STUDENT ASTRONAUT CHALLENGE

2020 Student Textbook

Directory

CHAPTER 1

Basics of Flight

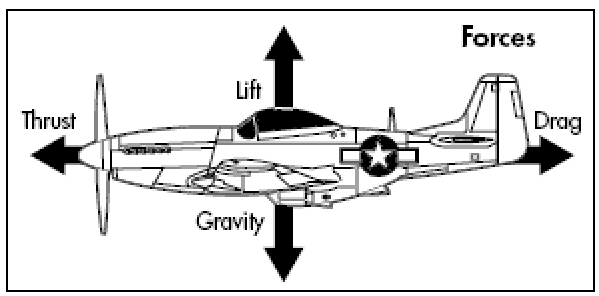
Introduction

The miracle of flight exists because humans have 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 flight (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.

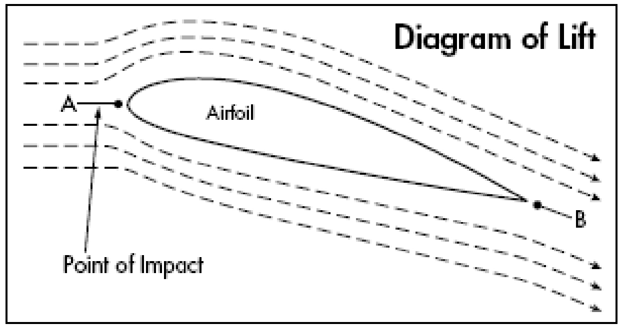


This creates a difference in air pressure above and below—a phenomenon called the *Bernoulli effect*. The pressure pushing up is greater than the downward pressure, and lift is created. If you're banking, lift occurs in a slightly sideways direction. If you're inverted, lift actually pulls you downward toward the ground. Note that lift occurs perpendicular to a line drawn parallel to the centerline of the wing and occurs at a slightly backward angle.

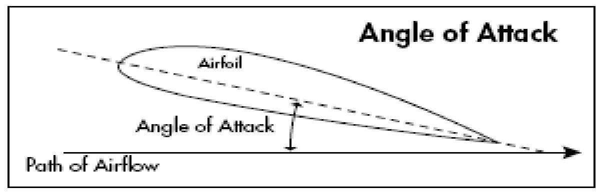
Several factors determine how much lift is created. First, consider the angle at which the wing hits the air. This is called the *angle of attack*, which is independent of the aircraft's flight path vector. The steeper this angle, the more lift occurs. At angles steeper than 30° or so, however, airflow 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 actually 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 wing (airfoil). The pressure in front of the wing is greater than the pressure behind the wing, which creates a net force that opposes thrust.

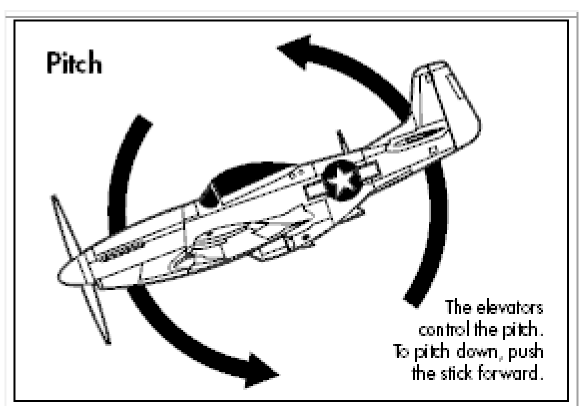


Gravity is actually a force of acceleration on an object. The Earth exerts this natural force on all objects. Being a constant force, it always acts in the same direction: downward. Thrust creates lift to counteract gravity. In order for an aircraft to take off, enough lift must be created to overcome 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.

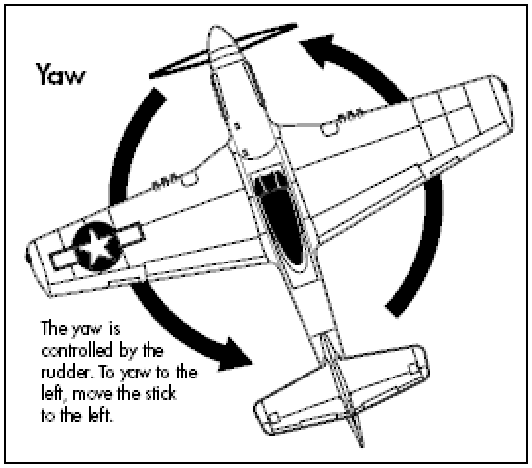


Movement Vectors

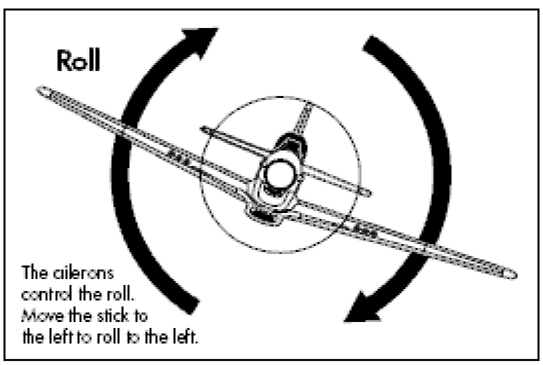
Pitch is the up and down movement of the aircraft's nose around an axis line drawn from wingtip to wingtip. When you apply pitch by pulling back on the stick, you angle the aircraft's elevators up, causing the nose to rise.



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 (a hinged surface in the trailing edge of an airplane wing, used to control lateral balance) to angle down and the other to angle up. These increases lift under one wingtip while decreasing lift under the other, creating roll.



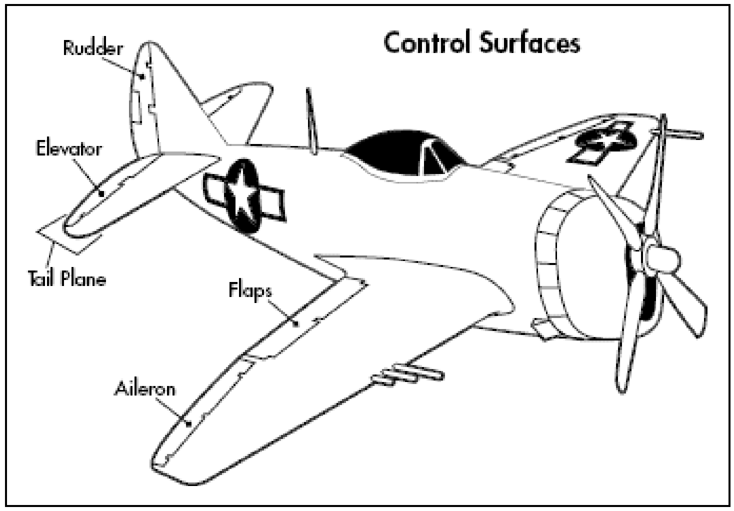
Bank - You can combine pitch and roll movements to make a banking turn. By pitching the nose up and applying right stick, you cause the aircraft to bank to the right. You can accomplish a left bank by pitching up and applying left stick. A banking turn changes both the angle of the nose and the direction 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- Similar to 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 can't move them until you slow down the aircraft.

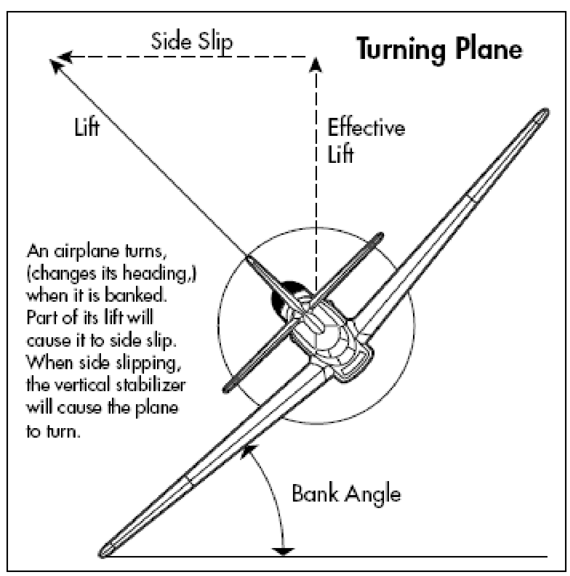
Flying the Shuttle

The wings on the shuttle have to produce enough lift to balance the weight of the shuttle. The faster the shuttle is traveling in the atmosphere the more lift the wings make. If the shuttle is flying fast enough the wings will produce enough lift to keep it in the air, due to the shuttles speed upon re-entry initially this is not a concern. But, the wings and the body of the shuttle also produce drag. The engines on the shuttle are not operable when in the earth's atmosphere, as a safety precaution, so there is no way to produce thrust therefore the shuttle has to generate speed in some other way. Angling the shuttle downward, trading altitude for speed, allows the shuttle to fly fast enough to generate the lift needed to support its weight.

Climbing - Upon re-entry into the earth's atmosphere the shuttle has significant forward velocity, so much so that if the pilot inadvertently pitches up too soon they could bounce right back into space. If it is necessary to climb pitch the nose slightly upward until it's at about a 20° angle. If you start to lose airspeed or if the STALL warning appears onscreen, dip the nose down until you're again flying level. Then, resume climbing at a gentler angle.

Descending– To descend redirect the nose by pitching down, by doing so you bleed off altitude in a hurry and gain airspeed. Be wary of prolonged dives or extremely steep dives at low altitude—your aircraft's controls may "freeze" due to compressibility (air moves so quickly over the control surfaces that they're rendered useless).

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 commonly 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. More often than not, 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 have to 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'll have enough altitude to recover and break out of the spin.

- Restore stick to center position
- Apply rudder opposite the spin (if you're spinning left, apply right rudder)
- Pitch down
- When you stop spinning, level out

Landing – Landing the shuttle is much like landing a conventional plane. When landing the shuttle the pilot needs to be able to control the glide path (the rate of descent relative to distance traveled) in order to bring the shuttle down in the right location. The pilot has to be able to reduce the amount of lift produced by the wings without changing the speed or attitude of the shuttle.

Landing takes a steady hand and a smooth series of changes in pitch. When you're ready to land, you need a range of at least 5 km from the airfield. Make sure you are flying level. In the shuttle it is essential that you do not drop the gear until you are close to the runway to prevent an increase in drag. By lowering the flaps you have more lift and can slow down without going into a stall. Gently pitch down to start your descent, striving for a maximum airspeed of about 190 km/h.

Once the aircraft reaches the edge of the runway, you should have between 6 to 9 meters of altitude. Pull the stick back firmly to raise the nose up past the horizon about 20 degrees. The main wheels will touch down. As your skills progress, you may even touch down all of the aircraft's tires simultaneously.

- Line up with the runway 5 km out
- Reduce speed until you're below 190 km/h
- Lower the landing flaps
- Gently pitch down
- Lower the landing gear
- Reduce airspeed even further
- At the edge of the runway, with 6 to 9 meters of altitude, pitch the nose up 20°
- Touchdown – apply the air brakes and tail drag chute.

Shuttle Landing Procedure Summary

After the de-orbit burn, the orbiter will begin to encounter the effects of the atmosphere which is known as entry interface. This point usually takes place at an altitude of about 80 miles, and more than 5,000 statute miles from the landing site.

Early in reentry, the orbiter's orientation is controlled by the aft steering jets, part of the reaction control system. Its aero-surfaces (the wing flaps and rudder) gradually become active as air pressure builds. As those surfaces become usable, the steering jets turn off automatically.

To use up excess energy, the orbiter performs a series of four steep banks, rolling over as much as 80 degrees to one side or the other, to slow down. The series of banks gives the shuttle's track toward landing an appearance similar to an elongated letter "S." As the orbiter slices through the atmosphere faster than the speed of sound, the sonic boom -- really, two distinct claps less than a second apart -- can be heard across parts of Florida, depending on the flight path.

The orbiter's velocity eases below the speed of sound at about 25 statute miles from the runway. As the orbiter nears the Shuttle Landing Facility, the commander takes manual control, piloting the vehicle to touchdown on one of two ends of the SLF.

As it aligns with the runway, the orbiter begins a steep descent with the nose angled as much as 19 degrees down from horizontal. This glide slope is seven times steeper than the average commercial airliner landing. During the final approach, the vehicle drops toward the runway 20 times faster than a commercial airliner as its rate of descent and airspeed increase. At less than 2,000 feet above the ground, the commander raises the nose and slows the rate of descent in preparation for touchdown.

When the orbiter is 15 seconds from landing, the main and nose landing gear are deployed and locked in place. The orbiter's main landing gear touches down on the runway at 214 to 226 miles per hour, followed by the nose gear. The drag chute is deployed, and the orbiter coasts to a stop.

Chapter 2

Basic Concepts of Orbital Spaceflight

Introduction

The common conception of orbital flight is that of an object flying through space, following a circular or elliptical path around another object. That description is accurate, but incomplete. It leaves out the most important element of orbital flight: gravity.

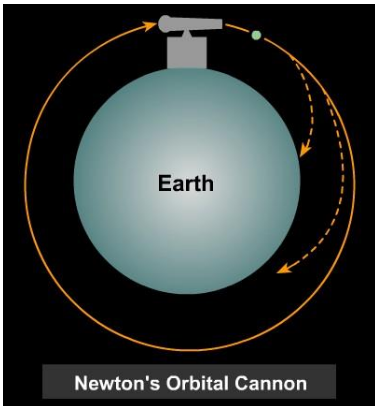
An orbit is the path of an object in space as it moves around another object due to the force of gravity. Orbital flight is not powered flight, it is the result of a careful balance between gravity and momentum. A rocket is used to carry a spacecraft into space, but once the spacecraft has achieved sufficient altitude and velocity, the rocket engine is turned off, and often discarded. At this point, the spacecraft will be held in orbit by gravity - the same force that holds the moon in orbit and makes the planets revolve around the sun.

Newton's Cannon

In 1687, in a book titled *Principia Mathematica*, the physicist Isaac Newton presented the first explanation of orbital motion. It is still one of the simplest and clearest explanations available.

Newton imagined a canon on top of a very high mountain. A cannonball is shot out, which travels for a distance, but eventually gravity pulls it down and it strikes the ground. On a second shot, more gunpowder is used, and the cannonball travels further before striking the ground. In each case, the cannonball follows a curved path to the ground.

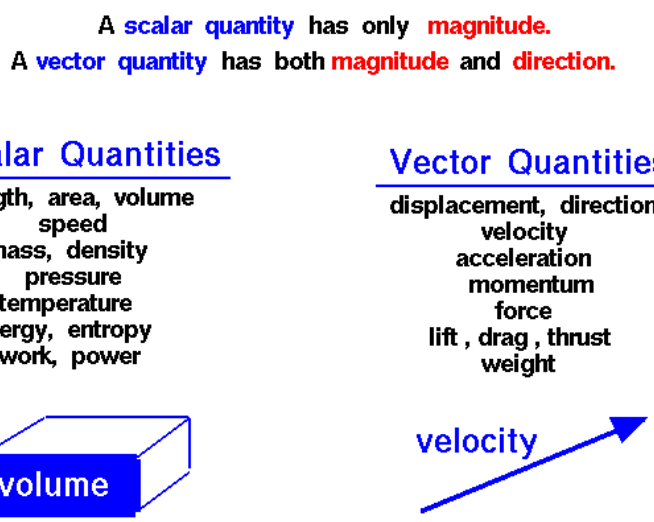
The surface of the earth is also curved. If enough gunpowder were used, Newton suggested, the curvature of the cannonball's trajectory would be the same as the curvature of the earth. The cannonball would be falling, but it would never reach the ground. The cannonball would "fall" all the way around the world and strike the cannoneer in the back of the head.



Basic Mechanics and Newton

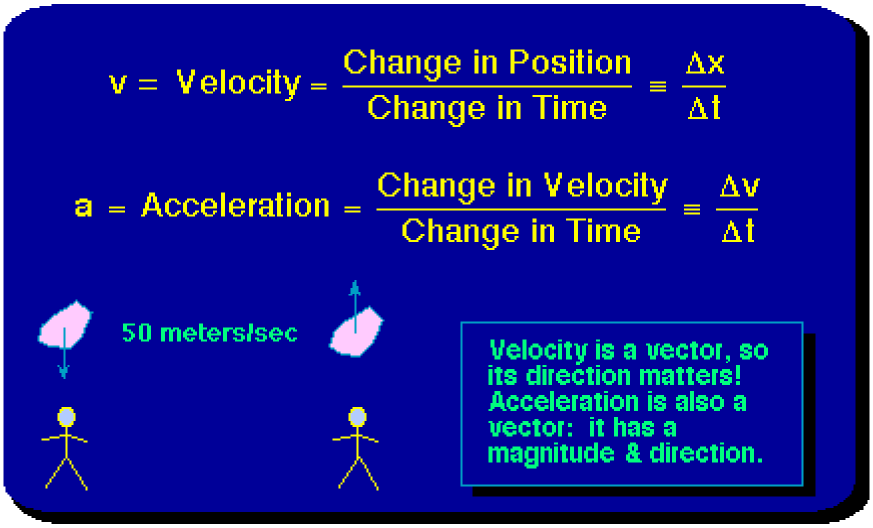
In order to understand the discoveries of Newton, we must have an understanding of three basic quantities: (1) velocity, (2) acceleration, and (3) force. Vectors are quantities that require not only a magnitude, but a direction to specify them completely. Let us illustrate by first citing some examples of quantities that are not vectors. The number of gallons of gasoline in the fuel tank of your car is an example of a quantity that can be specified by a single number---it makes no sense to talk about a "direction" associated with the amount of gasoline in a tank. Such quantities, which can be specified by giving a single number (in appropriate units), are called *scalars*. Other examples of scalar quantities include the temperature, your weight, or the population of a country; these are scalars because they are completely defined by a single number (with appropriate units).

However, consider a velocity. If we say that a car is going 70 km/hour, we have not completely specified its motion, because we have not specified the *direction* that it is going. Thus, velocity is an example of a vector quantity. A vector generally requires more than one number to specify it; in this example we could give the magnitude of the velocity (70km/hour), a compass heading to specify the direction (say 30 degrees from North), and an number giving the vertical angle with respect to the Earth's surface (zero degrees).



Velocity and Acceleration

Let us now give a precise definition of velocity and acceleration. They are vectors, so we must give a magnitude and a direction for them. The velocity *v* and the acceleration *a* are defined in the following illustration,



This illustration also demonstrates graphically that velocity (and therefore acceleration) is a vector: the direction of the rock's velocity is certainly of critical interest to the person standing under the rock in the two illustrations!

Uniform Circular Motion is Accelerated Motion

Notice that velocity, which is a vector, is changed if either its magnitude or its direction is changed. Thus, acceleration occurs when either the magnitude or direction of the velocity (or both) are altered.

Circular motion (even at uniform angular velocity) implies a continual acceleration, because the *direction* of the velocity is continuously changing, even if its magnitude is constant. This point, that motion on a curved path is accelerated motion, will prove crucial to our subsequent understanding of motion in gravitational fields.

Newton's Principles of Mechanics

Sir Isaac Newton realized that the force that makes apples fall to the ground is the same force that makes the planets "fall" around the sun. Newton had been asked to address the question of why planets move as they do. He established that a force of attraction toward the sun becomes weaker in proportion to the square of the distance from the sun.

Newton postulated that the shape of an orbit should be an ellipse. Circular orbits are merely a special case of an ellipse where the foci are coincident. Newton described his work in the *Mathematical Principles of Natural Philosophy* (often called simply the Principia), which he published in 1685. Newton gave his laws of motion as follows:

1. Every body continues in a state of rest, or of uniform motion in a straight line, unless it is compelled to change that state by forces impressed upon it.

2. The change of motion (linear momentum) is proportional to the force impressed and is made in the direction of the straight line in which that force is impressed.
3. To every action there is always an equal and opposite reaction; or, the mutual actions of two bodies upon each other are always equal, and act in opposite directions.

(Notice that Newton's laws describe the behavior of inertia, they do not explain what the nature of inertia is. This is still a valid question in physics, as is the nature of mass.)

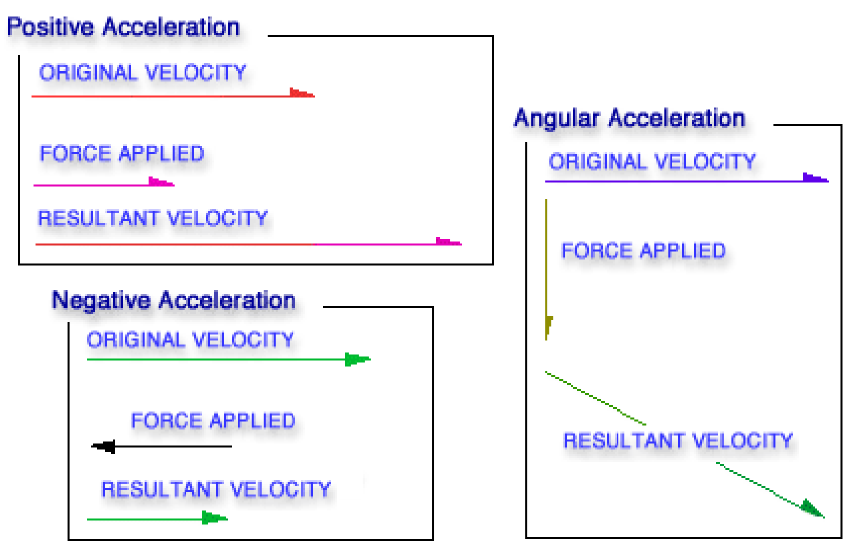
There are three ways to modify the momentum of a body. The mass can be changed; the velocity can be changed (acceleration), or both.

Acceleration

Force (F) equals change in velocity (acceleration, A) times mass (M):

$$F = MA$$

Acceleration may be produced by applying a force to a mass (such as a spacecraft). If applied in the same direction as an object's velocity, the object's velocity increases in relation to an un-accelerated observer. If acceleration is produced by applying a force in the opposite direction from the object's original velocity, it will slow down relative to an un-accelerated observer. If the acceleration is produced by a force at some other angle to the velocity, the object will be deflected. These cases are illustrated below.



The world standard of mass is the kilogram, whose definition is based on the mass of a metal cylinder kept in France. (Update: The kilogram, symbol kg, is the SI unit of mass. It is defined by taking the fixed numerical value of the Planck constant h to be $6.62607015 \times 10^{-34}$ when expressed in the unit J · s, which is equal to $kg \cdot m^2 \cdot s^{-1}$, where the meter and the second are defined in terms of the speed of light.) Previously, the standard was based upon the mass of one cubic centimeter of water being one gram, which is approximately correct. The standard unit of force is the Newton, which is the force required to accelerate a 1-kg mass 1 m/sec^2 (one meter per second per second). A Newton is equal to the force from the weight of about 100 g of water in Earth's gravity. That's about half a cup. A dyne is the force required to accelerate a 1-g mass 1 cm/s^2.

Acceleration in Orbit

Newton's first law describes how, once in motion, planets remain in motion. What it does not do is explain how the planets are observed to move in nearly circular orbits rather than straight lines. Enter the second law. To move in a curved path, a planet must have acceleration toward the center of the circle. This is called centripetal acceleration and is supplied by the mutual gravitational attraction between the sun and the planet.

Momentum

Momentum is the tendency of a moving object to stay in motion. When you are in a moving vehicle that stops suddenly, it is your own momentum that throws you forward. Momentum is related to velocity. The greater velocity an object has the more momentum it has.

This is the definition of an orbit. The momentum of the cannonball and the pull of gravity are balanced. The cannonball is in a continuous state of free fall, and will remain so until affected by another force (Newton's theoretical example assumes the cannon is high enough that the resistance of earth's atmosphere can be ignored).

Orbital Velocity

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.

Weightlessness

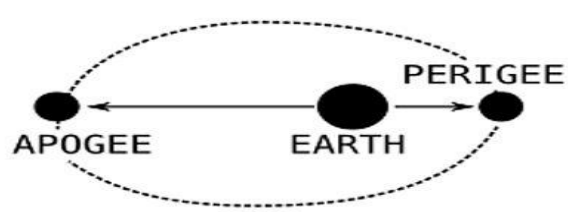
Weightlessness is an interesting side effect of being in orbit. A common misconception is that objects in space float because there is no gravity in space. The term "weightlessness" reinforces this idea, but the word is a misnomer. In fact, the pull of gravity on objects in orbit is diminished only by a small amount. For example, an astronaut that weighs 160 pounds on earth will weigh about 140 pounds while in orbit.

The astronaut feels weightless because he is in a constant state of free fall. Few of us have ever been in free fall long enough to notice, but a person in free fall doesn't feel his own weight. Only when something is opposing the pull of gravity do we experience the feeling of weight. On earth, gravity pulls us *into* something - the ground or the floor, for example - and this opposition to gravity is why we feel weight.

Everything in orbit with the astronaut floats around him because it all is continuously falling at the same rate as he is. Although travelling at thousands of miles per hour, these objects are not moving at all *relative to each other*, and they appear to be floating in space, or "weightless".

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.

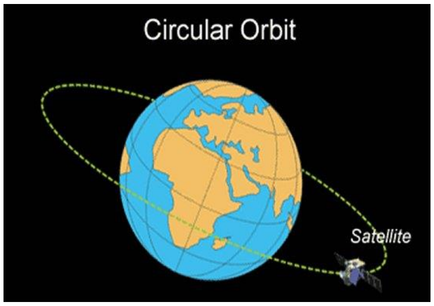
Atmospheric drag

Earth's atmosphere doesn't 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 human 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 then 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 to slow at a certain distance then its path will intersect with the object it was orbiting or if it travels to fast at a certain distance then it will never return (a.k.a escape velocity). Depending on the body that is being orbited the names of the closest and farthest approach change their suffix (e.g. apogee and perigee when orbiting the Earth, aphelion and perihelion when orbiting the Sun and apolune and perilune when orbiting the moon,

Gravitation and Mechanics

Gravitation is the mutual attraction of all masses in the universe. While its effect decreases in proportion to distance squared, it nonetheless applies, to some extent, regardless of the sizes of the masses or their distance apart.

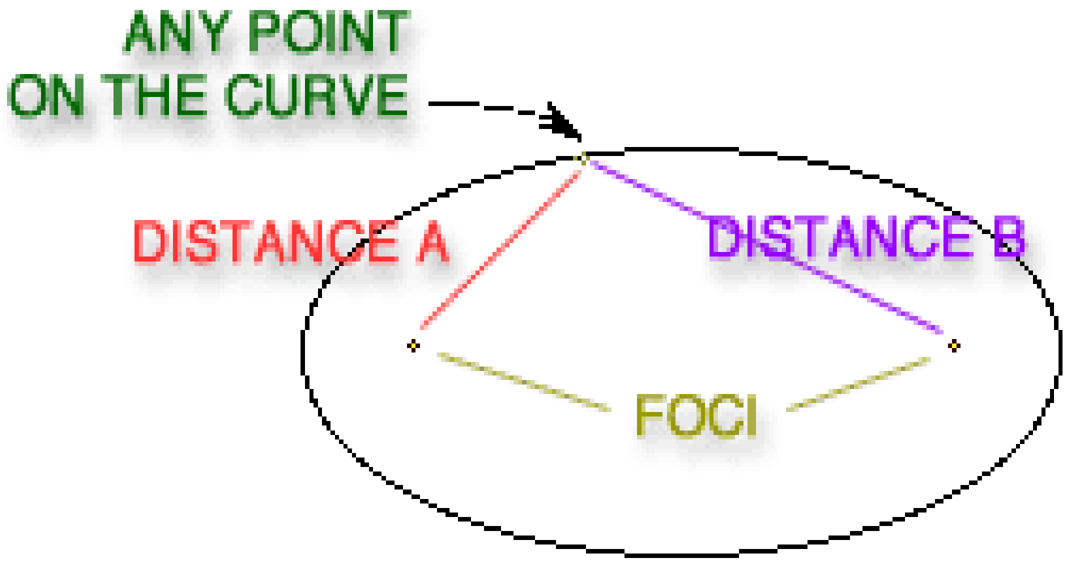
The concepts associated with planetary motions developed by Johannes Kepler (1571-1630) describe the positions and motions of objects in our solar system. Isaac Newton (1643-1727) later explained why Kepler's laws worked, by showing they depend on gravitation. Albert Einstein (1879-1955) posed an explanation of how gravitation works in his general theory of relativity.

In any solar system, planetary motions are orbits gravitationally bound to a star. Since orbits are ellipses, a review of ellipses follows.

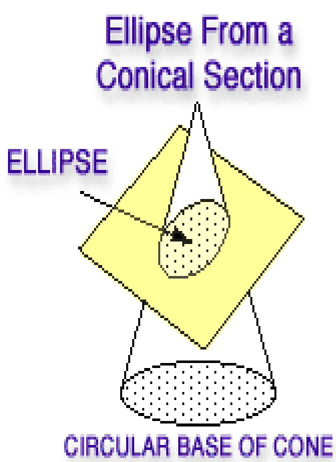
Ellipses

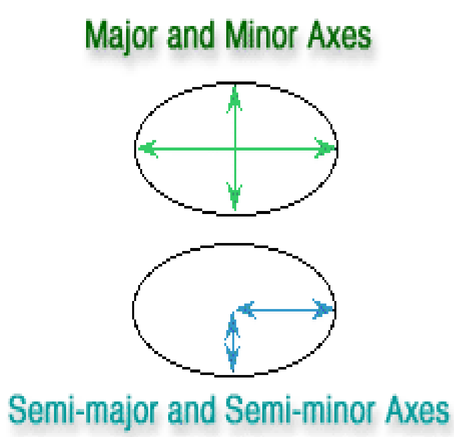
An ellipse is a closed plane curve generated in such a way that the sum of its distances from two fixed points (called the foci) is constant. In the illustration below, the sum of Distance A + Distance B is constant for any point on the curve.

Ellipse Foci

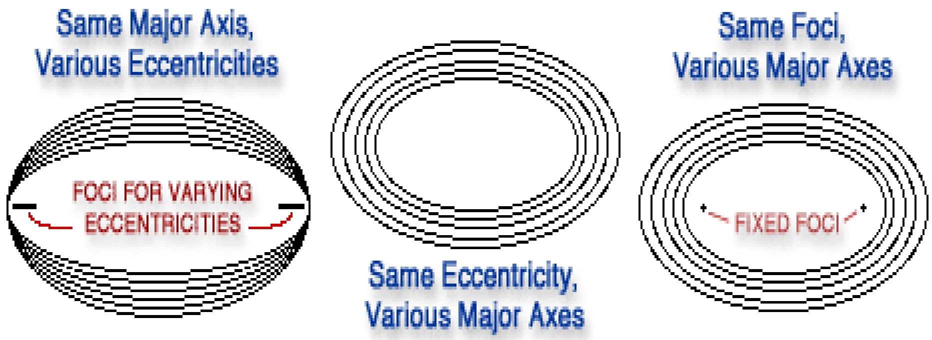


An ellipse results from the intersection of a circular cone and a plane cutting completely though the cone. The maximum diameter is called the major axis. It determines the size of an ellipse. Half the maximum diameter, the distance from the center of the ellipse to one end, is called the semi-major axis.

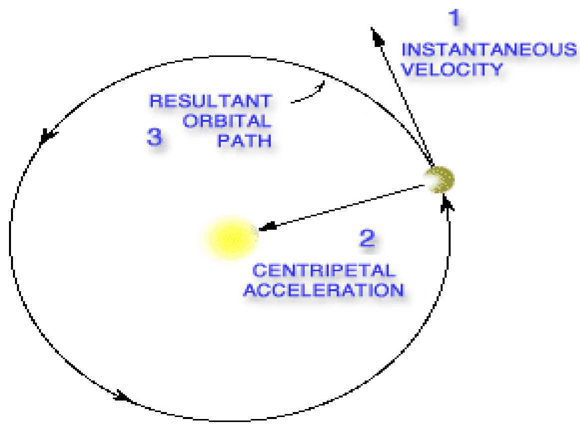




The shape of an ellipse is determined by how close together the foci are in relation to the major axis. Eccentricity is the distance between the foci divided by the major axis. If the foci coincide, the ellipse is a circle. Therefore, a circle is an ellipse with an eccentricity of zero.



Motion in a Circular Orbit



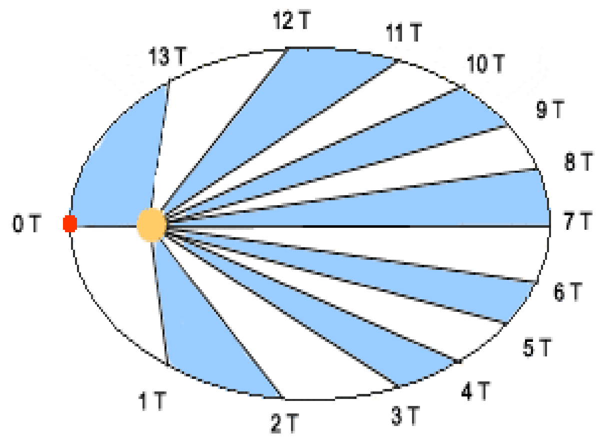
Kepler's Laws

Johannes Kepler's laws of planetary motion are:

1. The orbit of every planet is an ellipse with the Sun at one of the two foci.
2. A line joining a planet and the Sun sweeps out equal areas during equal intervals of time.
3. The square of the orbital period of a planet is directly proportional to the cube of the semi-major axis of its orbit.

The major application of Kepler's first law is to precisely describe the geometric shape of an orbit: an ellipse, unless perturbed by other objects. Kepler's first law also informs us that if a comet, or other object, is observed to have a hyperbolic path, it will visit the sun only once, unless its encounter with a planet alters its trajectory again.

Kepler's second law addresses the velocity of an object in orbit. Conforming to this law, a comet with a highly elliptical orbit has a velocity at closest approach to the sun that is many times its velocity when farthest from the sun. Even so, the area of the orbital plane swept is still constant for any given period of time.



T = any unit of time (hour, day, week, etc.)

Kepler's third law describes the relationship between the masses of two objects mutually revolving around each other and the determination of orbital parameters. Consider a small star in orbit about a more massive one. Both stars actually revolve about a common center of mass, which is called the barycenter. This is true no matter what the size or mass of each of the objects involved. Measuring a star's motion about its barycenter with a massive planet is one method that has been used to discover planetary systems associated with distant stars.

Obviously, these statements apply to a two-dimensional picture of planetary motion, which is all that is needed for describing orbits. A three-dimensional picture of motion would include the path of the sun through space.

Gravity Gradients & Tidal Forces

Gravity's strength is inversely proportional to the square of the objects' distance from each other. For an object in orbit about a planet, the parts of the object closer to the planet feel a slightly stronger gravitational attraction than do parts on the other side of the object. This is known as gravity gradient. It causes a slight torque to be applied to any orbiting mass which has asymmetric mass distribution (for example, is not spherical), until it assumes a stable attitude with the more massive parts pointing toward the planet. An object whose mass is distributed like a bowling pin would end up in an attitude with its more massive end pointing toward the planet, if all other forces were equal.

Consider the case of a fairly massive body such as our Moon in Earth orbit. The gravity gradient effect has caused the Moon, whose mass is unevenly distributed, to assume a stable rotational rate which keeps one face towards Earth at all times, like the bowling pin described above.

The Moon's gravitation acts upon the Earth's oceans and atmosphere, causing two bulges to form. The bulge on the side of Earth that faces the moon is caused by the proximity of the moon and its relatively stronger gravitational pull on that side. The bulge on the opposite side of Earth results from that side being attracted toward the moon less strongly than is the central part of Earth. Earth's atmosphere and crust are also affected to a smaller degree. Other factors, including Earth's rotation and surface roughness, complicate the tidal effect. On planets or satellites without oceans, the same forces apply, causing slight deformations in the body. This mechanical stress can translate into heat, as in the case of Jupiter's volcanic moon Io.

Reference Systems in Navigation

Spatial coordinates and timing conventions are adopted in order to consistently identify locations and motions of an observer, of natural objects in the solar system, and of spacecraft traversing interplanetary space or orbiting planets or other bodies. Without these conventions it would be impossible to navigate the solar system.

Terrestrial Coordinates

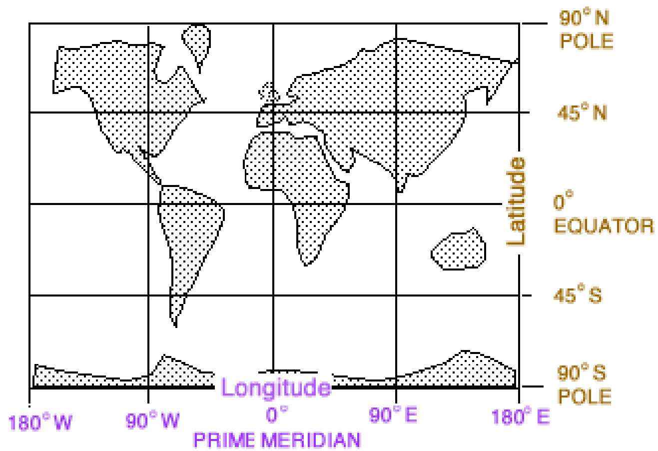
A great circle is an imaginary circle on the surface of a sphere whose center is the center of the sphere. Great circles that pass through both the north and south poles are called meridians, or lines of longitude. For any point on the surface of Earth a meridian can be defined.

The prime meridian, the starting point measuring the east-west locations of other meridians, marks the site of the old Royal Observatory in Greenwich, England. Longitude is expressed in degrees, minutes, and seconds of arc from 0 to 180 degrees eastward or westward from the prime meridian. For example, downtown Pasadena, California, is located at 118 degrees, 8 minutes, 41 seconds of arc west of the prime meridian: 118° 8' 41" W.

The starting point for measuring north-south locations on Earth is the equator, a great circle which is everywhere equidistant from the poles. Circles in planes parallel to the equator define north-south measurements called parallels, or lines of latitude. Latitude is expressed as an arc subtended between the equator and the parallel, as seen from the center of the Earth. Downtown Pasadena is located at 34 degrees, 08 minutes, 44 seconds latitude north of the equator: 34° 08' 44" N.

