
Japan (Kibo)
Europe (COF)
Canada (RMS)
Italy (MPLM)
Brazil (EXPRESS)

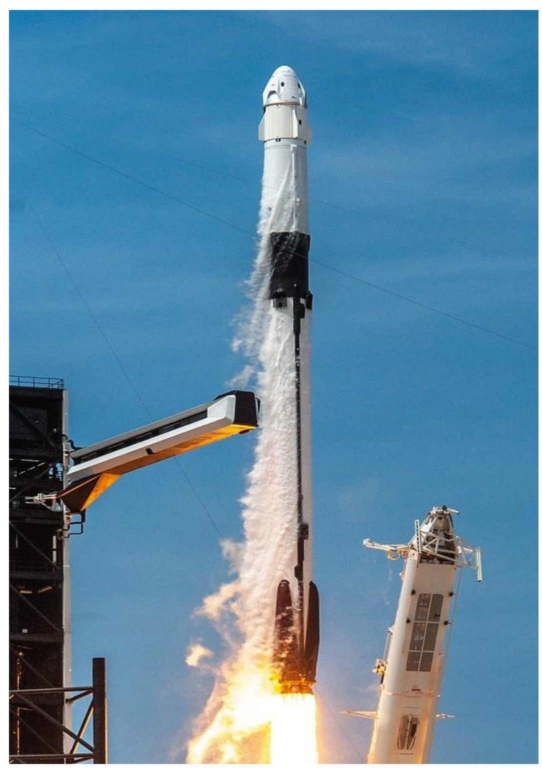
Chapter 5 Future of Space Exploration

With the retirement of the Space Shuttle NASA was limited to accessing the International Space Station through the Russian Space program and their tried and true Soyuz Space capsules. However, NASA began exploring the possibility of working with a new group of partners which would eventualy be called the Commercial Crew Program.

Private Space Companies

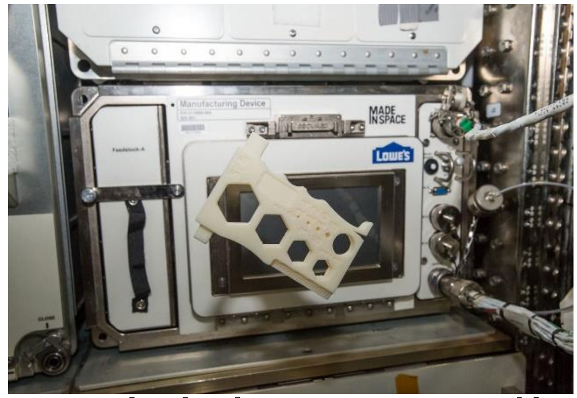
NASA hoped that new private companies would take over their repsonsibilities to ferrying supplies and personnel to the International Space Station (ISS), landing and reflying rockets, and manufacturing products off Earth. Working with two commercial organizations, NASA was able to resupply the ISS with the Dragon Capsule built by *SpaceX* mounted to the *Falcon 9 Rocket* built by Northrop Grumman's Cygnus spacecraft group.

About half of those *Dragon-Falcon 9* missions featured landings of the rocket's first stage, showcasing one of the important trends that SpaceX pioneered in the 2010s: the recovery and reuse of rockets by a private company. The goal of comercial companies was to reduce the cost of spaceflight to make it easier to support. Blue Origin, began routinely landing and reflying rockets in the 2010s. Blue Origin's new *Shepard Vehicle* had also performed successfully. Not all of the rocket action is being conducted by American companies, either. For example, Beijing-based *OneSpace*, which aims to give small payloads rides to



suborbital space and to orbit, launched for the first time in 2018.

Manufacturing in Space



The dawn of the off-Earth-manufacturing era occurred in September 2014, when a 3D printer built by California-based startup *Made In Space* rode to the ISS. Since then, *Made In Space* has launched a handful of other machines to the orbiting lab, including equipment that manufactures the high-value optical fiber. The company is also developing in-space assembly technology known as Archinaut, which *Made In Space* envisions will help repair, upgrade and refuel satellites in orbit and build entirely new structures as well. Advances by the private space sector have also made it much easier to see what's happening here on Earth. For instance, the San Francisco-based company *Planet First* launched its Dove Earth-observation satellites. These tiny spacecraft, each of which is about the size of a loaf of bread, capture imagery for use by a wide variety of customers. Communications technology also leaped ahead in the 2010s. SpaceX launched its first 120 Starlink spacecraft in 2019 and eventually aims to loft up to 12,000 of these satellites with several other companies, such as OneWeb and Amazon, having similar goals.

NASA has been encouraging increased private activity in deep space. In the past year or two, for example, the American space agency has started reserving space on commercial lunar landers. The eventual delivery of scientific experiments and technology demonstrations to the moon by these private robotic craft will help NASA return to the lunar surface and establish a sustainable human presence on and around Earth's nearest neighbor. NASA even wants the private sector to help get those astronauts to and from the lunar surface. Conmpanies are not stopping there, Virgin Galactic wants to fly paying customers to and from space aboard its six-passenger spaceliner called *SpaceShipTwo* and begin a new frontier in commercial space-tourism. Soon a private spaceship could carry people to deep

space for the first time. SpaceX is working on a 100-passenger, Mars-colonizing craft called Starship, and Japanese billionaire Yusaku Maezawa already booked a flight around the moon.

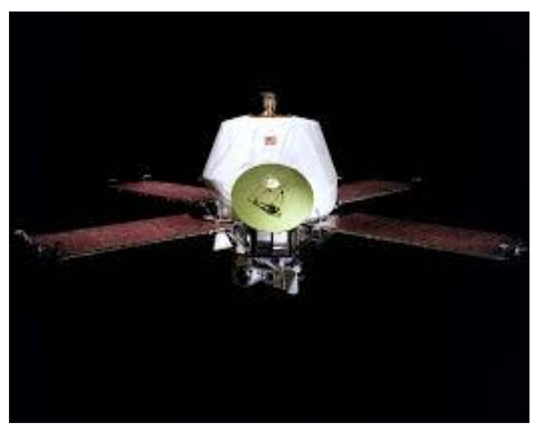
Mission to Mars

Since 1960, humanity launched dozens of missions to Mars to learn more about our planetary neighbor. Mars appears to be a world once rich in water and perhaps, in life, presenting an interesting counterpart to Earth. Since the first successful flyby in 1965, five space agencies have successfully made it to Mars: NASA, the former Soviet Union space program, the European Space Agency, the China National Space Administration, and the Indian Space Research Organization.

The Early Years of Mars Exploration

The first attempts to reach Mars happened near the dawn of space exploration. Considering that the first satellite, the Soviet Union's Sputnik, launched in 1957, it is extraordinary that only three years later, the Soviet Union space program looked to extend its reach to Mars. The Soviet Union made multiple attempts in the 1960s to reach the Red Planet, and NASA soon followed with its Mariner 3 spacecraft. While many of the first missions didn't reach their target, NASA's Mariner 4 finally did. The spacecraft launched on Nov. 28, 1964, and was the first to fly by Mars on July 14, 1965. It sent 21 photos of the Red Planet back to Earth.

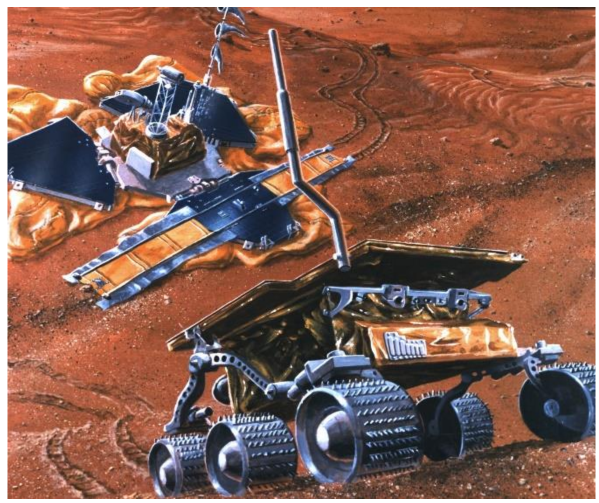
Exploration form 1970 -1980



The image of Mars changed with the arrival of NASA's Mariner 9 in November 1971. The spacecraft, which launched on May 30, 1971, arrived at Mars when the entire planet was engulfed in a dust storm. What's more, something mysterious was poking above the plumes of dust. When the debris settled to the surface, scientists discovered those unusual features were the tops of dormant volcanoes. Mariner 9 also discovered a huge rift across the surface of Mars, later called Valles Marineris after the spacecraft that discovered it. Mariner 9 spent nearly a year orbiting the Red Planet, and returned 7,329 photos. Then NASA sent two pairs of orbiters and landers toward Mars in 1975. Viking 1 and Viking 2 both arrived at the Red Planet in 1976, and sent their lander to the surface while the orbiter remained working above. The Viking program represented the first extended exploration of Mars, as each spacecraft lasted years and transmitted reams of information back to Earth.

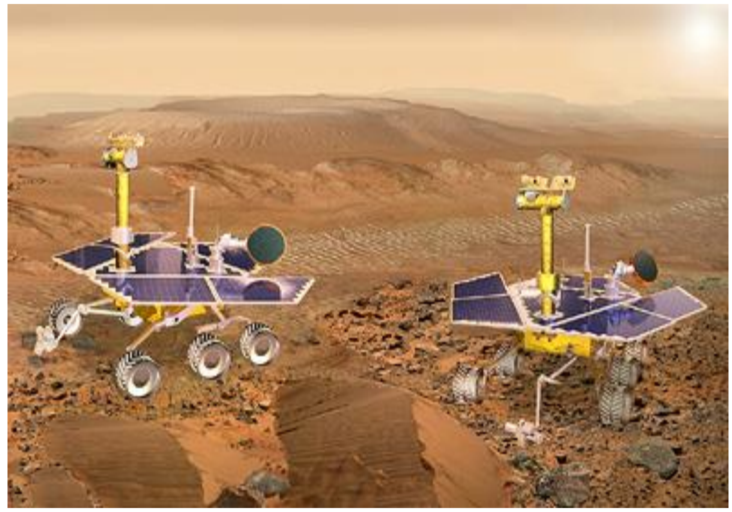
Exploration really begins in 1990

NASA's next attempt to reach the Red Planet came in the 1990s, when Mars Observer launched to the planet on Sept. 25, 1992. The spacecraft was lost just before it was supposed to achieve Mars orbit on Aug. 21, 1993. NASA's Mars Global Surveyor (MGS) left Earth on Nov. 7, 1996, and arrived at Mars on Sept. 12, 1997. Its mission was extended several times until NASA lost contact with it in 2006. MGS mapped the Red Planet from pole to pole, revealing many ancient signs of water, such as gullies and hematite (a mineral that forms in water). Data from MGS helped NASA decide where to land its future Mars rovers. MGS also took pictures of public interest, including re-imaging the famous "Face on Mars." The NASA Pathfinder lander and Sojourner rover arrived at Mars in July 1997. The lander was the first to use a set of airbags to cushion the landing, and Sojourner was the first rover to trundle around on Mars. Pathfinder was expected to last a month and Sojourner a week, but both remained in operation until September 1997, when contact was lost with Pathfinder.

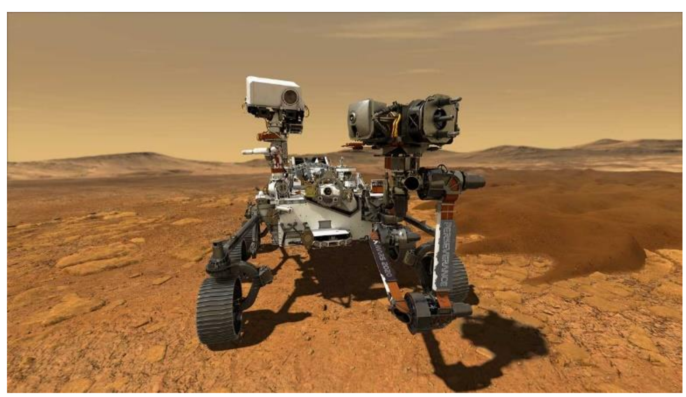


2000s to present: Rovers and orbiters

The discovery of ancient water evidence on Mars sparked a renewed interest in Mars exploration. NASA's Mars Odyssey launched March 7, 2001 and arrived at the Red Planet on Oct. 24, 2001. The orbiter is still conducting its extended science mission. It broke the record for the longest-serving spacecraft at Mars on Dec. 15, 2010. The spacecraft has returned about 350,000 images, mapped global distributions of several elements, and relayed more than 95 percent of all data from the Spirit and Opportunity rovers. NASA's two rovers, Spirit and Opportunity, were sent to the surface of Mars in 2004. Each discovered ample evidence that water once flowed on the Red Planet. Spirit died in a sand dune in March 2010, while Opportunity continued work for nearly another decade. Opportunity fell silent during a sandstorm in summer 2018 and NASA declared the mission over in early 2019. Another NASA orbiter, the Mars Reconnaissance Orbiter, launched on Aug. 12, 2005. It began orbiting the planet on March 12, 2006. The mission has returned more data than all previous Mars missions combined and continues to send high-resolution data of Red Planet features and weather. It also relays data from Martian surface missions back to Earth.