One degree of latitude equals approximately 111 km on the Earth's surface, and by definition exactly 60 nautical miles. Because meridians converge at the poles, the length of a degree of longitude varies from 111 km at the equator to 0 at the poles where longitude becomes a point.

Terrestrial Coordinates Grid



Rotation and Revolution

"Rotation" refers to an object's spinning motion about its own axis. "Revolution" refers the object's orbital motion around another object. For example, Earth *rotates* on its own axis, producing the 24-hour day. Earth *revolves* about the Sun, producing the 365-day year. A satellite revolves around a planet.

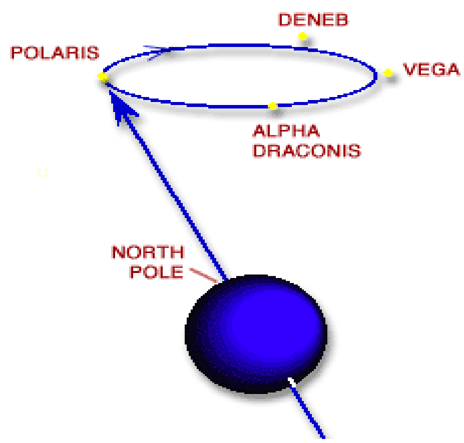
Earth's Rotation

The Earth rotates on its axis relative to the sun every 24.0 hours mean solar time, with an inclination of 23.45 degrees from the plane of its orbit around the sun. Mean solar time represents an average of the variations caused by Earth's non-circular orbit. Its rotation relative to "fixed" stars (sidereal time) is 3 minutes 56.55 seconds shorter than the mean solar day, the equivalent of one solar day per year.

Precession of Earth's Axis

Forces associated with the rotation of Earth cause the planet to be slightly oblate, displaying a bulge at the equator. The moon's gravity primarily, and to a lesser degree the sun's gravity, act on Earth's oblateness to move the axis perpendicular to the plane of Earth's orbit. However, due to gyroscopic action, Earth's poles do not "right themselves" to a position perpendicular to the orbital plane. Instead, they precess at 90 degrees to the force applied. This precession causes the axis of Earth to describe a circle having a 23.4 degree radius relative to a fixed point in space over about 26,000 years, a slow wobble reminiscent of the axis of a spinning top swinging around before it falls over.

Precession of Earth's Axis Over 26,000 Years



Because of the precession of the poles over 26,000 years, all the stars, and other celestial objects, appear to shift west to east at the rate of .014 degree each year (360 degrees in 26,000 years). This apparent motion is the main reason for astronomers as well as spacecraft operators to refer to a common epoch such as J2000.0.

At the present time in Earth's 26,000 year precession cycle, a bright star happens to be very close, less than a degree, from the north celestial pole. This star is called Polaris, or the North Star. Stars do have their own real motion, called proper motion. In our vicinity of the galaxy, only a few bright stars exhibit a large enough proper motion to measure over the course of a human lifetime, so their motion does not generally enter into spacecraft navigation. Because of their immense distance, stars can be treated as though they are references fixed in space. (Some stars at the center of our galaxy, though, display tremendous proper motion speeds as they orbit close to the massive black hole located there.)

Nutation

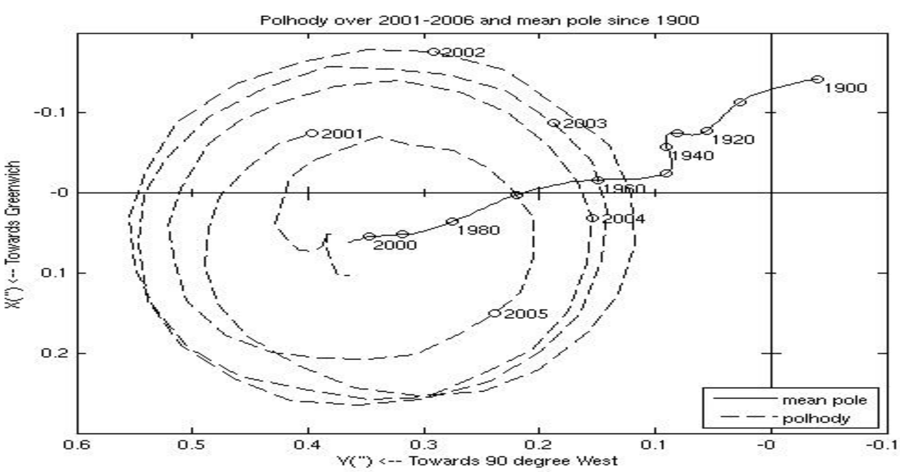
Superimposed on the 26,000-year precession is a small nodding motion with a period of 18.6 years and an amplitude of 9.2 arc seconds. This nutation can trace its cause to the 5 degree difference between the plane of the Moon's orbit, the plane of the Earth's orbit, and the gravitational tug on one other.

Revolution of Earth

Earth revolves in orbit around the sun in 365 days, 6 hours, 9 minutes with reference to the stars, at a speed ranging from 29.29 to 30.29 km/s. The 6 hours, 9 minutes adds up to about an extra day every fourth year, which is designated a leap year, with the extra day added as February 29th. Earth's orbit is elliptical and reaches its closest approach to the sun, a perihelion of 147,090,000 km, on about January fourth of each year. Aphelion comes six months later at 152,100,000 km.

Shorter-term Polar Motion

Aside from the long-term motions, the Earth's rotational axis and poles have two shorter periodic motions. One, called the Chandler wobble, is a free nutation with a period of about 435 days. There is also a yearly circular motion, and a steady drift toward the west caused by fluid motions in the Earth's mantle and on the surface. These motions are tracked by the International Earth Rotation and Reference Systems Service, IERS.



Movement of Earth's rotational poles 2001 to 2006, and the mean pole location from the year 1900 to 2000. Units are milliarcseconds.

Epochs

Because we make observations from Earth, knowledge of Earth's natural motions is essential. As described above, our planet rotates on its axis daily and revolves around the sun annually. Its axis precesses and nutates. Even the "fixed" stars move about on their own. Considering all these motions, a useful coordinate system for locating stars, planets, and spacecraft must be pinned to a single snapshot in time. This snapshot is called an epoch.

By convention, the epoch in use today is called J2000.0, which refers to the mean equator and equinox of year 2000, nominally January 1st 12:00 hours Universal Time (UT). The "J" means Julian year, which is 365.25 days long. Only the 26,000-year precession part of the whole precession/nutation effect is considered, defining the mean equator and equinox for the epoch.

The last epoch in use previously was B1950.0 - the mean equator and equinox of 1949 December 31st 22:09 UT, the "B" meaning Besselian year, the fictitious solar year introduced by F. W. Bessell in the nineteenth century. Equations are published for interpreting data based on past and present epochs.

Making Sense

Given an understanding of the Earth's suite of motions -- rotation on axis, precession, nutation, short-term polar motions, and revolution around the sun -- and given knowledge of an observer's location in latitude and longitude, meaningful observations can be made. For example, to measure the precise speed of a spacecraft flying to Saturn, you have to know exactly where you are on the Earth's surface as you make the measurement, and then subtract out the Earth's motions from that measurement to obtain the spacecraft's speed. The same applies if you are trying to measure the proper motion of a distant star -- or a star's subtle wobble, to reveal a family of planets.

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 actually in orbit about the sun, and the portion of its solar orbit between launch and destination is called the spacecraft's trajectory. Orbit determination involves finding the spacecraft's orbital elements and accounting for perturbations to its natural orbit. Flight path control involves commanding the spacecraft's propulsion system to alter the vehicle's velocity. Comparing the accurately determined spacecraft's trajectory with knowledge of the destination object's orbit is the bases for determining what velocity changes are needed.

Since the Earth's own orbital parameters and inherent motions are well known, the measurements we make of the spacecraft's motion as seen from Earth can be converted into the sun-centered or heliocentric orbital parameters needed to describe the spacecraft's trajectory. The meaningful measurements we can make from Earth of the spacecraft's motion are:

- Its distance or range from Earth,
- The component of its velocity that is directly toward or away from Earth, and
- To the extent discussed below, its position in Earth's sky.

Some spacecraft can generate a fourth type of nav data,

- Optical navigation, wherein the spacecraft uses its imaging instrument to view a target planet or body against the background stars.

By repeatedly acquiring these three or four types of data, a mathematical model may be constructed and maintained describing the history of a spacecraft's location in three-dimensional space over time. The navigation history of a spacecraft is incorporated not only in planning its future maneuvers, but also in reconstructing its observations of a planet or body it encounters. This is essential to constructing SAR (synthetic aperture radar) images, tracking the spacecraft's passage through planetary magnetospheres or rings, and interpreting imaging results.

Another use of navigation data is the creation of predicts, which are data sets predicting locations in the sky and radio frequencies for the Deep Space Network, DSN to use in acquiring and tracking the spacecraft.

Navigation Data Acquisition

The basic factors involved in acquiring the types of navigation data mentioned above are described below.

Spacecraft Velocity Measurement

Measurements of the Doppler shift of a coherent downlink carrier provide the radial component of a spacecraft's Earth-relative velocity. Doppler is a form of the tracking data type, TRK, provided by the DSN.

Spacecraft Distance Measurement

A uniquely coded ranging pulse can be added to the uplink to a spacecraft and its transmission time recorded. When the spacecraft receives the ranging pulse, it returns the pulse on its downlink. The time it takes the spacecraft to turn the pulse around within its electronics is known from pre-launch testing. For example, Cassini takes 420 nanoseconds, give or take 9 ns. There are many other calibrated delays in the system, including the several microseconds needed to go from the computers to the antenna within DSN, which is calibrated prior to each use. When the pulse is received at the DSN, its true elapsed time at light-speed is determined, corrections are applied for known atmospheric effects, and the spacecraft's distance is then computed. Ranging is also a type of TRK data provided by the DSN. Distance may also be determined using angular measurement.

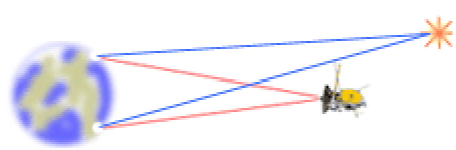
Spacecraft Angular Measurement

The spacecraft's position in the sky is expressed in the angular quantities Right Ascension and Declination. While the angles at which the DSN antennas point are monitored with an accuracy of thousandths of a degree, they are not accurate enough to be used in determining a distant interplanetary spacecraft's position in the sky for navigation. DSN tracking antenna angles are useful only for pointing the antenna to the predicts given for acquiring the spacecraft's signal.

Fairly accurate determination of Right Ascension is a direct byproduct of measuring Doppler shift during a DSN pass of several hours. Declination can also be measured by the set of Doppler-shift data during a DSN pass, but to a lesser accuracy, especially when the Declination value is near zero, i.e., near the celestial equator. Better accuracy in measuring a distant spacecraft's angular position can be obtained by:

- *VLBI*

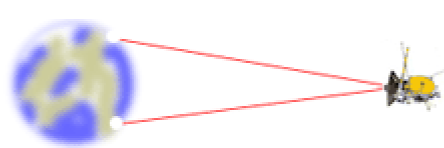
  Extremely accurate angular measurements can be provided by a process independent from Doppler and range, VLBI, Very Long Baseline Interferometry. A VLBI observation of a spacecraft begins when two DSN stations on different continents (separated by a VLB) track a single spacecraft simultaneously. High-rate recordings are made of the downlink's wave fronts by each station, together with precise timing data. After a few minutes, both DSN antennas slew directly to the position of a quasar, which is an extragalactic object whose position on the plane of the sky is known to a high precision. Recordings are made of the quasar's radio-noise wavefronts.

  Correlation and analysis of the recorded wavefronts yields a very precise triangulation from which the angular position may be determined by direct comparison to the position of a quasar whose RA and DEC are well known. VLBI is considered a distinct DSN data type, different from TRK and TLM. This VLBI observation of a spacecraft is called a "delta DOR," DOR meaning differenced one-way ranging, and the "delta" meaning the difference between spacecraft and quasar positions.

- *Precision Ranging*

  Precision ranging refers to a set of procedures to ensure that range measurements are

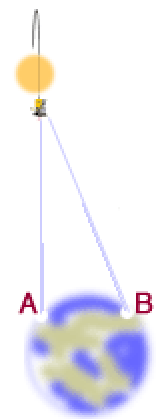
  

accurate to about 1 meter. Knowledge of the spacecraft's Declination can be improved with Range measurements from two stations that have a large north-south displacement, for example between Spain and Australia, via triangulation.

- *Differenced Doppler*

  Differenced Doppler can provide a measure of a spacecraft's changing three-dimensional position. To visualize this, consider a spacecraft orbiting a distant planet. If the orbit is in a vertical plane exactly edge on to you at position A, you would observe the downlink to take a higher frequency as it travels towards you. As it recedes away from you to go behind the planet, you observe a lower frequency.

  Now, imagine a second observer way across the Earth, at position B. Since the orbit plane is *not* exactly edge-on as *that* observer sees it, that person will record a slightly different Doppler signature. If you and the other observer were to compare notes and difference your data sets, you would have enough information to determine both the spacecraft's changing velocity and position in three-dimensional space.



  Two DSSs separated by a large baseline can do basically this. One DSS provides an uplink to the spacecraft so it can generate a coherent downlink, and then it receives two-way. The other DSS receives a three-way coherent downlink. The differenced data sets are frequently called "two-way minus three-way."

These techniques, combined with high-precision knowledge of DSN Station positions, a precise characterization of atmospheric refraction, and extremely stable frequency and timing references (F&T, which is another one of the DSN data types), makes it possible for DSN to measure spacecraft velocities accurate to within hundredths of a millimeter per second, and angular position on the sky to within 10 nano-radians.

Optical Navigation

Spacecraft that are equipped with imaging instruments can use them to observe the spacecraft's destination planet or other body, such as a satellite, against a known background starfield. These images are called opnav images. The observations are carefully planned and uplinked far in advance as part of the command sequence development process. The primary body often appears overexposed in an opnav, so that the background stars will be clearly visible. When the opnav images are downlinked in telemetry (TLM) they are immediately processed by the navigation team. Interpretation of opnavs provides a very precise data set useful for refining knowledge of a spacecraft's trajectory as it approaches a target. Note that this form of navigation data resides in the TLM data type.

Orbit Determination

The process of spacecraft orbit determination solves for a description of a spacecraft's orbit in terms of a state vector (position and velocity) at an epoch, based upon the types of observations and measurements described above. If the spacecraft is en route to a planet, the orbit is heliocentric; if it is in orbit about a planet, the orbit determination is made with respect to that planet. Orbit determination is an iterative process, building upon the results of previous solutions. Many different data inputs are selected as appropriate for input to computer software, which uses the laws of Newton. The inputs include the various types of navigation data described above, as well as data such as the mass of the sun and planets, their ephemeris and barycentric movement, the effects of the solar wind and other non-gravitational effects, a detailed planetary gravity field model (for planetary orbits), attitude management thruster firings, atmospheric friction, and other factors.

Flight Path Control

Trajectory Correction Maneuvers: Once a spacecraft's solar or planetary orbital parameters are known, they may be compared to those desired by the project. To correct any discrepancy, a Trajectory Correction Maneuver (TCM) may be planned and executed. This adjustment involves computing the direction and magnitude of the vector required to correct to the desired trajectory. An opportune time is determined for making the change.

For example, a smaller magnitude of change would be required immediately following a planetary flyby, than would be required after the spacecraft had flown an undesirable trajectory for many weeks or months. The spacecraft is commanded to rotate to the attitude in three-dimensional space computed for implementing the change, and its thrusters are fired for a determined amount of time. TCMs generally involve a velocity change (delta-V) on the order of meters, or sometimes tens of meters, per second. The velocity magnitude is necessarily small due to the limited amount of propellant typically carried.

Orbit Trim Maneuvers: Small changes in a spacecraft's orbit around a planet may be desired for the purpose of adjusting an instrument's field-of-view footprint, improving sensitivity of a gravity field survey, or preventing too much orbital decay. Orbit Trim Maneuvers (OTMs) are carried out generally in the same manner as TCMs. To make a change increasing the altitude of periapsis, an OTM would be designed to increase the spacecraft's velocity when it is at apoapsis. To decrease the apoapsis altitude, an OTM would be executed at periapsis, reducing the spacecraft's velocity. Slight changes in the orbital plane's orientation may also be made with OTMs. Again, the magnitude is necessarily small due to the limited amount of propellant spacecraft typically carry.

CHAPTER 3

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 fairly large areas. Still, these were not rockets in the traditional sense.

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. Far from demonstrating the reaction principle in a weapon, 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.

Hero Engine

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 sulphur. 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.

Solid propellants of the composite type contain separate fuel (or reducer, chemically) and oxidizer (in a separate compound) intimately mixed. While generally not considered as composite, black powder was in fact the oldest composite propellant. Before 1940 black powder, in common use, was nearly synonymous with the words `rocket motor'.

Black powder technically should not be called gunpowder because its use in rockets preceded that in guns. The ingredients are charcoal, Sulphur, and saltpeter (potassium nitrate). These three ingredients were known in China for many centuries, however, before they were combined into black powder. Charcoal was known from the earliest times, and Sulphur and saltpeter at least since the sixth century AD, and probably as far back as the first century BC That the saltpeter is definitely 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".

By 1045, just twenty-one years before William the Conqueror invaded Saxon England, the Chinese were well acquainted with black powder. The Wu-ching Tsung-yao (Complete Compendium of Military Classics) published that year, contained many references to the subject.

In black powder, saltpeter (potassium nitrate- $KNO3$) is the oxidizer, while Sulphur (S), and charcoal (mainly carbon- C) are the fuel. But, depending on the percentage of each ingredient, Sulphur may also act as an oxidizer for potassium in the reaction: $2KNO_3 + S + 3C = K_2S + N_2 + 3CO_2$.

Black powder had a very low specific impulse. 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.

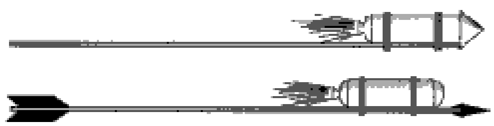
Chinese Rockets:

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.

Chinese soldier launches fire-arrow

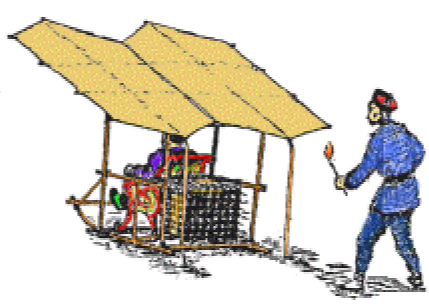
By 900 A.D., the Chinese began experimenting with the gunpowder-filled tubes. At some point, they attached bamboo tubes to arrows and launched them with bows. Soon they discovered that these gunpowder tubes could launch themselves just by the power produced from the escaping gas. The true rocket was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

The date reporting the first use of true rockets was in 1232. At this time, 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 through the air.



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.

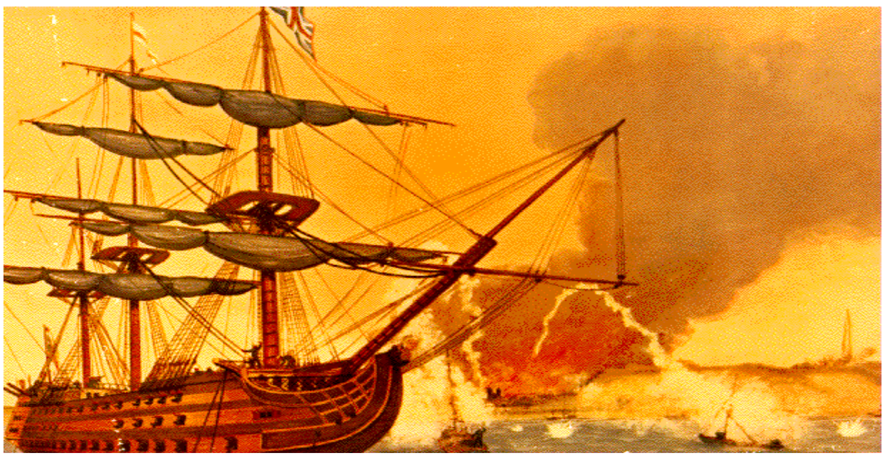


Legendary Chinese official Wan Hu braces himself for "liftoff"

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.

Rockets in Europe:

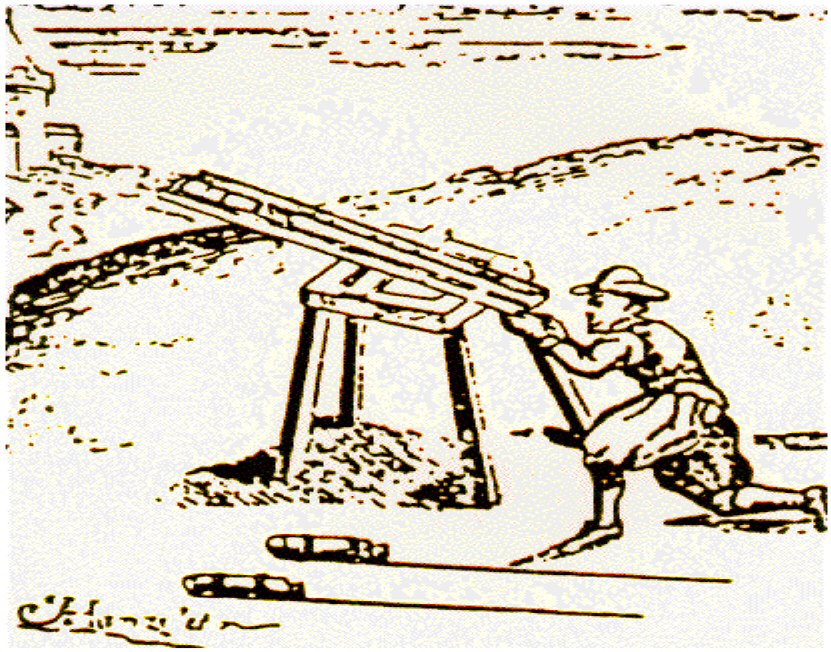
By the end of the 13th century, armies of Japan, Java, Korea and India are believed to have acquired sufficient knowledge of gunpowder and fire arrows to begin using them against the Mongols. Use of the weapons quickly spread throughout Asia and Eastern Europe. Military writings of al-Hasan al-Rammah 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 weighing 18, 24, 32, 42, 100 or 300 pounds. 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 a number of 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 more sturdy 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 a large number of 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 on toward its target. Boxer rockets were able to carry a durable half-inch hemp line a distance of 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.

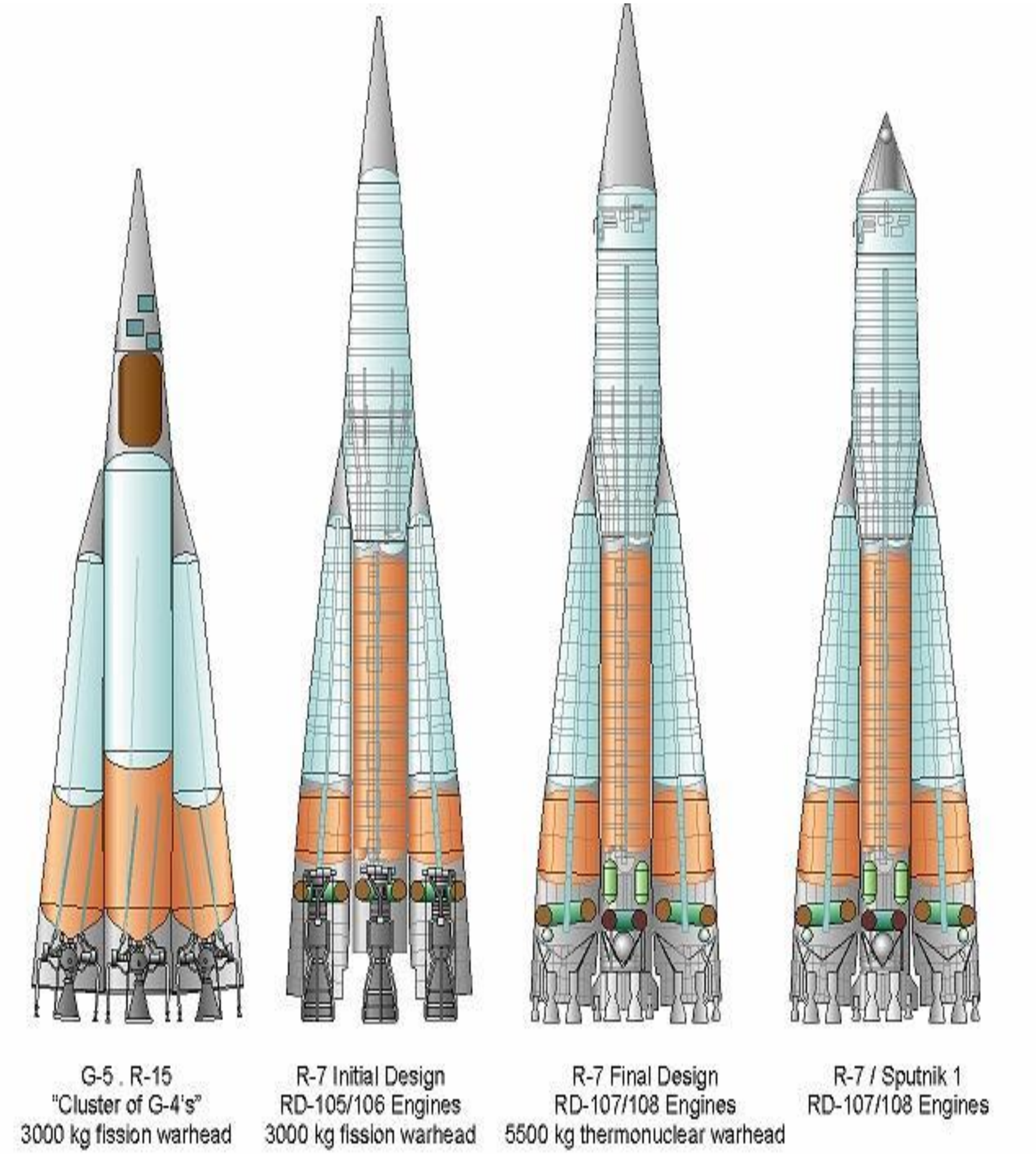
This forced both sides to develop new rockets if rockets were to be used at all. The resulting rockets were considered primitive, even by the standards of the day, due to their inaccuracy and unreliability. But, a variety of rockets were used during the Civil War by both sides. On July 3, 1862 Confederate 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 4

Modern Rocketry



Introduction

A consequence of Newton's laws of motion is that for any object, or collection of objects, forces which only involve those objects and nothing else ("internal forces") cannot shift the center of gravity. For example, an astronaut floating in a space suit cannot shift his position without involving something else, e. g. pushing against his spacecraft. The center of gravity--or "center of mass"--is a fixed point, which cannot be moved without outside help (turning around it, however, is possible).

By throwing a heavy tool in one direction, the astronaut could get moving in the opposite direction, though the common center of gravity of the two would always stay the same. Given a bottle of compressed oxygen, the same result follows from squirting out a blast of gas. A rocket does much the same, except that the cold gas is replaced by the much faster jet of glowing gas produced by the burning of suitable fuel. At present, rockets are the only means capable of achieving the altitude and velocity necessary to put a payload into orbit.

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 mean simply 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 a number of terms used to describe the power generated by a rocket.

- Thrust is the force generated, measured in pounds or kilograms. Thrust generated by the first stage must be greater than the weight of the complete launch vehicle while standing on the launch pad in order to get it moving. Once moving upward, thrust must continue to be generated to accelerate the launch vehicle against the force of the Earth's gravity. To place a satellite into orbit around the Earth, thrust must continue until the minimum altitude and orbital velocity have been attained or the launch vehicle will fall back to the Earth. Minimum altitude is rarely desirable; therefore thrust must continue to be generated to gain additional orbital altitude.

- The impulse, sometimes called total impulse, is the product of thrust and the effective firing duration. A shoulder fired rocket has an average thrust of 600 lbs and a firing duration of 0.2 seconds for an impulse of 120 lb-sec. The Saturn V rocket, used during the Apollo program, not only generated much more thrust but also for a much longer time. It had an impulse of 1.15 billion lb-sec.

- The efficiency of a rocket engine is measured by its specific impulse (Isp). Specific impulse is defined as the thrust divided by the mass of propellant consumed per second. The result is expressed in seconds. The specific impulse can be thought of as the number of seconds that one pound of propellant will produce one pound of thrust. If thrust is expressed in pounds, a specific impulse of 300 seconds is considered good. Higher values are better. A rocket's mass ratio is defined as the total mass at lift-off divided by the mass remaining after all the propellant has been consumed. A high mass ratio means that more propellant is pushing less launch vehicle and payload mass, resulting in higher velocity. A high mass ratio is necessary to achieve the high velocities needed to put a payload into orbit.

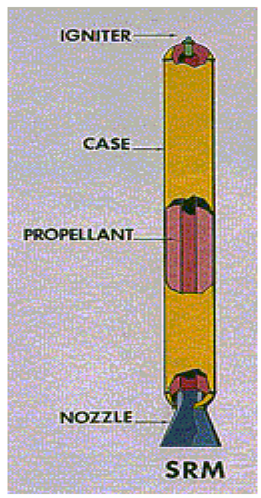
There are three categories of chemical propellants for rocket engines: liquid propellant, solid propellant, and hybrid propellant. The propellant for a chemical rocket engine usually consists of a fuel and an oxidizer. Sometimes a catalyst is added to enhance the chemical reaction between the fuel and the oxidizer. Each category has advantages and disadvantages that make them best for certain applications and unsuitable for others.

<u>Solid Propellant Rockets</u>:

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 together 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.

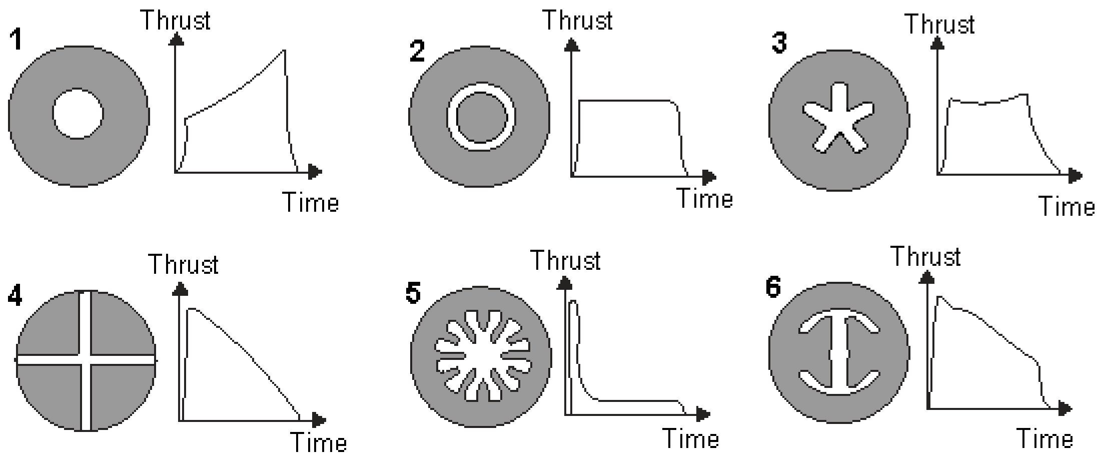
Solid rocket propellants, which are dry to the touch, contain both the fuel and oxidizer combined together in the chemical itself. Usually the fuel is a mixture of hydrogen compounds and carbon and the oxidizer is made up of oxygen compounds. The principal advantage is that a solid propellant is relatively 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.



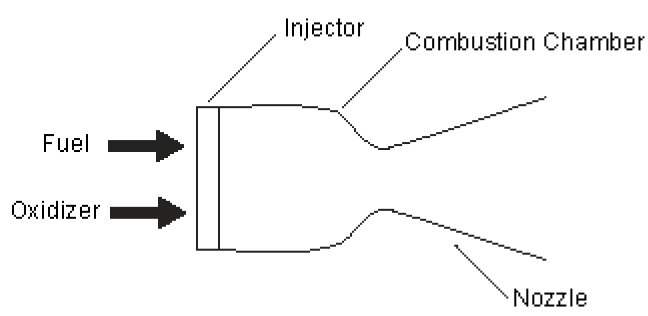
Cracks in the solid propellant increase the exposed surface area, thus the propellant burns faster than planned. If too many cracks develop, pressure inside the engine rises significantly and the rocket engine may explode. Manufacture of a solid propellant is an expensive, precision operation. Solid propellant rockets range in size from the Light Antitank Weapon to the 100 foot long Solid Rocket Boosters (SRBs) used on the side of the main fuel tank of the Space Shuttle.

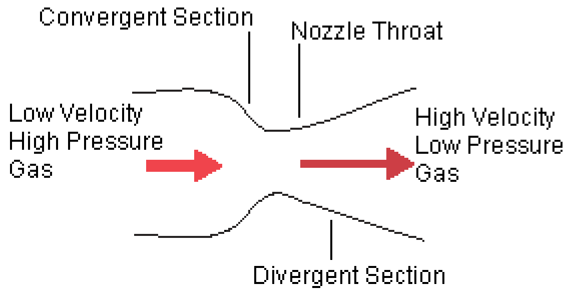
Many solid-propellant rocket engines feature a hollow core that runs through the propellant. Rockets that do not have the hollow core must be ignited at the lower end of the propellants and burning proceeds gradually from one end of the rocket to the other. In all cases, only the surface of the propellant 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 example of an electrically fired rocket is the space shuttle's SRM. 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 come into contact with 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.

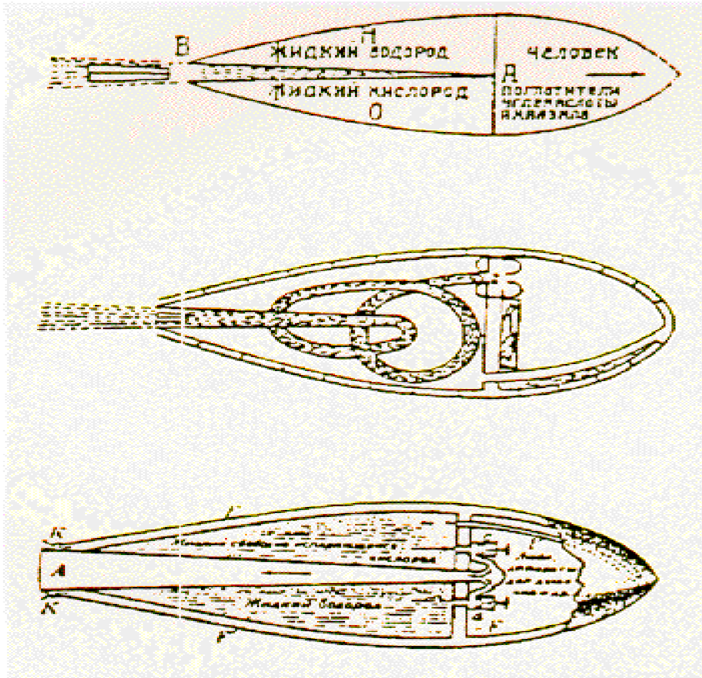
The easy start and restart capability of hypergolic propellants make them ideal for spacecraft maneuvering systems. They are also used for orbital insertion as their combustion can be easily controlled and thus allows the precise adjustments required for insertion into orbit. Hypergolic propellants are 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 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).



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 in order 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, 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.

From 1939 to 1945 he worked on German war rocket programs with such notables as Wernher von Braun. After the war he came to the United States where he again worked with von Braun. During the war one of the weapons the scientists were designing was reminiscent of Oberth's postal rocket. The German's wanted to build a rocket which would carry a bomb from Europe to strike New York City.

Most historians call Oberth and Tsiolkovsky the fathers of modern rocket theory. If that is so, an American, Dr. Robert H. Goddard, can be called the father of the practical rocket. His designs and working models eventually led to the German big rockets such as the V-2 used against the Allies in World War II. All three men are enshrined in the International Space Hall of Fame in Alamogordo, N.M.

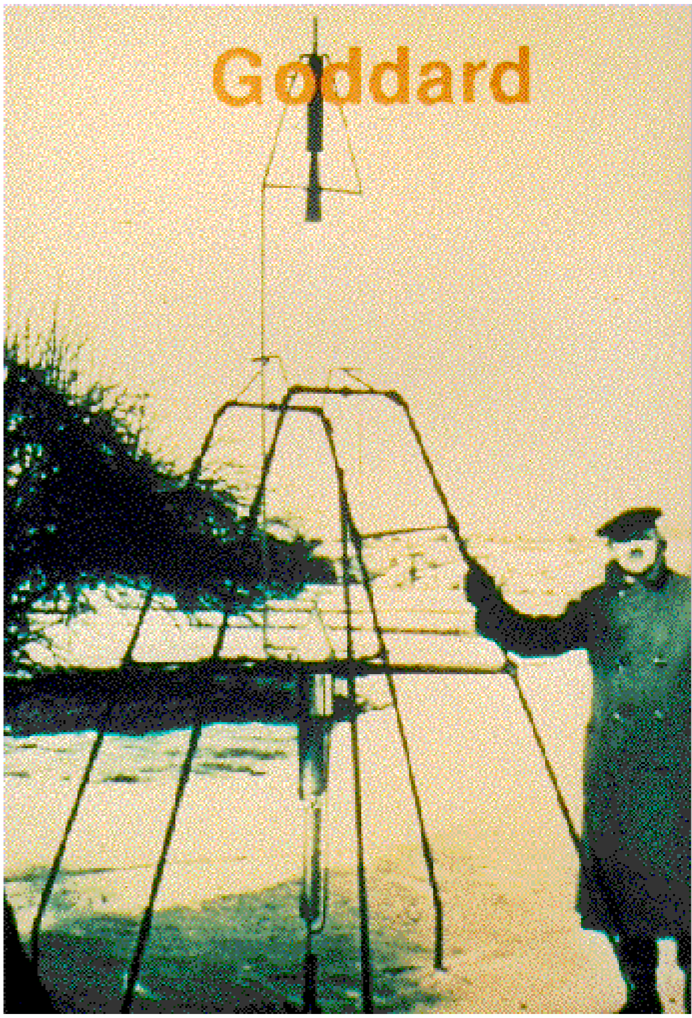
Although rockets were used during World War I, they were of limited value. As was the case during the U.S. Civil War, rockets were simply not as effective as artillery weapons of the day. Rockets sometimes were employed both on land and at sea to lay smoke screens. Allied forces also used rockets as 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. Again independent of Tsiolkovsky, he too theorized that a combination of liquid hydrogen and liquid oxygen would make an ideal propellant.