On Aug. 4, 2007, NASA launched a stationary lander called Mars Phoenix, which arrived at Mars on May 25, 2008, and found water ice beneath the surface. Phoenix's solar panels suffered severe damage from the harsh Martian winter, and communication with the $475 million lander was lost in November 2008. After repeated attempts to re-establish contact, NASA declared Phoenix dead in May 2010. The damage was confirmed in orbital photos taken at the Red Planet. NASA's powerful rover Curiosity, arrived at Gale Crater in 2012 to search for signs of ancient habitable environments. Its major findings include finding previously water-soaked areas, detecting methane on the surface and finding organic compounds. It was still going strong as of 2021. Curiosity's design inspired another rover, called Perseverance, which landed on Mars in February 2021 on a quest to find samples with potential signs of life in them, among numerous other investigations. Perseverance would save the most promising samples for a future



sample-return mission, tentatively scheduled for later in the decade and involving both NASA and the European Space Agency. Perseverance also carried a test helicopter, Ingenuity, which assessed the feasibility of flying on Mars.

Looking to the Moon

Moon missions are essential to the exploration of more distant worlds. After a long hiatus from the lunar neighborhood, NASA is again setting its sights on Earth’s nearest celestial neighbor with an ambitious plan to place a space station in lunar orbit sometime in the next decade. Sooner, though, the agency’s Artemis program, a sister to the Apollo missions of the 1960s and 1970s, is aiming to put the first woman (and the next man) on the lunar surface. Extended lunar stays build the experience and expertise needed for the long-term space missions required to visit other planets. As well, the moon may also be used as a forward base of operations from which humans learn how to replenish essential supplies, such as rocket fuel and oxygen, by creating them from local material.

Such skills are crucial for the future of human presence into deeper space, which demands more independence from Earth-based resources. And although humans have visited the moon before, there is still much to be explored including the presence of water ice near the moon's south pole, which is one of the top target destinations for space exploration. NASA is also working the private sector to help it reach the moon. It has awarded three contracts to private companies working on developing human-rated lunar landers including both Blue Origin and SpaceX. But the backbone of the Artemis program relies on a brand new, state-of-the-art spacecraft called Orion.

As part of the mission to return to the moon NASA created the Gateway project which will be an outpost orbiting the Moon that provides vital support for a sustainable, long-term human return to the lunar surface, as well as a staging point for deep space exploration. It is a critical component of NASA's Artemis program. The Gateway is a vital part of NASA's deep space exploration plans, along with the Space Launch System (SLS) rocket, Orion spacecraft, and human landing system that will send astronauts to the Moon. Gaining new experiences on and around the Moon will prepare NASA to send the first humans to Mars in the coming years, and the Gateway will play a vital role in this process. It is a destination for astronaut expeditions and science investigations, as well as a port for deep space transportation such as landers en route to the lunar surface or spacecraft embarking to destinations beyond the Moon.

Eventually Colonizing Mars

Permanent humans living on a planet other than the Earth is one of science fiction's most common subjects. As technology has advanced, and concerns about the future of humanity on Earth have increased, the argument that space colonization is a possible and important goal has become popular. Other reasons for colonizing space include economic interests, long-term scientific research best carried out by humans as opposed to robotic probes, and human curiosity. Many organizations support the colonization of Mars. They have also given different reasons and ways humans can live on Mars. One of the oldest organizations is the Mars Society. They promote a NASA program that supports human colonies on Mars. The Mars Society have set up Mars research stations in Canada and the United States.

Colonization requires the establishment of permanent bases that have the ability to support themselves. The surface gravity on Mars is 38% of that on Earth. It is unknown if this is enough to prevent weightlessness. Mars is much colder than Earth. Mars surface temperature is −63 °C and a low of −140 °C. The lowest temperature ever recorded on Earth was −89.2 °C, in Antarctica. There is no liquid water on the surface of Mars. Because Mars is further from the Sun, it takes longer for solar energy to reach the upper atmosphere of Mars. Mars' orbit is more eccentric than Earth's. Because of the low pressure and an atmosphere of mostly carbon dioxide on Mars humans must have pressure suits to survive and live in protective structures.

Interplanetary Spaceflight

A trip to Mars requires approximately seven to twelvce months in a tightly packed ship with very little room. This trip woud most likely occur with the astronauts in micro-gravity for a long time which can cause a lot of health problems for astronauts. Then there's the powerful cosmic radiation that comes mostly from our Sun. It can damage electronic equipment on board and create health problems for the crew as well. Many problems encountered during the mission will have to be solved by the crew on their own. Astronuts would have to know every detail of the spacecraft inside out and draw on extensive astronaut training to fix problems using only what they brought with them. For example, they may have to 3D print spare parts from materials like titanium or carbon fibre. Communication would be difficult as messages to earth take 20 minutes to reach its destination as a result video conferencing would not be possible

Human Health

Mars presents a hostile environment for human to live. Different technologies have been developed to assist long-term space exploration and may be adapted for living on Mars. The longest time spent outside the protection of the Earth's Van Allen radiation belt is about 12 days for the Apollo 17 moon landing. This is minor in comparison to the 1100 day journey planned by NASA as soon as the year 2028. Scientists asre also concerned that many different biological functions can be negatively affected by the environment of Mars colonies. Due to higher levels of radiation, there are a many physical side-effects that must be manged. Human survival on Mars would require complex life-support measures and living in artificial environments.

Physical Effects of Space

The difference in gravity will negatively affect human health by weakening bones and muscles. There is also risk of osteoporosis and cardiovascular problems. Current rotations on the International Space Station put astronauts in micro-gravity for six months, a comparable length of time to a one-way trip to Mars. This gives researchers the ability to better understand the physical state that astronauts going to Mars will arrive in. Once on Mars, surface gravity is only 38% of that on Earth. A study from the Journal of Cosmology by Dr. Nick Kanas states that "many factors will affect such a mission. A Mars crew will be tens of millions of miles away from home, engaged in a mission that will last around 2 1⁄2years. Crew members will experience a severe sense of isolation and separation from the Earth due to the communication delays. Researchers have developed a Martian simulation called HI-SEAS (Hawaii Space Exploration Analog and Simulation) that places scientists in a simulated Martian laboratory to study the psychological effects of isolation, repetitive tasks, and living in close-quarters with other scientists for up to a year at a time.

A New Era in Spaceflight

At present the Commercial Crew Program and partnering with private companies to reach the lunar surface is NASA's present focus in the hopes to change the cost of spaceflight. If space travel becomes cheaper and more accessible, it's possible that private citizens will routinely visit space, either from space capsules, space stations, or even space hotels like the inflatable habitats Bigelow Aerospace intends to build.

The United States isn't the only country with its eyes on the sky. Russia regularly launches humans to the International Space Station aboard its Soyuz spacecraft. China is planning a large, multi-module space station capable of housing three taikonauts, and has already launched two orbiting test vehicles called Tiangong-1 and Tiangong-2, both of which safely burned up in the Earth's atmosphere after several years in space.

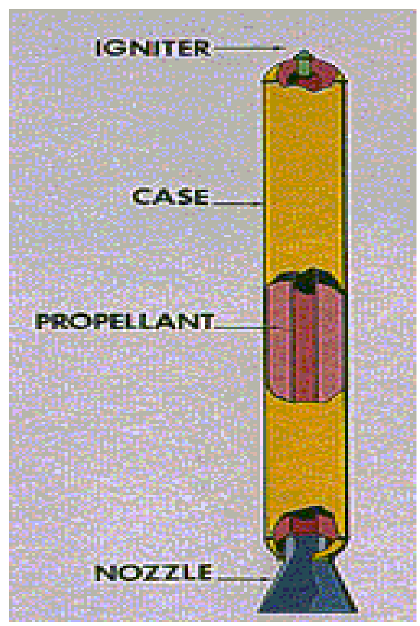
Now, more than a dozen countries have the ability to launch rockets into Earth orbit. A half-dozen space agencies have designed spacecraft that can leave Earth's gravity and traveled to the moon or Mars. While there are no set plans yet to send humans to Mars, these missions and the discoveries that will come out of them may help pave the way.

Chapter 6 How Rockets Work

Rocket Engines

A rocket engine is a machine that develops thrust by the rapid expulsion of matter. Most rockets today operate with either solid or liquid propellants. The word propellant does not simply mean fuel, as you might think; it means both fuel and oxidizer. The fuel is the chemical rockets burn but, for burning to take place, an oxidizer (oxygen) must be present. Jet engines draw oxygen into their engines from the surrounding air. Rockets do not have the luxury that jet planes have; they must carry oxygen with them into space, where there is no air. There are three categories of chemical propellants for rocket engines: liquid propellant, solid propellant, and hybrid propellant. The propellant for a chemical rocket engine usually consists of a fuel and an oxidizer. Each category has advantages and disadvantages that make them best for certain applications and unsuitable for others.

Solid Propellant Rockets

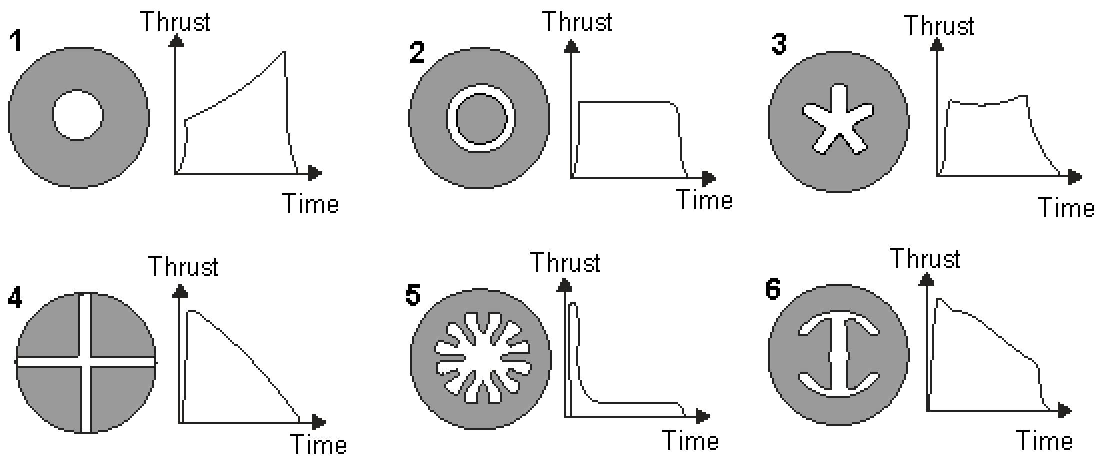


A solid-propellant rocket has the simplest form of engine. Solid propellant rockets are basically combustion chamber tubes packed with a propellant that contains both fuel and oxidizer blended uniformly. It has a nozzle, a case, insulation, propellant, and an igniter. The case of the engine is usually a relatively thin metal that is lined with insulation to keep the propellant from burning through. The propellant itself is packed inside the insulation layer.

Solid rocket propellants, which are dry to the touch, contain both the fuel and oxidizer combined in the chemical itself. Usually, the fuel is a mixture of hydrogen compounds and carbon and the oxidizer is made up of oxygen compounds. The principal advantage is that a solid propellant is relatively stable therefore it can be manufactured and stored for future use. Solid propellants have a high density and can burn very fast. They are relatively insensitive to shock, vibration, and acceleration. No propellant pumps are required thus the rocket engines are less complicated.