Considered a staunch patriot until his death, Goddard went to work for the Army in 1917 with the goal of designing rockets that would aid in the war effort. The work was conducted in California, and yielded the development of a small, hand-held rocket launcher similar to what was later called the bazooka. In 1919, Goddard published a work entitled "A Method of Reaching Extreme Altitudes", which contained a detailed compilation of much of the research he had completed to date. It also included speculation on the possibilities of spaceflight. Goddard concluded that a combination of liquid oxygen and gasoline were the only practical fuels that could be used in his continuing research in the development of liquid-fueled rocket motors.

By 1924, Goddard had developed and tested a liquid oxygen pump and engine that functioned. The unit, however, was too small to actually be employed on a working rocket. But, with a working design, he began to plan more elaborate research. Goddard successfully test fired a pressure-fed liquid oxygen engine inside the Clark University physics laboratory on December 6, 1925. The engine was attached to a small test rocket housed inside a fixed stand. The engine was fired for about 24 seconds and lifted the rocket for about 12 seconds within its stand.



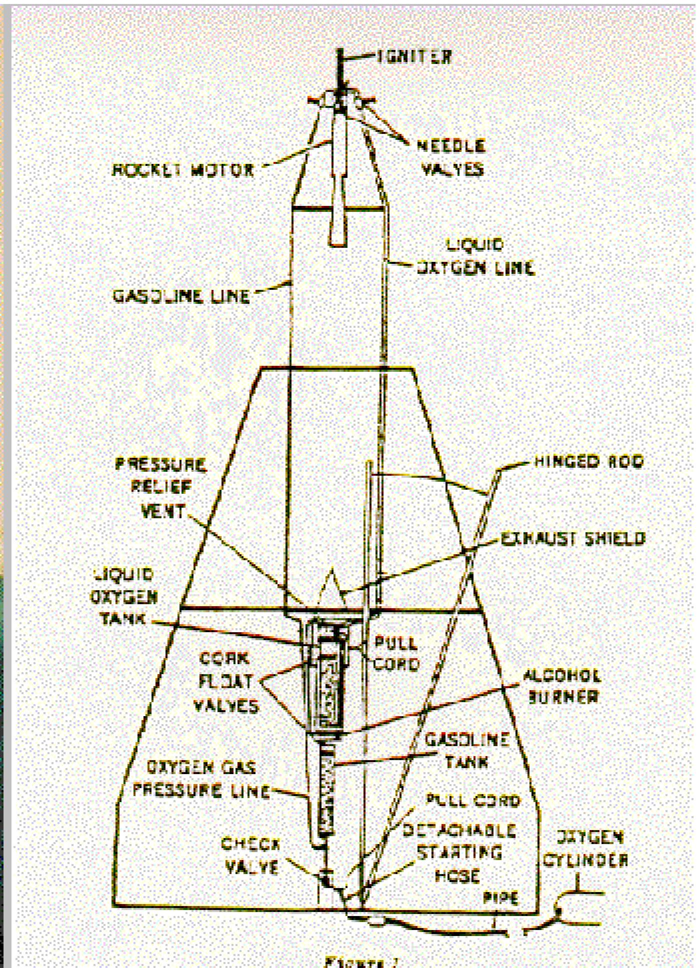
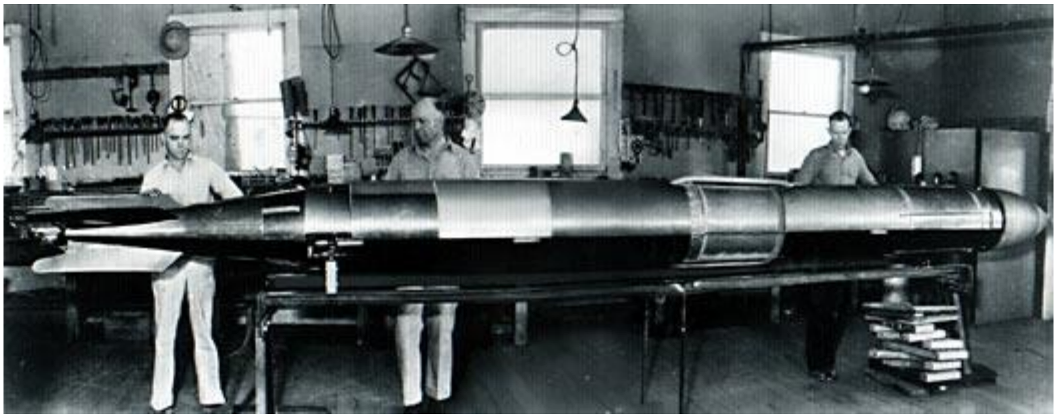


Figure 1
Dr. Goddard's 1926 Rocket

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 a distance of 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.

Following this flight, Goddard realized that his rocket was too small to be refined. He decided to develop larger rockets for further tests. Work was also begun on the development of a more elaborate launch tower. The new rockets incorporated innovative technology like flow regulators, multiple liquid injection, measurement of pressure and lifting force and an electrically fired igniter to replace a gunpowder fired igniter used previously. A turntable was also designed to produce spin stabilization.

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 a distance of 171 feet. The scientific payload was recovered safely via parachute. However, the launch was so noisy and bright that it captured much public attention. Many eyewitnesses believed an aircraft had crashed in the area. Local fire officials quickly forced Goddard to discontinue his launch operations at the Auburn site.



Goddard then made a large move after deciding to embark on his first full-time effort at constructing and testing rockets. He set up shop at the Mescalero Ranch near Roswell, New Mexico in July, 1930. The relocation was initially financed through the Guggenheim grant. 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. The Navy expressed a minor interest in liquid-fueled rockets. Goddard later characterized these responses as negative. Neither branch of service was interested in an innovative rocket aircraft that had been patented by Goddard on June 9, 1931. The lack of military interest in rocketry had confounded Goddard for years, since he understood that only the government had adequate resources to fund proper research.

Wernher von Braun:

In 1927, an eager 17-year-old scientist named Wernher von Braun joined the VfR, or Verein fur Raumschiffahrt (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. Membership in the VfR quickly soared to about 500, a sufficient member base to allow the publication of a periodic journal, "Die Rakete" (The Rocket). A number of VfR members, including Walter Hohmann, Willy Ley and Max Valier, had written, and continued to write, popular works on the field of rocketry.

Hohmann's book "Die Erreichbarkeit der Himmelskorper" (The Attainability of Celestial Bodies) published in 1925 was so technically advanced that it was consulted years later by NASA. Valier would later seek to popularize rocketry by helping to organize tests of German rocket cars, gliders, train cars and snow sleds. Other VfR members, including Hermann Oberth and von Braun, participated in the Ufa Film Company project in the late 1920's through 1930, which also sought to popularize the field of rocketry.

Germans also developed the first rocket-powered aircraft, the Ente (Duck), a sailplane powered by two Sander rockets. An Ente flew a distance of three-quarters of a mile in just under one minute during a test flight on June 11, 1928. The test was conducted by the German glider group Rhon-Rossitten Gesellschaft. Not to be out-done, the publicity-seeking Fritz von Opel piloted a glider powered by 16 Sander rockets on September 30, 1928. The glider reached a maximum speed of 95 m.p.h.

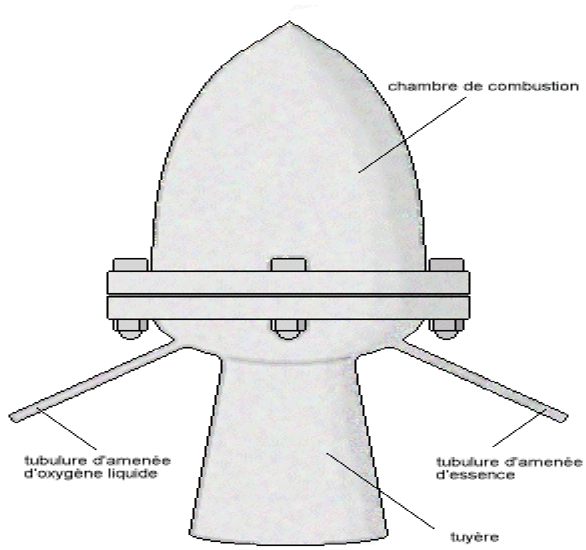
Russian Rocketry Research Continues:

In 1930, Russian government rocket design teams led by Fridrikh Arturovitch Tsander and Valentin Petrovitch Glushko began testing a number of liquid-fueled rocket engines. Tsander published "Problems of Flight by Means of Reactive Devices" in 1932 while Glushko published "Rockets, Their Construction and Utilization" in 1935. These Russian rocket tests continued through 1937, and tested liquid-fueled rocket engine concepts burning such combinations as gasoline/gaseous air, toluene/nitrogen tetroxide, gasoline/liquid oxygen, kerosene/nitric acid and kerosene/tetranitromethane.

One of the Russian rocket designs emerging from these tests was called GIRD-X, which weighed 65 pounds, was 8.5 feet long and 6 inches wide. A GIRD-X rocket reached a maximum altitude of three miles during a test on November 25, 1933. Another of the Russian rockets, called Aviavnito, weighed 213 pounds, was 10 feet long and 1 foot wide. An Aviavnito rocket reached an altitude of 3.5 miles in 1936.

VfR Rocket Tests:

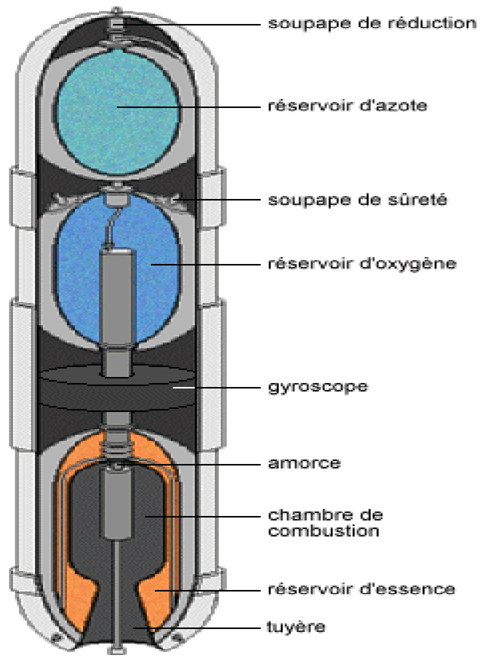
Also in 1930, the VfR set up permanent offices in Berlin and began testing rockets which would ultimately change the nature of warfare and propel the world into the space age. These at first humble tests began at an abandoned German ammunition dump at Reinickendorf nicknamed Raketenflugplatz (Rocket Airfield).



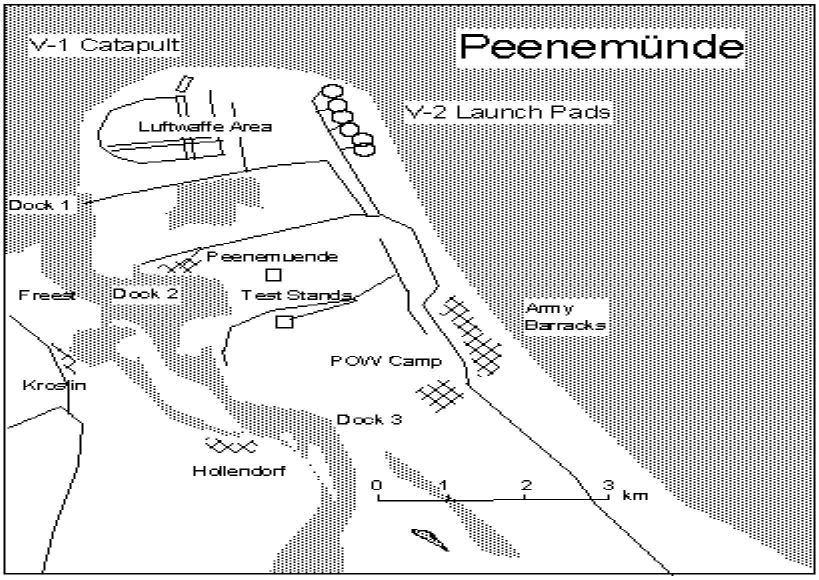
By August, 1930 tests began on the first of the VfR rockets, called Mirak-1 (Minimum Rocket-1). Powered by a combination of liquid oxygen and gasoline, Mirak-1 employed a 12-inch long liquid oxygen tank that shrouded a combustion chamber, thus cooling it. Gasoline was carried in a three-foot long tail stick. Mirak-1 was successfully static test fired in August, 1930 at Bernstadt, Saxony. During a second static test firing in September, 1930 Mirak-1 exploded when its liquid oxygen tank burst.

The VfR was forced to disband in the winter of 1933/1934 because the organization could not meet its financial obligations. Rocketry experiments ceased at the Raketenflugplatz facility in January, 1934 and the area resumed operation as an ammunition dump. Upon the disbanding of VfR, all private rocket testing in Germany ceased. Wernher von Braun, however, went to work officially for the German Army at Kummersdorf. There, the Heereswaffenamt-Prufwesen (Army Ordnance Research and Development Department) established the Versuchsstelle Kummersdorf-West as a static testing site for ballistic missile weapons.

Kummersdorf also became a site for the development and testing of a number of prototype jet-assisted take-off (JATO) units for aircraft. These tests were conducted by Wernher von Braun in association with Major von Richthofen and Ernst Heinkel. Under the direction of Captain Walter Dornberger, the Kummersdorf team was quickly able to design and build the A-1 (Aggregate-1) rocket. The A-1 was powered by a combination of liquid oxygen and alcohol, and could develop a thrust of about 660 pounds.

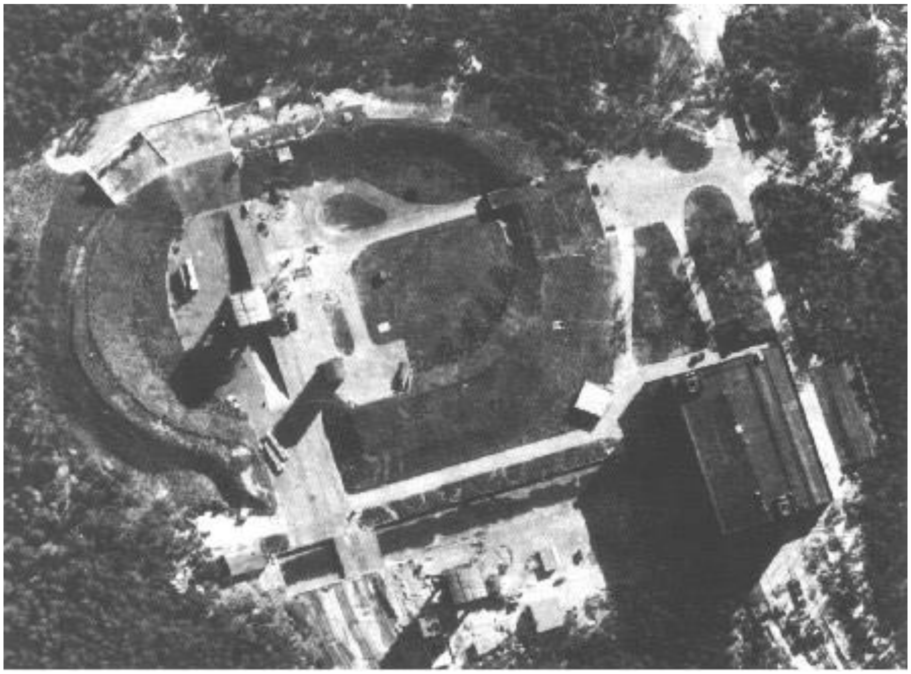


A 70-pound flywheel gyroscope was carried in the nose of the rocket to provide stability during flight. The A-1 was ultimately unsuccessful because its small fiberglass liquid oxygen tank housed inside its alcohol tank was fire prone. In addition, the gyroscope was located too far from the center of the rocket to be effective. The A-1 was soon followed by the A-2, which employed separate alcohol and liquid oxygen tanks. The A-2 gyroscope was located near the center of the rocket between the two fuel tanks. In December, 1934 two A-2 rockets, nicknamed Max and Moritz, were launched from the North Sea island of Borkum. Each reached an altitude of about 6,500 feet. But the feasibility of effective military rockets remained speculative at best, exemplified by the fact that in 1935, Adolph Hitler rejected a proposal from Artillery General Karl Becker for a long-range bombardment rocket.



German Rocket Tests Commence At Peenemunde

In April, 1937 all of the German rocket testing was relocated to a top-secret base at Peenemunde on the Baltic Coast. The first task of engineers at what was established as the Heeresversuchsstelle Peenemunde (Army Experimental Station Peenemunde) was to develop and test a new rocket called the A-3. By the end of 1937, the Peenemunde team had developed and tested the 1,650-pound, 21-foot long A-3 rocket, which burned a combination of liquid oxygen and alcohol. Although the propulsion system of the A-3 functioned well, its experimental inertial guidance system did not. The guidance problems were solved, and larger rockets were planned.



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 Peenemunde team develop a ballistic weapon that had a range of 150 to 200 miles and could carry a one-ton explosive warhead. An interim test vehicle to bridge the gap between the A-3 and the A-4 was named the A-5.

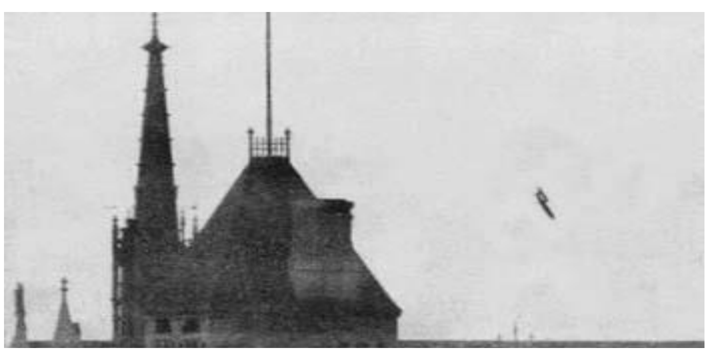
The A-5 was similar in design to the A-3, but employed a simpler, more reliable guidance system and stronger structure. The A-5 was fashioned with the exterior appearance of the proposed A-4 weapon. A-5 tests were conducted from the fall of 1938 through 1939. The rockets were launched both horizontally and vertically, and were often recovered by parachute and launched again. The first A-5 launched vertically reached an altitude of 7.5 miles.

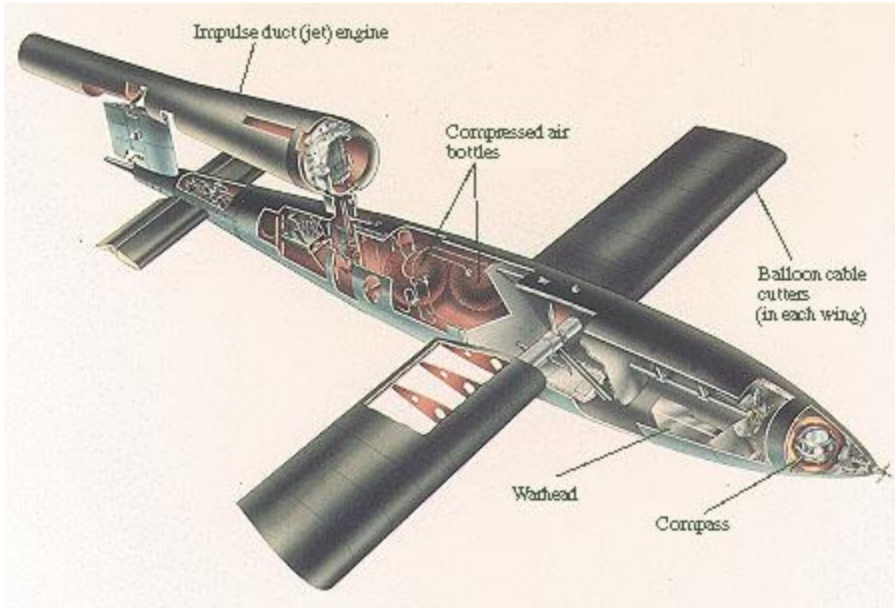
Civilian and military efforts in the field of rocketry in all other nations combined paled in comparison with the strides made in Germany, where the first A-4 was tested with complete success on October 3, 1942. The very first A-4 rocket reached an altitude of 50 miles and flew a distance of 120 miles. 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 a number of 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 that could produce a thrust of about 1,100 pounds. The entire V-1 weighed about 4,900 pounds. V-1 test flights began in 1941 over the Peenemunde range. The V-1 was originally called the Fieseler Fi-103. The V-1 bore no resemblance to the V-2, which was under development at Peenemunde at the same time.

British intelligence received information that secret weapons were under development at Peenemunde, so hundreds of Allied heavy bombers attacked Peenemunde on August 17, 1943. About 800 people were killed, including Dr. Walter Thiel, who at the time was in charge of V-2 engine development. Allied forces did not know the extent of weapons development at Peenemunde, nor that their bombing raids did not significantly hinder development of the weapons themselves. Indeed, the V-weapons were soon to be used in combat. 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.



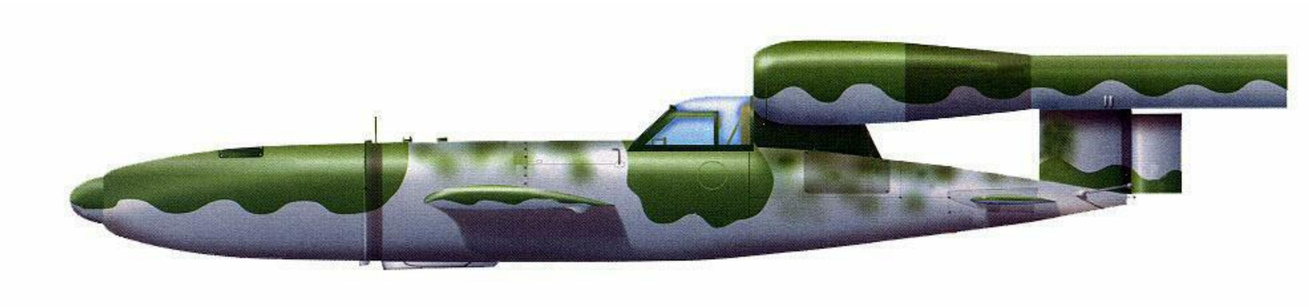


The distinctive sound of the V-1 engine resulted in the vehicle being nicknamed the "buzz bomb" by Allied forces. People on the ground knew they were relatively safe if the buzzing sound came and then faded as the weapon passed out of range. However, if the buzzing sound stopped abruptly, it was quickly understood that a powerful explosion could occur nearby. Each V-1 carried about 2,000 pounds of explosives, and was capable of causing 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 V-1 airframe was also prone to failure due to engine vibration. It is believed that about 25 percent of all V-1 missiles launched were destroyed by airframe failure before reaching their targets. Although specific numbers vary from source to source, a British report released after the war indicated that 7,547 V-1 missiles were launched at England. Of these, the report indicated that 1,847 were destroyed by fighter aircraft, 1,866 were destroyed by anti-aircraft artillery, 232 were destroyed by flying into barrage balloon cables and 12 were destroyed by Royal Navy ship artillery. That left about half of all V-1 missiles launched at England unaccounted for, and a large number were able to cause extensive property damage. 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.

A Pilot For The German V-1 Buzz Bomb

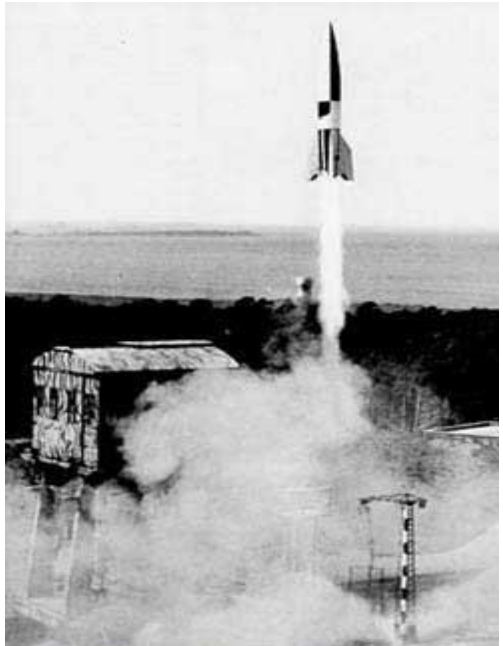
It is lesser known that the Germans designed a piloted version of the V-1 called the V-1e. The V-1e was not intended to be recovered. It would have been launched, then guided to its target by a pilot on a suicide mission. Similar to the Japanese kamikaze concept, the V-1e group was code-named Project Reichenberg. The V-1e was about 27 feet long and employed a cockpit and pilot instrumentation. The V-1e was test flown several times by German test pilot Hanna Reitsch.



Reitsch confirmed that the basic V-1 airframe was prone to severe vibration resulting from engine noise. She believed the deployment of the V-1e as introduced would result in significant pilot losses, even if the pilot had agreed to perform a suicide mission. The Germans could not sustain design changes late in the war, so the V-1e was never deployed in combat.

German V-2 Is Designed and Tested

The German V-2 rocket, developed under the designation A-4, is believed to be one of the most significant scientific advances of World War II, second only to the development of the atomic bomb. Aerodynamic data was generated for the basic V-2 design during wind tunnel tests conducted in 1936 and 1937. Certain V-2 components were in production as early as the spring of 1939, when launches of a test version of the rocket called the A-5 were being conducted. 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.



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

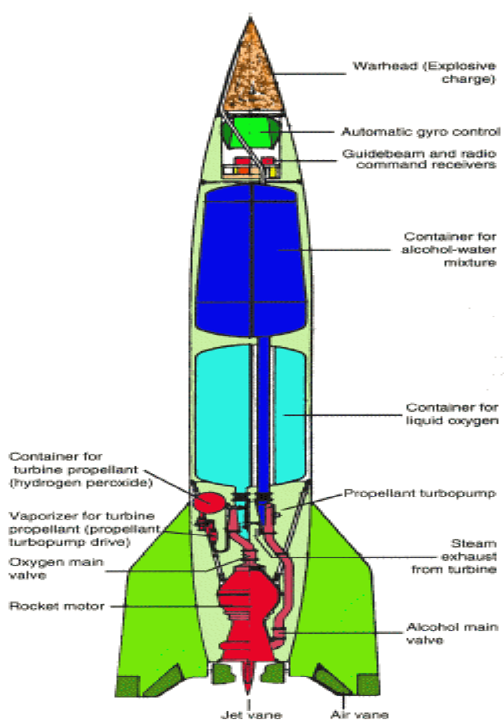
The first test launch of a V-2 occurred on June 13, 1942. The rocket pitched out of control and crashed as a result of a propellant feed system failure. The second V-2 test launch was conducted on August 16, 1942. This V-2 flight was also considered a failure, but the vehicle became the first guided missile to exceed the speed of sound. On just its third test launch on October 3, 1942 the V-2 scored a complete success. The rocket achieved a maximum altitude of 50 miles and maximum range of 120 miles, meeting the initial performance criteria for the weapon.

Following this achievement, Adolph Hitler, just a few years earlier unreceptive to the potential of guided ballistic missiles, established a military production committee within the Ministry of Armaments and War Production to manage further development of the V-2. While this did inject needed resources for the V-2 program, Wernher von Braun later stated that the military organization placed in charge of V-2 development by Hitler lacked scientific judgment, and ultimately hindered the capabilities of the weapon significantly. Indeed, von Braun was not to participate in the V-2 development program without great personal risk.

German V-2 Enters Production

Wartime production of the V-2 began at a virgin facility at the Peenemunde Experimental Center. Following the Allied bombing of Peenemunde on August 17, 1943 V-2 production was relocated to an underground facility at Mittelwerk, near Nordhausen in the Harz Mountains. The site was converted from an oil depot. The Mittelwerk site consolidated all of the production efforts previously carried out at Peenemunde, and eventually became the sole location for V-2 production. V-2 production plants were originally under construction at sites near Vienna, Berlin and Friedrichshafen, but construction of these sites was abandoned because of a persistent threat of Allied attacks.

Certain individual V-2 components were manufactured at sites throughout Germany, and troop training was also conducted at other sites. But V-2 production was based at the plant at Mittelwerk. A remarkable 900 V-2 missiles per month were being produced at the Mittelwerk plant by the close of the war.



German V-2 (A-4) Missile

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 top six feet of the V-2 was a warhead containing up to 2,000 pounds of conventional explosives. Below the warhead was a 5-foot section containing instrumentation, a 20-foot section containing the fuel tanks and a 15-foot section containing the engine. The instrumentation section contained an automatic pilot, accelerometer and radio equipment. The automatic pilot was made up of two electric gyroscopes that stabilized the rocket's pitch, roll and yaw motions. As the rocket moved about the axes of the gyroscopes, the movement was measured by electronic potentiometers. This caused electric command signals to be sent to a series of steering vanes at the base of the rocket.

The V-2 employed two sets of steering vanes. An external set of four steering vanes was made up of one steering vane at the base of each of the four V-2 fins. An internal set of four steering vanes was located at the base of the engine. Both sets of steering vanes were designed to work together to deflect the engine exhaust and steer the rocket. Movement of the steering vanes was intended to cause the potentiometers in the instrumentation section to read zero voltage, thus keeping the rocket on a predetermined path. Whenever the potentiometers read any voltage, an electric command would be sent to corresponding steering vanes to correct the motion of the rocket until the voltage again read zero. The steering vanes were controlled by electrohydraulic mechanisms. The accelerometer was used to measure the velocity of the rocket, while the radio equipment was used for a variety of purposes. In some instances, the radio equipment was used merely to receive commands from the ground to shut off fuel flow to the engine.

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 engine itself was composed of a combustion chamber, venturi, fuel pipes, a liquid oxygen fuel pump, an alcohol fuel pump, a steam-driven turbine that drove the two fuel pumps and hydrogen peroxide auxiliary fuel that operated the steam turbine. Through a natural chemical breakdown, the hydrogen peroxide decomposed into oxygen and water. The breakdown occurred at a high enough temperature to instantly turn the water into steam, which in turn drove the turbine. The turbine then pumped fuel into the engine.

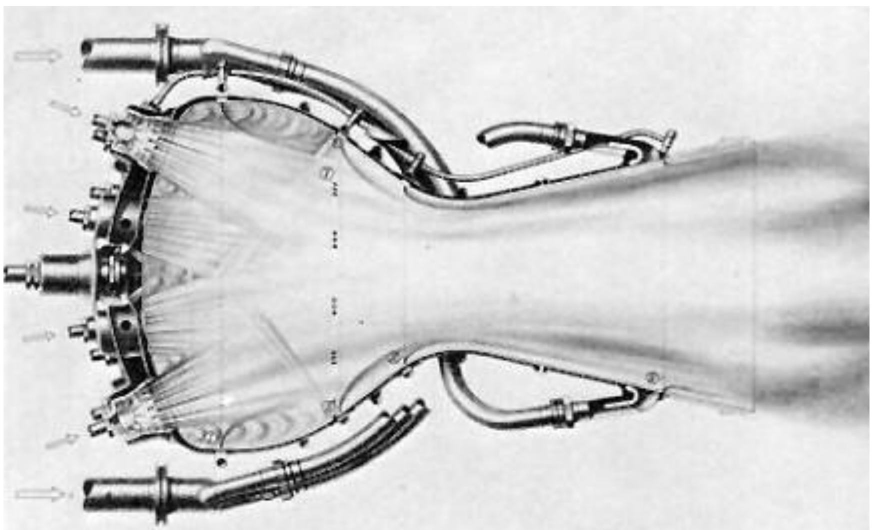
German V-2 Deployment And Launch

Completed V-2 rockets were transported by rail car from the factory to storage areas, where they were moved to special trailers by portable cranes. Storage time was kept to a few days, since testing determined that excessive storage time resulted in more V-2 failures. After being stored, the V-2 rockets were moved by truck and trailer to their launch sites. Although deploying the V-2 at fixed launch sites would simplify launch processing, it was felt that fixed launch sites would be too prone to attack. Therefore, the V-2 was deployed as a mobile missile.

Prior to launch, each V-2 missile was transferred to a vehicle called a "meillerwagen". Here, the rocket was clamped to a cradle in a horizontal position. The cradle on the "meillerwagen" was then raised by hydraulic pistons until the rocket reached a vertical position. A launching platform was then raised up until it assumed the full weight of the rocket. The cradle clamps were then released, and the "meillerwagen" was withdrawn several feet. 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, the "meillerwagen", 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. Electrical power for the V-2 was provided by ground sources when it rested on the launching platform and by batteries while in flight. Ground power was necessary for launch preparations, including the firing system.

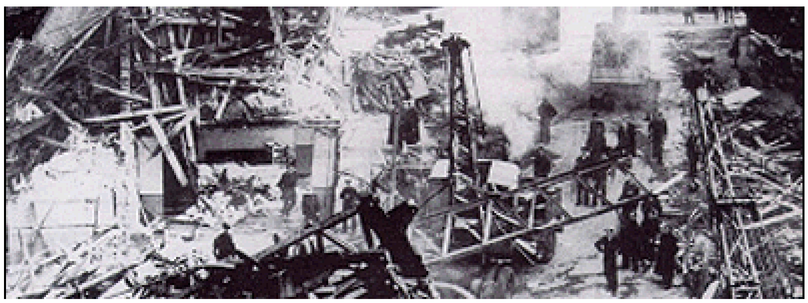
The actual launch was controlled from a remote location some 200 to 300 yards away from the rocket. An armored vehicle of some type was typically used as a "firing room". When the rocket was ready for launch, the control officer would fire the igniters by electric command. The flow of fuel would then be activated by solenoid valves. The liquid oxygen and alcohol then flowed by gravity to the exhaust nozzle, where they were lit by the igniters, which resembled a 4th of July pinwheel. This burning in itself was not sufficient to launch the rocket, but it did give the control officer a visual indication that the rocket was functioning properly. Once the control officer believed the rocket was ready for launch, an electric command was sent to start the fuel pumps. After about three seconds, the fuel pump steam turbine reached full speed, the fuel flow reached its full value of 275 pounds-per-second and the engine thrust reached about 69,000 pounds.



The V-2 was then launched, and began to rise slowly. It continued in a vertical rise for about four seconds, then was pitched to its programmed launch angle by the gyroscopic guidance system. The maximum pitch angle was typically about 45 degrees, which produced the greatest range. After about 70 seconds, the V-2 fuel flow was stopped, and the engine shut down. By this time, the rocket had achieved a speed of 5,000 to 6,000 feet-per-second. The rocket would then complete an unpowered ballistic trajectory, reaching its target just five minutes after being launched. Achieving a maximum altitude of 50 to 55 miles, the V-2 could impact a target within an operational design range of 180 to 190 miles, although some are believed to have flown as many as 220 miles. Because the V-2 flew so high and so fast, there was no defense against it. The missiles could not be detected until they exploded on the ground.

German V-2 Becomes A Weapon Of War

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.

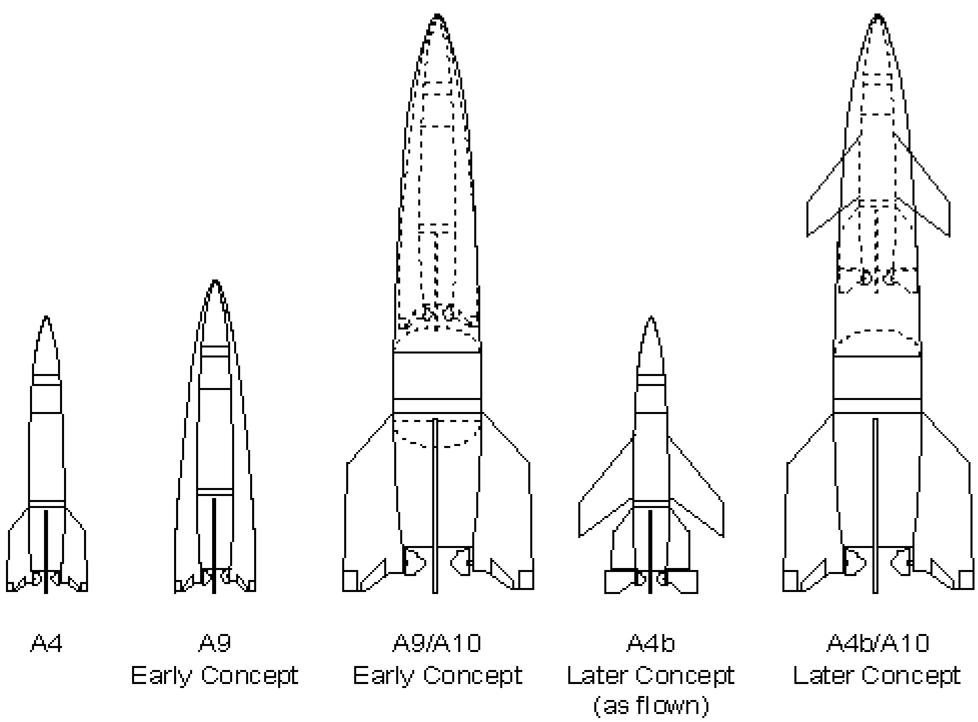


Specific numbers vary from source to source, but it is generally believed that about 1,100 V-2 missiles reached England until V-2 attacks ceased on March 27, 1945. About 2,800 people are believed to have been killed and another 6,500 injured as a direct result of V-2 attacks. It is generally believed 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 a number of 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 sufficient numbers to overwhelm Allied advances.

It should be noted that a number of follow-up versions of the V-2 were envisioned by German engineers, and historians will continue to wonder how World War II would have played out if Germany had the time to develop these concepts, along with perhaps an atomic or biological weapons payload. The German concept weapons carried the "A" designation, like the A-4 which eventually became known as the V-2. The A-5 actually preceded the A-4, and was used as an interim test prototype of the A-4. German concept vehicles considered to follow the V-2 began with the A-6.