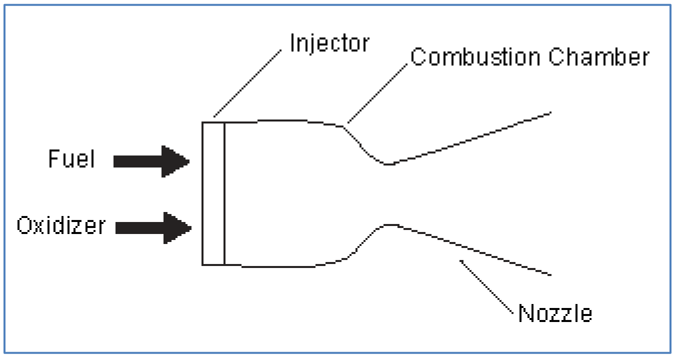
Disadvantages are that, once ignited, solid propellants cannot be throttled, turned off and then restarted because they burn until all the propellant is used. The surface area of the burning propellant is critical in determining the amount of thrust being generated. Many solid-propellant rocket engines feature a hollow core that runs through the propellant. Rockets that do not have the hollow core must be ignited at the lower end of the propellants and burning proceeds gradually from one end of the rocket to the other.

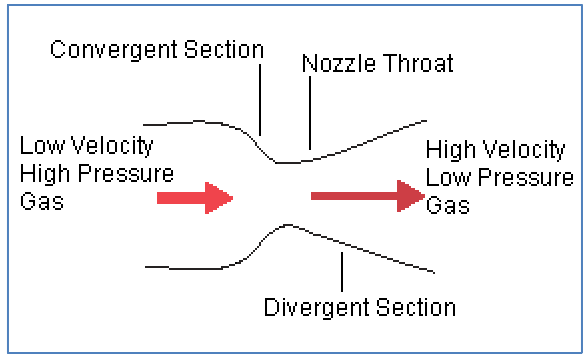
In all cases, only the surface of the propellant burns. However, to get higher thrust, the hollow core is used. This increases the surface of the propellants available for burning. The propellants burn from the inside out at a much higher rate, and the gases produced escape the engine at much higher speeds. This gives a greater thrust. Some propellant cores are star shaped to increase the burning surface even more.



To fire solid propellants, many kinds of igniters can be used. Fire-arrows were ignited by fuses, but sometimes these ignited too quickly and burned the rocketeer. A far safer and more reliable form of ignition used today is one that employs electricity. An electric current, coming through wires from some distance away, heats up a special wire inside the rocket. The wire raises the temperature of the propellant it is in contact with to the combustion point.

The nozzle in a solid-propellant engine is an opening at the back of the rocket that permits the hot expanding gases to escape. The narrow part of the nozzle is the throat. Just beyond the throat is the exit cone. The purpose of the nozzle is to increase the acceleration of the gases as they leave the rocket and thereby maximize the thrust. It does this by cutting down the opening through which the gases can escape.





To see how this works, you can experiment with a garden hose that has a spray nozzle attachment. This kind of nozzle does not have an exit cone, but that does not matter in the experiment. The important point about the nozzle is that the size of the opening can be varied. Start with the opening at its widest point. Watch how far the water squirts and feel the thrust produced by the departing water. Now reduce the diameter of the opening, and again note the distance the water squirts and feel the thrust. Rocket nozzles work the same way.

As with the inside of the rocket case, insulation is needed to protect the nozzle from the hot gases. The usual insulation is one that gradually erodes as the gas passes through. Small pieces of the insulation get very hot and break away from the nozzle. As they are blown away, heat is carried away with them.

Liquid Propellant Rockets

The other main kind of rocket engine is one that uses liquid propellants. This is a much more complicated engine, as is evidenced by the fact that solid rocket engines were used for at least seven hundred years before the first successful liquid engine was tested. Liquid propellants have separate storage tanks - one for the fuel and one for the oxidizer. They also have pumps, a combustion chamber, and a nozzle. The fuel of a liquid-propellant rocket is usually kerosene or liquid hydrogen; the oxidizer is usually liquid oxygen. They are combined inside a cavity called the combustion chamber.

High pressure turbo pumps provide an example of the rocket engine. Here the propellants burn and build up high temperatures and pressures, and the expanding gas escapes through the nozzle at the lower end. To get the most power from the propellants, they must be mixed as completely as possible. Small injectors (nozzles) on the roof of the chamber spray and mix the propellants at the same time. Because the chamber operates under high pressures, the propellants need to be forced inside. Powerful, lightweight turbine pumps between the propellant tanks and combustion chambers take care of this job.

The major components of a chemical rocket assembly are a rocket motor or engine, propellant consisting of fuel and an oxidizer, a frame to hold the components, control systems and a cargo such as a satellite. A rocket differs from other engines in that it carries its fuel and oxidizer internally, therefore it will burn in the vacuum of space as well as within the Earth's atmosphere. The cargo is commonly referred to as the payload. A rocket is called a launch vehicle when it is used to launch a satellite or other payload into space. A rocket becomes a missile when the payload is a warhead, and it is used as a weapon.

Many different types of rocket engines have been designed or proposed. Currently, the most powerful are the chemical propellant rocket engines. Other types being designed or that are proposed are ion rockets, photon rockets, magneto hydrodynamic drives and nuclear fission rockets; however, they are generally more suitable for providing long term thrust in space rather than launching a rocket and its payload from the Earth's surface into space.

A cryogenic propellant is one that uses very cold, liquefied gases as the fuel and the oxidizer. Liquid oxygen boils at -297 F and liquid hydrogen boils at -423 F. Cryogenic propellants require special insulated containers and vents to allow gas from the evaporating liquids to escape. The liquid fuel and oxidizer are pumped from the storage tanks to an expansion chamber and injected into the combustion chamber where they are mixed and ignited by a flame or spark. The fuel expands as it burns, and the hot exhaust gases are directed out of the nozzle to provide thrust.

Advantages of liquid propellant rockets include the highest energy per unit of fuel mass, variable thrust, and a restart capability. Raw materials, such as oxygen and hydrogen are in abundant supply and a relatively easy to manufacture. Disadvantages of liquid propellant rockets include requirements for complex storage containers, complex plumbing, precise fuel and oxidizer injection metering, high speed/high-capacity pumps, and difficulty in storing fueled rockets.

Hypergolic Propellant Rockets

A hypergolic propellant is composed of a fuel and oxidizer that ignite when they meet each other. There is no need of an ignition mechanism in order to bring about combustion. In hypergolic propellants, the fuel part normally includes hydrazine, and the oxidizer is generally nitrogen tetroxide or nitric acid. The easy start and restart capability of hypergolic propellants make them ideal for spacecraft maneuvering systems. They are also used for orbital insertion as their combustion can be easily controlled and thus allows the precise adjustments required for insertion into orbit. Hypergolic propellants are also employed for altitude control.

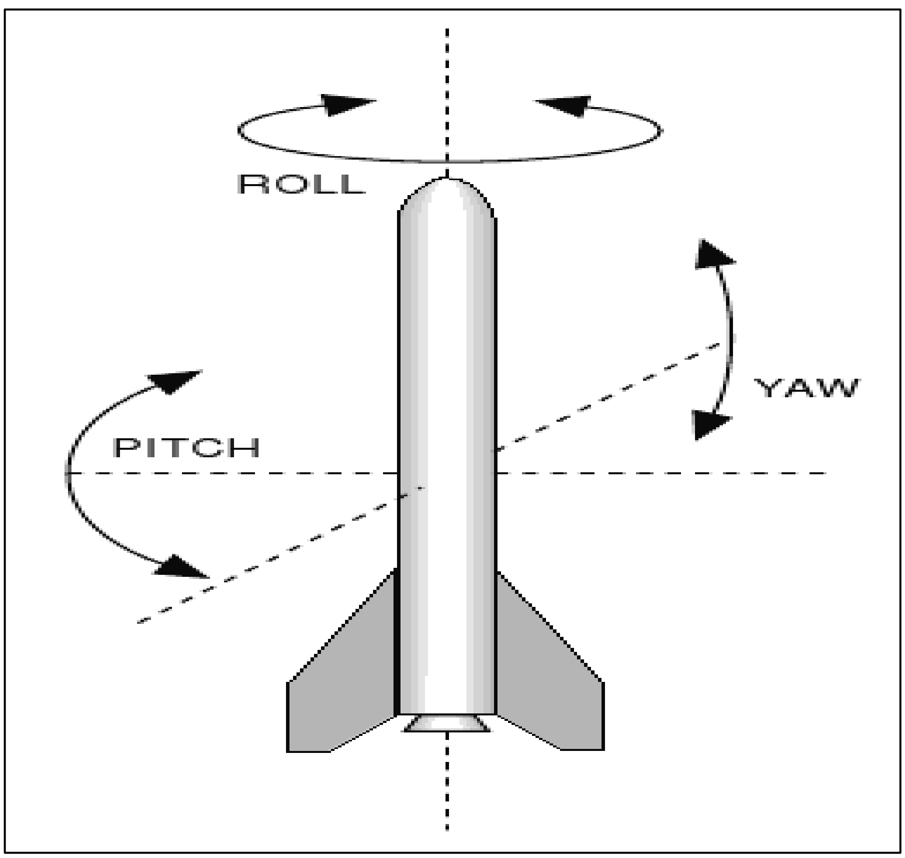
Hypergolic propellants remain in liquid state at normal temperatures. They do not need the temperature-controlled storage as in case of cryogenic propellants. But, as compared to cryogenic propellants, hypergolic propellants are less energetic. That is they produce less energy per unit mass. For example: in a moon bound shuttle, 75% of the onboard mass would be fuel, in case of cryogenic propellants. But in case of hypergolic propellants, the number raises to 90%. In comparison to cryogenic propellants, hypergolic propellants are very poisonous. They react with living tissues as well cause injuries. So it is mandatory for technicians to wear full-body Self-Contained Atmospheric Protection Ensemble (SCAPE) suits. They are corrosive therefore storage requires special containers and safety facilities. It is necessary that they be stored safely, with no possible contacts between the fuel parts.

The Rocket System

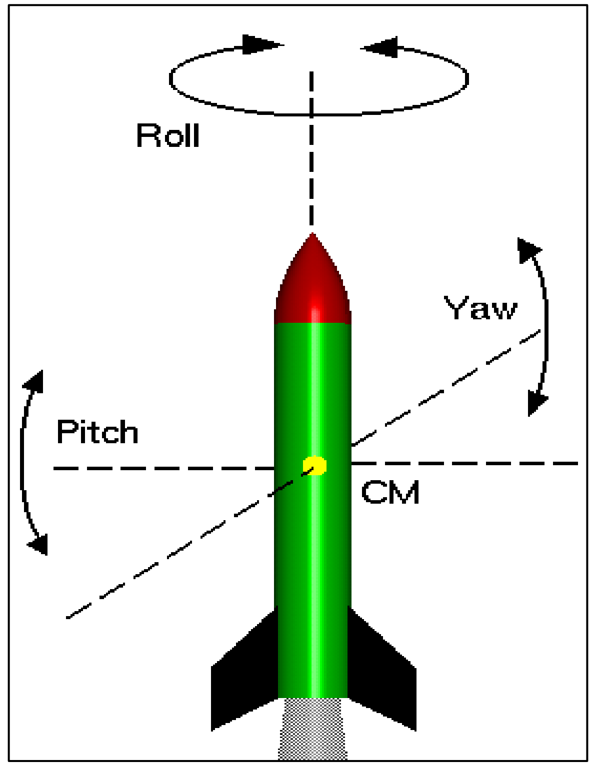
A Rocket system consist of the rocket engine that provides propulsion and all the other systems that keep it stable in flight. A stable rocket is one that flies in a smooth, uniform direction. An unstable rocket flies along an erratic path, sometimes tumbling or changing direction. Unstable rockets are dangerous because it is not possible to predict where they will go. They may even turn upside down and suddenly head back directly to the launch pad. Making a rocket stable requires some form of control system.

The center of mass is important in rocket flight because it is around this point that an unstable rocket tumble. As a matter of fact, any object in flight tends to tumble. Throw a stick, and it tumbles end over end. Throw a ball, and it spins in flight. The act of spinning or tumbling is a way of becoming stabilized in flight. A Frisbee will go where you want it to only if you throw it with a deliberate spin. Try throwing a Frisbee without spinning it. If you succeed, you will see that the Frisbee flies in an erratic path and falls far short of its mark. In flight, spinning or tumbling takes place around one or more of three axes and they are called pitch, yaw, and roll.

- Pitch is a measure of how high or low the nose cone is pointing.
- Yaw is a measure of how far to the left or the right the nose cone is pointing.
- Roll is a measure of how much the rocket has rotated on its longest axis.

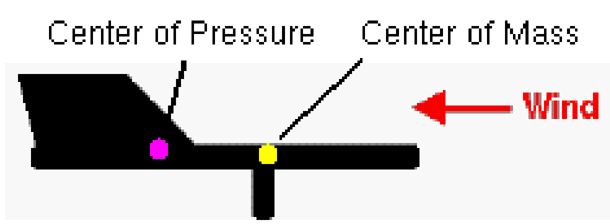


The point where all three of these axes intersect is the center of mass. For rocket flight, the pitch and yaw axes are the most important because any movement in either of these two directions can cause the rocket to go off course. The roll axis is the least important because movement along this axis will not affect the flight path. With rockets, thrust from the engine is still being produced while the rocket is in flight. Unstable motions about the pitch and yaw axes will cause the rocket to leave the planned course. To prevent this, a control system is needed to prevent or at least minimize unstable motions.



Center of Pressure

In addition to center of mass, there is another important center inside the rocket that affects its flight. This is the center of pressure (CP). The center of pressure exists only when air is flowing past the moving rocket. This flowing air, rubbing and pushing against the outer surface of the rocket, can cause it to begin moving around one of its three axes. Think for a moment of a weathervane. A weathervane is an arrow-like stick that is mounted on a rooftop and used for telling wind direction. The arrow is attached to a vertical rod that acts as a pivot point. The arrow is balanced so that the center of mass is right at the pivot point. When the wind blows, the arrow turns, and the head of the arrow points into the on-coming wind. The tail of the arrow points in the downwind direction.



The reason that the weathervane arrow points into the wind is that the tail of the arrow has a much larger surface area than the arrowhead. The flowing air imparts a greater force to the tail than the head, and therefore the tail is pushed away. There is a point on the arrow where the surface area is the same on one side as the other. This spot is called the center of pressure. The center of pressure is not in the same place as the center of mass. If it were, then neither end of the arrow would be favored by the wind and the arrow would not point. The center of pressure is between the center of mass and the tail end of the arrow. This means that the tail end has more surface pressure than the head end.

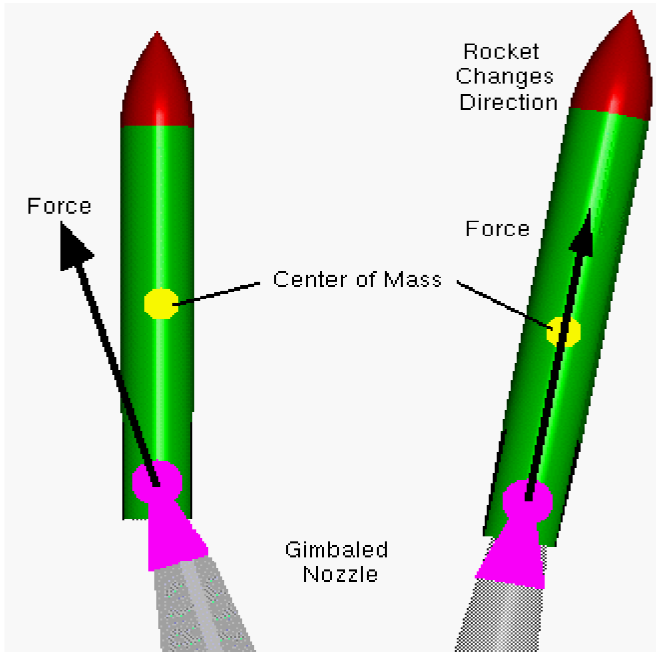
It is extremely important that the center of pressure in a rocket be located toward the tail and the center of mass be located toward the nose. If they are in the same place or very near each other, then the rocket will be unstable in flight. The rocket will then try to rotate about the center of mass in the pitch and yaw axes, producing a dangerous situation. With the center of pressure located in the right place, the rocket will remain stable.

Control Systems

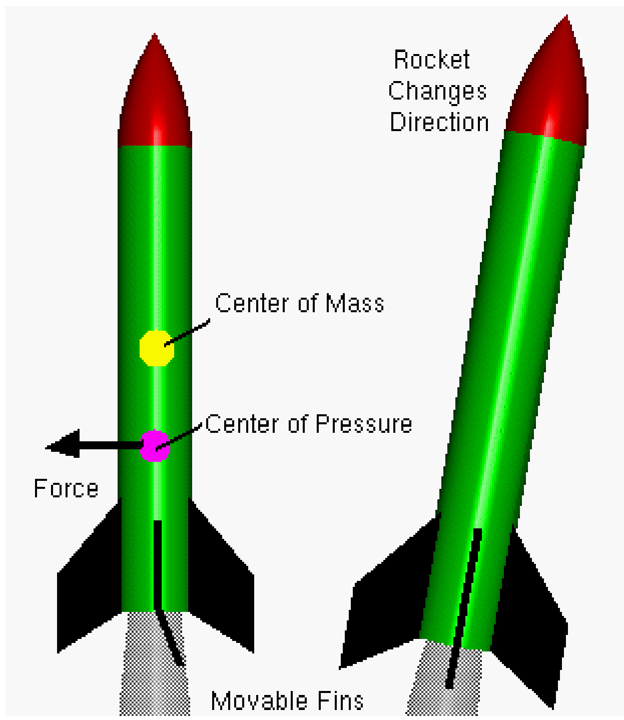
Control systems for rockets are intended to keep a rocket stable in flight and to steer it. Small rockets usually require only a stabilizing control system. Large rockets, such as the ones that launch satellites into orbit, require a system that not only stabilizes the rocket, but also enable it to change course while in flight. Controls on rockets can either be active or passive. Passive controls are fixed devices that keep rockets stabilized by their very presence on the rocket's exterior. Active controls can be moved while the rocket is in flight to stabilize and steer the craft.

An important improvement in rocketry came with the use of clusters of lightweight fins mounted around the lower end near the nozzle. Fins could be made from lightweight materials and be streamlined in shape. They gave rockets a dartlike appearance. The large surface area of the fins easily kept the center of pressure behind the center of mass. Some experimenters even bent the lower tips of the fins in a pinwheel fashion to promote rapid spinning in flight. With these "spin fins," rockets become much more stable in flight. But this design also produces more drag and limits the rocket's range.

With the start of modern rocketry in the 20th century, new ways were sought to improve rocket stability and at the same time reduce overall rocket weight. The answer to this was the development of active controls. Active control systems included vanes, movable tail fins, canards, gimbaled nozzles, vernier rockets, and attitude-control rockets. Tilting tail fins and canards are quite like each other in appearance. The only real difference between them is their location on the rockets. Canards are mounted on the front end of the rocket while the tilting fins are at the rear. In flight, the fins, and canards tilt like rudders to deflect the air flow and cause the rocket to change course. Motion sensors on the rocket detect unplanned directional changes, and corrections can be made by slight tilting of the fins and canards. The advantage of these two devices is size and weight. They are smaller and lighter and produce less drag than the large fins.



Other active control systems can eliminate fins and canards altogether by tilting the angle at which the exhaust gas leaves the rocket engine, course changes can be made in flight. Several techniques can be used for changing exhaust direction. Vanes are small finlike devices that are placed inside the exhaust of the rocket engine. Tilting the vanes deflects the exhaust, and by action-reaction the rocket responds by pointing the opposite way.



Another method for changing the exhaust direction is to gimbal the nozzle. A gimbaled nozzle is one that can sway while exhaust gases are passing through it. By tilting the engine nozzle in the proper direction, the rocket responds by changing course. Vernier rockets can also be used to change direction. These are small rockets mounted on the outside of the large engine. When needed they fire, producing the desired course change.

In space, only by spinning the rocket along the roll axis or by using active controls involving the engine exhaust can the rocket be stabilized or have its direction changed. Without air, fins and canards have nothing to work upon. The most common kinds of active control used in space are attitude-control rockets. Small clusters of engines are mounted all around the vehicle. By firing the right combination of these small rockets, the vehicle can be turned in any direction. As soon as they are aimed properly, the main engines fire, sending the rocket off in the new direction.

Chapter 7 Terrestrial Flight

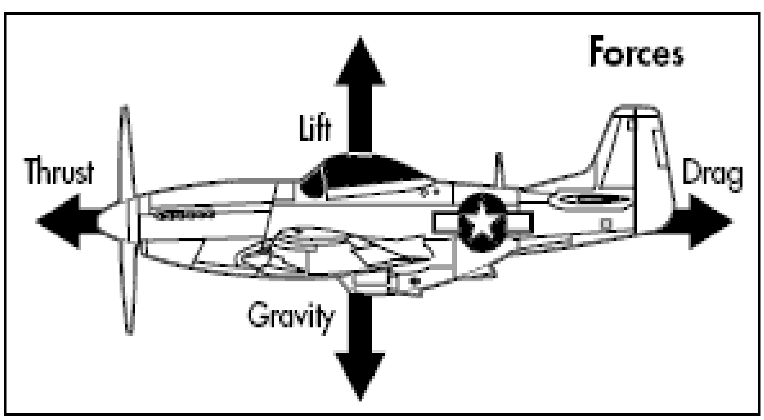
Introduction

The miracle of flight exists because man has the technology to oppose natural forces that keep all objects on the ground. Four forces affect an aircraft — two assist flight (thrust and lift), and two resist flights (gravity and drag). The important thing to note here is that when an aircraft is flying straight and level, all four of these forces are balanced, or in equilibrium.

Physics of Flight

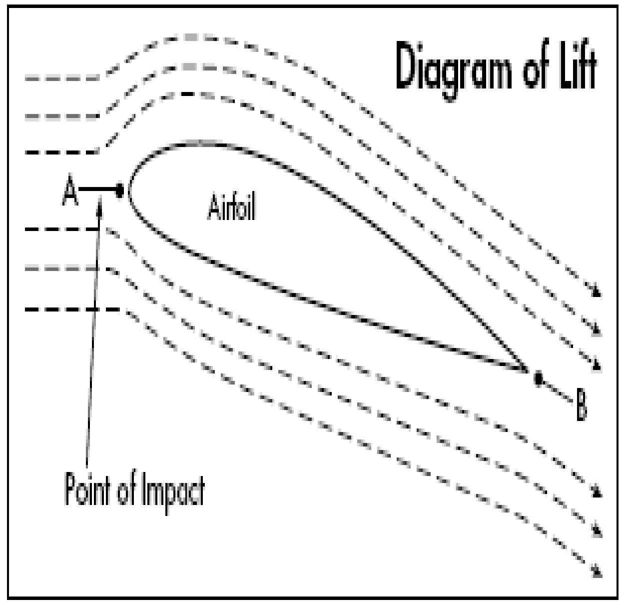
Thrust is created by engines. In powered aircraft as the propeller forces air back (or in a jet fuel is combusted) it provides force that makes the aircraft move forward. As the wings cut through the air in front of the aircraft, *lift* is created. This is the force that pushes an aircraft up into the air, however in gliding vehicles thrust is not a factor.

Lift occurs because air flows both over and under the surface of the wing. The wing is designed so that the top surface is "longer" than the bottom surface in any given cross-section. In other words, the distance between points **A** to **B** is greater along the top of the wing than under it. The air moving over the wing must travel from **A** to **B** in the same amount of time. Therefore, the air is moving faster along the top of the wing. This creates a difference in air pressure above and below—a phenomenon called the *Bernoulli effect*. The pressure pushing up is greater than the downward pressure, and lift is created.

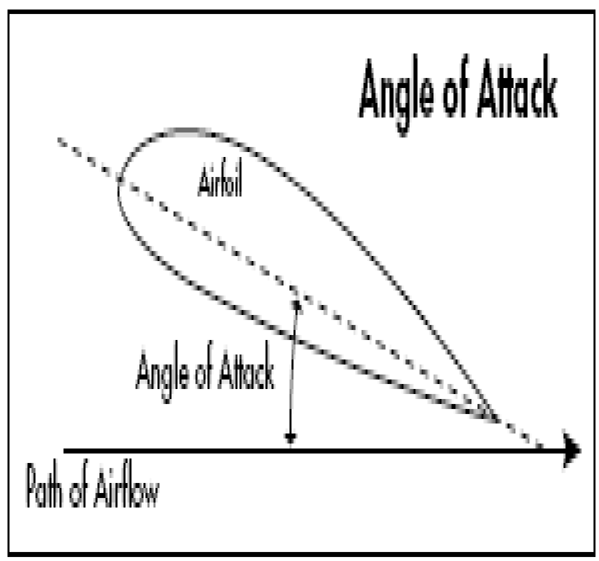


Several factors determine how much lift is created. First, consider the angle at which the wing hits the air. This is called the *angle of attack*, which is independent of the aircraft's flight path vector. The steeper this angle, the more lift occurs. At angles steeper than 30° or so, however, airflow is disrupted, and an aircraft *stall* occurs. During a stall, no lift is created. The aircraft falls into a dive and can recover lift only after gaining airspeed. *Drag* opposes thrust. Although it mainly occurs because of air resistance as air flows around the wing, several different types of drag exist. Drag is mainly created by simple skin friction as air molecules "stick" to the wing's surface. Smoother surfaces incur less drag, while bulky structures create additional drag.