Although design of the A-6 was completed, the vehicle was never built. The A-6 would have been identical to the V-2 with the exception of fuel. The A-6 would have used nitric-sulfuric acid as oxidizer and vinyl isobutyl ether mixed with aniline as fuel. These fuels were storable, and were intended to quicken the speed and ease with which the weapons could be handled and launched. The same operational improvement was incorporated when the U.S. Air Force liquid-oxygen burning Titan I was replaced by the Titan II, which employed storable propellants.



The A-7 was a winged missile based upon the design of the A-5. Dummy versions of the A-7 were dropped from aircraft for the purpose of gathering ballistic flight data. Test versions of the A-7 were launched using a 3,500-pound thrust engine adapted from the A-5. The A-7 was found to have a 30-mile glide path when launched from an aircraft flying at an altitude of five miles, or a 15-mile range when launched from the ground. The vehicle was intended for testing only, and was never deployed as a weapon. The A-8, which was never built, would have been a winged version of the A-6.

The A-9, similar in concept to the short-lived A-4b, was proposed to increase the range of the V-2 to 400 miles through the incorporation of wings. The wings would allow the A-9 to glide toward its target, rather than drop to the ground, at the end of its ballistic flight. However, since the A-9 would have a greater range than the V-2, it would be required to glide toward its target at relatively low speeds. Like the V-1, the A-9 would have been relatively easy to intercept in flight. As a result, the A-9 was neither built nor tested. An interesting application of the A-9 concept was a piloted version of the A-9 employing a triangular landing gear. Had it been built, the piloted A-9 could potentially have carried a pilot a distance of 400 miles in just 17 minutes.

The designation A-10 was given to what would have been the first stage of a missile employing the A-9 as a second stage. The A-10 stage would have been 65 feet long and had a diameter of 13 feet, 8 inches. It was designed to produce a 400,000-pound thrust by burning nitric acid and diesel oil. Calculations indicated that the A-10 first stage coupled with an A-9 second stage could carry a 2,000-pound payload a distance of 2,500 miles. If built, this would have been the world's first intermediate-range ballistic missile.

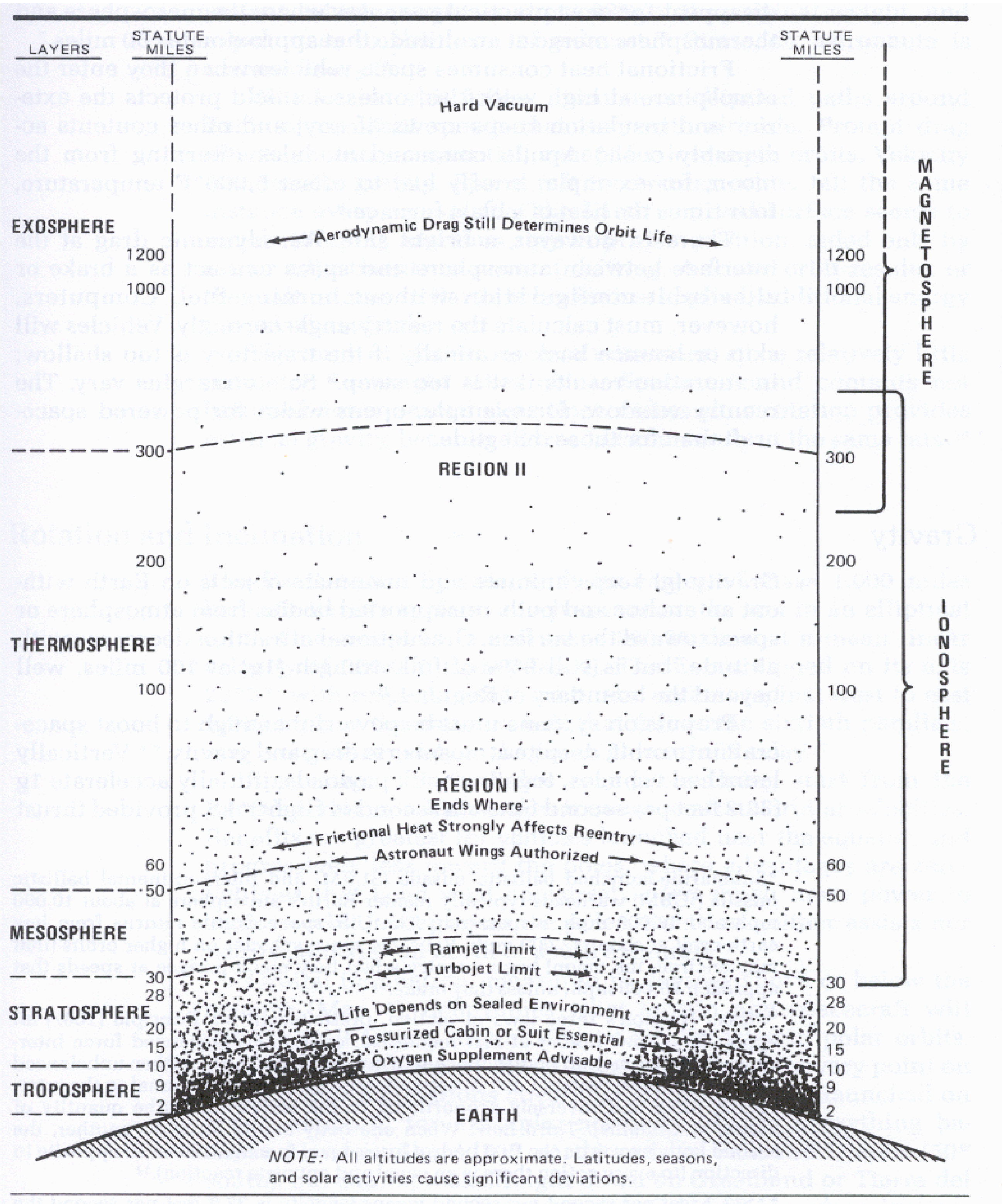
But, the von Braun design team did not stop there and indeed had plans on the drawing board that could have resulted in the first space launch vehicles.

The designation A-11 was given to the first stage of a vehicle that would have employed an A-10 as second stage and an A-9 as third stage. The specific intention of von Braun was to carry a piloted A-9 third stage into space.

The A-12 designation was given to a powerful first stage concept capable of producing a liftoff thrust of 2.5 million pounds. The A-12 would have been mated to an A-11 second stage and an A-10 third stage. Calculations indicated that the total vehicle could have carried a 60,000-pound payload into space.

CHAPTER 5

Outer Space



Introduction

During the 1940's and 50's rockets were achieving higher and higher attitudes 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. A bureaucratic agency might have one definition and an international organization may have another.

Obviously space does not start at the surface of the Earth because that is where our atmosphere pragmatically begins. If we climb to about 3000 meters (m) (10000 feet) we find that the amount of oxygen present and the pressure with which this oxygen enters our bodies is really not enough to keep a human body operating efficiently, although numerous people have adapted to live and work at this level (e.g. LaPaz, Bolivia; Quito, Equador; Katmandu, Nepal). The Federal Aviation Administration has dictated a regulation that whenever pilots fly above 3000 m (10000 feet) they will have supplemental oxygen available for them and their passengers. The United States Air Force goes a little further and states that their pilots will be on oxygen above 10,000 feet cabin pressure altitude. As altitude increases, the need for supplemental oxygen also increases.

At 5309 m (18000 feet) one half of the mass of the atmosphere is below this attitude. At this point a pilot who is at this cabin altitude must be on oxygen or a condition known as hypoxia (lack of oxygen to the blood or circulatory system) will render the aviator unconscious within 30 minutes.

At 16,000 m (16 km or nine miles) the use of supplemental oxygen fails as a sustainer for human life. At this altitude the combined pressure of carbon dioxide and water vapor in the lungs equals the outside atmospheric pressure and supplemental oxygen alone cannot reach the blood without additional pressure. Therefore, an individual must be in a pressurized cabin or wearing a pressure suit.

At 20 km (12 miles) the outside atmospheric pressure equals the vapor pressure of the human body or about 47 millimeters of mercury. In this environment bubbles of water and other gases begin to form in the body. The bodily fluids begin to literally boil. A pressurized cabin or a pressure suit is a requirement to protect an individual at this altitude from this violent condition.

At 24 km (15 miles) an aircraft's pressurization system no longer functions economically. There is so little oxygen and nitrogen at this altitude that it cannot be compressed to protect the pilot, crew, or passengers from the outside elements. Also at this altitude, the ozone layer begins to form in the atmosphere. Even though ozone consists of three atoms of oxygen per molecule, this substance is poisonous to the human body and compressing ozone would poison the cabin and its occupants. At this altitude the cabin or space suit must have its own pressure and oxygen independent of the outside atmosphere. For the human body space begins at this point because above this altitude a human must carry everything in order for the body to survive. This is probably the medical definition of where space begins.

At 32 km (20 miles) turbojets can no longer function. Used today as a means of propulsion for all modern jet aircraft, turbojets intake air and compress it by means of fans to mix with fuel for combustion. At 32 km there is not enough air to compress for mixing with the fuel; above this altitude aircraft must use ramjets. A ramjet operates similar to a turbojet except that a ram jet compresses air using supersonic shockwaves rather than fans. The speed of the air going through the shockwave compresses it much more efficiently than the mechanical turbojet.

At 45 km (28 miles) there is not enough air even for a ramjet to operate. Above this altitude a propulsion system needs to provide its own oxygen, also known as oxidizer, as well as fuel, i.e. a rocket. To a propulsion engineer space begins above this altitude.

At 81 km (50 miles) one government agency, the United States Department of Defense says that space begins because it awards all pilots who fly above this altitude astronaut wings. This group not only includes all the people who have flown the space shuttle and various other craft into space, but also the X-15 pilots who flew above this altitude.

At 100 km (62 miles) aerodynamic forces are no longer effective enough to move the various control surfaces to control an aircraft. The rudder, the aileron, and the elevator are no longer effective because there is not enough atmosphere for either lift or drag the two major aerodynamic forces to be effective. At this altitude the sky is dark; the stars no longer shimmer, but are hard points of light. Other than on-board equipment, there is no sound; no sonic booms, no explosions, or no shockwaves can be heard in space.

International law states that there is no definitive point where the atmosphere ends and space begins. The major space powers accept the following definition: Space begins at " the lowest perigee attained by orbiting space vehicles...", although this will vary with the size and shape of the vehicle. Perigee is the closest approach point to the Earth in an elliptical orbit. A potential challenge to this definition occurred in 1976 when eight equatorial nations issued declarations of sovereignty over the geosynchronous orbit belt which lies 35862 kilometers above the equator. Columbia, Equador, Brazil, People's Republic of the Congo, Zaire, Kenya, Uganda, and Indonesia also stated that they would defend such areas. But in 1980 the United Nations determined that such claims were null and void because Outer Space is international territory.

Sputnik:

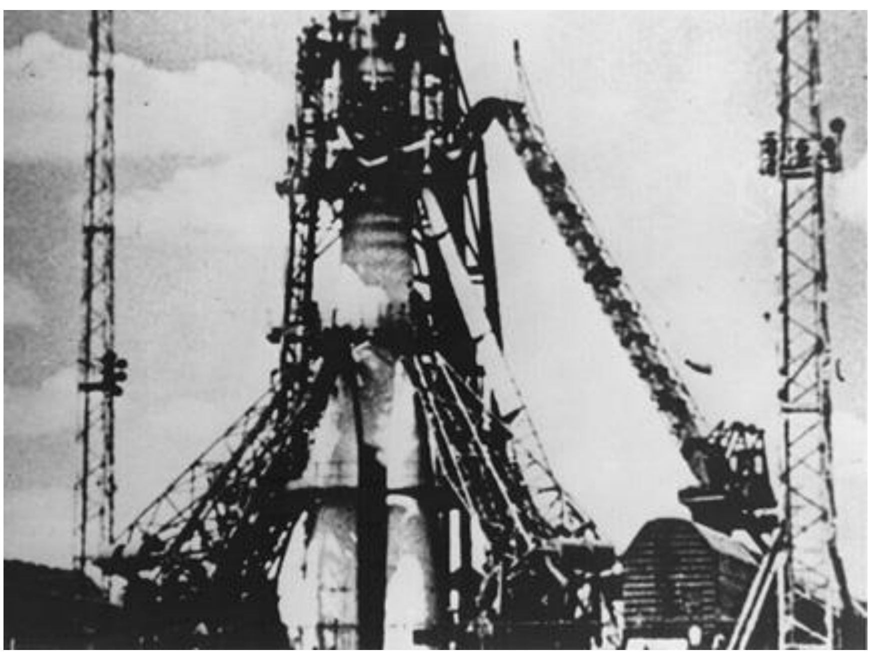
As the result of a large dedicated effort by scientific-research institutes and construction bureaus, the world's first artificial satellite of the Earth "Sputnik" (the Russians' word for "traveling companion") was been created on 4 October, 1957. Poems lyricized the event, like "Leap into the Future" and "Scouting the Celestial Deep." An ephemeris, showing the times when the carrier rocket would be visible over cities in the USSR, as well as Detroit and Washington, was printed like a train timetable.

With the development of large Soviet ICBM's, it quickly became obvious that a missile that could lift a 5 ton nuclear warhead across an ocean on a ballistic orbit could lift a small payload into a stable, low-Earth orbit. Work began in early 1956 on object D (or D-1) was so named since it would be the fifth type of payload to be carried on an R-7 rocket. Objects A, B, V, and G were designations for different nuclear warhead containers. The satellite was a complex scientific laboratory, far more sophisticated than any other science proposal from the period. While Soviet engineers depended a great deal on Tikhonravov's early work on satellites, much of the actual design was a journey into uncharted territory. There was little precedent for creating pressurized containers and instrumentation for work in Earth orbit, while long-range communications systems had to be designed without the benefit of prior experience.

The engineers were aware of the trajectory tracking and support capabilities for the R-7 missile, and this provided a context for determining the levels of contact with the vehicle. The fact that the object would be out of contact with the ground for long periods of time (unlike sounding rockets) meant that new self-switching automated systems would have to be used. The selection of metals to construct the satellite also presented problems to the engineers, since the effects of continuous exposure to the space environment was still in the realm of conjecture. The experiments and experience from sounding rocket tests provided a database for the final selection.

Technical work on the vehicle officially began on 25 February 1956 with actual construction beginning on 5 March. By 14 June, engineers finalized the necessary changes to the basic version of the R-7 ICBM in order to use it for a satellite launch. The new booster would incorporate a number of major changes including the use of uprated main engines, deletion of the central radio package on the booster, and a new payload fairing replacing the old one used for a nuclear warhead.

By 25 January 1957, the Chief Designer approved the initial design details of the satellite, now officially designated Simple Satellite No. 1 (PS-1). On 15 February, the USSR Council of Ministers formally signed a decree (no. 171-83ss) entitled "On Measures to Carry Out in the International Geophysical Year," approving the new proposal. The two new satellites, PS-1 and PS-2, would weigh approximately 100 kilograms and be launched in April-May 1957 after one or two fully successful R-7 launches. Eisenhower's plan to launch an American satellite during IGY was the deciding factor on a launch date. The Object D launch meanwhile was pushed back to April 1958.



The first three launches of the R-7 ICBM in May-July 1957 were all failures, completely disrupting the schedule to launch a satellite before the beginning of the IGY. There was severe criticism from higher officials and even talk of curtailing the entire program. Back at the launch range of Tyura-Tam, the fourth R-7 launch on 21 August 1957 was successful. The missile and its payload flew 6,500 kilometers, the warhead finally entering the atmosphere over the target point at Kamchatka.

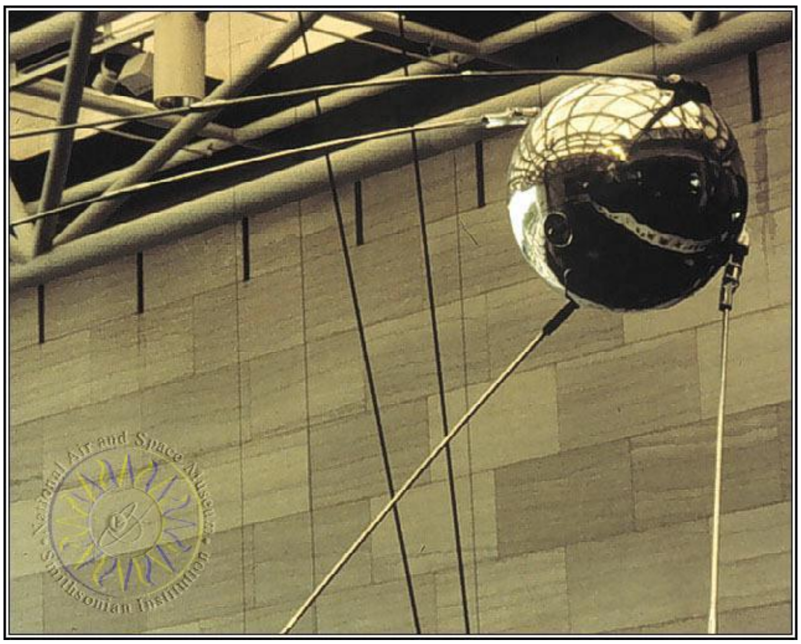
Work on the 'simple satellite' PS-1 had continued at an uneven pace since development of the object began in January 1957. Between March and August, engineers carried out computations to select and refine the trajectory of the launch vehicle and the satellite during launch. These enormously complicated computations for the R-7 program were initially done by hand using electrical arithrometers and six-digit trigonometric tables. When more complex calculations were required, engineers at the OKB-1 were offered the use of a 'real' computer recently installed at the premises of the Academy of Sciences. The gigantic machine filled up a huge room at the department and may have been the fastest computer in the USSR in the late 1950s: it could perform ten thousand operations per second, a high-end capability for Soviet computing machines of the time.

There were many debates on the shape of the first satellite, with most senior OKB-1 designers preferring a conical form since it fit well with the nose cone of the rocket. At a meeting early in the year, the Chief Designer had a change-of-heart and suggested a metal sphere at least one meter in diameter. There were six major guidelines followed in the construction of PS-1:

- the satellite would have to be of maximum simplicity and reliability while keeping in mind that methods used for the spacecraft would be used in future projects;
- the body of the satellite was to be spherical in order to determine atmospheric density in its path;
- the satellite was to be equipped with radio equipment working on at least two wavelengths of sufficient power to be tracked by amateurs and to obtain data on the propagation of radio waves through the atmosphere;
- the antennae were to be designed so as to not affect the intensity of the radio signals due to spinning;
- the power sources were to be onboard batteries ensuring work for two to three weeks; and
- the attachment of the satellite to the core stage would be such that there would be no failure to separate.

The five primary scientific objectives of the mission were:

- to test the method of placing an artificial satellite into Earth orbit;
- to provide information on the density of the atmosphere by calculating its lifetime in orbit;
- to test radio and optical methods of orbital tracking;
- to determine the effects of radio wave propagation through the atmosphere; and
- to check principles of pressurization used on the satellite.



The satellite as it eventually emerged was a pressurized sphere, 58 centimeters in diameter made of an aluminum alloy. The sphere was constructed by combining two hemispherical casings together. The pressurized internal volume of the sphere was filled with nitrogen at 1.3 atmospheres which maintained an electro-chemical source of power (three silver-zinc batteries), two D-200 radio-transmitters, a DTK-34 thermo-regulation system, a ventilation system, a communications system, temperature and pressure transmitters, and associated wiring.

The two radio transmitters operated at frequencies of 20.005 and 40.002 megacycles at wavelengths of 1.5 and 7.5 meters. The signals on both the frequencies were spurts lasting 0.2 to 0.6 seconds, providing the famous 'beep-beep' sound to the transmissions. The antennae system comprised four rods, two with a length of 2.4 meters each and the remaining two with a length of 2.9 meters each. Tests of this radio system were completed as early as 5

May 1957 using a helicopter and a ground station. The total mass of the satellite was 83.6 kilograms of which 51.0 kilograms was simply the power source.

The R-7 that launched Sputnik 1 was transported and installed on the launch pad in the early morning of 3 October escorted on foot by Korolev, Ryabikov, and other members of the State Commission. Fueling began early the following morning at 0545 hours local time. 51 Korolev, under a great amount of pressure, remained cautious throughout the proceedings. He told his engineers, "Nobody will hurry us. If you have even the tiniest doubt, we will stop the testing and make the corrections on the satellite. There is still time..." Most of the engineers, understandably enough, did not have time to ponder over the historical value or importance of the upcoming event. PS-1's deputy designer Ivanovskiy recalled "...Nobody back then was thinking about the magnitude of what was going on: everyone did his own job, living through its disappointments and joys."

On the night of the 4th, huge flood lights illuminated the launchpad as the engineers in their blockhouse checked off all the systems. In the command bunker accompanying Korolev were some of the senior members of the State Commission. All launch operations for Sputnik were handled by two men, a civilian and a military officer. Representing the civilians was Korolev's deputy Leonid A. Voskresenskiy, one of the most colorful characters in the history of the Soviet space program. A daredevil motorcyclist with a legendary penchant for taking risks, he had been with the program since the early days in 1945 when the Soviets had scoured Germany for the remains of the A-4 missile. Lt.-Col. Aleksandr I. Nosov represented the military.

Both men were 44 years old at the time. The actual command for launch was entrusted to the hands of Boris S. Chekunov, a young artillery forces lieutenant. He later recalled the final moments as the clock ticked past midnight local time: "When only a few minutes remained until lift-off, Korolev nodded to his deputy Voskresenskiy. The operators froze, awaiting the final order. Nosov, the chief of the launch control team, stood at the periscope. He could see the whole pad. 'One minute to go!,' he called."

With the exception of the operators, everybody was standing. The launch director began issuing commands. The seconds counted down to zero and the launch director shouted the command for lift-off. Chekunov immediately pressed the lift-off button. At exactly 2228 hours 34 seconds Moscow Time on 4 October, the engines ignited and the 272,830 kilogram booster lifted off the pad in a blaze of light and smoke. The five engines of the R-7 generated about 398 tons of thrust at launch. Although the rocket lifted off gracefully, there were problems.

Delays in the firing of several engines almost resulted in a launch abort. Additionally, at T+16 seconds, the System for the Simultaneous Emptying of the Tanks (SOBIS) failed, which resulted in higher than normal kerosene consumption. A turbine failure due to this resulted in main engine cut-off one second prior to the planned moment. Separation from the core stage, however, occurred successfully at T+324.5 seconds, and the 83.6 kilogram PS-1 successfully flew into a free-fall elliptical trajectory. The first human-made object entered orbit around the Earth inaugurating a new era in exploration.

U.S. Orbital Program

People the world over speak of the `Space Age' as beginning with the launching of the Russian Sputnik on 4 October 1957. Yet Americans might well set the date back at least to July 1955 when the White House, through President Eisenhower's press secretary, announced that the United States planned to launch a man-made earth satellite as an American contribution to the International Geophysical Year (1957). If the undertaking seemed bizarre to much of the American public at that time, to astrophysicists and some of the military the government's decision was a source of elation: after years of waiting they had won official support for a project that promised to provide an invaluable tool for basic research in the regions beyond the upper atmosphere. Six weeks later, after a statement came from the Pentagon that the Navy was to take charge of the launching program, most Americans apparently forgot about it. It would not again assume great importance until October 1957.

In the decade before Sputnik, laymen tended to ridicule the idea of putting a man-made object into orbit about the earth. Even if the feat were possible, what purpose would it serve except to show that it could be done? Indeed until communication by means of radio waves had developed far beyond the techniques of the 1930s and early 1940s, the launching of an inanimate body into the heavens could have little appeal for either the scientist or the romantic dreamer. And in mid-century only a handful of men were fully aware of the potentialities of telemetry.

Only a mighty rocket could reach beyond the blanket of the earth's atmosphere; and in the United States only the armed services possessed the means of procuring rockets with sufficient thrust to attain the necessary altitude. At the same time a number of officers wanted to experiment with improving rockets as weapons. Each group followed a somewhat different course during the next few years, but each gave some thought to launching an `earth-circling spaceship,' since, irrespective of ultimate purpose, the requirements for launching and flight control were similar. The character of those tentative early plans bears examination, if only because of the consequences of their rejection.

Project Rand mathematicians and engineers declared technology already equal to the task of launching a spaceship. The ship could be circling the earth, they averred, within five years, namely by mid-1951. They admitted that it could not be used as a carrier for an atomic bomb and would have no direct function as a weapon, but they stressed the advantages that would nevertheless accrue from putting an artificial satellite into orbit: `To visualize the impact on the world, one can imagine the consternation and admiration that would be felt here if the United States were to discover suddenly that some other nation had already put up a successful satellite.'

With the outbreak of the Korean War, the tempo of missile research heightened in the Defense Department. While the Navy was working on a guided missile launchable from shipboard and a group at NRL on radio interferometers for tracking it, rocketeers at Redstone Arsenal in Alabama were engaged in getting the `bugs' out of a North American Aviation engine for a ballistic missile with a 200-mile range, and RAND was carrying on secret studies of a military reconnaissance satellite for the Air Force.

Without attempting to describe the type of launching vehicle that would he needed, the RAND study spelled out the reasons why space exploration would bring rich rewards. Six appendixes, each written by a scientist dealing with his own special field, pointed to existing gaps in knowledge which an instrumented satellite might fill. Ira S. Bowen, director of the Palomar Observatory at Mt. Wilson, explained how the clearer visibility and longer exposure possible in photoelectronic scanning of heavenly phenomena from a body two hundred miles above the earth would assist astronomers. Howard Schaeffer of the Naval School of Aviation Medicine wrote of the benefits of obtaining observations on the effects of the radiation from outer space upon living cells. In communications, John R. Pierce, whose proposal of 1952 gave birth to Telstar a decade later, discussed the utility of a relay for radio and television broadcasts. Data obtainable in the realm of geodesy, according to Major John O'Keefe of the Army Map Service, would throw light on the size and shape of the earth and the intensity of its gravitational fields, information which would be invaluable to navigators and mapmakers. The meteorologist

Eugene Bollay of North American Weather Consultants spoke of the predictable gains in accuracy of weather forecasting. Perhaps most illuminating to the nonscientifically trained reader was Homer E. Newell's analysis of the unknowns of the ionosphere which data accumulated over a period of days could clarify.

Confusing and complex happenings in the atmosphere, wrote Newell, were `a manifestation of an influx of energy from outer space. What was the nature and magnitude of that energy? Much of the incoming energy was absorbed in the atmosphere at high altitudes. From data transmitted from a space satellite five hundred miles above the earth, the earth-hound scientist might gauge the nature and intensity of the radiation emanating from the sun, the primary producer of that energy. Cosmic rays. meteors, and micrometeors also brought in energy. Although they probably had little effect on the upper atmosphere, cosmic rays, with their extremely high energies, produced ionization in the lower atmosphere.

Low-energy particles from the sun were thought to cause the aurora and to play a significant part in the formation of the ionosphere. Sounding rockets permitted little more than momentary measurements of the various radiations at various heights, but with a satellite circling the earth in a geomagnetic meridian plane it should be possible to study in detail the low-energy end of the cosmic ray spectrum, a region inaccessible to direct observation within the atmosphere and best studied above the geomagnetic poles. Batteries charged by the sun should be able to supply power to relay information for weeks or months.

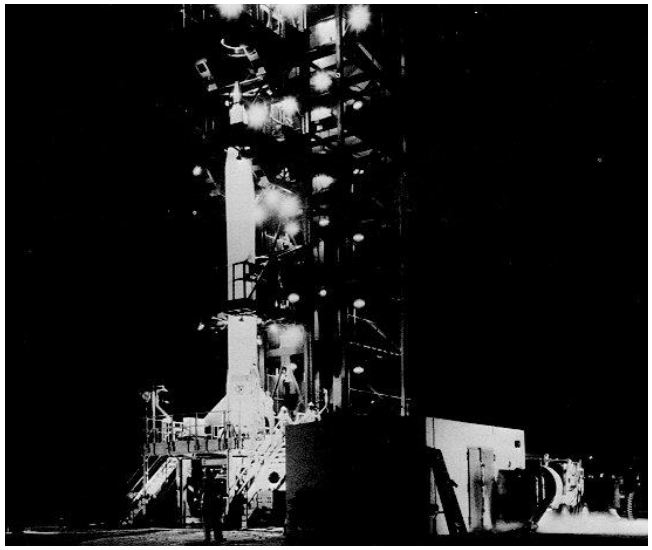
Contrary to what an indifferent public might have expected from rocket `crackpots,' the document noted that `to create a satellite merely for the purpose of saying it has been done would not justify the cost. Rather, the satellite should serve useful purpose-purposes which can command the respect of the officials who sponsor it, the scientists and engineers who produce it, and the community who pays for it.' The appeal was primarily to the scientific community, but the intelligent layman could comprehend it. and its publication in an engineering journal in February 1955 gave the report a diversified audience.

Viking

In 1949, tests began on the new sounding rocket built for NRL by the Glenn L. Martin Company. Named `Neptune' at first and then renamed `Viking,' the first model embodied several important innovations: a gimbaled motor for steering, aluminum as the principal structural material, and intermittent gas jets for stabilizing the vehicle after the main power cut off. Reaction Motors Incorporated supplied the engine, one of the first three large liquid-propelled rocket power plants produced in the United States. Viking No. 1, fired in the spring of 1949, attained a 50-mile altitude; Viking No. 4, launched from shipboard in May 1950, reached 104 miles. Modest compared to the power displayed by the Bumper-Wac, the thrust of the relatively small single-stage Viking nevertheless was noteworthy.

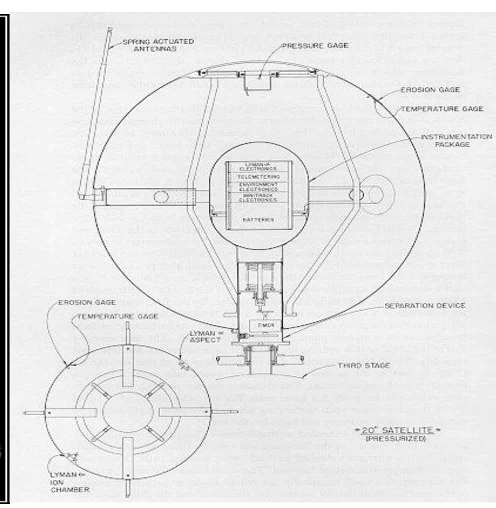
While modifications to each Viking in turn brought improved performance, the Electron Optics Branch at NRL was working out a method of using ion chambers and photon counters for x-ray and ultraviolet wavelengths, equipment which would later supply answers to questions about the nuclear composition of solar radiation. Equally valuable was the development of an electronic tracking device known as a `Single-Axis Phase-Comparison Angle-Tracking Unit,' the antecedent of `Minitrack,' which would permit continuous tracking of a small instrumented body in space. When the next to last Viking, No. 11, rose to an altitude of 158 miles in May 1954, the radio telemetering system transmitted data on cosmic ray emissions, just as the Viking 10, fired about two weeks before, had furnished scientists with the first measurement of positive ion composition at an altitude of 136 miles.

This remarkable series of successes achieved in five years at a total cost of less than $6 million encouraged NRL in 1955 to believe that, with a more powerful engine and the addition of upper stages, here was a vehicle capable of launching an earth satellite.



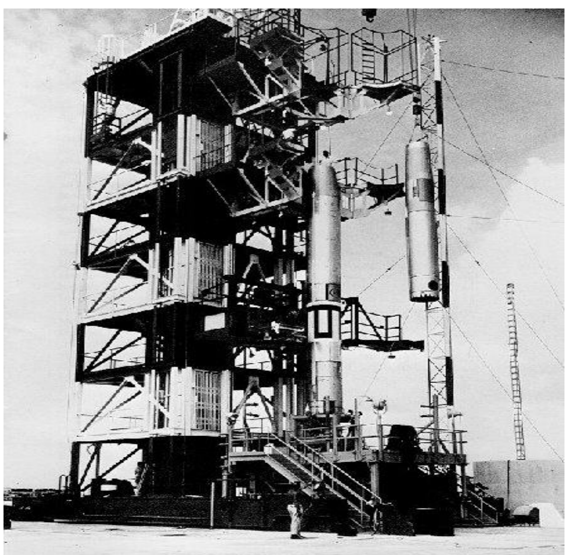
<u>Vanguard</u>

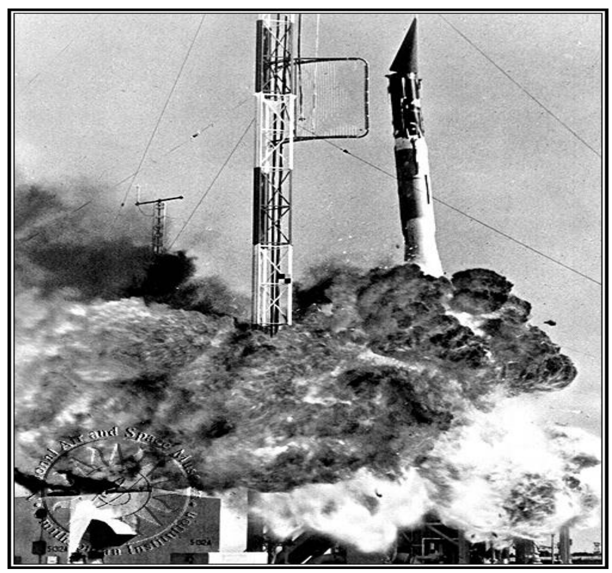
In 1955 President Eisenhower announced that the United States planned to launch a small robotic earth orbiting satellite as part of the country's participation in the International Geophysical Year that was to run from mid-1957 to mid-1958. The US Navy's proposal, entitled Vanguard, was selected among those submitted by the three services. The Naval Research Laboratory was given overall responsibility for the project while funding came from the National Science Foundation. The Glenn L. Martin Company, which had built the Navy's Viking rocket, was prime contractor for the launch vehicle and its operation.



The satellite proper was built at the Naval Research Laboratory in Washington. The payload for the Test Vehicle (TV) series consisted of seven mercury cell batteries (in a hermetically sealed container), two tracking radio transmitters, a temperature sensitive crystal, and six clusters of solar cells on the surface of the sphere. The two radio transmitters would allow earth stations to track its flight; this would allow scientists to obtain data on the Earth's shape and variations in its gravitational field.

Six 12-inch antennas projected perpendicularly from the surface of the sphere, with three each disposed symmetrically in each hemisphere prior to launch. Approximately 2-inch square solar cells are attached to the surface of the sphere between each pair of antennae. A container inside the sphere holds mercury batteries and two radio transmitters. Separation from the launch rocket was achieved by a strap and pull-in pin method. An acceleration-activated timing motor released a retaining pin, which began the separation and activated the batteries.





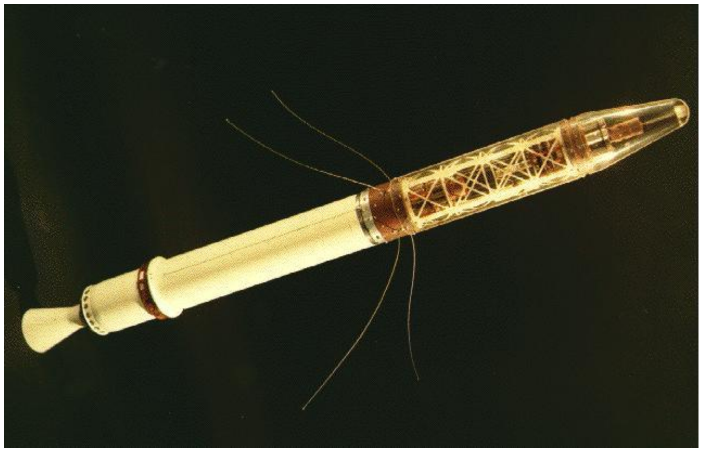
The Vanguard team was still working on a test vehicle (TV-2) designed to test the first stage of the rocket when they learned of the launch of the world's first artificial satellite, Sputnik I, by the USSR on October 4, 1957. On December 2, the Department of Defense announced the imminent launch of TV-3.

The scheduled countdown began shortly after 5 PM on December 5; the first stage was ignited at 11:45 AM on December 6. The rocket rose about four feet into the air and immediately sank back down and exploded. The payload nosecone detached in the process and landed free of the exploding rocket. The satellite, too damaged for further use, was salvaged.

On March 17, 1958, the program successfully launched the Vanguard satellite, TV-4. This satellite was identical to TV-3BU, also in the NASM collection, which was the backup for TV-3. TV-4 achieved a stable orbit with an apogee of 2466 miles and a perigee of 404 miles; it was estimated that it would remain in orbit for 240 years. The radio continued to transmit until 1965. Tracking data obtained with this satellite revealed that the earth is not quite round--it is elevated at the North Pole and flattened at the South Pole. The Vanguard program was transferred to NASA when that agency was created in mid-1958. The program ended with the launch of Vanguard 3 in 1959.

While Project Vanguard had been officially "phased out" by NASA's first anniversary, the project left an invaluable legacy whose influence is still seen to this day. Even before the project's first successful launch, Vanguard's upper stages had been modified for use on the Thor-Able which launched the nation's first Moon probes. By the end of the Vanguard program, plans were already well underway to use these same stages with the Atlas-Able to launch NASA's new series of Pioneer probes to the Moon and beyond. The Thor-Able hardware would later be significantly modified to become the famous Delta launch vehicle whose descendants still fly today. The X-248 rocket motor would also be used in NASA's low-cost Scout solid propellant satellite launcher.

The Vanguard satellite hardware itself would also prove to be valuable. Much of the hardware (e.g., telemetry systems, tracking beacons, miniature tape recorders, etc.) developed for the program had already been "borrowed" by other satellite programs and future satellite hardware would be based on this newly proven technology. Vanguard's network of tracking facilities would serve as the basis of NASA's worldwide tracking network. Management techniques developed run the project were also adopted by NASA. The list goes on and on. Although Project Vanguard often gets pushed aside because of its poor flight record of only three successes in 11 attempts, it left a powerful legacy that immeasurably aided America's push into space.