Some drag has nothing to do with air resistance and is a secondary result of lift. Because lift angles backward slightly, it is has both an upward, vertical force and a horizontal, rearward force. The rearward component is drag. Another type of drag is induced at speeds near Mach 1, when a pressure differential starts building up between the front and rear surface of the airfoil. The pressure in front of the wing is greater than the pressure behind the wing, which creates a net force that opposes thrust.

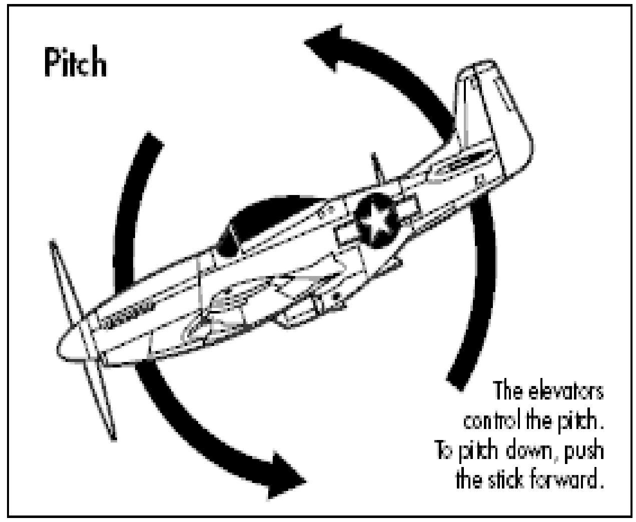


Gravity is a force of acceleration on an object. The Earth exerts this natural force on all objects. Being a constant force, it always acts in the same direction: downward. Thrust creates lift to counteract gravity. For an aircraft to take off, enough lift must be created to overcome the force of gravity pushing down on the aircraft. Related to gravity are G-forces—artificially created forces that are measured in units' equivalent to the force of gravity.

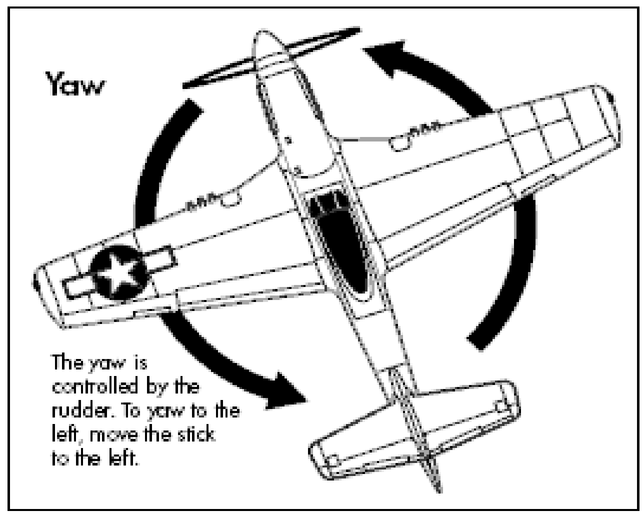


Movement Vectors

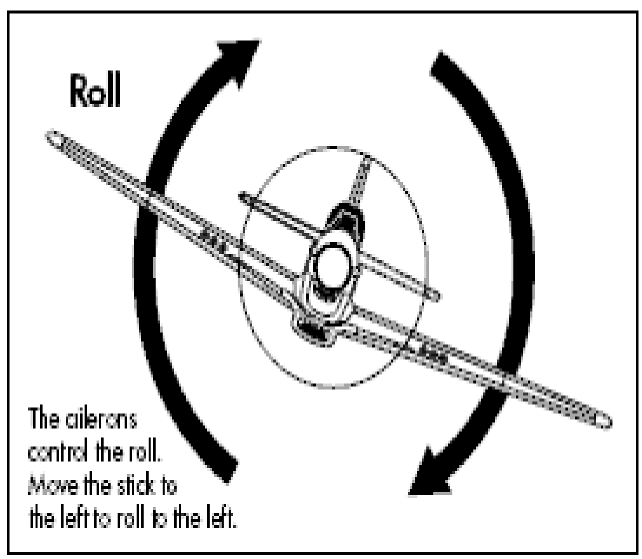
Pitch is the up and down movement of the aircraft's nose around an axis line drawn from wingtip to wingtip. When you apply pitch by pulling back on the stick, you angle the aircraft's elevators up, causing the nose to rise.



Yaw is the side-to-side rotation of the aircraft's nose around a vertical axis through the center of the aircraft. It changes the direction of horizontal flight but does not affect altitude. You use the rudder to angle the aircraft's rudder left or right, which creates yaw.



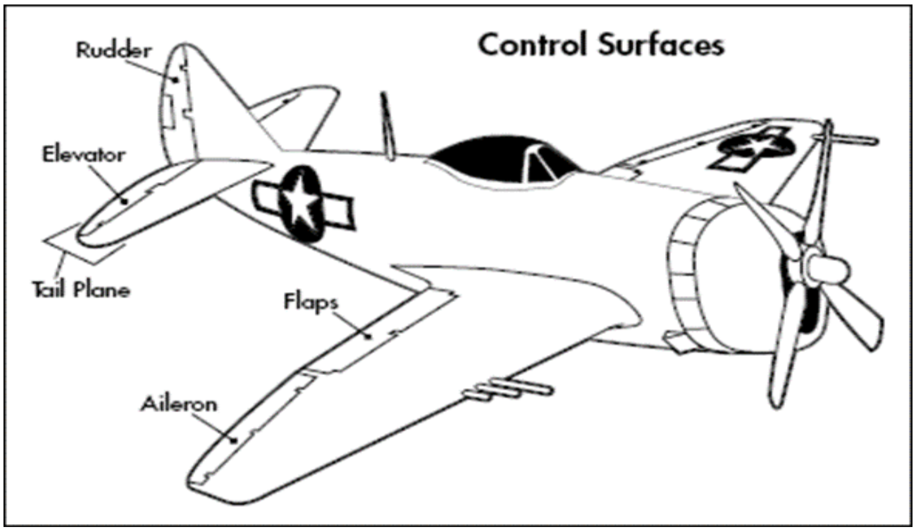
Roll is the tipping of the wings up or down. The aircraft maintains its current direction of flight, but the wings spin around an imaginary line drawn from the nose through the tail. Roll occurs when you push the stick left or right, causing one aileron to angle down and the other to angle up. These increases lift under one wingtip while decreasing lift under the other, creating roll.



Bank - You can combine pitch and roll movements to make a banking turn. By pitching the nose up and applying right stick, you cause the aircraft to bank to the right. You can accomplish a left bank by pitching up and applying left stick. A banking turn changes both the angle of the nose and the direction of flight. One side-effect of a banked turn is that you lose both lift and airspeed.

Shuttle Control Surfaces

All control surfaces utilize the principle of lift, but they apply lift forces in different directions. These forces act either independently or in conjunction with one another to produce various maneuvers. Each maneuver is the net resultant force of all individual forces. (A resultant force is the average force that results when two forces are combined. For example, a pure vertical force and a pure horizontal force create an angled force.)



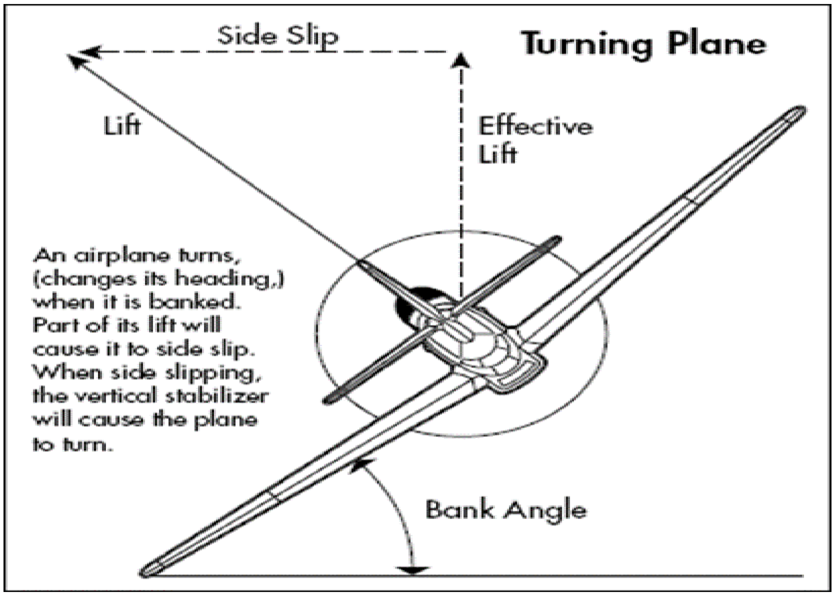
Elevators - Elevators are flat, hinged surfaces on the tail plane (the horizontal part of the tail assembly). While the entire tail plane surface helps stabilize the aircraft during flight, the elevators apply pitch by angling the trailing (rear) edge of the tail plane up or down. To create pitch, gently pull the flight stick back or push it forward. Take care not to perform pitch maneuvers too quickly. If the angle of attack (angle that the air meets the wing) becomes too steep, the flow of air around the wings can become disrupted. Air no longer flows smoothly over the wing; instead, it buffets in several different directions and disrupts the air pressure around the wing's surface. This situation is called a *stall*. Stalls can also occur from lack of airspeed, when not enough air flows over the wings to create lift. This is commonly encountered in propeller-powered aircraft, especially during steep climbs in which gravity reduces airspeed. Note that climbing steeply is not the same thing as pitching up too quickly. The former type of stall is caused by lack of airspeed, while the second type is due to disrupted airflow around the wing.

Rudders - The rudder is the vertical component of the tail assembly. The rear half of the vertical tail section is hinged, allowing it to angle left or right. When you apply rudder, you redirect the aircraft's nose either left or right. Applying left rudder yaws the nose to the left, while applying right rudder veers the nose to the right. Note that applying rudder also produces a very slight rolling movement, which can be negated by pushing the stick in the opposite direction.

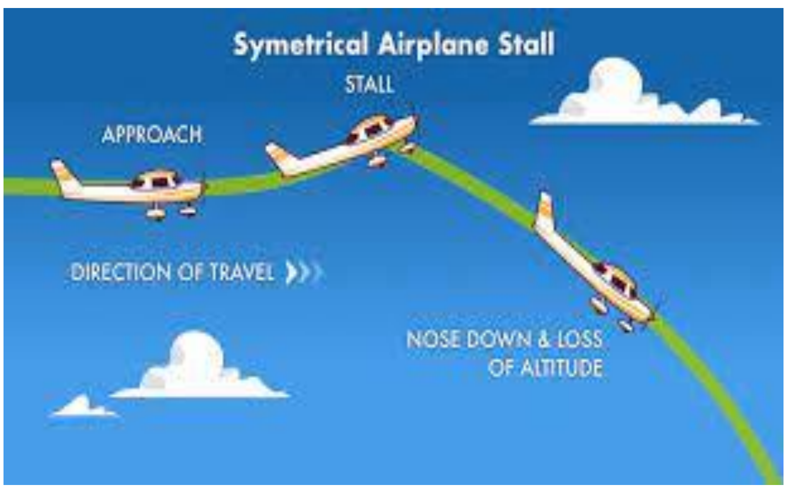
Ailerons-Ailerons are thin, hinged surfaces on the outer, trailing edge of each wing. They angle in opposite directions to waggle the wings up and down or roll the aircraft about its nose-tail axis. If you apply stick left or right, one wing's aileron angles down and the other angles up. This rolls one wing up and forces the other wing down, effectively rolling the airplane. When you apply left stick, the left aileron raises and the right one drops, and the aircraft rolls to the left. The opposite occurs if you push the stick in the opposite direction.