Jupiter/Explorer

The Vanguard field crew was still struggling at Cape Canaveral to put up TV-2, its third test vehicle-the one designed to test the first stage, when on Friday, 4 October 1957, the news broke that Sputnik I, a 184-pound sphere had been launched about 5:30 p.m. that day by the Soviet Union and was circling the earth. Earlier in the week, on Monday, 30 September, scientists representing the Soviet Union, the United States, and five other nations had assembled at the National Academy of Sciences in Washington, D.C., for a six-day conference on the rocket and satellite activities of the International Geophysical Year.

A speaker at the opening session was Sergei M. Poloskov, member of the Soviet delegation. Poloskov's subject was "Sputnik," the Russians' word for "traveling companion" and the name they had chosen for the satellite they were preparing to launch. The U.S.S.R. had long since served notice of its intent to develop a satellite-launching program as one of its contributions to the IGY. Nevertheless, there was a stir among Poloskov's listeners when he used an expression that could be literally translated as "now, on the eve of the first artificial earth satellite."

It was a gracious and dignified beginning to a period of mental turmoil and vocal soul-searching in the United States that can scarcely be described as dignified. In retrospect it is easy to smile at some of the exaggerated alarms and groundless assumptions that filled newspaper columns and trumpeted from public platforms as the significance of the Soviet feat became apparent. The smug chuckle of hindsight, however, cannot efface either the importance of the event or the intensity of the change it wrought in American thinking. Girdling the earth once every 96.17 minutes, the first Russian satellite-later referred to as Sputnik I to distinguish it from its successor-was a sphere approximately twenty-two inches in diameter, made of aluminum alloys and equipped with four spring-loaded whip antennas. The satellite itself would fall from orbit on 4 January 1958. "Sputnik night," as the night of 4-5 October 1957 came to be called, was an historic watershed. Almost immediately two new phrases entered the language-"pre-Sputnik" and "post-Sputnik." In England the London Daily Mirror proclaimed the birth of the "Space Age" in huge headlines, and changed its slogan to claim, not the "biggest daily sale in the world" but the "biggest in the Universe." 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.

Within hours after the first Soviet launch, the Senate Preparedness Subcommittee chairmanned by Lyndon B. Johnson initiated a "full, complete, and exhaustive inquiry into the state" of the nation's satellite and missile efforts. On 9 October Hagen and Admiral Bennett went "up the Hill" to tell the Vanguard story to attorney Edwin L. Weisl of New York, the Johnson subcommittee's chief investigator, and his staff. Accompanying them was Brigadier General Austin W. Betts of the Department of the Army, whose task was to answer questions concerning the possibility, then under intensive discussion, of using the Army's Jupiter C, a version of its intermediate-range ballistic missile, as the basis of a backup satellite-launching program for Project Vanguard.

Most of the Senate investigators' questions reflected current criticisms of the manner in which the United States had handled its satellite program. Considerable discussion dealt with the President's order that the satellite effort be kept "separate and distinct" from the country's military missile effort. There were rocket men in and out of the Army who viewed this arrangement as an inadvisable "division of the indivisible." In answer to the Senate investigators' queries, Hagen and Bennett explained that "the decision" to separate the two programs arose from the fear that "the military program might be delayed if this were not done." They added that subsequent to the separate-but-highly-unequal decision, it had become "apparent that the Jupiter C missile of the Army" could be "used as a booster for an earth satellite.

However, the time required to make the necessary modifications to the Jupiter C would not have resulted in a material saving in time and might have reduced the scientific value of the earth satellite." The investigators concluded the session with a request that the Vanguard managers supply them with a report on the background, status, and plans of the project. During the preceding summer, fortunately, Hagen had directed his aides to prepare a chronological history of the project. Within a reasonably short time, this and other pertinent material were on their way up the Hill, to be digested by the Johnson subcommittee staff in preparation for a projected series of hearings by the subcommittee itself.

What must have been welcome news to many anxious Americans came five days after Sputnik II with an announcement from the Pentagon that the Army Ballistic Missile Agency (ABMA) at Redstone Arsenal in Huntsville, Alabama, a unit commanded by Major General John B. Medaris, had received permission to participate in the American satellite program on a backup basis.

"The Secretary of Defense today," the department's 8 November release read in part, "directed the Department of the Army to proceed with launching an earth satellite using a modified Jupiter C. This program will supplement the Vanguard program.... The decision to proceed with the additional program was made to provide a second means of putting into orbit, as part of the IGY program, a satellite which will carry radio transmitters compatible with minitrack ground stations and scientific instruments selected by the National Academy of Sciences."

Some of them had been discussing the feasibility of such a move since the fall of 1955 when the Stewart Committee rejected Project Orbiter, the Army's satellite-launching proposal, in favor of the Navy proposal that had become Project Vanguard. For Project Orbiter the Army-directed rocket team headed by Wernher von Braun had designed a four-stage launching vehicle, to consist of the liquid-fueled Redstone rocket, the Army's short-range tactical missile, and three solid stages made up first of clusters of Loki and later of scaled-down Sergeant rockets. When subsequently the Army rocket experts embarked on a series of tests designed to bring their nosecones safely back into the atmosphere during flight, common sense dictated that they use the four-stage vehicle they had planned for Project Orbiter as the basis for creating a suitable test missile. To this end they had developed what by 1957 was known as the Jupiter C, the "C" standing for "Composite Re-entry Test Vehicle," In this way the Army was able to carry on its vehicle development under military priority, an advantage denied the Vanguard program. Had the Jupiter missile been chosen in the first place as the IGY vehicle, it too might have had to undergo development outside military priority. Created by the Army in collaboration with the Jet Propulsion Laboratory of the California Institute of Technology, the Jupiter C was an elongated Redstone with three solid-fuel upper stages-two of them live, and the top one filled with sand to preserve the balance of the vehicle.

The addition to the American satellite effort of the Army team-the Army Ballistic Missile Agency (ABMA) at Redstone Arsenal in Huntsville, Alabama, and its partner, the Jet Propulsion Laboratory (JPL) of the California Institute of Technology in Pasadena-called for a series of high-level decisions in Washington. Some dealt with the scheduling of launches. This was an involved maneuver since both the Vanguard and Army teams would be using the same Cape Canaveral range. They would also be using much the same tracking, telemetry and orbit-computation systems, namely those that the Vanguard electronics experts had developed for their project, supplemented by microlock, a tracking and telemetry network that the Army had been using with its missiles since 1953. Because of these overlaps, sufficient time had to elapse between shots for AFMTC to prepare the requisite range support and for the units in charge of the electronics services to put their equipment in order.

Complex as these arrangements were, most of them had been worked out by the end of 1957. By this time the Department of Defense had authorized the Army team to make two "earnest tries" to orbit a small cylinder-shaped satellite to be known as "Explorer," and the Naval Research Laboratory had transferred to the Army a scientific experiment that it had originally assembled for one of the Vanguard satellites. Scientists at the Jet Propulsion Laboratory were modifying this instrumentation for use in the Army payload, and the Army's four-stage Jupiter C missile had reached Cape Canaveral, where a field crew was readying it for erection on the firing table at launch complex 26A, one of the Redstone pads at AFMTC. In addition, the Army had selected 29 January 1958 for its initial launch attempt, with the understanding that the Vanguard team would try to put up another of its vehicles earlier that month.

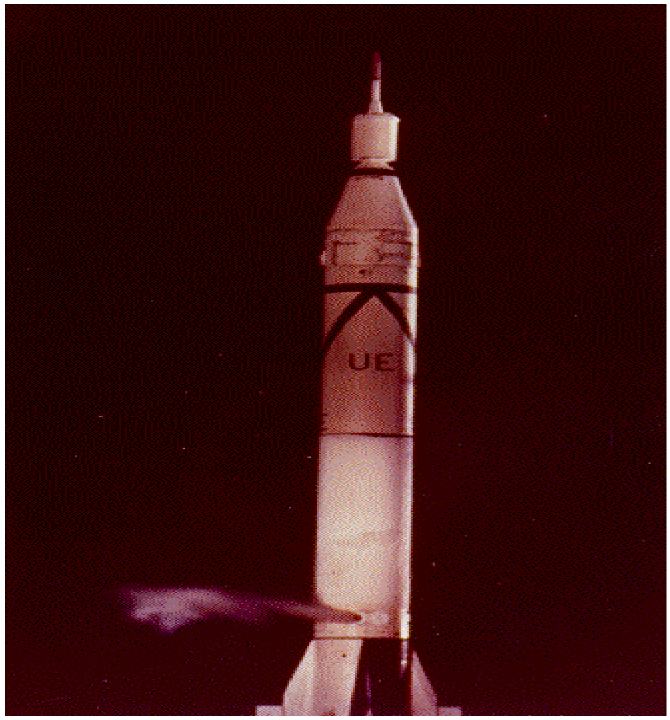
Since AFMTC could provide range support for only one shot at a time, this left the Army team with a discouragingly short period-less than a week-in which to make its first launch attempt. Fortunately its preflight preparations at Cape Canaveral were not excessively demanding. The Jupiter C had undergone several flight tests. Moreover, such static tests as the forthcoming attempt necessitated had been taken care of at Redstone Arsenal before the missile moved east. The major activities at the pad consisted of checking out the hazardous solid-propellant upper stages of the vehicle and of making sure that when the tub containing these rockets started to spin on top of the elongated Redstone booster, it would do so smoothly and without destructive vibration. Well in advance of the scheduled launch date, these procedures had been concluded, and preparations for the flight test itself were moving at a satisfactory rate.

Advance publicity was restrained and the launch date was withheld from the press until twenty-four hours prior to the anticipated firing. This policy reflected the determination of General Medaris, the ABMA commander, to protect the Army team as much as possible from the misleadingly optimistic type of attention that the press had heaped on Project Vanguard prior to the TV-3 explosion. Summoned to Washington in late 1957 and again in early 1958 to testify at the Johnson Senate subcommittee hearings on American missile and satellite programs, the general ducked the questions of reporters looking for more specific information. The Senate subcommittee itself gave him no problems on this score.

When the matter of the Army's launch schedule came up, Cyrus Vance of the investigating staff informed Medaris that "I am not going to ask you about the date." Medaris' reply was "I am thankful for that, Sir." Appearing before the subcommittee on three occasions, the striking-looking ABMA chief was a colorful and articulate witness and both the senators and their staff handled him with a gentleness that must have made John Hagen, the beleaguered Vanguard director, sigh with envy.

On 29 January, launch day, the Explorer vehicle, its satellite and its field crew were ready, but disturbing reports were coming in from the AFMTC meteorologists. On the surface the weather was fine. Instrumented-balloon soundings, however, had revealed the presence high above the Cape of a jet stream, a swiftly-moving river of air, almost certain to destroy the missile. Heeding a teletyped advisory from his structural analysis engineers at Redstone Arsenal, Medaris decided to play it safe. Next mornings weather reading was slightly more encouraging. At noon he authorized the crew to begin an eight-hour countdown, only to call it off a few hours later following a report that the jet stream was again menacing.

At this point-Thursday evening, 30 January-time was running out for the Army team. Project Vanguard's next flight test of TV-3BU was still tentatively set for 3 February, and word from ICY headquarters in Washington was that the electronics units would need three days of preparation for it. The Army must either put up its vehicle on the following day-31 January-or hold off until the Vanguard team had completed its scheduled attempt. Medaris and his crew could only wait and hope. Next mornings 7 o'clock weather reading, as interpreted by the structural analysis engineers, was just favorable enough. "Things look good," it read. "The jet stream has moved off to the north, and by evening should be down to 100 knots." To Medaris that "still sounded like a lot of wind, but it meant the difference between a strain that we knew the missile could stand and one that was dangerous." In a now-or-never spirit, the ABMA commander set in motion another eight-hour countdown, prayerfully heading, as on the day before, for a firing at 10:30 that evening.



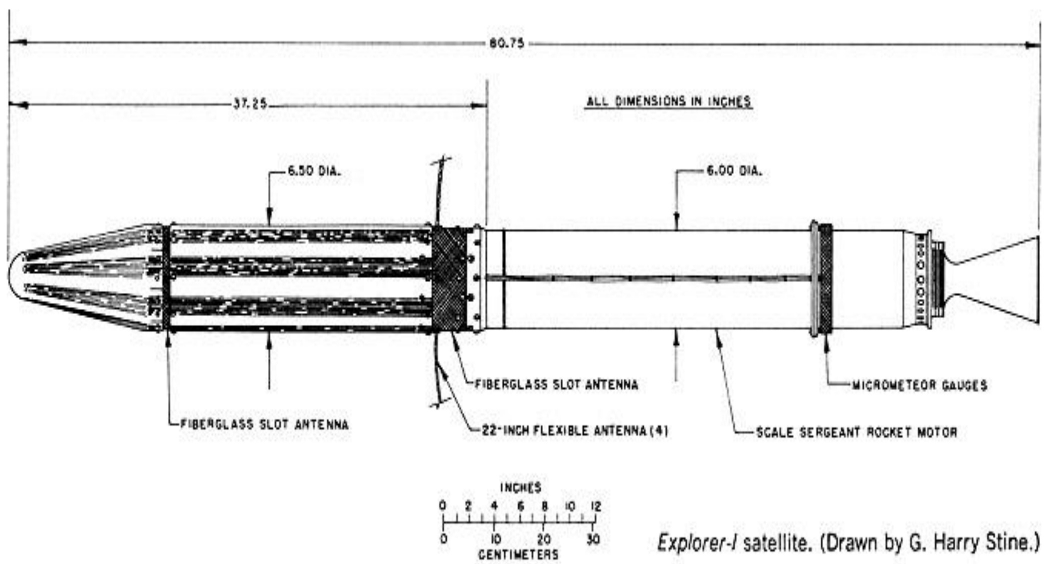
Beginning at 1:30 p.m., the countdown encountered no serious hitches. Late in the afternoon there was a half-hour hold to complete a number of operations that had fallen behind schedule, seemingly because crew members were still suffering from exhaustion after the exertions of the day before. Later they made up for the lost time. At 9:45 p.m., with the countdown exactly on schedule, there was a second hold when someone spotted a hydrogen-peroxide leakage in the tail of the missile.

Workmen drained the line and stopped the leak. When at 10 p.m. the countdown resumed, it was only 15 minutes behind. At T-12 seconds-X-12, in Army terminology-the motors started to spin the top stages of the vehicle, technicians in the control room of the Redstone blockhouse transferred power from the ground power supplies to onboard sources, and at 10:48 p.m. the Jupiter C lifted off. It rose smoothly from its firing stand. A complex rocket, however, can fail even after a perfect start. There were jittery moments for the crew members while they awaited assurance that the upper stages had fired.

For its later satellite-bearing missiles, ABMA would contrive an onboard system capable of igniting the upper stages automatically. No such system flew with the first Explorer missile because the ABMA scientists and engineers had not yet contrived a dependable one. Instead they had developed a method for ground-command firing the second stage at almost the precise second the missile reached its absolute apex following liftoff. This was done from the Redstone hangar. There, at an exactly and swiftly calculated moment, approximately 404 seconds after launch, a scientist pushed a button to fire the second stage. A simple timer then controlled the ignition of the third and fourth stages, operating so as to allow the full thrust of each to be applied before the next one fired.

Word that the upper stages had fired in response to ground command marked the start of still another period of nervous waiting and wondering. Was the satellite in orbit? Tracking stations on the West Coast would have to answer that. One or more of them would be the first to pick up the radio signal showing that the payload had circled the globe. General Medaris has described with understandable feeling the moment when "someone came up and shoved a piece of paper in my hands on which were these magic words: Goldstone has the bird."

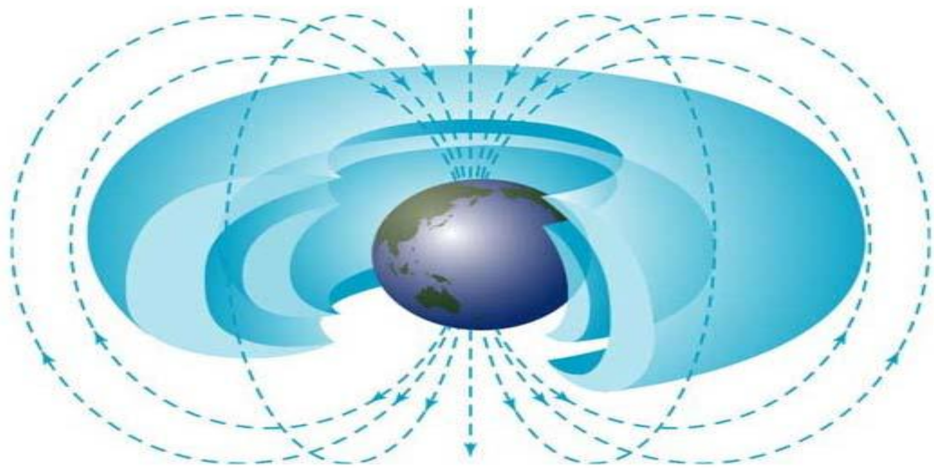
This meant that at 12:51 a.m., 1 February 1958-one hour and fifty-three minutes after liftoff-a newly installed tracking station in California had picked up the satellite "on its first trip back around over the United States." The big headlines in that mornings newspapers invoked an all but audible sigh of relief across the country. The challenge of the Russian Sputniks had been met. America's first artificial satellite, Explorer I, was orbiting the earth.



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

The science instruments on Explorer I consisted of a cosmic ray detector, internal and external temperature sensors, a micrometeorite impact detector, and instruments to determine micrometeorite erosion. 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 a much lower cosmic ray count than expected. Van Allen theorized that the instrument may have been saturated by very strong radiation from a belt of charged particles trapped in space by Earth's magnetic field. The existence of these radiation belts was confirmed by another U.S. satellite launched two months later, and they became known as the Van Allen Belts in honor of their discoverer.



Explorer 1 revolved around Earth in a looping orbit that took it as close as 354 kilometers (220 miles) to Earth and as far as 2,515 kilometers (1,563 miles). It made one orbit every 114.8 minutes, or a total of 12.54 orbits per day. The satellite itself was 203 centimeters (80 inches) long and 15.9 centimeters (6.25 inches) in diameter. Explorer 1 made its final transmission on May 23, 1958. It entered Earth's atmosphere and burned up on March 31, 1970, after more than 58,000 orbits. The satellite weighed 14 kilograms (30.8 pounds).

Sputnik 2 and 3

The foremost practical outcome of their cooperative labors was that the American tracking teams were ready when on 3 November 1957 the Russians sent their second satellite, Sputnik II, into orbit.

Unlike its predecessor, the second Soviet moon was not a special device, orbiting apart from its carrier. It was the last stage of the launching vehicle. Circling the world once every 103.7 minutes, Sputnik II had an apogee of 1,038 miles, a perigee of 140 miles. It remained in space 162 days, falling into the earth's atmosphere on 14 April 1958. Weighing at least 1,120 pounds, it carried the 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 biomedical effect of space travel on animal life, solar influence on upper atmosphere densities, and the shape of the earth.

This time the satellite weighed 508.3 kilograms. Biological data was returned for approximately a week (the first data of its kind). The data showed scientists how Laika was adapting to space -- information important to the human missions already being planned. There was no safe re-entry possible at the time, so Laika was put to sleep. The satellite itself remained in orbit 162 days.

The third Sputnik satellite was launched on April 27, 1958, but it failed to reach orbit. It was destroyed 88 seconds after launch. It was not given a numeric designation.

Sputnik 3 was launched on May 15, 1958. It was designed to be a geophysical laboratory, performing experiments on the Earth's magnetic field, radiation belt, and ionosphere. It weighed 1,327 kilograms. The data was used as part of the International Geophysical Year efforts. The satellite orbited Earth and transmitted data until April 6, 1960. However, its tape recorder failed rendering it unable to map the Van Allen belts.

CHAPTER 6

Human Spaceflight

Vostok:

In the spring of 1957 the Soviets organized project section 9 to design new spacecraft. Simultaneous with this they were building the first earth satellites - the PS-1, PS-2 and Object D (which would be Sputniks 1, 2, and 3). By April they had completed a research plan to build a piloted spacecraft and a robotic lunar probe, using the R-7 as the basis for the launch vehicle. Studies indicated that the R-7 with a third stage could lift 5 tons into low earth orbit.

The human-rated spacecraft work led them into new fields of research in re-entry, thermal protection, and hypersonic aerodynamics. The initial study material was reviewed by mathematicians at the Academy of Science. It was found that a maximum of 10 G's would result in a ballistic re-entry from earth obit. From September 1957 to January 1958 section 9 examined heating conditions, surface temperatures, heat shield materials, and obtainable maximum payloads for a wide range of aerodynamic forms with hypersonic lift to drag ratios ranging from zero to a few points. Parametric trajectory calculations were made using successive approximations on the BESM-1 electromechanical computer.

It was found that the equilibrium temperatures for winged spacecraft with the highest L/D ratios (lift-to-drag) exceeded the capability of available heat resistant alloy construction methods. These designs also had the lowest net payloads. The final conclusion was:

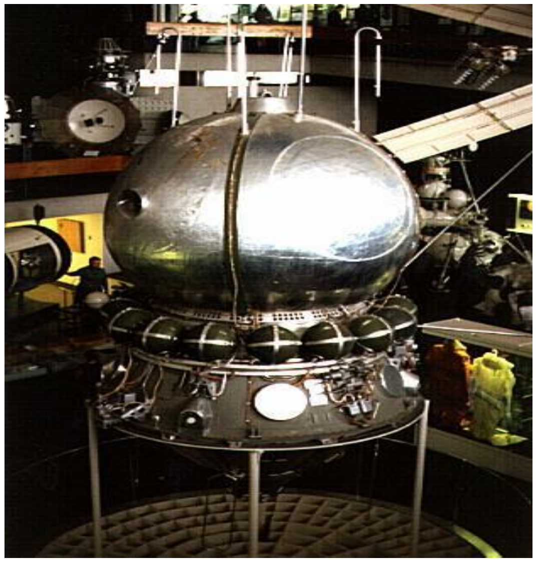
- L/D ratio should be greater than zero, between 0.0 to 0.5 G's, in order to provide body lift and reduce the G forces a pure ballistic re-entry would inflict on the human passenger
- The spacecraft form should be a cone with a rounded nose and spherical base, with a maximum diameter of 2.0 m - the 'headlight' shape later used for the Soyuz capsule.
- The pilot would eject at a few kilometers altitude after re-entry and land by parachute. The capsule would not be recovered.

The necessity to refine and qualify the lifting design seemed a major impediment to meeting a quick program schedule. Then in April 1958 aviation medicine research using human subjects in a centrifuge showed that pilots could endure up to 10 G's without ill effects. This allowed a pure ballistic design, removing a major stumbling block, and allowing the study to move quickly to the advanced project stage. Detailed design of the spacecraft layout, structures, equipment, and materials were all done in parallel. This required everything to be redesigned 2 to 3 times, but resulted in a quick final design. The advance project was completed by the middle of August 1958.

After selection of the ballistic concept, the shape of the re-entry vehicle had to be symmetrical. A sphere was the simplest such form, having the same aerodynamic characteristics at all angles of attack and all velocities. By putting the center of mass aft of the center of the sphere, the re-entry vehicle would naturally assume the correct orientation for re-entry.

Redundancy of all systems became a new strategic design principle for this first human spacecraft. The final report 'Material on the research question of a manned Sputnik' (OD-2) gave the following flight characteristics:

- Mass 4,500 - 5,500 kg, launched by a three stage version of the R-7 into a circular orbit with a minimum altitude of 250 km
- Payload of a single human, life support supplies, and scientific equipment
- Spherical ballistic re-entry capsule, with a 2500 to 3500 deg C surface temperature on re-entry, 8 to 9 G's maximum load, with a resulting heat shield mass of 1300 to 1500 kg
- 65,000 to 85,000 kgf-sec re-entry burn
- Minus 2 degree re-entry angle at 100 km altitude
- Landing accuracy plus 175 km / minus 100 km from aim point
- Pilot to eject from capsule at 8 to 10 km altitude
- Insulation to keep acoustic and vibration levels within cabin to tolerable levels
- Assumption that pilot will not control spacecraft in first flight
- Orientation control system using cold gas jets and flywheels
- Limited avionics: orientation control system, guidance command processor, redundant voice radio
- Orbital flight equipment and deorbit braking rocket contained in a separate module from re-entry vehicle



Development program:

- Test stands in the factory
- Ejection seat test from aircraft and R-2, R-5, or R-7 core launch vehicles
- Sub-scale heat shield tests
- Instrumented full size prototype flights
- Two flights with mannequins

On 10 December 1959 a decree setting forth the work on the first human spacecraft was issued. In April 1960 the draft project was completed. This defined the various versions of the spacecraft to be produced:

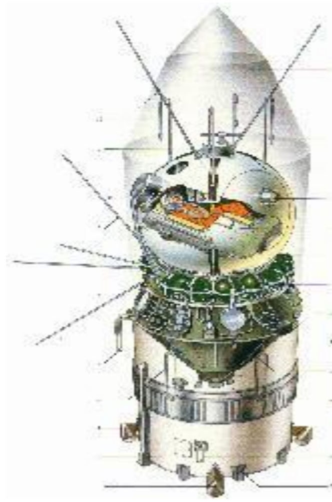
- Vostok-1 (1K) prototype spacecraft to test basic systems and prove the concept
- Vostok-2 (2K) photo-reconnaissance spacecraft, designed for lower resolution route surveys and signals intelligence. This was later redesigned the Zenit-2.
- Vostok-3 (3K) manned spacecraft

The Vostok crew accommodation was for 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, equipped with the Vzor optical device for orientation of the spacecraft. Attitude control was by cold gas thrusters for on-orbit orientation; passive control for the capsule during re-entry.

A single parachute allowed recovery of the capsule. There was no soft-landing system; the pilot ejected for a separate landing under his own parachute. Instrumentation on the Vostoks was rudimentary in the extreme. There were no gyros and no eight-ball for maneuvering as on Mercury or Gemini. To decide when to re-enter, the cosmonaut had a little clockwork globe that showed current position over the earth. By pushing a button to the right of the globe, it would be advanced to the landing position assuming a standard re-entry at that moment.

The spherical design itself was ingenious - it has no maneuvering engines to orient it, since it is like a ball with the heavy weight concentrated at one end - if you throw it in the air (or re-enter the atmosphere with it) it will automatically swing around with the heavy end downward. The only problem is that it is only capable of a purely ballistic re-entry, which means 8 G's for the occupant from earth orbit and 20 G's from the moon. Mercury was ballistic, but Gemini, Apollo, and Soyuz all had the center of gravity offset, so they could produce lift, lower the G forces, and maneuver somewhat to vary the landing point. This reduced G's to 3 G for earth orbit returns and 8 G's for lunar returns.

First human spacecraft. Derivatives were still in use over thirty years later, for military photo-reconnaissance, earth resources, mapping, and biological missions.



Construction drawings were issued beginning in the fall of 1958. The official decree to begin development was issued only on 22 May 1959. From the end of 1960 six uncrewed Vostok variants were launched. The military developed the recovery forces and techniques, including appropriate aircraft, helicopters, and handling equipment. At that time it was felt that there was a 60% chance on each launch of an abort requiring rescue operations for the cosmonaut.

The Vostok and Voskhod spacecraft, like the US Mercury, could not perform orbital maneuvers - they could only be translated around their axes. The main engine was not restartable and was used only at the end of the mission for the re-entry braking maneuver. Instrumentation on the Vostoks was rudimentary in the extreme. There was no gyro platform and no eight-ball for maneuvering as on Gemini. The re-entry maneuver was normally handled automatically by radio command. The spacecraft was oriented horizontally using infrared sensors. Alignment along the orbital axis was made using sun and star sensors.

In the event of failure of the automatic systems, the cosmonaut could take manual control of the spacecraft. This was done by using the ingenious Vzor periscope device mounted on the floor of the cabin. This had a central view and eight ports arranged in a circle around the center. When the spacecraft was perfectly centered in respect to the horizon, all eight of the ports would be lit up. Alignment along the orbit was judged by getting lines on the main scope to be aligned with the landscape flowing by below. In this way, the spacecraft could be oriented correctly for the re-entry maneuver.

The Soviet Union launched a Vostok 1KP prototype human spacecraft (without heat shield; not recoverable) into near-earth orbit. Called Sputnik IV by the Western press. On May 19, at 15:52 Moscow time, the spacecraft was commanded to retrofire. However the guidance system had oriented the spacecraft incorrectly and the TDU engine instead put the spacecraft into a higher orbit. Soviet scientists said that conditions in the cabin, which had separated from the remainder of the spacecraft, were normal.

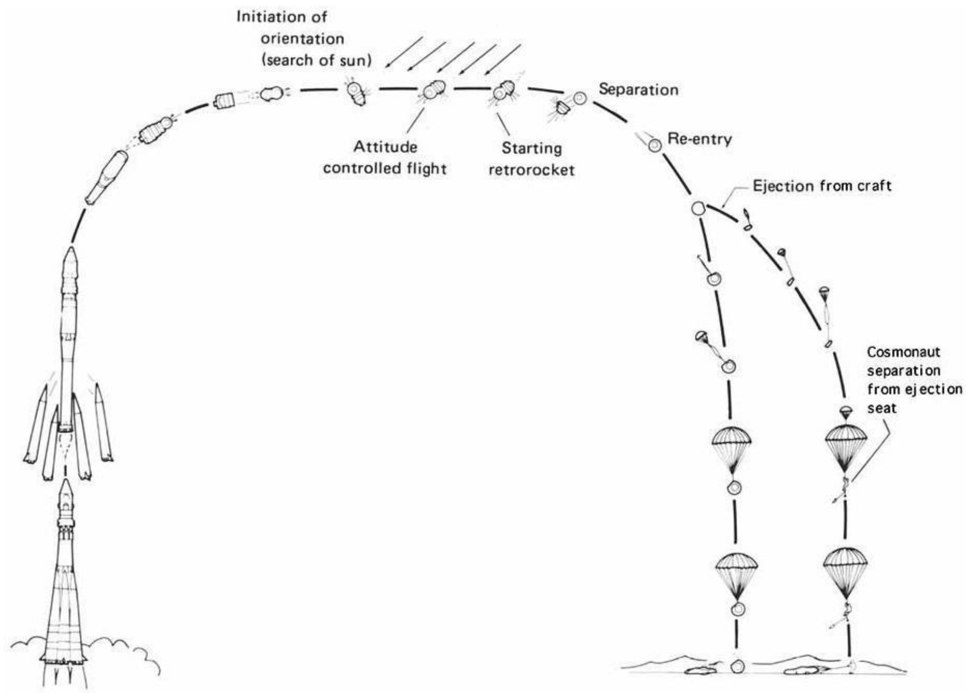
The Soviet Union launched its second test of the Vostok spacecraft, the Korabl Sputnik II, or Sputnik V. The spacecraft carried two dogs, Strelka and Belka, in addition to a gray rabbit, rats, mice, flies, plants, fungi, microscopic water plants, and seeds. Electrodes attached to the dogs and linked 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 and biological specimens were reported to be in good condition.

The Soviet Union launched its third spaceship satellite, Korabl Sputnik III, or Sputnik VI. The spacecraft, similar to those launched on May 15 and August 19, carried the dogs Pcheka and Mushka in addition to other animals, insects, and plants. Deorbited December 2, 1960 7:15 GMT. Burned up on reentry due to steep entry angle (retrofire engine did not shut off on schedule and burned to fuel depletion).

Cosmonaut candidates began training in March 1960, and the original group of official cosmonauts was selected in May. The group included Anatoly Kartashov, Yuri Gagarin, Andriyan Nikolayev, Pavel Popovich, Gherman Titov and Valentin Varlamov. A lot of regrouping went on before the final Vostok missions.

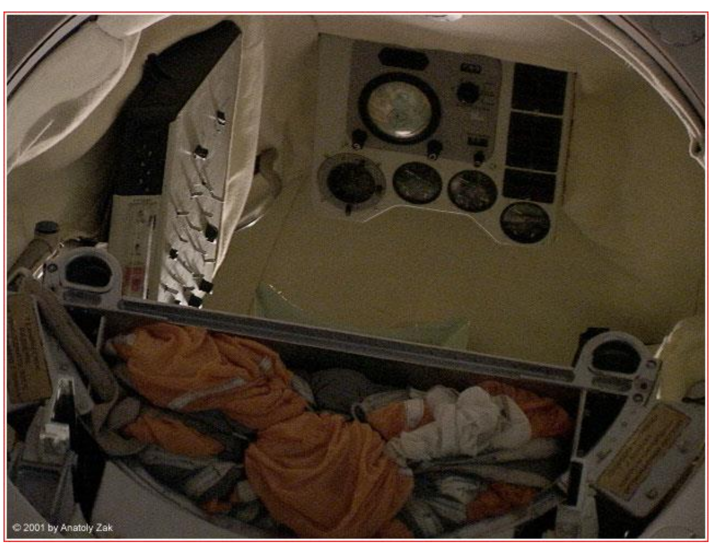
The Soviet Union accomplished the feat of placing the first human in space with the launch of Yuri Gagarin on April 13, 1961 in the Vostok 1 spacecraft. Three press releases were prepared, one for success, two for failures. It was only known ten minutes after burnout, 25 minutes after launch, if a stable orbit had been achieved. The payload included life-support equipment and radio and television to relay information on the condition of the pilot.

The flight was automated; Gagarin's controls were locked to prevent him from taking control of the ship. A key was available in a sealed envelope in case it became necessary to take control in an emergency. After retrofire, the service module remained attached to the Sharik reentry sphere by a wire bundle. The joined craft went through wild gyrations at the beginning of reentry, before the wires burned through. The Sharik, as it was designed to do, then naturally reached aerodynamic equilibrium with the reentry shield positioned correctly.



Typical mission profile for Vostok flights.

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 as long as 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 adaptability to weightlessness.



The Vostok class of space capsule incorporated many features that would be used by all the major spacefaring countries for the next 20 years or so. The capsule consisted of two sections, a crew section and a service module. The crew section was a spherical compartment that was designed to separate from the service module for reentry. Once in the atmosphere, the crew module would deploy a set of parachutes to slow its decent. Most Russian built space vehicles of the time were designed to touch down on land after their missions. Although his landing was rough, Major Gagarin suffered no injuries upon reentry.

Vostok 1 Specifications:

- Length: 6.7 meters
- Diameter: 4.3 Meters
- Mass: 4734.5 kg
- Propulsion: Chemical
- Duration: 12 days
- Crew: 1

Mercury Program:

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 feasibility of human space flight. Implementation was initiated to establish a national human space-flight project, later named Project Mercury, on October 7, 1958.

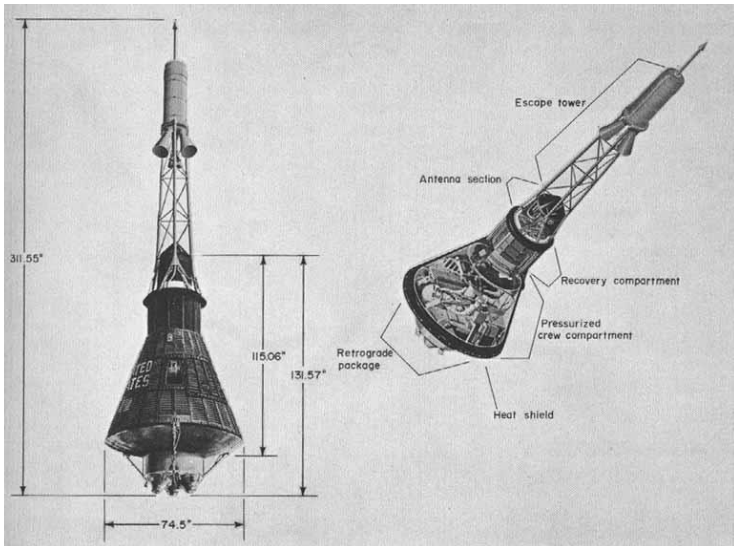
The United States' first human space flight project was successfully accomplished in a 4 2/3 year period of dynamic activity which saw more than 2,000,000 people from many major government agencies and much of the aerospace industry combine their skills. initiative, and experience into a national effort. In this period, six crewed space flights were accomplished as part of a 25-flight program. These crewed space flights were accomplished with complete pilot safety and without change to the basic Mercury concepts. It was shown that man can function ably as a pilot-engineer-experimenter without undesirable reactions or deteriorations of normal body functions for periods up to 34 hours of weightless flight.

The objectives of the Mercury Project, as stated at the time of project go-ahead, were as follows:

- Place a manned spacecraft in orbital flight around the earth.
- Investigate man's performance capabilities and his ability to function in the environment of space.
- Recover the man and the spacecraft safely.

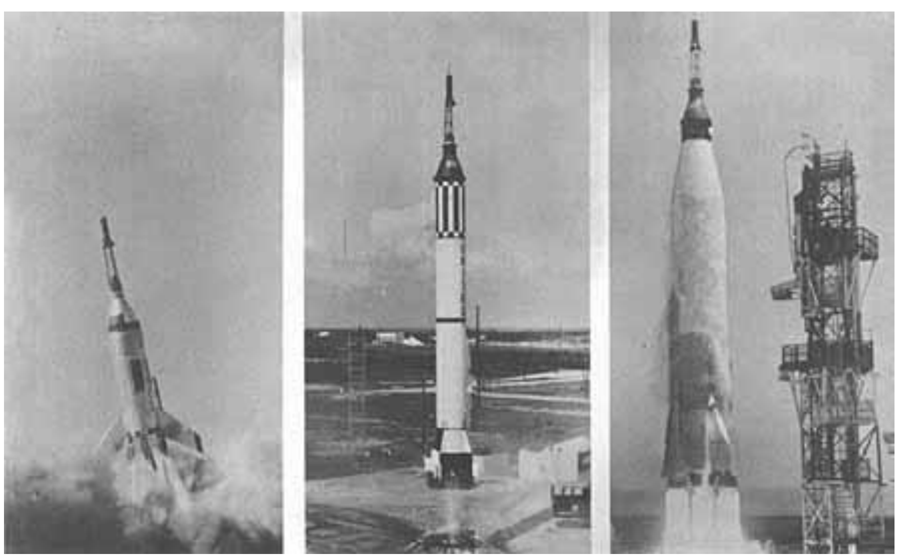
After the objectives were established for the project, a number of guidelines were established to insure that the most expedient and safest approach for attainment of the objectives was followed. The basic guidelines that were established are as follows:

- Existing technology and off-the-shelf equipment should be used wherever practical.
- The simplest and most reliable approach to system design would be followed.
- An existing launch vehicle would be employed to place the spacecraft into orbit.
- A progressive and logical test program would be conducted.