Flaps- Like ailerons, flaps are thin, hinged surfaces on the trailing edge of the wing. However, they are located nearer to the wing root than ailerons and operate in tandem. (If one flap is lowered or raised, so is the other.) A raised flap conforms to the wing's natural shape. A lowered flap alters the airflow around the wing, effectively changing the wing's aerodynamic shape and increasing the amount of available lift. You extend flaps during takeoff to gain additional lift, then retract them during flight to maximize your airspeed. While flaps increase your aircraft's angle of attack, they also increase drag. In a pinch, you can use flaps while chopping the throttle to quickly reduce your airspeed. One point to note is that flaps can only be extended at low to medium speeds. If the aircraft is traveling too fast, air flows too fast over the flaps, and they cause drag. In high-speed dives, flaps and other control surfaces may become unusable—air travels so fast over them that you cannot move them until you slow down the aircraft.

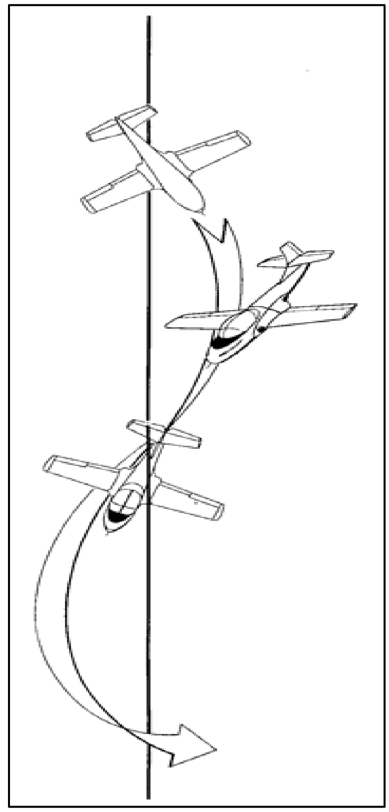
Banked turns - Turning is also known as banking or combining pitch and roll maneuvers to alter your heading. By pulling the stick back and either left or right, you make a banked turn. You can also apply rudder in the intended direction of the turn to make the turn more quickly. As you enter a banked turn you lose altitude, airspeed, or both by the time you finish turning. This occurs for two reasons. First, you change the angle of attack (angle of the wings as they meet the airflow). This creates drag that slows down the aircraft. Secondly, lift acts nearly perpendicular to your aircraft's wings. If the wings are angled, so is the lift vector. You have less pure vertical force, so you drop in altitude.



Stalls- A stall is the loss of lift. They occur because your aircraft's speed has dropped below the airspeed required to maintain lift, in the shuttle this occurs around 120 knots. Without lift, your aircraft falls toward the ground and your control surfaces are useless, much like a sail without a breeze to propel it. Stalls are most experienced during tight turns, steep climbs, loops, and landings. To solve a stall situation, let the aircraft fall and try to keep the nose oriented toward the ground (most aircraft nose down automatically). Eventually, this buys enough airspeed to restore airflow over the control surfaces and let you regain control of your aircraft.



Spins - A spin is a special type of stall that happens when one wing loses lift, but the other does not. Often, a spin occurs when you make a hard turn and have the nose pitched too steeply. Lift fails on one wing, and it begins to drop toward the ground. Meanwhile, the opposing wing keeps producing lift and rising. If the rudder is engaged, it rotates the aircraft about its yaw axis. The result is a spinning corkscrew motion. All aircraft have a critical angle of attack, or a maximum angle at which the wings can still provide lift. If you nose up drastically at high speeds, you may surpass this angle and initiate a stall or spin. To recover from a spin, you must neutralize the aircraft's rotating motion. The best way to accomplish this is to center the stick and apply rudder in the opposite direction of the spin. Then, nose the plane downward. Hopefully, you will have enough altitude to recover and break out of the spin.



Basic Concepts of Orbital Spaceflight

The velocity needed to maintain a given orbit is called orbital velocity. The velocity required depends on the altitude of the orbit. The closer an orbiting spacecraft is to earth, the higher the velocity required to remain in that orbit. To give you an idea of the speeds required, maintaining a circular orbit at an altitude of 100 miles requires a velocity of 17,478 miles per hour.

Getting into Orbit

Rockets are used to give a spacecraft sufficient altitude and velocity to achieve orbit. A rocket is launched vertically, but as it ascends it adjusts its trajectory to become more horizontal. This puts the spacecraft in the proper position for orbit. When the desired altitude and velocity have been reached, the rocket engine is cut off. If altitude and velocity are correct, the spacecraft will be in orbit. The path of the orbit is determined by the spacecraft's velocity.

Once in the desired orbit, the spacecraft's velocity must be carefully monitored. Changes in velocity will change the path of the orbit. In fact, this is how a spacecraft in orbit returns to earth. Small rockets, known as retrorockets, fire briefly against the direction of flight, changing the velocity of the spacecraft. This changes the path of the spacecraft's orbit to one that will bring the spacecraft back into the atmosphere.

Apogee and Perigee

Not all orbits are circular. Many take the shape of an ellipse. The point of highest altitude in an elliptical orbit is called the apogee, and the lowest point is the perigee. A circular orbit is just a special case of an elliptical orbit where the apogee and perigee are the same. In a circular orbit, the velocity of an object is constant, while velocity varies throughout an elliptical orbit. In such an orbit, velocity is greatest at the perigee, and lowest at apogee.

Atmospheric drag

Earth's atmosphere does not end suddenly at the edge of space. It gradually thins out. A spacecraft in low-earth orbit will experience drag, or resistance, from the thin atmosphere it encounters. This drag will cause an orbit to deteriorate, or decay, over time. All current manned space activity takes place in low earth orbit and must take drag into account. The International Space Station, for example, must periodically be boosted to its proper altitude and velocity to compensate for the effects of atmospheric drag.

What is an Orbit?

An orbit is the movement of a (small body) object around a usually much larger body (e.g., planet or moon) in space in the shape of an elliptical. The elliptical shape is determined by the velocity of the small body and its distance to the center of gravity of the larger body. The location of the closest and farthest point of an orbiting object around a body is fixed irrespective of the larger bodies' rotation. This brings up the difference between a revolution and an orbit. A revolution is defined relative to a position on the body that you are orbiting.

For example, since the Earth turns around its axis a revolution around the Earth will be more than an orbit if you orbit in the direction of the rotation. So, the time to complete an orbit may not be the same as the revolution time. An object in orbit is continuously falling towards the body that it is orbiting but because of its velocity never reaches the surface. When an object moves in an elliptical orbit there will be a point where it is closest (periapsis) to the body it orbits and a point where it is farthest (apoapsis).

When in apoapsis the object has its slowest speed in the orbit and will start falling back to the body and exchange potential energy for kinetic energy. If the object travels too slow at a certain distance, then its path will intersect with the object it was orbiting or if it travels too fast at a certain distance then it will never return (escape velocity).

Spacecraft Navigation

Spacecraft navigation comprises two aspects: (1) knowledge and prediction of spacecraft position and velocity, which is orbit determination, and (2) firing the rocket motor to alter the spacecraft's velocity, which is flight path control. A spacecraft on its way to a distant planet is in orbit about the sun, and the portion of its solar orbit between launch and destination is called the spacecraft's trajectory.

For the spacecraft to navigate it needs three types of information, these three types of data are used to create a mathematical model that can be used to determine a spacecraft's location in three-dimensional space.

- Its distance from Earth,
- Its velocity that is directly toward or away from Earth
- Its position in Earth's sky which is obtained from imaging instrument that view a target planet or moon against the background stars.

Chapter 8 The Space Shuttle Description

The space shuttle was the world's first reusable spacecraft, and the first spacecraft in history that could carry large satellites both to and from orbit. The shuttle launched like a rocket, maneuvered in Earth orbit like a spacecraft and landed like an airplane.

Because of these requirements the Shuttle was shaped to look like an aircraft but to operate as a spacecraft. The structure of the Shuttle Orbiter comprised nine separate sections, or elements: the forward fuselage, the forward reaction control system module, the mid-fuselage, the payload bay doors, the aft fuselage, the vertical tail, the two orbital maneuvering system/reaction control modules and the wing.

The demands are greater than is usually the case with a conventional aircraft because the stresses imposed upon the structure are unique to the Shuttle. Because of this, the design team at North American Aviation had no precedents on which to base their prototype. It was the first of its kind, without the advantage of any previous learning curve, and one of a kind without parallel.

Columbia was the first space shuttle orbiter to be delivered to NASA's Kennedy Space Center, Fla., in March 1979. Columbia and the STS-107 crew were lost Feb. 1, 2003, during re-entry. The orbiter Challenger was delivered to KSC in July 1982 and was destroyed in an explosion during ascent in January 1986. Discovery was delivered in November 1983. Atlantis was delivered in April 1985. Endeavour was built as a replacement following the Challenger accident and was delivered to Florida in May 1991. An early space shuttle orbiter, the Enterprise, never flew in space but was used for approach and landing tests at the Dryden Flight Research Center and several launch pad studies in the late 1970s.

A typical shuttle mission lasted seven to eight days but could extend to as much as 14 days depending upon the objectives of the mission.

Launching the Space Shuttle

To lift the 4.5-million-pound (2.05 million kg) shuttle from the pad to orbit (115 to 400 miles/185 to 643 km) above the Earth, the shuttle used the following components:

- two solid rocket boosters (SRB)
- three main engines of the orbiter

- the external fuel tank (ET)
- orbital maneuvering system (OMS) on the orbiter

Solid Rocket Boosters

The SRBs are solid rockets that provide most of the main force or thrust (71 percent) needed to lift the space shuttle off the launch pad. In addition, the SRBs support the entire weight of the space shuttle orbiter and fuel tank on the launch pad. Each SRB has the following parts:

- solid rocket motor - case, propellant, igniter, nozzle
- solid propellant fuel - atomized aluminum (16 percent) oxidizers - ammonium perchlorate (70 percent) catalyst - iron oxide powder (0.2 percent) binder - polybutadiene acrylic acid acrylonite (12 percent) curing agent - epoxy resin (2 percent)
- jointed structure
- synthetic rubber o-rings between joints
- flight instruments
- recovery systems parachutes (drogue, main) floatation devices signaling devices
- explosive charges for separating from the external tank
- thrust control systems
- self-destruct mechanism

Because the SRBs are solid rocket engines, once they are ignited, they could not be shut down and therefore, they were the last component to light at launch.

Main Engines

The orbiter had three main engines located in the aft (back) fuselage (body of the spacecraft). Each engine is 14 feet (4.3 m) long, 7.5 feet (2. 3 m) in diameter at its widest point (the nozzle) and weighs about 6,700 lb (3039 kg).

The main engines provide the remainder of the thrust (29 percent) to lift the shuttle off the pad and into orbit. The main engines burn liquid hydrogen and liquid oxygen as fuel which are stored in the external fuel tank (ET), at a ratio of 6:1. They draw liquid hydrogen and oxygen from the ET at an amazing rate, equivalent to emptying a family swimming pool every 10 seconds! The fuel is partially burned in a pre-chamber to produce high pressure, hot gases that drive the turbo-pumps (fuel pumps). The fuel is then fully burned in the main combustion chamber and the exhaust gases (water vapor) leave the nozzle at approximately 6,000 mph (10,000 km/h). Each engine can generate between 375,000 and 470,000 lb (1,668,083 to 2,090,664 N) of thrust; the rate of thrust can be controlled from 65 percent to 109 percent maximum thrust. The engines are mounted on gimbals (round bearings) that control the direction of the exhaust, which controls the forward direction of the rocket.

External Fuel Tank

As mentioned above, the fuel for the main engines was stored in the ET. The ET is 158 ft (48 m) long and has a diameter of 27.6 ft (8.4 m). When empty, the ET weighs 78,000 lb (35,455 kg). It holds about 1.6 million lb (719,000 kg) of propellant with a total volume of about 526,000 gallons (2 million liters).

The ET was made of aluminum and aluminum composite materials. It had two separate tanks inside, the forward tank for oxygen and the aft tank for hydrogen, separated by an inter-tank region. Each tank had baffles to dampen the motion of fluid inside. Fluid flows from each tank through a 17-inch (43 cm) diameter feed line out of the ET through an umbilical line into the shuttle's main engines. Through these lines, oxygen can flow at a maximum rate of 17,600 gallons/min (66,600 l/min) and hydrogen can flow at a maximum rate of 47,400 gallons/min (179,000 l/min).

The ET was covered with a 1-inch (2.5 cm) thick layer of spray-on, polyisocyanurate foam insulation. The insulation keeps the fuels cold, protects the fuel from heat that builds up on the ET skin in flight, and minimizes ice formation. When Columbia launched in 2003, pieces of the insulating foam broke off the ET and damaged the left wing of the orbiter, which ultimately caused Columbia to break up upon re-entry.