More detailed requirements for the spacecraft were established as follows:

- The spacecraft must be fitted with a reliable launch-escape system to separate the spacecraft and its crew from the launch vehicle in case of impending failure.
- The pilot must be given the capability of manually controlling spacecraft attitude.
- The spacecraft must carry a retrorocket system capable of reliably providing the necessary impulse to bring the spacecraft out of orbit.
- A zero-lift body utilizing drag braking would be used for reentry.
- The spacecraft design must satisfy the requirements for a water landing.



There are three primary types of tests included in these, one type being the research-and-development tests, another being primarily flight qualification of the production spacecraft, and the third being the human orbital flight tests. In addition, the tests with the Mercury-Redstone launch vehicle provided some early ballistic flights for pilot training. Involved in the planned flight-test program were four basic types of launch vehicles, the Little Joe, the Mercury-Redstone, the Mercury-Jupiter, and the Mercury-Atlas.

Little Joe 1. The flight test program was initiated with the Little Joe 1 research-and-development mission that was scheduled for July of 1959. The actual launch attempt came in the following month, on August 21, at the NASA launch site, Wallops Station, Va. A nearly catastrophic failure occurred at a time late in the launch countdown as the vehicle battery-power supply was being charged. At this time,the escape-rocket sequence was unintentionally initiated and the spacecraft was separated from the launch vehicle and propelled into the air as in a pad-abort sequence. The escape sequence was accomplished correctly, though initiated by a fault. The tower was jettisoned properly, the drogue parachute was deployed as it should have been, but the main parachute deployment circuitry was not activated because of a lack of sufficient electrical power. The spacecraft was destroyed on impact with the water. The cause of the failure was determined by detailed analysis to be a "backdoor" circuit which permitted the launch-escape system to be activated when a given potential had been supplied to the battery by ground charging equipment. The launch vehicle, though fully loaded with six solid-propellant rocket motors, was left undamaged on the launcher.

Big Joe 1. Spacecraft checkout for the launch of Big Joe 1 was accomplished at the Cape Canaveral launch site starting in June of 1959. The primary purpose of the flight was to investigate the performance of the ablation heat shield during reentry, as well as to investigate spacecraft reentry dynamics with an instrumented boilerplate spacecraft. Other items that were planned for investigation on this flight were afterbody heating for both the exit and reentry phases of flight, drogue and main parachute deployment, dynamics of the spacecraft system with an automatic control system in operation, flight loads, and water-landing loads.

Recovery aids, such as SOFAR bombs, radio beacons, flashing light, and dye markers, had been incorporated. This spacecraft was not equipped with all escape system. The mission was accomplished on September 9, 1959. Because of the failure of the Atlas booster engines to separate, the planned trajectory was not followed exactly, but the conditions which were achieved provided a satisfactory fulfillment of the test objectives. The landing point of the spacecraft was about 1,300 nautical miles from the lift-off point, which was about 500 nautical miles short of the intended landing point. Even so, the recovery team retrieved the spacecraft about 7 hours after landing.

Little Joe 2. The Little Joe 2 mission, which was intended to validate the proper operation of the spacecraft for a high altitude abort, was accomplished on December 4, 1959, from the Wallops Stationlaunch site. The abort sequence was initiated at an altitude of almost 100,000 feet and approximated a possible set of abort conditions that could be encountered during a Mercury-Atlas exit flight to orbit. In addition to the first-order objectives, the spacecraft reentry dynamics behavior without a control system was found to be satisfactory.

The spacecraft dynamic stability on descent through the atmosphere was found to be as expected. Additional information was obtained on the operation of the Mercury parachute, the Mercury spacecraft flotation characteristics, and the operational requirements of spacecraft recovery by surface vessels. A monkey was a passenger on this mission; both the monkey and the spacecraft were recovered in satisfactory condition at the end of the mission.

Mercury-Atlas 1. The Mercury-Atlas 1 (MA-1) vehicle was launched from the Cape Canaveral test site on July 29, 1960. The primary purpose of the MA-1 flight was to test the structural integrity of n production Mercury spacecraft and its heat-protection elements during reentry from an exit abort condition that would provide the maximum heating rate on the after body of the spacecraft. The spacecraft involved was production item 4 and was equipped with only those systems which were necessary for the mission. An escape system was not provided for this spacecraft.

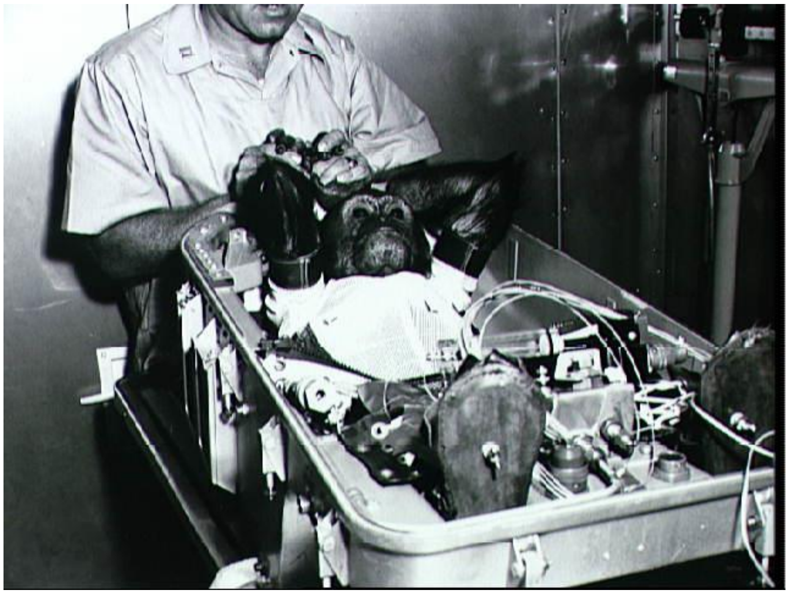
The mission failed about 60 seconds after lift-off. The spacecraft and launch vehicle impacted in the water east of the launch complex. Because of this failure, an intensive investigation into the probable causes was undertaken. As a result of this investigation modifications were made to the interface area between the launch vehicle and the spacecraft to increase the structural stiffness. This inflight failure and subsequent intensive investigation resulted in a considerable delay in the launch schedule and the next Mercury-Atlas launch was not accomplished until almost 7 months later.

Mercury/Redstone 1 and 1A. The Mercury-Redstone 1 (MR-1), which was to provide qualification of a nearly complete production spacecraft number 2, in flight with a Mercury-Redstone launch vehicle, was attempted on November 21, 1960, at the Cape Canaveral launch site. The mission was not successful. At lift-off, the launch-vehicle engine was shut down and the launch vehicle settled back on the launcher after vertical motion of only a few inches. The spacecraft also received the shutdown signal and its systems reacted accordingly. The escape-rocket system was jettisoned and the entire spacecraft landing system operated as it had been designed. Analysis of the cause of malfunction showed the problem to have been caused by failure of two ground umbilicals to separate from the launch vehicle in the proper sequence. In the wrong sequence, one umbilical provided an electrical path from launch-vehicle power through blockhouse ground and the launch-vehicle engine cut-off relay coil to launch-vehicle ground that initiated the cut-off signal.

Except for loss of expendable items on the spacecraft, such as the escape system and the parachutes and the peroxide, the spacecraft was in flight condition. The launch vehicle was slightly damaged in the aft section by recontact with the launcher The spacecraft and launch vehicle were demated. The launch vehicle was replaced by another Mercury-Redstone launch vehicle, and the spacecraft was again prepared for its mission. Modifications included a long ground strap that was placed between the launch vehicle and the launcher to maintain electrical ground until umbilicals had been separated. The refurbished spacecraft and new Mercury-Redstone launch vehicle were launched successfully as mission MR-1A on December 19,1960. At this time, all test objectives were met. All major spacecraft systems performed well [8] throughout the flight. The launch-vehicle performance was normal except for a higher shall nominal cut-off velocity. The only effects of this anomaly were to increase the range, maximum altitude, and maximum acceleration during reentry. The spacecraft was picked up by a helicopter 15 minutes after landing and was delivered back to the launch site on the morning after the launch.

Mercury-Redstone 2. The MR-2 mission was accomplished on January 31, 1961 from the Cape Canaveral test site with a chimpanzee as a passenger. Production spacecraft 5 was used. The mission was successful and the majority of the test objectives were met. Analysis of launch-vehicle data obtained during the flight revealed that launch-vehicle propellant depletion occurred before the velocity cut-off system was armed and before the thrust chamber abort switch was disarmed.

This combination of events resulted in an abort signal being transmitted to the spacecraft from the launch vehicle. The spacecraft reacted correctly to the abort signal and an abort sequence was properly made. The greater than normal launch-vehicle velocity combined with the velocity increment obtained unexpectedly from the escape-rocket motor produced a flight path that resulted in a landing point about 110 nautical miles farther downrange than the planned landing point. This extra range, of course, was the prime factor in the 2 hours and 56 minutes that it took to locate and recover the spacecraft.

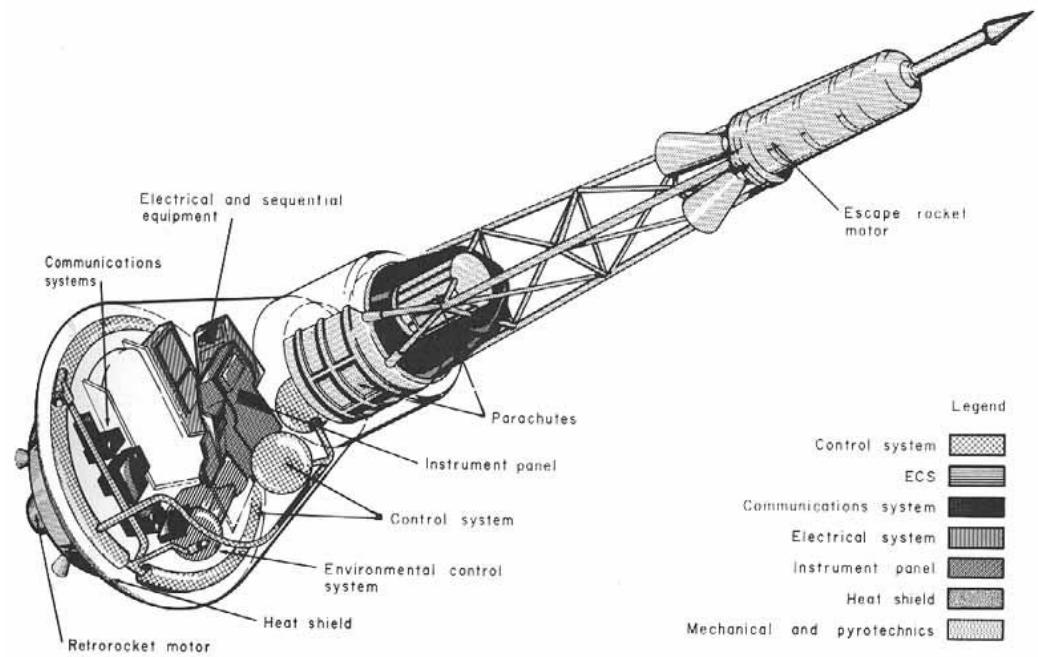


The chimpanzee was recovered in good condition, even though the flight had been more severe than planned. By the time the spacecraft was recovered, it had nearly filled with water. Some small holes had been punctured in the lower pressure bulkhead at landing. Also, the heat-shield retaining system was fatigued by the action of the water and resulted in loss of the heat shield. Another anomaly that occurred during the flight was the opening of the spacecraft cabin inflow valve during ascent, which prevented the environmental control system from maintaining pressure at the design level. Because the pressure dropped below the design level, the emergency environmental system was exercised, and it performed satisfactorily. From the experiences of this flight, a number of modifications were made to the spacecraft systems to avoid recurrence of the malfunctioning items.

Flight A members for the Mercury program were selected based on the following criteria:

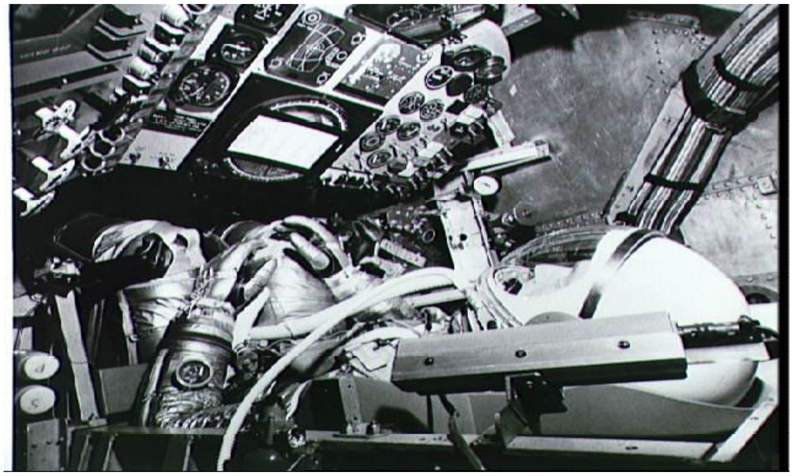
- High IQ
- Good engineering knowledge and education
- Knowledge of opertaional and flight-test procedures
- Scientific knowledge and research skills
- Psychomotor skills required for flying high-preformance aircraft
- Good stress tolerance
- Good decision-making abilities
- Ability to work both as an individual and as a team member
- Emotional maturity
- Freedom from disease or disabilities
- resistance to the physical stresses of space flight
- Medium height and weight

Seven 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: Capts. Leroy G. Cooper, Jr., Virgil I. Grissom, and Donald K. Slayton, (USAF); Lt. Malcolm S. Carpenter, Lt. Comdr. Alan B. Shepard, Jr., and Lt. Comdr. Watler M. Schirra, Jr. (USN); and Lt. Col. John H. Glenn (USMC).

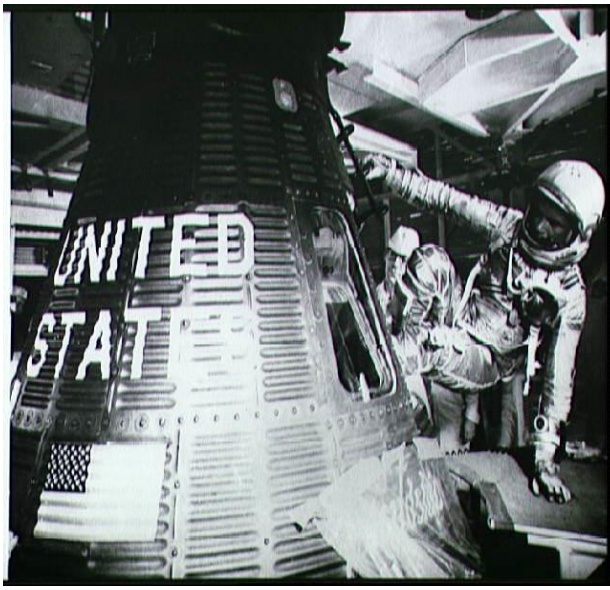


Mercury-Redstone 3. The Mercury-Redstone 3 (MR-3) mission, the first human space flight by the United States, was successfully accomplished on May 5, 1961, from the Cape Canaveral launch site. Astronaut Alan B. Shepard was the pilot. The space vehicle was composed of production spacecraft 7 and a Mercury-Redstone launch vehicle, which was essentially identical to the one used for the MRBD launch-vehicle qualification mission. Analysis of the results of the mission showed that Astronaut Shepard satisfactorily performed his assigned tasks during all phases of the flight. Likewise, launch vehicle and spacecraft systems performed as planned. The spacecraft achieved an altitude of about 101 nautical miles and was in weightless flight for slightly over 5 minutes.

Postflight examination of Astronaut Shepard and inspection of the spacecraft showed both to be in excellent condition. A helicopter pickup was made of the spacecraft after the pilot had made his egress from the side hatch of the spacecraft and had been hoisted aboard the helicopter. The pilot and the spacecraft were landed aboard an aircraft carrier 11 minutes after spacecraft landing, and the spacecraft was brought back to the launching site the morning after the flight.



Mercury-Redstone 4. The Mercury-Redstone 4 (MR-4) flight was successfully made on July 21,1961, from the Cape Canaveral launch site. Astronaut Virgil I. Grissom was the pilot. The space vehicle was made up of the 11th production spacecraft and a Mercury-Redstone launch vehicle essentially identical to the one used for MR-3 mission. The spacecraft on this mission was somewhat different from spacecraft 7, in that, for the first time, a crewed spacecraft had a large top window, a side hatch to be opened by an explosive charge, and a modified instrument panel. The spacecraft achieved a maximum altitude of about 103 nautical miles, with a period of weightlessness of about 5 minutes. The flight was successful. After landing, premature and unexplained actuation of the spacecraft explosive side hatch resulted in an emergency situation in which the space craft was lost but the pilot was rescued from the surface of the water. Analysis of the data from the flight and debriefing by the astronaut indicated that, in general, the spacecraft systems performed as planned, except for the action of the spacecraft hatch. An intensive investigation of the hatch actuation resulted in a change in operational procedures. No fault was found in the explosive device.



Mercury-Atlas 6. Mercury-Atlas 6 (MA-6), the first crewed orbital space flight made from the United States, was successfully made on February 20, 1962, from the Cape Canaveral test site. Astronaut John H. Glenn, Jr., was the pilot. The flight was planned for three orbital passes to evaluate the performance of the human spacecraft systems and to evaluate the effects of space flight on the astronaut and to obtain the astronaut's evaluation of the operational suitability of his spacecraft and supporting systems. All mission objectives for this flight were accomplished. The astronaut's performance during all phases of the mission was excellent, and no deleterious effects of weightlessness were noted. In general, the spacecraft, launch vehicle, and network system functioned well during the mission.

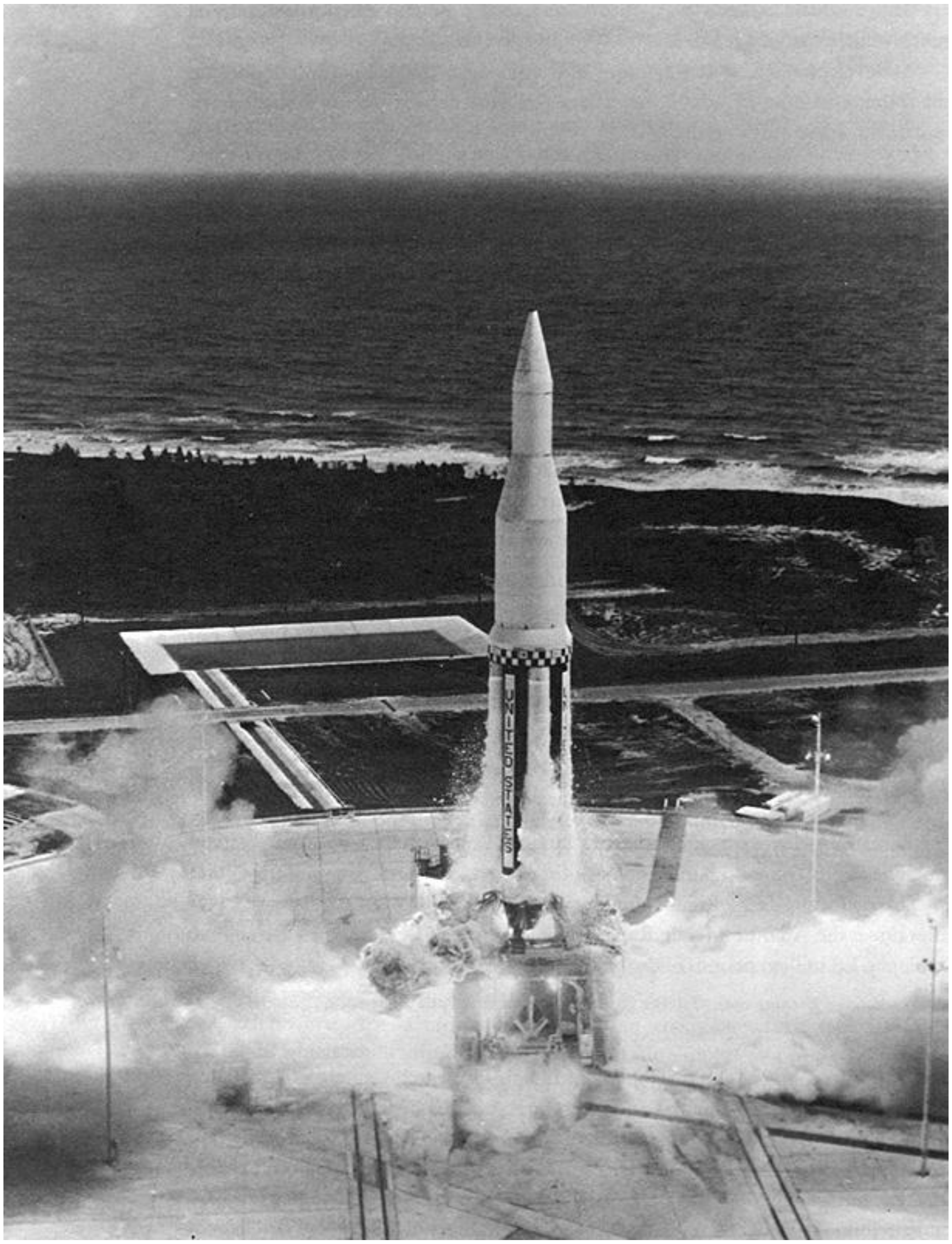
The main anomaly in spacecraft operation was the loss of thrust of two of the 1-pound thrusters which required the astronaut to control the spacecraft for a large part of the mission manually. The orbit was approximately as planned, with perigee at 86.9 nautical miles and apogee at 140.9 nautical miles. During the second and third passes, a false indication from a sensor indicated that the spacecraft heat shield might be unlocked. This indication caused considerable concern and real-time analysis resulted in the recommendation that the expended retro package be retained on the spacecraft during reentry at the end of the third pass to hold the heat shield in place in the event it was unlatched. The presence of the retropackage during reentry had no detrimental effect on the motions of the spacecraft. Network operation, including telemetry reception, radar tracking, communications, command control, and computing, were excellent and permitted effective flight control during the mission.

The spacecraft for this mission was production unit number 13 which was essentially the same as spacecraft 9 used in the MA-5 mission except for those differences required to accommodate the pilot such as the couch, a personal equipment container, filters for the window, and some minor instrumentation and equipment modifications. The launch vehicle was Atlas 109-D. It differed from the MA-a launch vehicle in only one major respect. For this launch vehicle, the insulation and its retaining bulkhead between the lox and fuel tank dome was removed when it was discovered that fuel had leaked into this insulation prior to launch. The spacecraft landed in the planned recovery area, close to one of the recovery ships. The spacecraft, with the astronaut inside, was recovered approximately 17 minutes after landing. The astronaut was in excellent shape.

An examination of the history of the major flight tests will show that the basic objectives of the Mercury Project were achieved 3 1/3 years after official project approval, with the completion of Astronaut John Glenn's successful orbital flight on February 20, 1962. Subsequently, Astronaut Carpenter completed a similar mission. Then, Astronauts Schirra and Cooper completed orbital missions of increased duration to provide additional information about man's performance capabilities and functional characteristics in the space environment. In addition, increasing numbers of special experiments, observations, and evaluations performed during these missions by the pilots as their capabilities were utilized have provided our scientific and technical communities with much new information. It is emphasized that goals beyond those originally established were achieved in a period of 4 2/3 years after the beginning of the project with complete pilot safety and without change to the basic concepts that were used to establish the feasibility of the Mercury Project.

Chapter 7

The Saturn 5 and Apollo



Saturn I:

The Saturn series of launch vehicles are large-scale rockets developed for NASA's Apollo lunar landing program. This type of rocket was originally proposed by Wernher Von Braun in 1957, who at that time was assigned to the Army Ballistic Missile Agency (ABMA). Following its establishment in 1958, Von Braun and other U.S. Army scientists were transferred to NASA, with the Saturn rocket development program subsequently becoming a NASA endeavor.

The Saturn IB launch vehicle was conceived in 1962 at the NASA Marshall Space Flight Center as the quickest, most reliable, and most economical means of providing a booster with greater payload capability than the Saturn I. The new launch vehicle would be used for earth orbital missions with the Apollo spacecraft before the Saturn V lunar launch vehicle would be available.

The initially developed Saturn I adopted clusters of 8 engines essentially the same as used in the Jupiter rocket. Test firing of the Saturn I began in 1961. From 1966, the Saturn IB was developed, incorporating the hydrogen fuel J-2 engine for the rocket second stage. Saturn IB, including the spacecraft and tower, stands approximately 224 feet tall, and is about 21.7 feet in diameter. Total weight empty is about 85 tons, and liftoff weight fully fueled, will be approximately 650 tons. First-stage flight is powered by eight H-1 engines generating 200,000 pounds of thrust each, for a total of 1.6 million pounds. In approximately 2.5 minutes of operation, it will burn 41,000 gallons of RP-1 fuel and 66,000 gallons of liquid oxygen, to reach an altitude of approximately 42 miles at burnout. H-1 engines for later S-IB vehicles will be uprated to 205,000 pounds of thrust each.

SA-201 lifted off from SLC34 on 2/26/1966. NASA called the successful 39 minute suborbital mission Apollo-Saturn (AS) 201. The S-IVB J-2 engine and the Apollo Service Module engine both worked well on this, their first flight. Saturn accelerated Apollo to 29,000 kilometers per hour, pushing it to a 488 km apogee. The CM splashed down 8,472 km downrange, east of Ascension Island. Problems with CSM-011 delayed the next planned Saturn 1B mission, which used booster SA-202, so SA-203 was launch first. SA-203, flying the AS-203 mission, was an extended orbital test of the S-IVB stage. An aerodynamic shroud topped off the SLA in place of a CSM.

Crews stacked SA-203 on refurbished LC37B beginning in April. By June, SA-203 was joined by SA-202, standing on nearby LC34, and, several miles to the north, SA-500F, the Saturn V facilities checkout vehicle, standing on LC39A. SA-203 lifted off on July 5 and performed a perfect four-orbit mission in a 185 x 189 km orbit. The AS-202 mission, another successful suborbital flight, finally took place on August 25. This time, the CSM apogee was 1,143 km and the spacecraft nearly completed one orbit before it splashed down in the Pacific Ocean.

NASA declared Apollo-Saturn 1B ready for crewed flight. At LC34, SA-204 was prepared for the first crewed Apollo mission, which was to be called AS-204. CSM-012 was stacked and tested. On January 27, 1967, however, a flash fire in the capsule during the final countdown demonstration test killed astronauts Grissom, White, and Chaffee.

The disaster halted crewed Apollo flights for 21 months and stunted the Saturn 1B program. The SA-204 vehicle was de-stacked, stored, and, eventually, restacked on LC37B, where it stood for months waiting for delayed LM-1. The rocket did not fly until January 22, 1968, when it carried LM-1 into orbit beneath another aerodynamically-shrouded SLA on the Apollo 5 mission. SA-204 injected LM-1 into an initial 222 x 163 km orbit. The LM descent engine fired for the first time, followed by the ascent engine. After the ascent burn, LM-1 was left in a 961 x 172 km orbit. The entire mission was complete after four orbits.

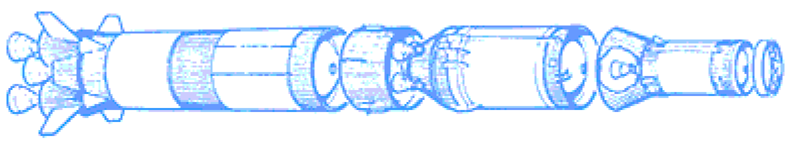
SA-205 finally carried the first crewed Apollo 7 mission aloft from LC34 on 10/11/1968. Onlookers did not know at the time that SA-205 would be the last Saturn I launched from Cape Canaveral. The rocket boosted CSM-101 into a 140 x 183 mi orbit.

Astronauts Walter Schirra, Don Eisele, and Walter Cunningham orbited the earth 163 times in Apollo 7 during a 10 day 20 hour mission before landing near Bermuda in the Atlantic.

The Saturn IB version was also used to launch the crews of the Skylab 2,3 and 4 missions in 1972 and 73, and for the Apollo-Soyuz Program carried out jointly with the Soviet Union in 1975. The most famous of the Saturn Missiles is the Saturn V, that launched man to the moon.

Saturn V:

When the United States made the decision in 1961 to undertake a human lunar landing effort as the focal point of a broad new space exploration program. there was no rocket in the country even approaching the needed capability. There was a sort of "test bed" in the making, a multi-engine vehicle now known as Saturn I. It had never flown. And it was much too small to offer any real hope of sending a trio to the moon, except possibly through as many as a half dozen separate launchings from earth and the perfection of rendezvous and docking techniques, which had never been tried.



That was the situation that brought about the announcement on Jan. 10, 1962, that the National Aeronautics and Space Administration would develop a new rocket, much larger than any previously attempted. It would be based on the F-1 rocket engine. the development of which had been underway since 1958. and the hydrogen-fueled J-2 engine, upon which work had begun in 1960.

The Saturn V then, is the first large vehicle in the U.S. space program to be conceived and developed for a specific purpose. The lunar landing task dictated the make-up of the vehicle, but it was not developed solely for that mission. As President Kennedy pointed out when he issued his space challenge to the Congress on May 25, 1961, the overall objective is for "this Nation to take a clearly leading role in space achievement which in many ways may hold the key to our future on earth." He said of the lunar landing project: "No single space project in this period will be more exciting. or more impressive to mankind, or more important for the long-range exploration of space; and none will be so difficult or expensive to accomplish... "

The Saturn V program is the biggest rocket effort undertaken in this country. Its total cost, including the production of 15 vehicles between now and early 1970 will be above $7 billion.

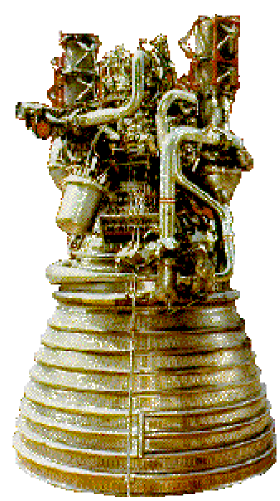
NASA formally assigned the task of developing the Saturn V to the Marshall Space Flight Center on Jan. 25, 1962. Launch responsibility was committed to the Kennedy Space Center. (The "Manned Spacecraft Center", the third center in human space flight, is responsible for spacecraft development, crew training, and inflight control.)

Marshall Center rocket designers conceived the Saturn V in 1961 and early 1960. They decided that a three-stage vehicle would best serve the immediate needs for a lunar landing mission and would serve well as a general purpose space exploration vehicle.

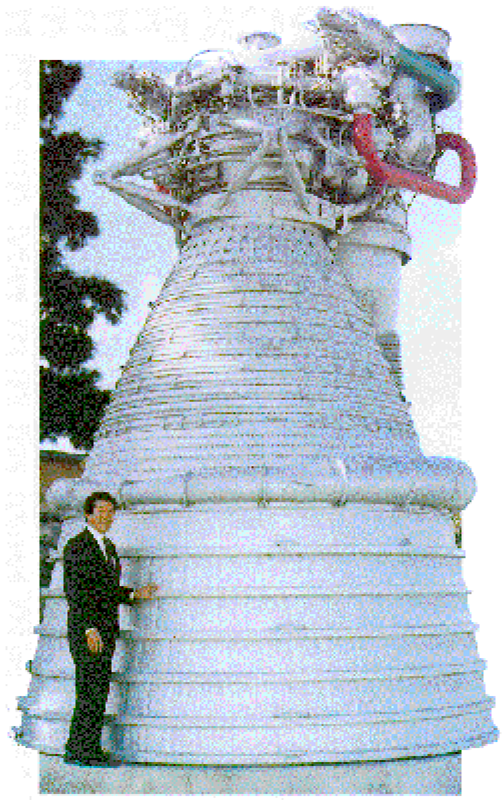
One of the more important decisions made early in the program called for the fullest possible use of components and techniques proven in the Saturn I program. As a result, the Saturn V third stage (S- IVB) was patterned after the Saturn I second stage (S-IV). And the Saturn V instrument unit is an outgrowth of the one used on Saturn I. In these areas, maximum use of designs and facilities already available was incorporated to save time and costs.

Many other components were necessary, including altogether new first and second stages (S-IC and S- II). The F-1 and J-2 engines were already under development, although much work remained to be done. The guidance system was to be an improvement on that of the Saturn I.

The Rocketdyne H-1 engine was the workhorse of the early Apollo-Saturn program. The Saturn 1 and Saturn 1B rockets used eight of these capable engines in the first stage booster. The first Apollo astronauts roared into space atop an H-1 powered Saturn 1B, as did all the Skylab mission crews. The 205,000 lb thrust H-1 is a fixed-thrust, single-start gimbaled engine that employs a propellant system of RP-1 (kerosene) and liquid oxygen. Advances include a turbopump with a one-piece gearbox and fuel additive lubrication, a solid propellant gas generator for start-up, propellant valve sequencing, and hypergolic start-up in the thrust chamber.



The Rocketdyne J-2 engine may be the most important engine in the development history of human space flight propulsion. The J-2 was the first crewed booster engine that used liquid hydrogen as a propellant. The J-2 was also the first large booster engine designed to be restarted multiple times during a mission. The J-2 engine was so versatile that it was used for both the second and third stages of the Saturn V moon rocket. And a modified J-2 engine was used to demonstrate principles that lead to the development of Rocketdyne's Space Shuttle Main Engine. The 230,000 lb thrust J-2 features independently driven pumps for both liquid oxygen and liquid hydrogen, a gas generator to supply hot gas to two turbines running in series, pneumatic and electrical control interlocks, altitude restart capability, and a propellant utilization system.



The Mighty F-1 was perhaps Rocketdyne's greatest contribution to the American space program. Just one F-1 engine provided as much thrust as all three Space Shuttle Main Engines! Even more amazing is that a cluster of five F-1 engines were used in the first stage of the 363-foot tall Saturn V rocket. A single-start, fixed-thrust engine, the F-1 is gimbaled and uses liquid oxygen as the oxidizer, while RP-1 (kerosene) is used as the fuel, the turbopump lubricant, and the control system fluid. A gas generator utilizing the same propellants drives the turbine, which is direct-coupled to the turbopump.

The Saturn V, including the Apollo spacecraft. is 364 feet tall. Fully loaded, the vehicle will weigh some 6.1 million pounds.

The 300,000-pound first stage is 33 feet in diameter and 138 feet long. It is powered by five F-1 engines generating 7.5 million pounds thrust. The booster will burn 203,000 gallons of RP-1 (refined kerosene) and 331,000 gallons of liquid oxygen (LOX} in 2.5 minutes.

Saturn V's second stage is powered by five J-2 engines that generate a total thrust of a million pounds. The 33-foot diameter stage weighs 95,000 pounds empty and more than a million pounds loaded. It burns some 260,000 gallons of liquid hydrogen and 83,000 gallons of liquid oxygen during a typical 6- minute flight.

Third stage of the vehicle is 21 feet and 8 inches in diameter and 58 feet and 7 inches long. An inter-stage adapter connects the larger diameter second stage to the smaller upper stage. Empty weight Off the stage is 34,000 pounds and the fueled weight is 262,000 pounds. A single J-2 engine developing up to 225,000 pounds of thrust powers the stage. Typical burn time is 2.75 minutes for the first burn and 5.2 minutes to a trans-lunar injection.

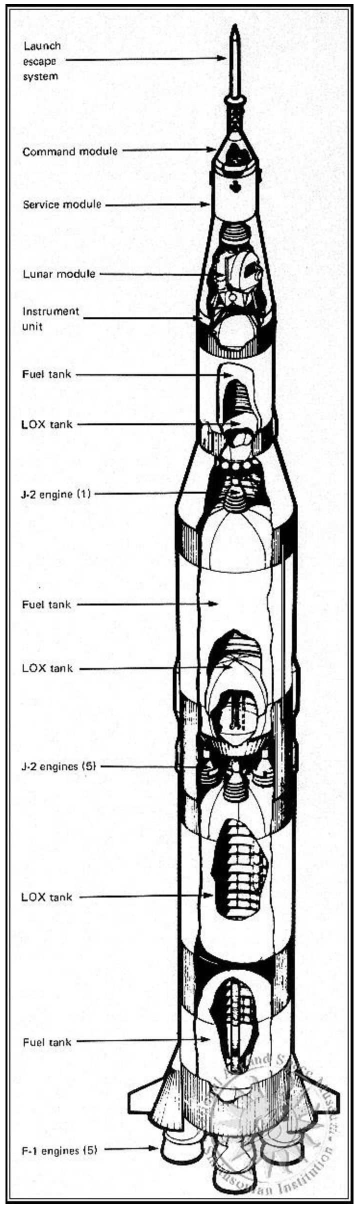
The vehicle instrument unit sits atop the third stage. The unit, which weighs some 4,500 pounds, contains the electronic gear that controls engine ignition and cutoff, steering, and all other commands necessary for the Saturn V mission. Diameter of the instrument unit is 21 feet and 8 inches, and height is 3 feet.

Directly above the instrument unit in the Apollo configuration is the Apollo spacecraft. It consists of the lunar module. the service module, the command module, and the launch escape system. Total height of the package is about 80 feet.

The jumping-off place for a trip to the moon is NASA's Launch Complex 39 at the Kennedy Space Center. After the propellants are loaded, the three astronauts will enter the spacecraft and check out their equipment.

While the astronauts tick off the last minutes of the countdown in the command module, a large crew in the launch control center handles the complicated launch operations. For the last two minutes, the countdown is fully automatic.

At the end of countdown, the five F-1 engines in the first stage ignite, producing 7.5 million pounds of thrust. The hold-down arms release the vehicle, and three astronauts begin their ride to the moon.



Turbopumps, working together with the strength of 30 diesel locomotives, force 15 tons of fuel per second into the engines. Steadily increasing acceleration pushes the astronauts back into their couches as the rocket generates 4-5 times the force of earth gravity.

After 2.5 minutes, the first stage has burned its 4,492,000 pounds of propellants and is discarded at about 38 miles altitude. The second stage's five J-2 engines are ignited. Speed at this moment is 5,330 miles per hour.

The second stage's five J-2 engines burn for about 6 minutes, pushing the Apollo spacecraft to an altitude of nearly 115 miles and near orbital velocity of 15,300 miles per hour. After burnout the second stage drops away and retrorockets slow it for its fall into the Atlantic Ocean west of Africa.

The single J-2 engine in the third stage now ignites and burns for 2.75 minutes. This brief burn boosts the spacecraft to orbital velocity, about 1,500 miles an hour. The spacecraft, with the third stage still attached, goes into orbit about 12 minutes after liftoff. Propellants in the third stage are not depleted when the engine is shut down. This stage stays with the spacecraft in earth orbit. for its engine will be needed again.

Throughout the launch phase of the mission, telemetry systems are transmitting continuously, tracking systems are locked on, and voice communications are used to keep in touch with the astronauts. All stage separations and engine thrust terminations are reported to the Mission Control Center at Houston.

The astronauts are now in a weightless condition as they circle the earth in a "parking orbit" until the timing is right for the next step to the moon.

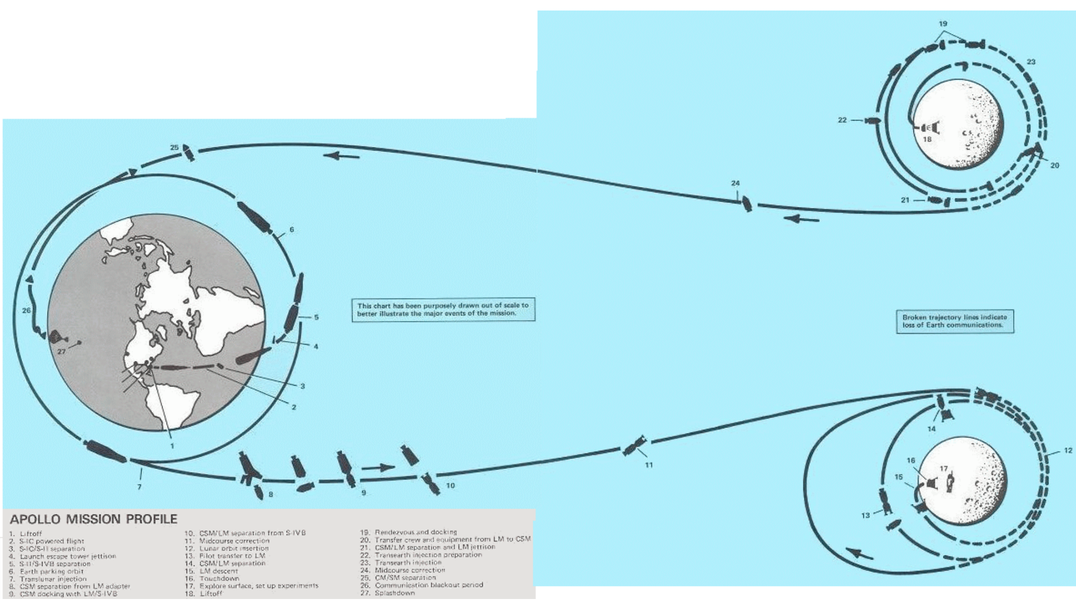
The first attempt at a lunar landing is planned as an "open-ended" mission with detailed plans at every stage for mission termination if necessary. A comprehensive set of alternate flight plans will be laid out and fuller rehearsed for use if such a decision should prove necessary. For example, a decision might be made in the earth parking orbit not to continue with the mission. At ever: stage of the mission, right up to touchdown on the moon, this termination decision can be made and an earth flight plan initiated.

During the one to three times the spacecraft circles the earth, the astronauts make a complete check of the third stage and the spacecraft. Then the precise moment comes for injection into a trans-lunar trajectory, the third stage J- 2 engine is reignited. Burning slightly over 5 minutes, it accelerates the spacecraft from its earth orbital speed of 17,500 miles an hour to about 24,500 miles an hour in a trajectory which could carry the astronauts around the moon. Without further thrust, the spacecraft would return to earth for re-entry.

If everything is operating on schedule, the astronauts will turn their spacecraft around and dock with the lunar landing module. After the docking maneuver has been completed, the lunar module will be pulled out of the forward end of the third stage which will be abandoned. Abandonment completes the Saturn V's work on the lunar mission.

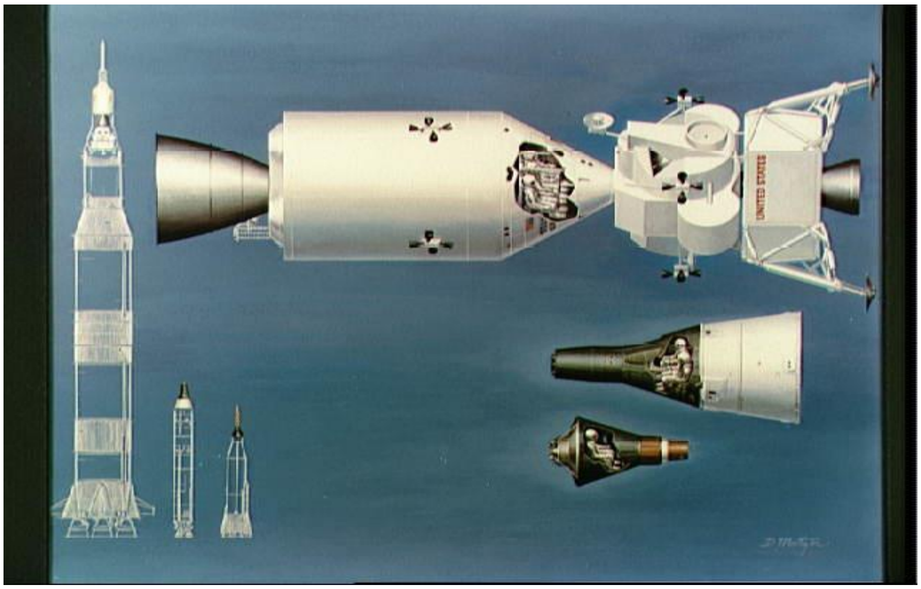
Apollo Program:

The Apollo program included a large number of 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 funding for the Apollo program was approximately $20,443,600,000.

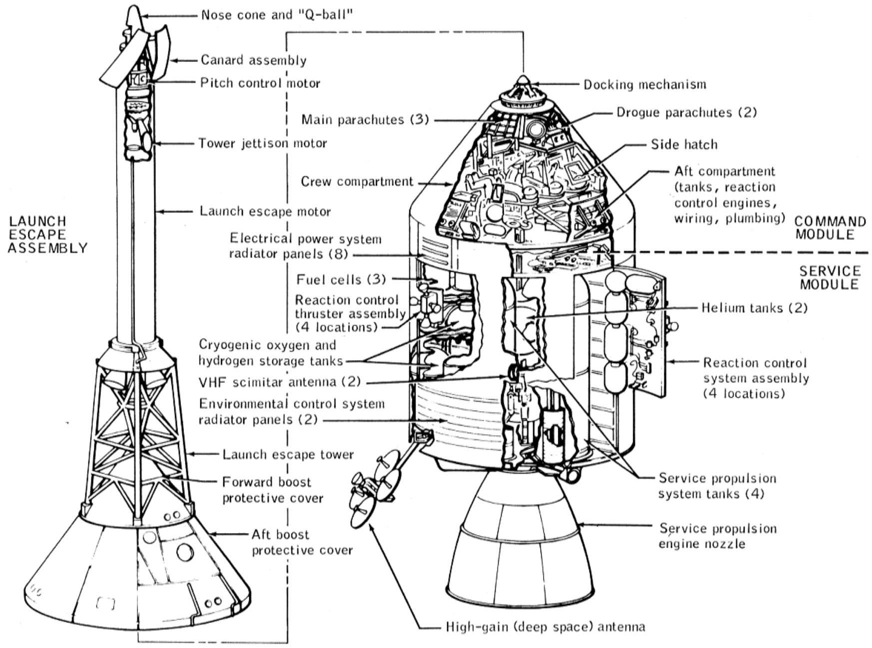


Spacecraft and Subsystems :

As the name implies, the Command and Service Module (CSM) was comprised of two distinct units: the Command Module (CM), which housed the crew, spacecraft operations systems, and re-entry equipment, and the Service Module (SM) which carried most of the consumables (oxygen, water, helium, fuel cells, and fuel) and the main propulsion system. The total length of the two modules attached was 11.0 meters with a maximum diameter of 3.9 meters. Block II CSM's were used for all the crewed Apollo missions. The Apollo 11 CSM mass of 28,801 kg was the launch mass including propellants and expendables; of this the Command Module (CM 107) had a mass of 5557 kg and the Service Module (SM 107) 23,244 kg.



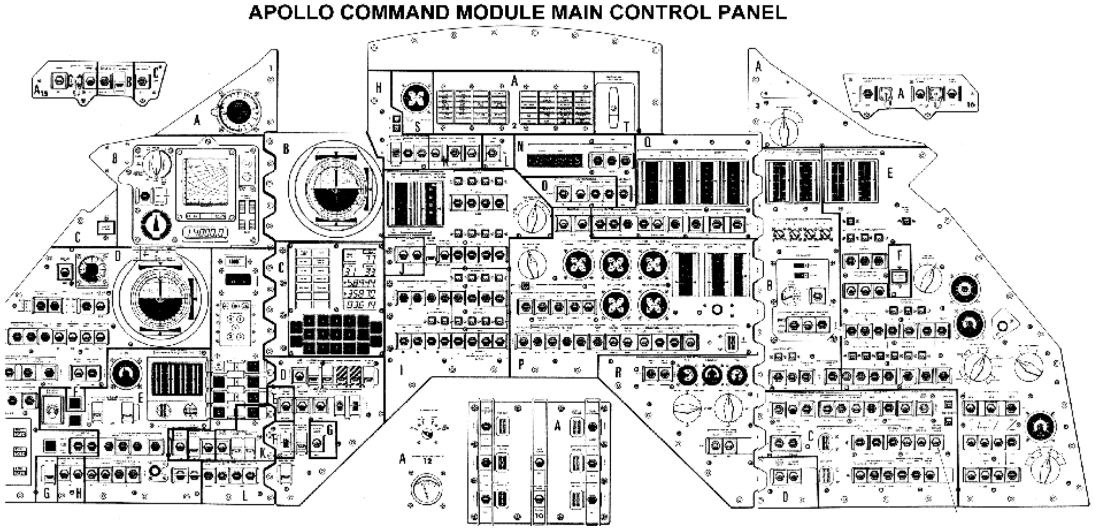
Telecommunications included voice, television, data, and tracking and ranging subsystems for communications between astronauts, CM, LM, and Earth. Voice contact was provided by an S-band uplink and downlink system. Tracking was done through a unified S-band transponder. A high gain steerable S-band antenna consisting of four 79-cm diameter parabolic dishes was mounted on a folding boom at the aft end of the SM. Two VHF scimitar antennas were also mounted on the SM. There was also a VHF recovery beacon mounted in the CM. The CSM environmental control system regulated cabin atmosphere, pressure, temperature, carbon dioxide, odors, particles, and ventilation and controlled the temperature range of the electronic equipment.



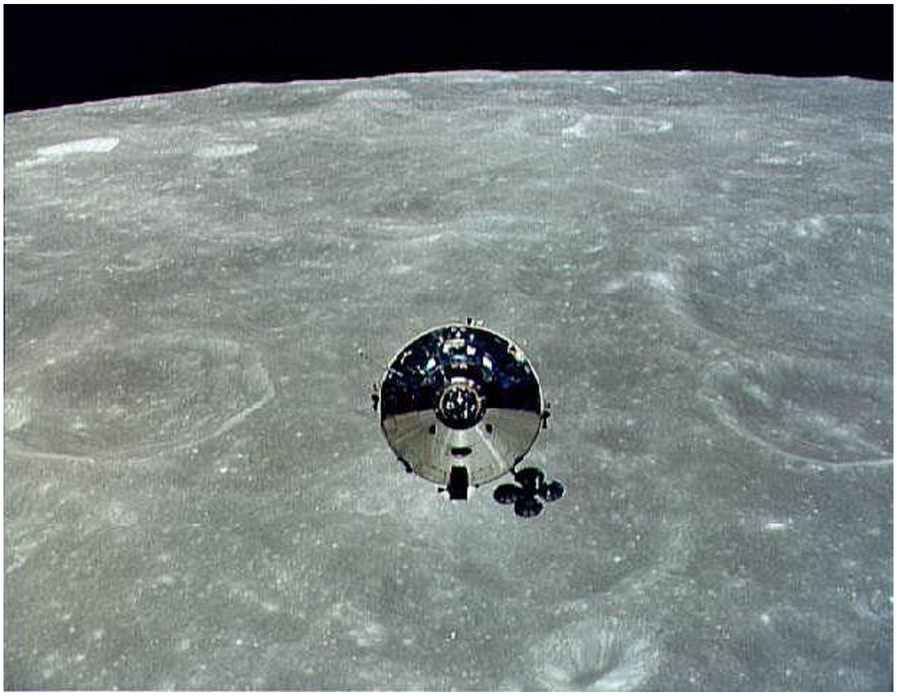
APOLLO COMMAND AND SERVICE MODULES AND LAUNCH ESCAPE SYSTEM

The CM was a conical pressure vessel with a maximum diameter of 3.9 m at its base and a height of 3.65 m. It was made of an aluminum honeycomb sandwich bonded between sheet aluminum alloy. The base of the CM consisted of a heat shield made of brazed stainless steel honeycomb filled with a phenolic epoxy resin as an ablative material and varied in thickness from 1.8 to 6.9 cm. At the tip of the cone was a hatch and docking assembly designed to mate with the lunar module. The CM was divided into three compartments. The forward compartment in the nose of the cone held the three 25.4 m diameter main parachutes, two 5 m drogue parachutes, and pilot mortar chutes for Earth landing. The aft compartment was situated around the base of the CM and contained propellant tanks, reaction control engines, wiring, and plumbing.

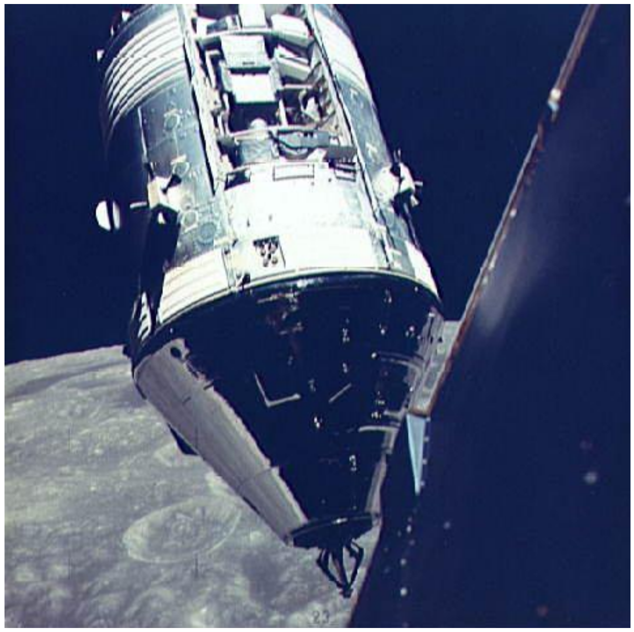
APOLLO COMMAND MODULE MAIN CONTROL PANEL



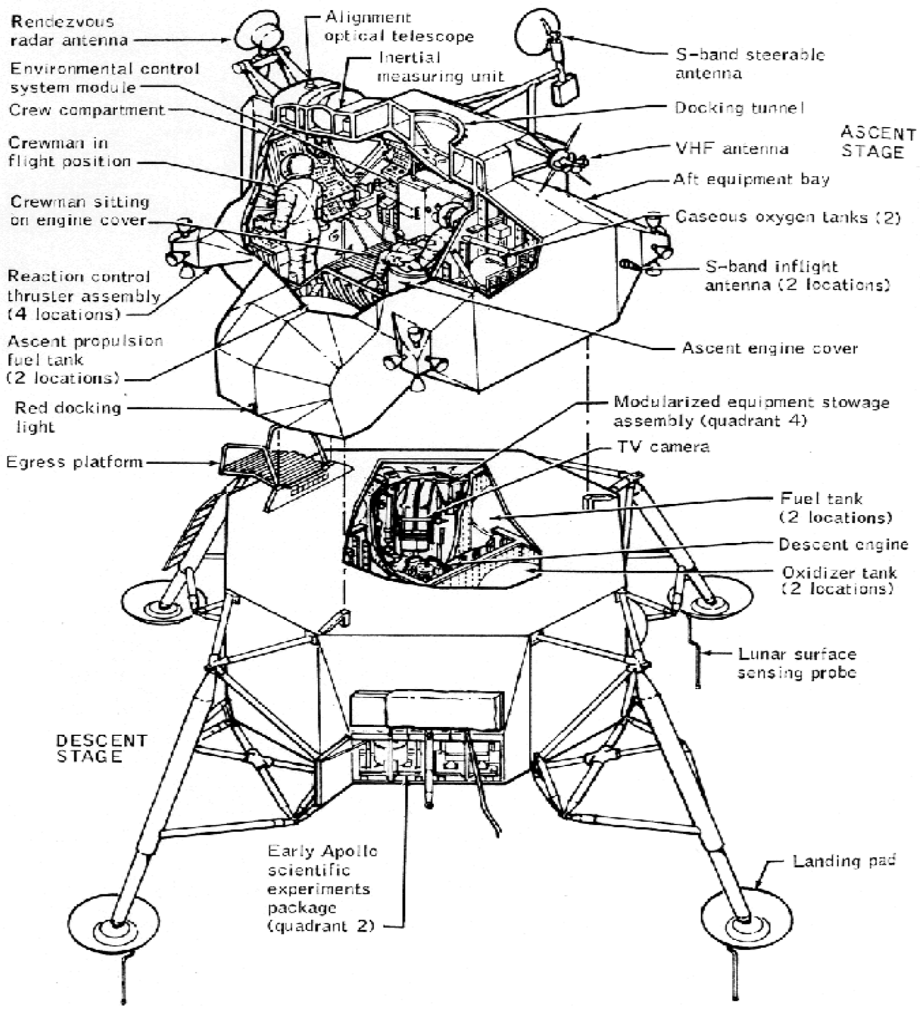
The crew compartment comprised most of the volume of the CM, approximately 6.17 cubic meters of space. Three astronaut couches were lined up facing forward in the center of the compartment. A large access hatch was situated above the center couch. A short access tunnel led to the docking hatch in the CM nose. The crew compartment held the controls, displays, navigation equipment and other systems used by the astronauts. The CM had five windows: one in the access hatch, one next to each astronaut in the two outer seats, and two forward-facing rendezvous windows. Five silver/zinc-oxide batteries provided power after the CM and SM detached, three for re-entry and after landing and two for vehicle separation and parachute deployment. The CM had twelve 420 N nitrogen tetroxide/hydrazine reaction control thrusters. The CM provided the re-entry capability at the end of the mission after separation from the Service Module.



The SM was a cylinder 3.9 meters in diameter and 7.6 m long which was attached to the back of the CM. The outer skin of the SM was formed of 2.5 cm thick aluminum honeycomb panels. The interior was divided by milled aluminum radial beams into six sections around a central cylinder. At the back of the SM mounted in the central cylinder was a gimbal mounted re-startable hypergolic liquid propellant 91,000 N engine and cone shaped engine nozzle. Attitude control was provided by four identical banks of four 450 N reaction control thrusters each spaced 90 degrees apart around the forward part of the SM.



The six sections of the SM held three 31-cell hydrogen oxygen fuel cells which provided 28 volts, two cryogenic oxygen and two cryogenic hydrogen tanks, four tanks for the main propulsion engine, two for fuel and two for oxidizer, and the subsystems the main propulsion unit. Two helium tanks were mounted in the central cylinder. Environmental control radiator panels were spaced around the top of the cylinder and electrical power system radiators near the bottom.



LUNAR MODULE CONFIGURATION FOR INITIAL LUNAR LANDING

The Ascent Stage of the Lunar Module (LM) is the crew portion of the space vehicle. It contains a crew compartment, hypergolic ascent engine, an aft equipment bay and tank section, and 16 reaction control engines. The crew compartment is used as an operations center by the astronauts during their lunar stay. Lunar descent, lunar landing, lunar launch, and rendezvous and docking with the Command and Service Module (CSM) are also controlled from this compartment.

All or parts of the following subsystems are contained in the Ascent Stage:

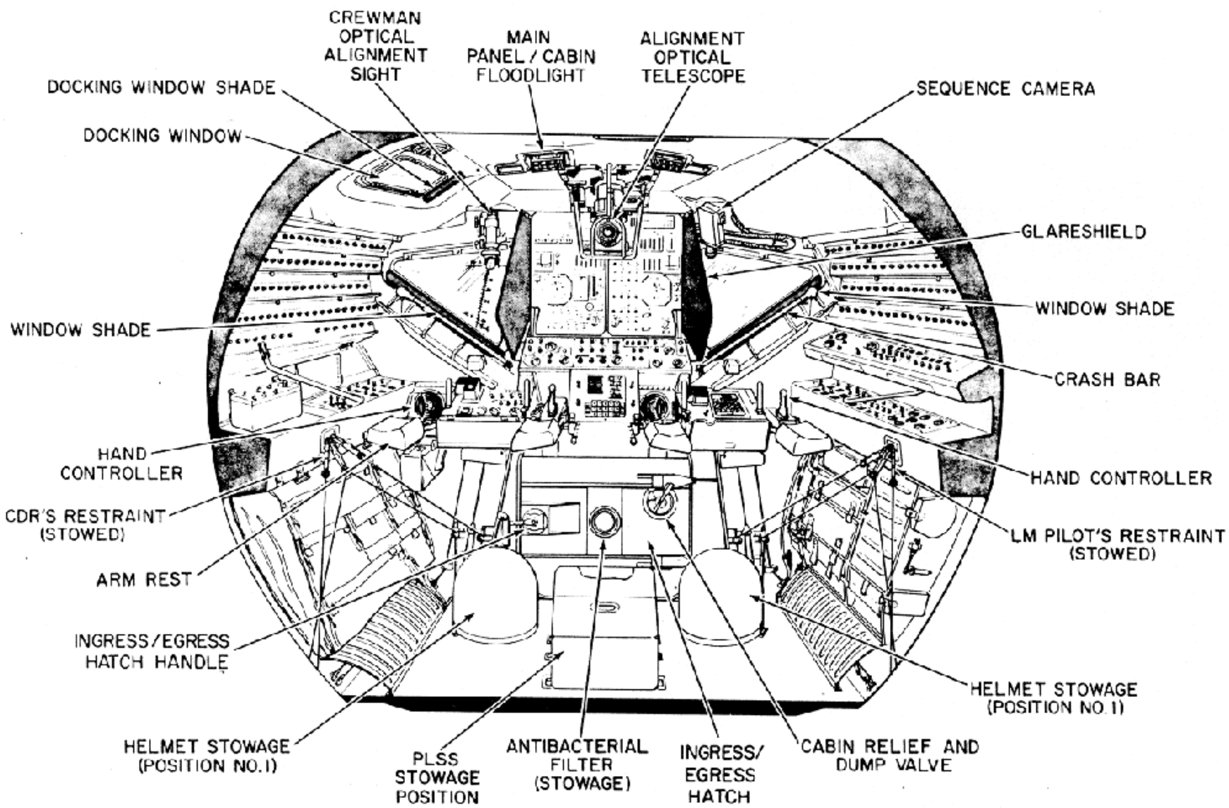
- Guidance, Navigation & Control
- Crew Provisions/Displays
- Environmental Control
- Electro-Explosive Devices
- Instrumentation
- Electrical Power
- Propulsion

- Reaction Control
- Communications

The uncrewed Descent Stage contains equipment essential for landing on the lunar surface and serves as a platform for launching the Ascent Stage after completion of the lunar mission. In addition to the descent engine and its pressurization and propel- lant components, the Descent Stage houses the landing radar, electrical power and pyrotechnics components, and the Apollo Lunar Surface Experiments Package (ALSEP). It also contains outriggers that extend from the ends of the structural beams. These outriggers have provisions for:

- Attaching the cantilever-type landing gear.
- Locating the Lunar Module within the shroud of the Saturn V aerodynamic shell.

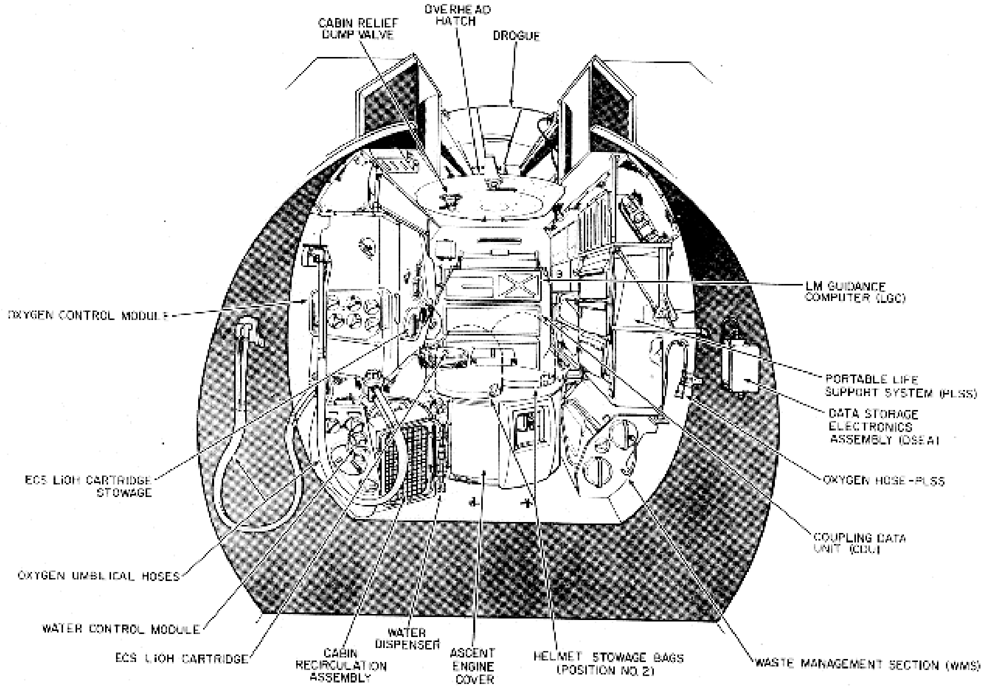
LUNAR MODULE ASCENT STAGE INTERIOR VIEW LOOKING FORWARD



The Ascent Stage structure consists of the following subassemblies: front face, cabin skin, mid section and aft equipment bay. The front face is mechanically assembled from 10 welded and machined sections. After a sealing and curing operation, the outer flange contour is machined for accurate mating to the cabin skin subassembly. The installation of secondary structure (stringers, shelves, brackets, etc.) completes the front face assembly.

The cabin skin subassembly is fabricated from formed chemmilled skin panels that are welded and mechanically fastened. Sealing of the mechanical joints, trimming of the forward edge to match the front face contour, and the addition of formed longerons and stringers complete the operation for this assembly.

LUNAR MODULE ASCENT STAGE INTERIOR VIEW LOOKING AFT



The mid-section, the largest of the subassemblies in the Ascent Stage, consists basically of two machined bulkheads, an upper deck tunnel weldment, a lower (engine) deck weldment and chem-milled skins. The mid-section is mechanically joined with the front face and cabin skin subassembly and sealed to form the cabin pressure shell of the Ascent Stage.

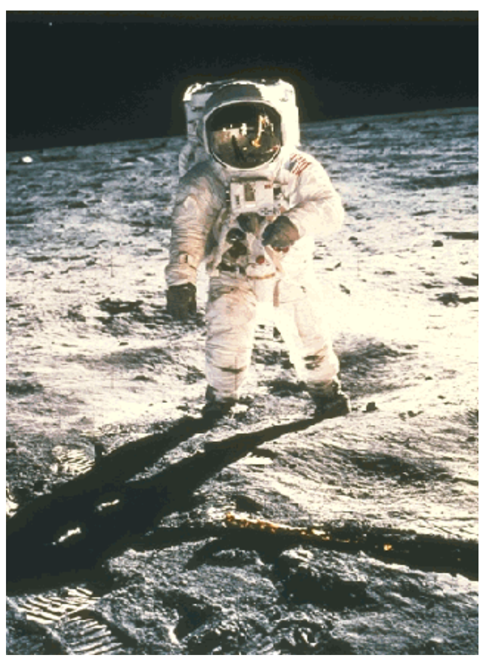
Cold rails, chem-milled beams, struts, and machined fittings comprise the major structural components in the aft equipment bay. The attachment of this subassembly to the cabin pressure shell completes the Ascent Stage structure.

The Descent Stage structure consists primarily of machined parts and chem-milled panel/stiffener assemblies that are mechanically fastened. Fabrication of the Descent Stage begins with the joining of the machined picture frames and the chem-milled panel/stiffener assemblies to form the engine compartment. After the outrigger bulkhead assemblies are attached to the engine compartment with machined cap strips, the eight remaining panel/stiffener assemblies, the upper and lower machined decks, and the machined interstage fittings are added to complete the Descent Stage structure.

The cantilever-type landing gear is attached externally to the Descent Stage and folds inward to fit within the shroud of the Saturn V aerodynamic shell. It consists of four sets of legs connected to outriggers that extend from the ends of the Descent Stage structural beams. Each landing gear consists of a primary strut and foot pad, a drive-out mechanism, two secondary struts, two down-lock mechanisms, and a truss. The struts are machined aluminum with machined fittings mechanically attached at the ends. The foot pads consist of inner and outer layers of spun aluminum that are bonded to honeycomb core. The formed aluminum tube probes on the foot pads are each equipped with a sensing device. The side braces are made of swaged tubing.

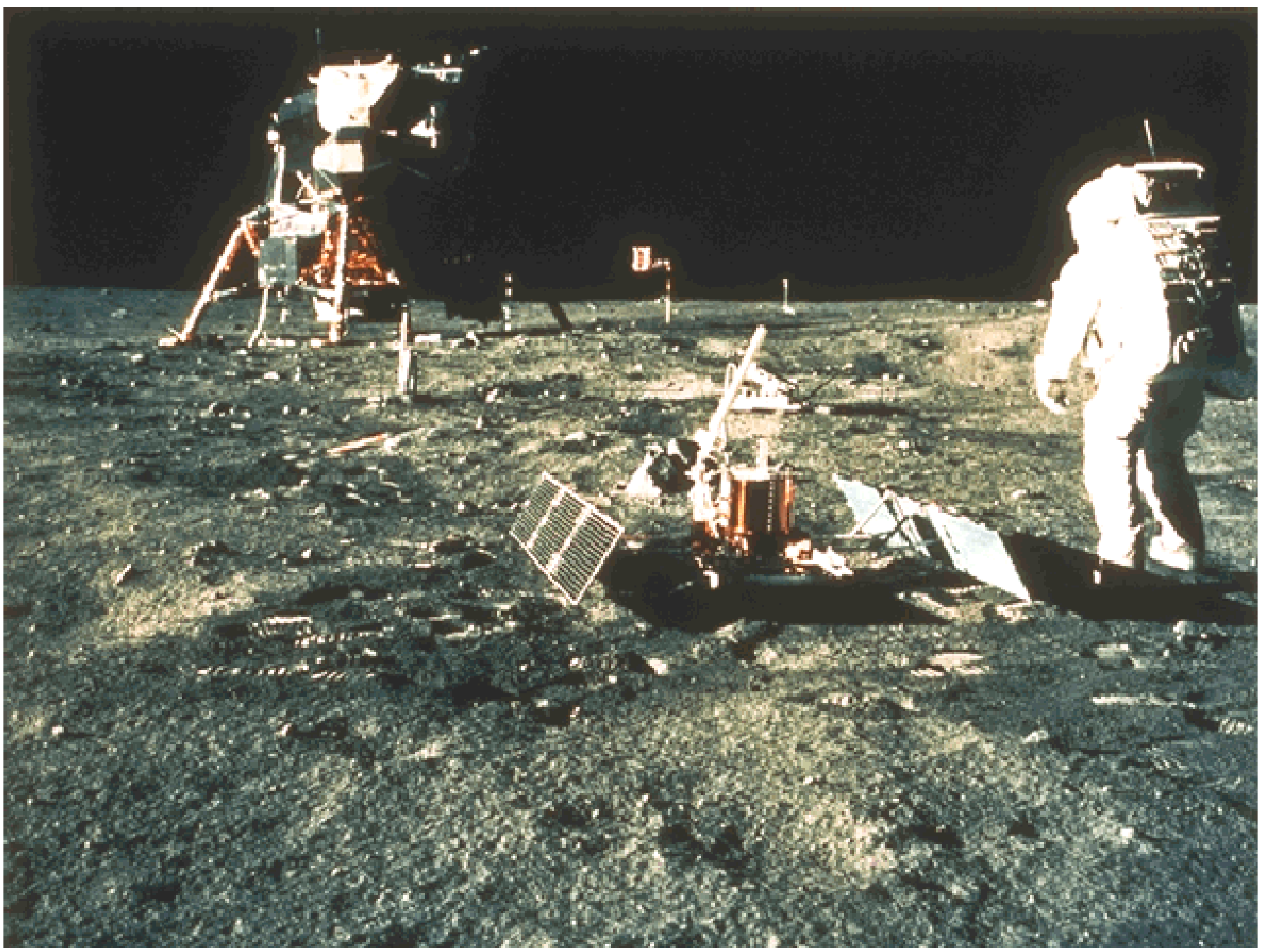
Apollo 11:

Apollo 11 was the first mission in which humans walked on the lunar surface and returned to Earth. On 20 July 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 21 July and the astronauts returned to Earth on 24 July.



After launch on Saturn V SA-504 on 16 July 1969 at 13:32 UT (9:32 a.m. EDT) from pad 39A of Kennedy Space Center, Apollo 11 entered Earth orbit. After 1 1/2 Earth orbits, the S-IVB stage was re-ignited at 16:16:16 UT for a translunar injection burn of 5 minutes, 48 seconds putting the spacecraft on course for the Moon. The CSM separated from the S-IVB stage containing the LM 33 minutes later, turned around and docked with the LM at 16:56:03 UT.

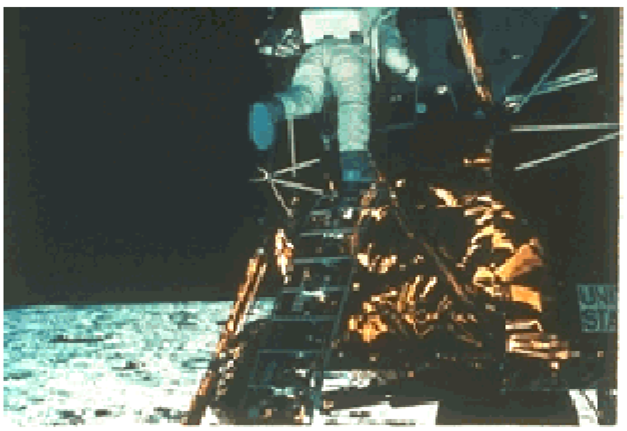
About an hour and 15 minutes later the S-IVB stage was injected into heliocentric orbit. During translunar coast a color TV transmission was made from Apollo 11 and on 17 July a 3-second mid-course correction burn of the main engine was performed. Lunar orbit insertion was achieved on 19 July at 17:21:50 UT by a retrograde firing of the main engine for 357.5 seconds while the spacecraft was behind the Moon and out of contact with Earth. A later 17 second burn circularized the orbit. On 20 July Armstrong and Aldrin entered the LM for final checkout. At 18:11:53 the LM and CSM separated. After a visual inspection by Collins, the LM descent engine fired for 30 seconds at 19:08 UT, putting the craft into a descent orbit with a closest approach 14.5 km above the Moon's surface. At 20:05 the LM descent engine fired for 756.3 seconds and descent to the lunar surface began.