Space Shuttle Liftoff

The two orbital maneuvering systems' (OMS) engines were in pods on the aft section of the orbiter, one on either side of the tail. These engines placed the shuttle into final orbit, change the shuttle's position from one orbit to another, and slow the shuttle down for re-entry.

The OMS engines burn monomethyl hydrazine fuel (CH_3NHNH_2) and nitrogen tetroxide oxidizer (N_2O_4). Interestingly, when these two substances come in contact, they ignite and burn automatically (i.e., no spark required) in the absence of oxygen. The fuel and oxidizer were kept in separate tanks, each pressurized by helium. The helium pushes the fluids through the fuel lines (i.e., no mechanical pump required). In each fuel line, there were two spring-loaded solenoid valves that close the lines. Pressurized nitrogen gas, from a small tank located near the engine, opened the valves, and allowed the fuel and oxidizer to flow into the combustion chamber of the engine. When the engines shut off, the nitrogen went from the valves into the fuel lines momentarily to flush the lines of any remaining fuel and oxidizer; this purge of the line prevents any unwanted explosions. During a single flight, there was enough nitrogen to open the valves and purge the lines 10 times!

Either one or both of the OMS engines could fire, depending upon the orbital maneuver. Each OMS engine can produce 6,000 lb (26,400 N) of thrust. The OMS engines together could accelerate the shuttle by 2 ft/s2 (0.6 m/s2). This acceleration could change the shuttle's velocity by as much as 1,000 ft/s (305 m/s). To place into orbit or to de-orbit took about 100-500 ft/s (31-153 m/s) change in velocity. Orbital adjustments took about 2 ft/s (0.61 m/s) change in velocity. The engines could start and stop 1,000 times and had a total of 15 hours of burn time.

Profile of shuttle launch and ascent into orbit

As the shuttle rests on the pad fully fueled, it weighs about 4.5 million pounds or 2 million kg. The shuttle rested on the SRBs as pre-launch and final launch preparations were going on through T minus 31 seconds:

1. T minus 31 s - the on-board computers take over the launch sequence.
2. T minus 6.6 s - the shuttle's main engines ignite one at a time (0.12 s apart). The engines build up to more than 90 percent of their maximum thrust.
3. T minus 3 s - shuttle main engines are in lift-off position.
4. T minus 0 s -the SRBs are ignited, and the shuttle lifts off the pad.
5. T plus 20 s - the shuttle rolls right (180-degree roll, 78 degree pitch).
6. T plus 60 s - shuttle engines are at maximum throttle.
7. T plus 2 min - SRBs separate from the orbiter and fuel tank at an altitude of 28 miles (45 km). Main engines continue firing. Parachutes deploy from the SRBs. SRBs will land in

the ocean about 140 miles (225 km) off the coast of Florida. Ships will recover the SRBs and tow them back to Cape Canaveral for processing and re-use.

8. T plus 7.7 min - main engines throttled down to keep acceleration below 3g's so that the shuttle does not break apart.
9. T plus 8.5 min - main engine shut down.
10. T plus 9 min - ET separates from the orbiter. The ET will burn up upon re-entry.
11. T plus 10.5 min - OMS engines fire to place the shuttle in a low orbit.
12. T plus 45 min - OMS engines fire again to place the shuttle in a higher, circular orbit (about 250 miles/400 km).

Orbiter in Space

Once in space, the shuttle orbiter was the home for astronauts for seven to 14 days. The orbiter could be oriented so that the cargo bay doors face toward the Earth or away from the Earth depending upon the mission objectives; in fact, the orientation could be changed throughout the mission. One of the first things that the commander would do was to open the cargo bay doors to cool the orbiter.

The orbiter consists of the following parts:

- crew compartment - where astronauts live and work
- forward fuselage (upper, lower parts) - contains support equipment (fuel cells, gas tanks) for crew compartment
- forward reaction control system (RCS) module - contains forward rocket jets for turning the orbiter in various directions
- movable airlock - used for spacewalks and can be placed inside the crew compartment or inside the cargo bay
- mid-fuselage: contains essential parts (gas tanks, wiring, etc.) to connect the crew compartment with the aft engines; forms the floor of the cargo bay
- cargo bay doors - roof of the cargo bay and essential for cooling the orbiter
- remote manipulator arm - located in the cargo bay: moves large pieces of equipment in and out of the cargo bay; platform for spacewalking astronauts
- aft fuselage - contains the main engines

- OMS/RCS pods (2) - contain the orbital maneuvering engines and the aft RCS module; turn the orbiter and change orbits airplane parts of the orbiter - fly the shuttle upon landing (wings, tail, body flap)
- The crew compartment is in the forward fuselage. The crew compartment has 2,325 cu.ft. of space with the airlock inside or 2,625 cu.ft with the airlock outside. The crew compartment has three decks:
- Flight deck - uppermost deck
  1. forward deck - contains all of the controls and warning systems for the space shuttle (also known as the cockpit)
  2. seats - commander, pilot, specialist seats (two)
- aft deck - contains controls for orbital operations: maneuvering the orbiter while in orbit (rendezvous, docking, deploying payload, and working the remote manipulator arm

Mid-deck

- living quarters (galley, sleeping bunks, toilet)
  - stowage compartments (personal gear, mission-essential equipment, experiments)
  - exercise equipment
  - airlock - on some flights
  - entry hatch
- lower deck (equipment bay)
- contains life support equipment, electrical systems, etc..

Living Environment

The shuttle orbiter provides an environment where astronauts can live and work in space. The shuttle provides the following:

- life support - atmosphere control, supply and recycling; water; temperature control; light; food supply; waste removal; fire protection
- ability to change position and change orbits
- capability to talk with ground-based flight controllers (communications and tracking)

- stellar navigation to find its way around in orbit
- make its own electrical power
- coordinate and handle information (computers)
- base from which to launch/retrieve satellites; construction - such as building the International Space Station and conduct experiments

The orbiter had to provide astronauts with an environment like Earth. The shuttle had to have air, food, water, and a comfortable temperature. The orbiter had to take away the waste products produced by the astronauts (carbon dioxide, urine, feces) and protect them from fire. Our atmosphere is a mixture of gases (78 percent nitrogen, 21 percent oxygen, 1 percent other gases) at a pressure of 14 lbs/in2 (1 atm) that we breathe in and out. The space shuttle had to provide a similar atmosphere. To do this, the orbiter carried liquid oxygen and liquid nitrogen in two systems of pressurized tanks, which was in the mid-fuselage (each system had two tanks for a total of four tanks). The cabin pressurization system combined the gases in the correct mixture at normal atmospheric pressure. While in orbit, only one oxygen-nitrogen system was used to pressurize the orbiter. During launch and landing, both systems of each gas were used.

- Five loops of fans circulate the atmosphere. The circulated air picks up carbon dioxide, heat and moisture:
- Chemical carbon dioxide canisters remove carbon dioxide by reacting it with lithium hydroxide. These canisters are located in the lower deck of the crew compartment and are changed every 11 hours.
- Filters and charcoal canisters remove trace odors, dust and volatile chemicals from leaks, spills and out gassing.
- A cabin heat exchanger in the lower deck cools the air and condenses the moisture, which collects in a slurper. Water from the slurper is moved with air to a fan separator, which uses centrifugal force to separate water from air. The air is re-circulated, and the water goes to a wastewater tank.

Besides air, water was the most important quantity aboard the orbiter. Water is made from liquid oxygen and hydrogen in the space shuttle's fuel cells (the fuel cells can make 25 lb (11 kg) of water per hour). The water passed through a hydrogen separator to eliminate any trapped hydrogen gas (excess hydrogen gas is dumped overboard). The water was then stored in four water storage tanks located in the lower deck. Each tank can hold 165 lb (75 kg).

The water tanks were pressurized by nitrogen so that water could flow to the mid-deck for use by the crew. Drinkable water was then filtered to remove microbes and could be warmed or chilled through various heat exchangers depending upon the use (food preparation, consumption, personal hygiene). Excess water produced by the fuel cells was routed to a wastewater tank and subsequently dumped overboard.

Bn Outer space is an extremely cold environment and temperatures will vary drastically in different parts of the orbiter. You might think that heating the orbiter would be a problem. However, the electronic equipment generates more than enough heat for the ship. The problem is getting rid of the excess heat. So, the temperature control system has to carry out two major functions:

- Distribute heat where it is needed on the orbiter (mid-fuselage and aft sections) so that vital systems do not freeze in the cold of space.
- Get rid of the excess heat.
- To do this, the shuttle has two methods to handle temperature control:

Passive methods - generally simple methods that handle small heat loads and require little maintenance; insulating materials (blankets), surface coatings, paints, all reduce heat loss through the walls of the various components just like home insulation. Electrical heaters - use electrically heated wires like a toaster to heat various areas.

Active methods – generally more complex, these systems use fluid to handle large heat loads and require maintenance. Cold plates are metal plates that collect heat by direct contact with equipment or conduction. Heat exchangers are used to collect heat from equipment using fluid. The equipment radiates heat to a fluid (water, ammonia) which in turn passes heat on to Freon. Both fluids are pumped and re-circulated to remove heat. Pumps, lines, valves - transport the collected heat from one area to another. Radiators - located on the inside surfaces of the cargo bay doors that radiate the collected heat to outer space Flash evaporator/ammonia boilers - these devices are located in the aft fuselage and transfer heat from Freon coolant loops overboard when cargo bay doors are closed or when cargo bay radiators are overloaded. Flash evaporator

Freon coolant loops wrap around an inner core. The evaporator sprays water on the heated core. The water evaporates removing heat. The water vapor is vented overboard. Ammonia boiler Freon coolant loops pass through a tank of pressurized ammonia. Heat released from the Freon causes the ammonia to boil. Ammonia vapor is dumped overboard.

The cabin heat exchanger also controls the cabin temperature. It circulates cool water to remove excess heat (cabin air is also used to cool electronic equipment) and transfers this heat to a Freon exchanger. The Freon then transfers the heat to other orbiter systems (e.g., cryogenic gas tanks, hydraulic systems) and radiates excess heat to outer space.

The orbiter has internal fluorescent floodlights that illuminate the crew compartment. The orbiter has external floodlights to illuminate the cargo bay. Finally, the control panels are lighted internally for easy viewing.

Food is stored on the mid-deck of the crew compartment. Food comes in several forms (dehydrated, low moisture, heat-stabilized, irradiated, natural and fresh). The orbiter has a galley-style kitchen module along the wall next to the entry hatch, which is equipped with the following:

- food storage compartments
- food warmers
- a food preparation area with warm and cold-water outlets
- metal trays so the food packages and utensils do not float away

Like any home, the orbiter must be kept clean, especially in space when floating dirt and debris could present a hazard. Wastes are made from cleaning, eating, work and personal hygiene. To maintain general housecleaning, the astronauts use various wipes (wet, dry, fabric, detergent and disinfectant), detergents, and wet/dry vacuum cleaners are used to clean surfaces, filters and the astronauts themselves. Trash is separated into wet trash bags and dry trash bags, and the wet trash is placed in an evaporator that will remove the water. All trash bags are stowed in the lower deck to be returned to Earth for disposal. Solid waste from the toilet is compacted, dried and stored in bags where it is returned to Earth for disposal (burning). Liquid waste from the toilet goes to the wastewater tank where it is dumped overboard.

Fire is one of the most dangerous hazards in space. The orbiter has a Fire Detection and Suppression Subsystem that consists of the following:

- area smoke detectors on each deck
- smoke detectors in each rack of electrical equipment
- alarms and warning lights in each module
- non-toxic portable fire extinguishers (carbon dioxide-based)
- personal breathing apparatus - mask and oxygen bottle for each crew member

After a fire is extinguished, the atmosphere control system will filter the air to remove particulates and toxic substances.

Work aboard the Shuttle

The shuttle was designed to deploy and retrieve satellites as well as deliver payloads to Earth orbit. To do this, the shuttle uses the Remote Manipulator System (RMS). The RMS was built by Canada and is a long arm with an elbow and wrist joint. The RMS can be controlled from the aft flight deck. The RMS can grab payloads (satellites) from the cargo bay and deploy them or grab on to payloads and place them into the bay.

In the past, the shuttle was used for delivering satellites and conducting experiments in space. Within the mid-deck, there are racks of experiments to be conducted during each mission. When more space was needed, the mission used the Spacelab module, which was built by the European Space Agency (ESA). It fit into the cargo bay and was accessed by a tunnel from the mid-deck of the crew compartment. It provided a "shirt-sleeve" environment in which you could work. The Spacelab was lost along with Columbia in 2003. Now, most experiments are conducted aboard the International Space Station.

The shuttle's major role was to build and re-supply the International Space Station. The shuttle delivers components built on Earth. Astronauts use the RMS to remove components from the cargo bay and to help attach them to existing modules in space station.

Space Shuttle Positioning, Communication and Navigation

To change the direction that the orbiter is pointed (attitude), the reaction control system (RCS) located on the nose and OMS pods of the aft fuselage is used.

The RCS has 14 jets that can move the orbiter along each axis of rotation (pitch, roll, yaw). The RCS thruster’s burn monomethyl hydrazine fuel and nitrogen tetroxide oxidizer just like the OMS engines described previously. Attitude changes are required for deploying satellites or for pointing (mapping instruments, telescopes) at the Earth or stars. To change orbits (e.g., rendezvous, docking maneuvers), you must fire the OMS engines. As described above, these engines change the velocity of the orbiter to place it in a higher or lower orbit.

Tracking and Communication

The astronauts talk with flight controllers on the ground daily for the routine operation of the mission. In addition, they must be able to communicate with each other inside the orbiter or its payload modules and when conducting spacewalks outside.

NASA's Mission Control in Houston will send signals to a 60 ft. radio antenna at White Sands Test Facility in New Mexico. White Sands will relay the signals to a pair of Tracking and Data Relay satellites in orbit 22,300 miles above the Earth. The satellites will relay the signals to the space shuttle. The system works in reverse as well.

The orbiter has two systems for communicating with the ground:

- S-band - voice, commands, telemetry and data files
- Ku-band (high bandwidth) - video and transferring two-way data files

The orbiter has several intercom plug-in audio terminal units located throughout the crew compartment. Each astronaut wears a personal communications control with a headset. The communications control is battery-powered and can be switched from intercom to transmit functions. They can either push to talk and release to listen or have a continuously open communication line. To talk with spacewalkers, the system uses a UHF frequency, which is picked up in the astronaut's space suit. The orbiter also has a series of internal and external video cameras to see inside and outside.

Navigation, Power and Computers

The orbiter must be able to know precisely where it is in space, where other objects are and how to change orbit. To know where it is and how fast it is moving, the orbiter uses global positioning systems (GPS). To know which way, it is pointing (attitude), the orbiter has several gyroscopes. All this information is fed into the flight computers for rendezvous and docking maneuvers, which are controlled in the aft station of the flight deck.

All the on-board systems of the orbiter required electrical power. Three fuel cells make electricity; they are in the mid fuselage under the payload bay. These fuel cells combine oxygen and hydrogen from pressurized tanks in the mid fuselage to make electricity and water. Like a power grid on Earth, the orbiter has a distribution system to supply electrical power to various instrument bays and areas of the ship. The water is used by the crew and for cooling.

The orbiter has five on-board computers that handle data processing and control critical flight systems. The computers monitor equipment and talk to each other and vote to settle arguments. Computers control critical adjustments especially during launch and landing:

- operations of the orbiter (housekeeping functions, payload operations, rendezvous/docking)
- interface with the crew
- caution and warning systems
- data acquisition and processing from experiments
- flight maneuvers

Pilots essentially fly the computers, which fly the shuttle. To make this easier, the shuttles have a Multifunctional Electronic Display Subsystem (MEDS), which is a full color, flat, 11-panel display system. The MEDS, also known as the "glass cockpit", provides graphic portrayals of key light indicators (attitude, altitude, speed). The MEDS panels are easy to read and make it easier for shuttle pilots to interact with the orbiter.

The Shuttle's Return to Earth

For a successful return to Earth and landing, dozens of things have to go just right. First, the orbiter must be maneuvered into the proper position. This is crucial to a safe landing. When a mission is finished and the shuttle is halfway around the world from the landing site (Kennedy Space Center, Edwards Air Force Base), mission control gives the command to come home, which prompts the crew to:

1. Close the cargo bay doors. In most cases, they have been flying nose-first and upside down, so they then fire the RCS thrusters to turn the orbiter tail first.
2. Once the orbiter is tail first, the crew fires the OMS engines to slow the orbiter down and fall back to Earth; it will take about 25 minutes before the shuttle reaches the upper atmosphere.
3. During that time, the crew fires the RCS thrusters to pitch the orbiter over so that the bottom of the orbiter faces the atmosphere (about 40 degrees) and they are moving nose first again.
4. Finally, they burn leftover fuel from the forward RCS as a safety precaution because this area encounters the highest heat of re-entry.

Because it is moving at about 17,000 mph (28,000 km/h), the orbiter hits air molecules and builds up heat from friction (approximately 3000 degrees F, or 1650 degrees C). The orbiter is covered with ceramic insulating materials designed to protect it from this heat. The materials include:

- Reinforced carbon-carbon (RCC), used in the nose cap and wing leading edges. Used where reentry temperature exceeds 1,260 °C (2,300 °F).
- High-temperature reusable surface insulation (HRSI) tiles, used on the orbiter underside. Made of coated LI-900 Silica ceramics. Used where reentry temperature is below 1260 °C.
- Fibrous refractory composite insulation (FRCI) tiles, used to provide improved strength, durability, resistance to coating cracking and weight reduction. Some HRSI tiles were replaced by this type.
- Flexible Insulation Blankets (FIB), a quilted, flexible blanket-like surface insulation. Used where reentry temperature is below 649 °C (1,200 °F).
- Low-temperature Reusable Surface Insulation (LRSI) tiles, formerly used on the upper fuselage, but now mostly replaced by FIB. Used in temperature ranges roughly similar to FIB.
- Toughened uni-piece fibrous insulation (TUFI) tiles, a stronger, tougher tile which came into use in 1996. Used in high and low temperature areas.

- Felt reusable surface insulation (FRSI). White Nomex felt blankets on the upper payload bay doors, portions of the mid-fuselage and aft fuselage sides, portions of the upper wing surface and a portion of the OMS/RCS pods. Used where temperatures stay below 371 °C (700 °F).

Maneuvering of the orbiter for re-entry

These materials are designed to absorb large quantities of heat without increasing their temperature very much. In other words, they have a high heat capacity. During re-entry, the aft steering jets help to keep the orbiter at its 40-degree attitude. The hot ionized gases of the atmosphere that surround the orbiter prevent radio communication with the ground for about 12 minutes (i.e., ionization blackout).

When re-entry is successful, the orbiter encounters the main air of the atmosphere and can fly like an airplane. The orbiter is designed from a lifting body design with swept back "delta" wings. With this design, the orbiter can generate lift with a small wing area. At this point, flight computers fly the orbiter. The orbiter makes a series of S-shaped, banking turns to slow its descent speed as it begins its final approach to the runway. The commander picks up a radio beacon from the runway (Tactical Air Navigation System) when the orbiter is about 140 miles (225 km) away from the landing site and 150,000 feet (45,700 m) high. At 25 miles (40 km) out, the shuttle's landing computers give up control to the commander. The commander flies the shuttle around an imaginary cylinder (18,000 feet or 5,500 m in diameter) to line the orbiter up with the runway and drop the altitude. During the final approach, the commander steepens the angle of descent to minus 20 degrees (almost seven times steeper than the descent of a commercial airliner).

Shuttle flight path for landing

When the orbiter is 2,000 ft. (610 m) above the ground, the commander pulls up the nose to slow the rate of descent. The pilot deploys the landing gear and the orbiter touches down. As the commander applies the wheel brakes, the speed brake on the vertical tail is opened to help slow down the shuttle. A parachute is deployed from the back to help stop the orbiter. The parachute and the speed brake on the tail increase the drag on the orbiter. The orbiter stops about midway to three-quarters of the way down the runway.

After landing, the crew goes through the shutdown procedures to power down the spacecraft. This process takes about 20 minutes. During this time, the orbiter is cooling and noxious gases, which were made during the heat of re-entry, blow away. Once the orbiter is powered down, the crew exits the vehicle. Ground crews are on-hand to begin servicing the orbiter.

Glossary of Essential Terms

AC Bus Sensor - A three-bus system that distributes electrical power to the forward, mid, and aft sections of the orbiter for equipment used in those areas.

Apoapsis - the farthest point in an orbit from the body being orbited.

APU – (Auxiliary Power Unit) The Space Shuttle APUs provides hydraulic pressure. The Space Shuttle has three redundant APUs, powered by hydrazine fuel. They function during powered ascent, re-entry, and landing. During ascent, the APUs provides hydraulic power for gimballing of Shuttle's engines and control surfaces. During landing, the power the control surfaces and brakes.

Boiler System – this water system cools the Auxiliary Power Unit (APU) lubrication oil and hydraulic fluid. Three independent Water Spray Boilers each serve a corresponding APU. The Water Spray Boiler System sprays water onto the APU lubrication oil and hydraulic fluid lines, thus cooling the fluids within them.

COMM – communication system

CRT - Display System that allows onboard monitoring of orbiter systems, computer software processing and manual control for flight crew data and software manipulation.

DAP – The Digital Auto Pilot controls the RCS thrusters while in orbit.

GPC – General Purpose Computer Control. When the toggle switch is in the straight up or middle position (not on or off) it allows the valve to be controlled by the flight software loaded in the general-purpose computer.

Helium System - During prelaunch, the pneumatic helium supply provides pressure to operate the liquid oxygen and hydrogen pre-valves and outboard and inboard fill and drain valves. The three engine helium supply systems are used to provide anti-icing purges.

Hydraulic System - this system distributes the hydraulic pressure produced by the Auxiliary Power Unit (APU) System. The Hydraulic System is made up of three independent hydraulic systems, each of which is mated to a corresponding APU.

IMU – The Inertial Measurement Units consist of an all-attitude, four-gimbal, inertially stabilized platform. They provide inertial attitude and velocity data to the Navigation software. Guidance uses the attitude data, along with state vector from the navigation software, to develop steering commands for flight control.

Isolation valves - The propellant tank isolation valves are located between the propellant tanks and the manifold isolation valves and are used to isolate the propellant tanks from the remainder of the propellant distribution system.

Main propulsion System - Within the orbiter aft fuselage, liquid hydrogen and liquid oxygen pass through the manifolds, distribution lines and valves of the propellant management subsystem. During prelaunch activities, this subsystem is used to control the loading of liquid oxygen and liquid hydrogen in the external tank. During SSME thrusting periods, propellants from the external tank flow into this subsystem and to the three SSMEs. The subsystem also provides a path that allows gases tapped from the three SSMEs to flow back to the external tank through two gas umbilical’s to maintain pressure in the external tank's liquid oxygen and liquid hydrogen tanks. After MECO, this subsystem controls MPS dumps, vacuum inerting and MPS re-pressurization for entry.

MECO - Main Engine Cut Off is where the engines shutdown at about 8 minutes and 30 seconds into the flight.

MFD - Multi-function display is a small screen in an aircraft or spacecraft that can be used to display information to the pilot in numerous configurable ways.

OMS - The Space Shuttle Orbital Maneuvering System, is a system of rocket engines for use on the space shuttle orbiter for orbital injection and modifying its orbit.

Periapsis - The point in the orbit closest to the body being orbited.

Prograde - Orbital motion in the usual direction of celestial bodies within a given system, i.e. in the direction of the planet's rotation.

RCS – The reaction control system is a subsystem of a spacecraft whose purpose is attitude control and steering using thrusters. An RCS system can provide small amounts of thrust in any desired direction or combination of directions The RCS engines use a Hypergolic Fuel which lights up when its two components (Fuel and Oxidizer) come into contact. This allows the system to be almost fail-safe due to the simple nature of the system.

Retrograde - Motion in an orbit opposite to the usual orbital direction of celestial bodies within a given system, i.e., in the opposite direction of the planet's rotation.

RGA - The orbiter rate gyro assemblies are used by the flight control system during ascent, entry and aborts as feedbacks to final rate errors that are used to augment stability and for display on the commander's and pilot's attitude director indicator.

SSME - Space Shuttle Main Engines are reusable liquid-fuel rocket engines, each Space Shuttle ascent to orbit is propelled by three engines.

Star tracker - The star tracker system is part of the orbiter's navigation system which works to help maintain the IMU during flight.

TCS - Thermal Conditioning System consists of an air revitalization system, water coolant loop systems, atmosphere revitalization pressure control system, active thermal control system, supply water and wastewater system, waste collection system and airlock support system. These systems interact to provide a habitable environment for the flight crew in the crew compartment in addition to cooling or heating various orbiter systems or components.

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