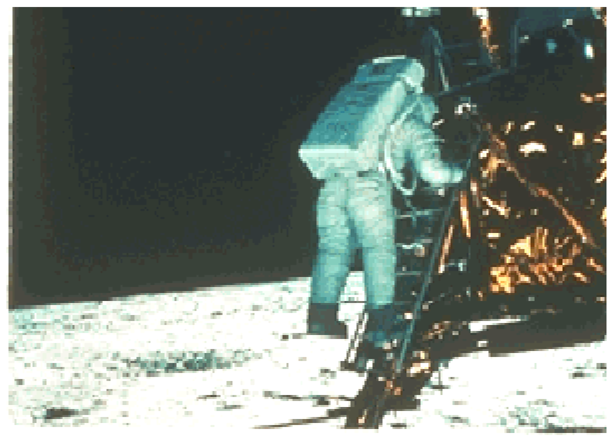


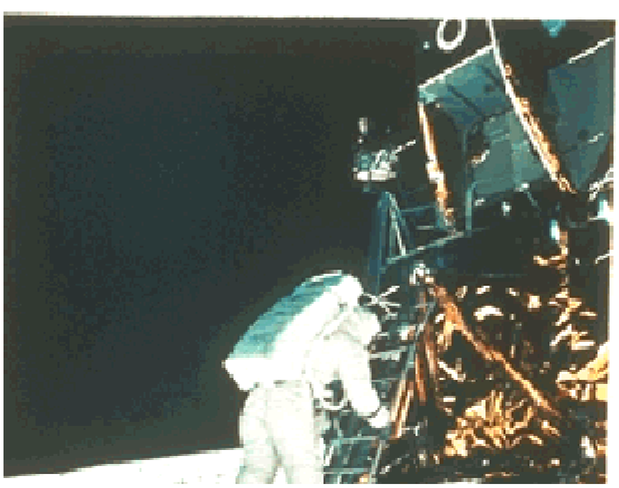
The LM landed at 20:17:40 UT (4:17:40 p.m. EDT) in Mare Tranquilitatis (the Sea of Tranquility), Armstrong reporting, "Houston, Tranquility Base here - the Eagle has landed." Armstrong stepped onto the lunar surface at 02:56:15 UT on 21 July (10:56:15

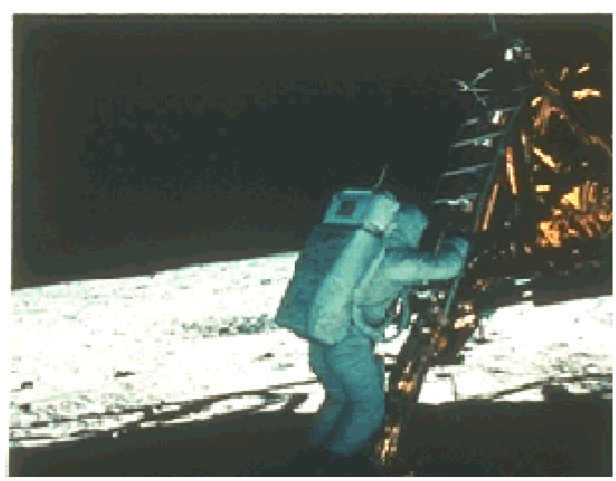
p.m. July 20 EDT) stating, "That's one small step for man, one giant leap for mankind", and Aldrin followed 19 minutes later. The astronauts deployed the EASEP and other instruments, took photographs, and collected 21.7 kg of lunar rock and soil. The astronauts traversed a total distance of about 250 meters. The EVA ended at 5:11:13 UT when the astronauts returned to the LM and closed the hatch.

The LM lifted off from the Moon at 17:54:01 UT on 21 July after 21 hours, 36 minutes on the lunar surface. After docking with the CSM at 21:34:00 UT, the LM was jettisoned into lunar orbit at 00:01:01 UT on 22 July. Transearth injection began at 04:54:42 UT on 22 July with a 2 1/2 minute firing of the CSM main engine. A mid-course correction was made later on 22 July. The CM separated from the SM at 16:21:13 UT on 24 July. Apollo 11 splashed down in the Pacific Ocean on 24 July 1969 at 16:50:35 UT (12:50:35 p.m. EDT) after a mission elapsed time of 195 hrs, 18 mins, 35 secs. The splashdown point was 13 deg 19 min N, 169 deg 9 min W, 400 miles SSW of Wake Island and 24 km (15 mi) from the recovery ship USS Hornet.







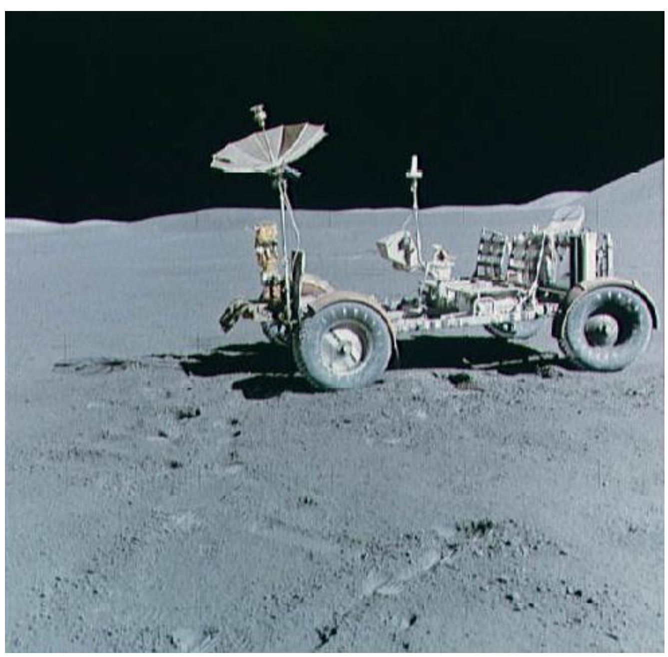


The primary mission goal of landing astronauts on the Moon and returning them to Earth was achieved. Armstrong was a civilian on his second spaceflight (he'd previously flown on Gemini 8), Aldrin was a USAF Colonel on his second spaceflight (Gemini 12), Collins was a USAF Lt. Colonel also on his second flight (Gemini 10).

Lunar Rover:

The Lunar Roving Vehicle (LRV) 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 LRVs 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. Each rover was used on three traverses, one per day over the three day course of each mission. On Apollo 15 the LRV was driven a total of 27.8 km in 3 hours, 2 minutes of driving time. The longest single traverse was 12.5 km and the maximum range from the LM was 5.0 km. On Apollo 16 the vehicle traversed 26.7 km in 3 hours 26 minutes of driving. The longest traverse was 11.6 km and the LRV reached a distance of 4.5 km from the LM. On Apollo 17 the rover went 35.9 km in 4 hours 26 minutes total drive time. The longest traverse was 20.1 km and the greatest range from the LM was 7.6 km.

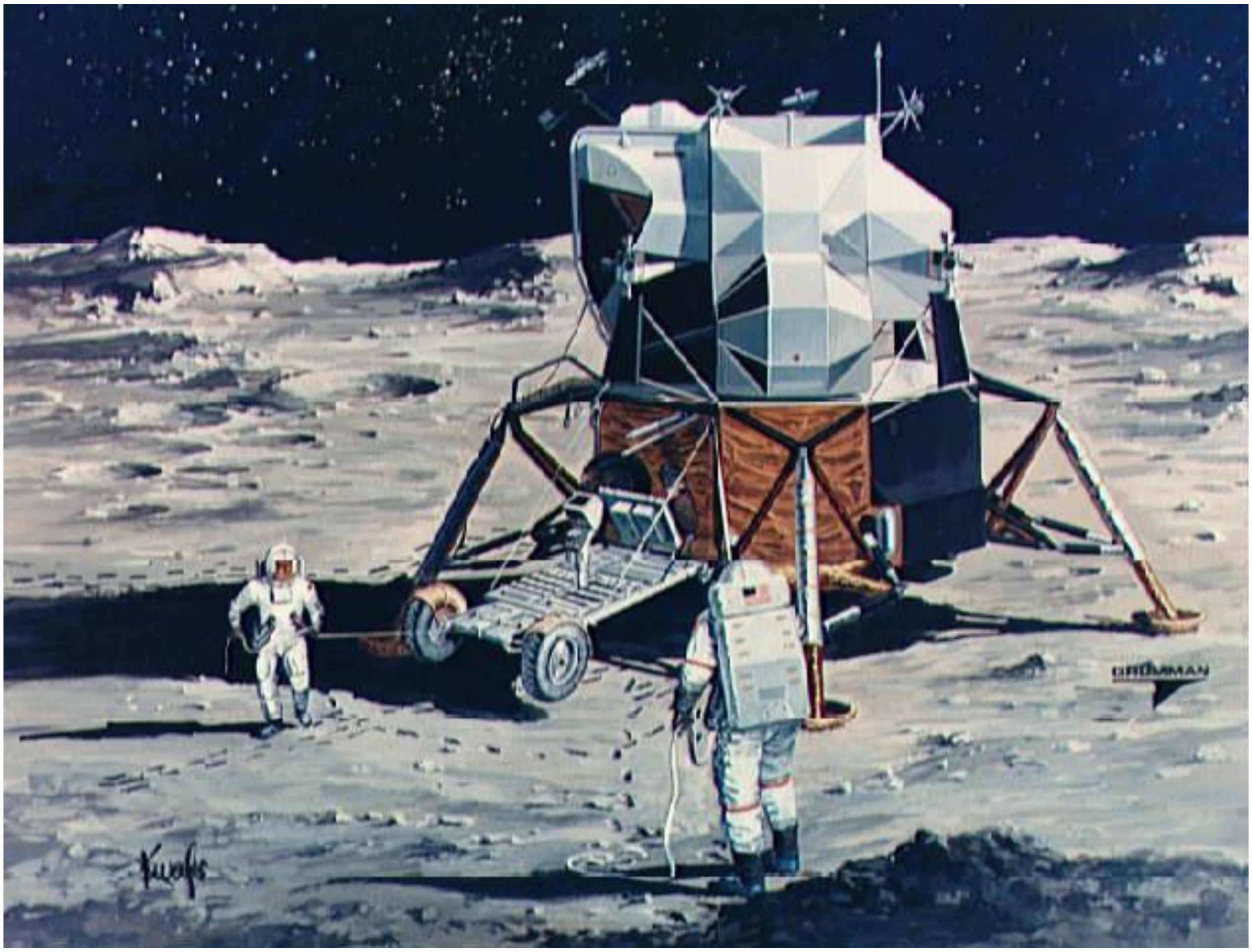
It looked like a golf cart, or a stripped-down dune buggy, but was an engineering marvel. Equipped with a color television camera able to send images back to Earth via satellite, it traveled about 10 mph, carried four times its own weight and had woven piano-wire mesh-like wheels to negotiate the strange lunar surface. An LRV traveled to the moon folded up and stuffed into a small storage space on the side of the Lunar Module on Apollo missions 15, 16 and 17.



The Lunar Roving Vehicle had a mass of 210 kg and was designed to hold a payload of an additional 490 kg on the lunar surface. The frame was 3.1 meters long with a wheelbase of 2.3 meters. The maximum height was 1.14 meters. The frame was made of aluminum alloy 2219 tubing welded assemblies and consisted of a 3 part chassis which was hinged in the center so it could be folded up and hung in the Lunar Module quad 1 bay. It had two side-by-side foldable seats made of tubular aluminum with nylon webbing and aluminum floor panels. An armrest was mounted between the seats, and each seat had adjustable footrests and a velcro seatbelt. A large mesh dish antenna was mounted on a mast on the front center of the rover. The suspension consisted of a double horizontal wishbone with upper and lower torsion bars and a damper unit between the chassis and upper wishbone. Fully loaded the LRV had a ground clearance of 36 cm.

The wheels consisted of a spun aluminum hub and an 81.8 cm diameter, 23 cm wide tire made of zinc coated woven 0.083 cm diameter steel strands attached to the rim and discs of formed aluminum. Titanium chevrons covered 50% of the contact area to provide traction. Inside the tire was a 64.8 cm diameter bump stop frame to protect the hub. Dust guards were mounted above the wheels. Each wheel had its own electric drive, a DC series wound 0.25 hp motor capable of 10,000 rpm, attached to the wheel via an 80:1 harmonic drive, and a mechanical brake unit. Maneuvering capability was provided through the use of front and rear steering motors. Each series wound DC steering motor was capable of 0.1 hp. Both sets of wheels would turn in opposite directions, giving a steering radius of 3.1 meters, or could be decoupled so only one set would be used for steering. Power was provided by two 36-volt silver-zinc potassium hydroxide non-rechargeable batteries with a capacity of 121 amp-hr. These were used to power the drive and steering motors and also a 36 volt utility outlet mounted on front of the LRV to power the communications relay unit or the TV camera. Passive thermal controls kept the batteries within an optimal temperature range.

A T-shaped hand controller situated between the two seats controlled the four drive motors, two steering motors and brakes. Moving the stick forward powered the LRV forward, left and right turned the vehicle left or right, pulling backwards activated the brakes. Activating a switch on the handle before pulling back would put the LRV into reverse. Pulling the handle all the way back activated a parking brake. The control and display modules were situated in front of the handle and gave information on the speed, heading, pitch, and power and temperature levels. Navigation was based on continuously recording direction and distance through use of a directional gyro and odometer and inputting this data to a computer which would keep track of the overall direction and distance back to the LM. There was also a Sun-shadow device which could give a manual heading based on the direction of the Sun, using the fact that the Sun moved very slowly in the sky. The image at left shows a diagram of the layout of the control and display module, the Sun-shadow device is at top center between the heading and speed readouts.

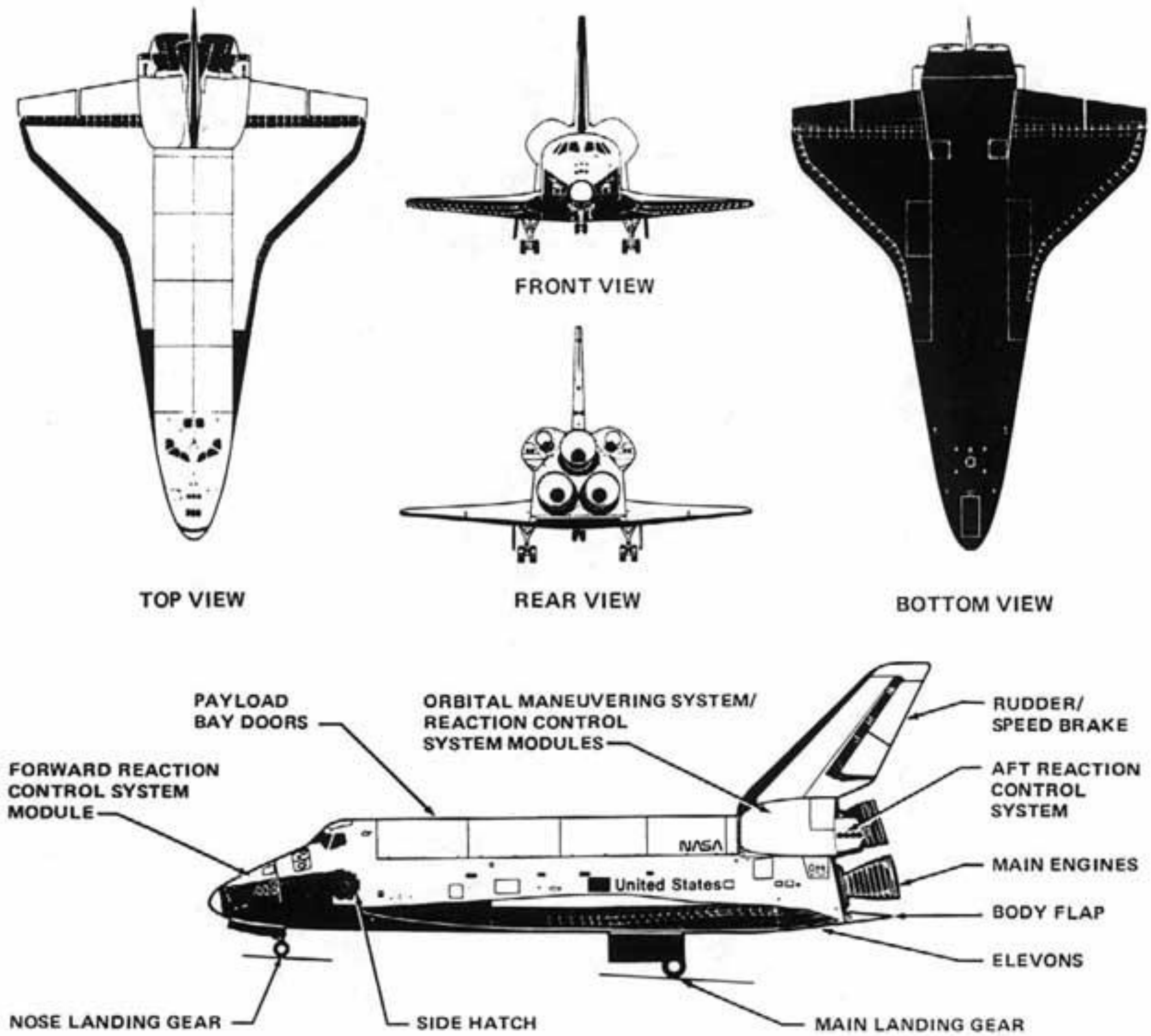


Deployment of the LRV from the LM quad 1 by the astronauts was achieved with a system of pulleys and braked reels using ropes and cloth tapes. The rover was folded and stored in quad 1 with the underside of the chassis facing out. One astronaut would climb the egress ladder on the LM and release the rover, which would then be slowly tilted out by the second astronaut on the ground through the use of reels and tapes. As the rover was let down from the bay most of the deployment was automatic. The rear wheels folded out and locked in place and when they touched the ground the front of the rover could be unfolded, the wheels deployed, and the entire frame let down to the surface by pulleys. The rover components locked into place upon opening. Cabling, pins, and tripods would then be removed and the seats and footrests raised.

The Lunar Roving Vehicles gave the astronauts the ability to do three times the amount of work done on the earlier voyages. The battery-powered vehicles operated faultlessly in temperatures ranging from minus 200 to more than 200 degrees Fahrenheit. After the Apollo program ended, the moon cars were left parked on the surface, awaiting the next generation of astronauts. The legacy of the LRV, however, extended back to Earth, where its technology helped evolve the motorized wheelchairs that today provide many people with a way of negotiating around this world.

CHAPTER 8

The Space Shuttle



DIMENSIONS AND WEIGHT

WING SPAN	23.79 m	(78.06 FT)
LENGTH	37.24 m	(122.17 FT)
HEIGHT	17.25 m	(56.58 FT)
TREAD WIDTH	6.91 m	(22.67 FT)
GROSS TAKEOFF WEIGHT		VARIABLE
GROSS LANDING WEIGHT		VARIABLE
INERT WEIGHT (APPROX)	74 844 kg	(165 000 LB)

MINIMUM GROUND CLEARANCES

BODY FLAP (AFT END)	3.68 m	(12.07 FT)
MAIN GEAR (DOOR)	0.87 m	(2.85 FT)
NOSE GEAR (DOOR)	0.90 m	(2.95 FT)
WINGTIP	3.63 m	(11.92 FT)

Introduction

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, maneuvers in Earth orbit like a spacecraft and lands 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 comprises 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 lasts seven to eight days, but can 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 uses 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

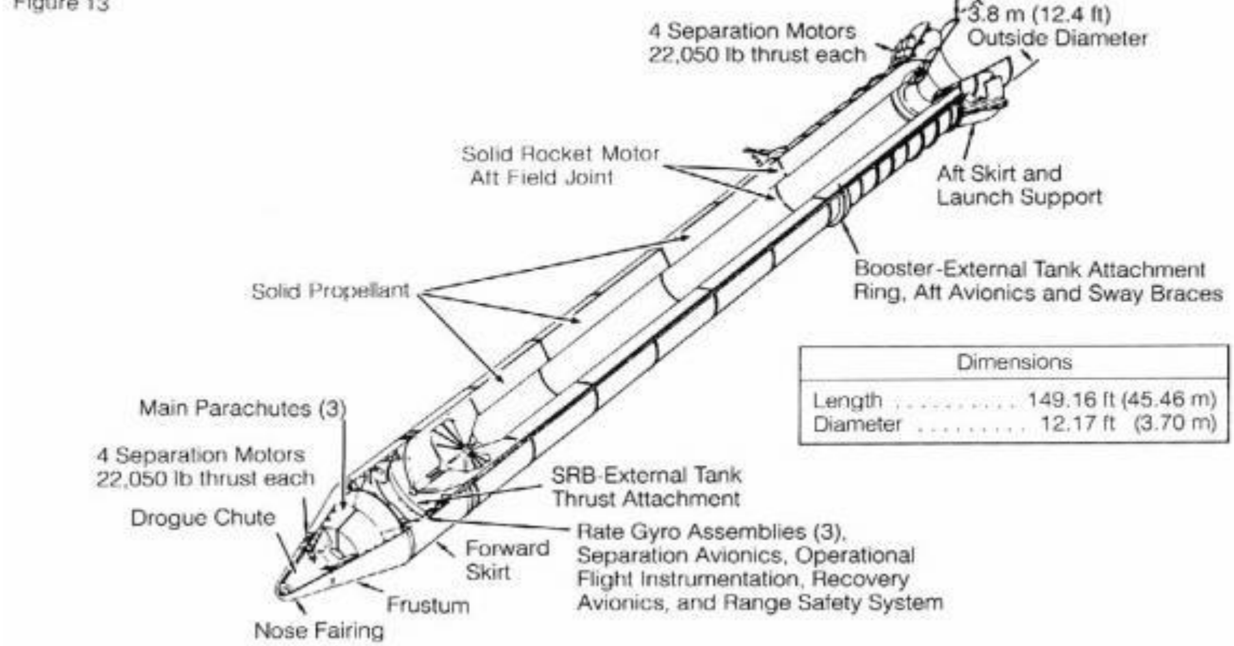
Solid Rocket Boosters

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 cannot be shut down. Therefore, they are the last component to light at launch.

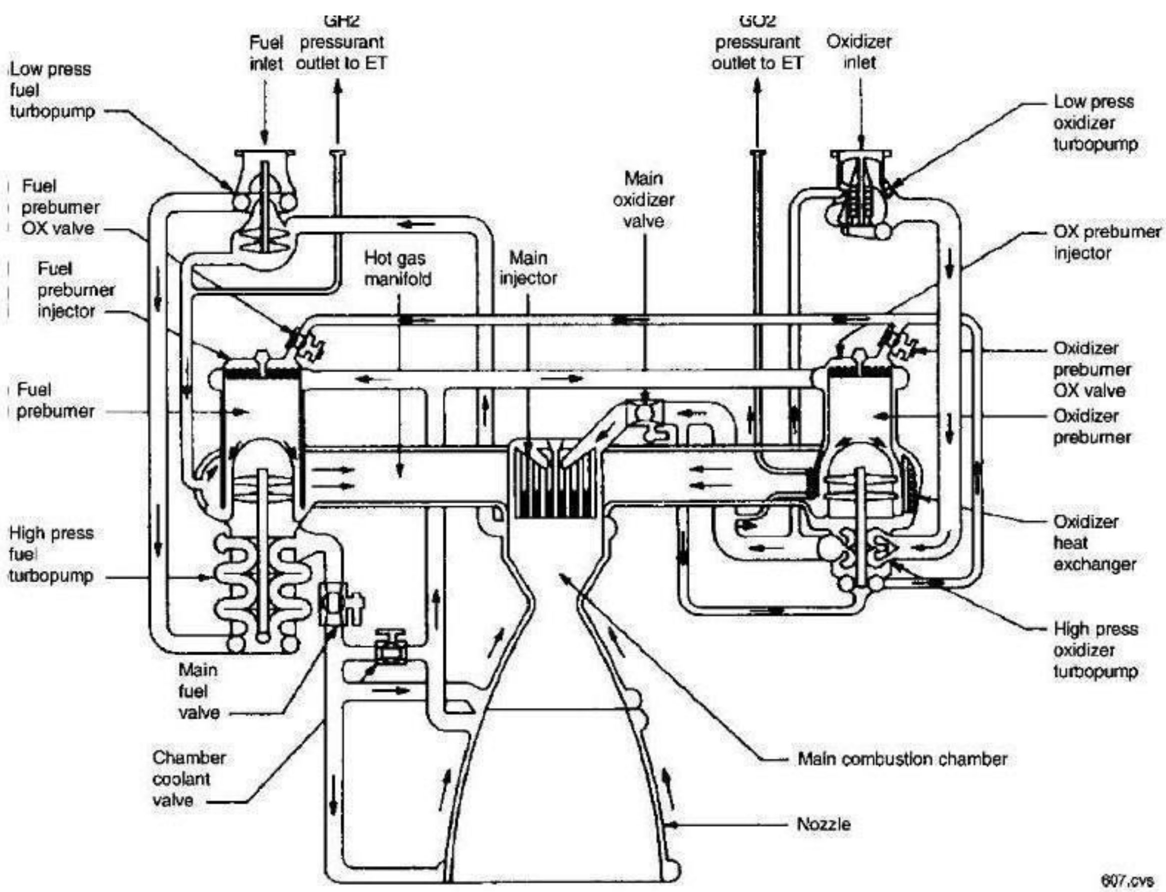
Cutaway view of the Solid Rocket Booster showing Solid Rocket Motor propellant and aft field joint
Figure 13



Main Engines

The orbiter has 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



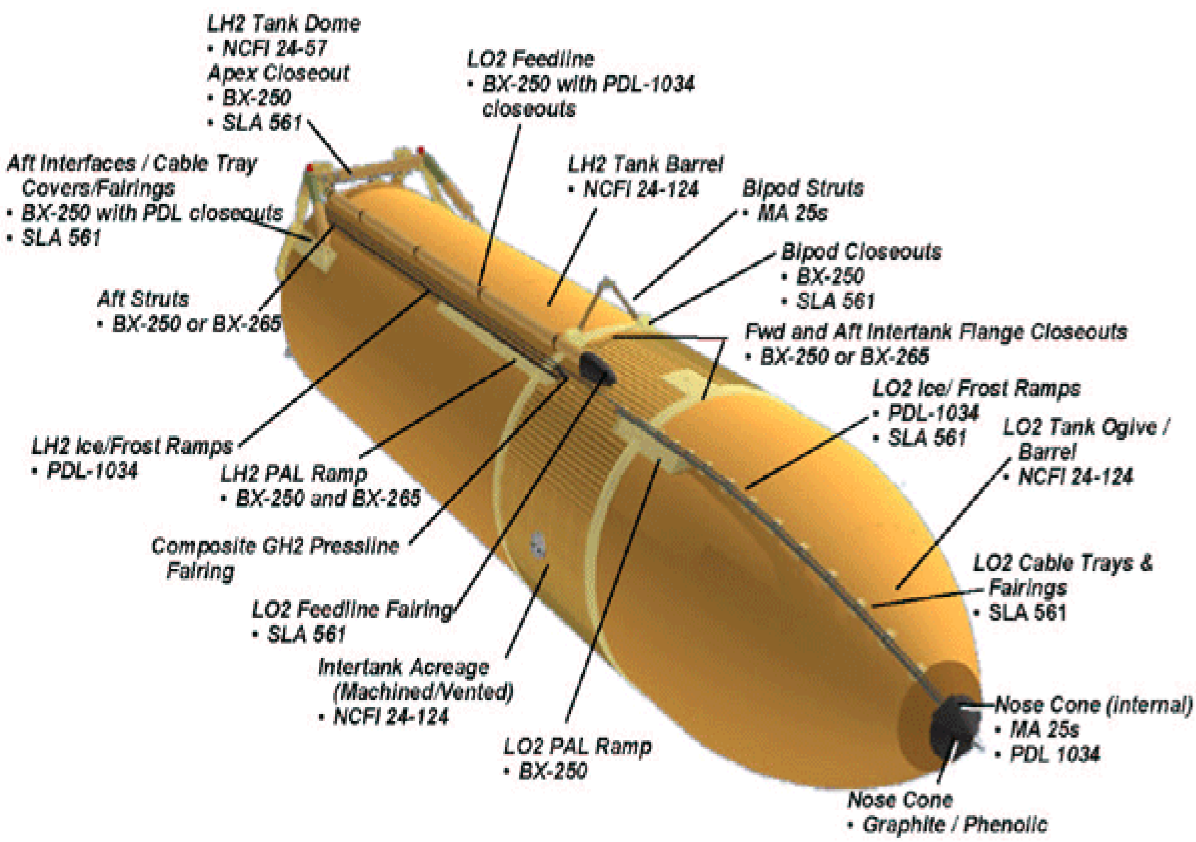
Main Engine Schematic

External Fuel Tank

As mentioned above, the fuel for the main engines is 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 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. 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 is 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 are located in pods on the aft section of the orbiter, one on either side of the tail. These engines place 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 are 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 are two spring-loaded solenoid valves that close the lines. Pressurized nitrogen gas, from a small tank located near the engine, opens the valves and allows the fuel and oxidizer to flow into the combustion chamber of the engine. When the engines shut off, the nitrogen goes 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 is enough nitrogen to open the valves and purge the lines 10 times!

Either one or both of the OMS engines can fire, depending upon the orbital maneuver. Each OMS engine can produce 6,000 lb (26,400 N) of thrust. The OMS engines together can accelerate the shuttle by 2 ft/s^2 (0.6 m/s^2). This acceleration can change the shuttle's velocity by as much as 1,000 ft/s (305 m/s). To place into orbit or to de-orbit takes about 100-500 ft/s (31-153 m/s) change in velocity. Orbital adjustments take about 2 ft/s (0.61 m/s) change in velocity. The engines can start and stop 1,000 times and have 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 rests on the SRBs as pre-launch and final launch preparations are 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 can be the home for astronauts for seven to 14 days. The orbiter can 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 can be changed throughout the mission. One of the first things that the commander will do is 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 located 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:

<u>Flight deck - uppermost deck</u>

•forward deck - contains all of the controls and warning systems for the space shuttle (also known as the cockpit)

•seats - commander, pilot, specialist seats (two)

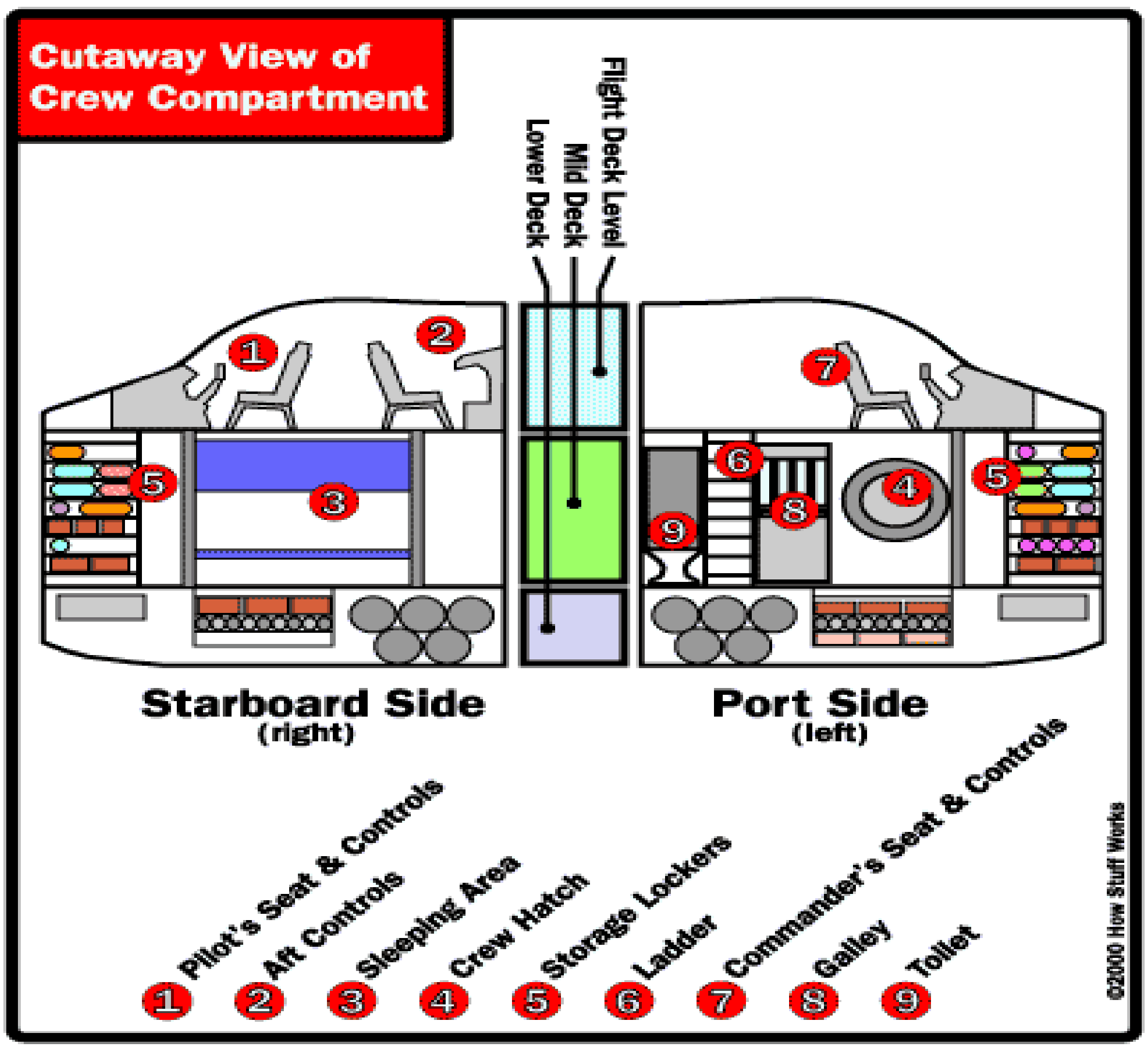
•aft deck - contains controls for orbital operations: maneuvering the orbiter while in orbit (rendezvous, docking, deploying payload, and working the remote manipulator arm

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 must provide astronauts with an environment similar to Earth. The shuttle must have air, food, water, and a comfortable temperature. The orbiter must also take away the wastes 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/in^2 (1 atm) that we breathe in and out. The space shuttle must provide a similar atmosphere. To do this, the orbiter carries liquid oxygen and liquid nitrogen in two systems of pressurized tanks, which are located in the mid-fuselage (each system has two tanks for a total of four tanks). The cabin pressurization system combines the gases in the correct mixture at normal atmospheric pressure. While in orbit, only one oxygen-nitrogen system is used to pressurize the orbiter. During launch and landing, both systems of each gas are 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 is 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 passes through a hydrogen separator to eliminate any trapped hydrogen gas (excess hydrogen gas is dumped overboard). The water is then stored in four water storage tanks located in the lower deck. Each tank can hold 165 lb (75 kg).

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

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 of 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 of the on-board systems of the orbiter require electrical power. Three fuel cells make electricity; they are located 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) on the wing surfaces and underside

•High-temperature black surface insulation tiles on the upper forward fuselage and around the windows

•White Nomex blankets on the upper payload bay doors, portions of the upper wing and mid/aft fuselage

•Low-temperature white surface tiles on the remaining areas

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 is able to 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.

Space Shuttle Emergency Management

When an emergency occurs it is Mission Controls responsibility to evaluate the event, triage the process, and evaluate the most important jobs that need to be accomplished. The safety of the flight crew is the primary focus of an emergency as Mission Control takes on a new series of responsibilities.

Understandably the flight crew gets very engaged after an anomaly. They want to help ensure the mission is a success and failure is a big concern. They need to be provided frequent updates on findings and progress and participate in the evaluation of the emergency and its mitigation. This mission is very important to the flight crew but reason and balance needed to prevail.

The first concern is to “stop the bleeding”, questions naturally begin to surface about why the anomaly occurred. These queries, while important to understanding your continuing risk, should not distract the team from focusing their attention on continuing the mission and managing the problem.

Watch for Things Getting Complicated

After the anomaly, Mission Control needs to work through the data, consider responses, and to solve the problem. Teams have a tendency to create complex, multilayer solutions to mitigate the problem. Sometimes discussions work their way from one incremental fix to another, arriving at complex fixes and patches that would move the team far from its operations training and might not address the real problem. This complexity growth actually grows risk that the system will become so sophisticated it will be prone to operator error or create unforeseen interactions. In the heat of battle, there needs to be someone who keeps an eye on the risk of the solution. This is the responsibility of Mission Control, someone needs to ask, “Do we need to go that far, or can we live with just the first corrective measure?” Sometimes you need to agree that you can accept residual risk after addressing the principal problem. Missions have been lost because smart people did well-intended things that made problems worse.

Meeting the Challenge of the Emergency

The triage process must be a mix of urgency and focus, which comes from many, many operational rehearsals where the team trains for what is supposed to happen and even what is not supposed to happen. You need to focus not just on the specifics of what could go wrong, but on your behavior and process when something goes wrong.

Mission Control has many responsibilities when an emergency happens. You will have to depend on individual and team capabilities, training, and roles in ways that are hard to describe. You know that you must trust the team's abilities and judgment, but also watch for signs, both within the team and outside, of good intentions yielding problematic results. You must be reasonable and evenhanded, understanding that you cannot eliminate risk. The emergency is a time when a mission team shows what it is really made of.

Space Shuttle Abort Modes

The worst possible outcome of an Emergency is the "Mission Abort". To meet this need NASA developed multiple procedures to mitigate this specific possibility. A Space Shuttle abort procedure is an emergency procedure that is needed due to equipment failure on NASA's Space Shuttle, most commonly during ascent. A main engine failure was a typical abort scenario. There were fewer abort options during reentry and descent. For example, the Columbia disaster happened during reentry, and there were no alternatives in that portion of flight.

Later in descent, certain failures were survivable, although not usually classified as an abort. For example, a flight control system problem or multiple auxiliary power unit failure would make reaching a landing site impossible, thus requiring the astronauts to bail out.

There were five abort modes available during ascent, in addition to pad (RSLS) aborts. These were divided into the categories of intact aborts and contingency aborts. The choice of abort mode depended on how urgent the situation was, and what emergency landing site could be reached. The abort modes covered a wide range of potential problems, but the most commonly expected problem was Space Shuttle Main Engine (SSME) failure, causing inability either to cross the Atlantic or to achieve orbit, depending on timing and number of failed engines. Other possible non-engine failures necessitating an abort included multiple auxiliary power unit (APU) failure, cabin leak, and external tank leak (ullage leak).

Redundant Set Launch Sequencer (RSLS) Abort

The main engines were ignited roughly 6.6 seconds before liftoff. From that point to ignition of the Solid Rocket Boosters at T - 0 seconds, the main engines could be shut down. This was called a "Redundant Set Launch Sequencer Abort", and happened five times, on STS-41-D, STS-51-F, STS-51, STS-55, and STS-68. It always happened under computer (not human) control, caused by computers sensing a problem with the main engines after starting but before the SRBs ignited. The SRBs could not be turned off once ignited, and afterwards the shuttle was committed to take off. If an event such as an SSME failure requiring an abort happened after SRB ignition, acting on the abort would have to wait until SRB burnout 123 seconds after launch. No abort options existed if that wait was not possible.

Intact abort modes

There were four intact abort modes for the Space Shuttle. Intact aborts were designed to provide a safe return of the orbiter to a planned landing site or to a lower orbit than planned for the mission.

Return To Launch Site (RTLS)

In a Return To Launch Site (RTLS) abort, the Shuttle would have continued downrange until the solid rocket boosters were jettisoned. It would then pitch around, so the SSMEs fired retrograde. This maneuver would have occurred in a near-vacuum above the appreciable atmosphere and was conceptually no different from the OMS engines firing retrograde to de-orbit. The main engines continued burning until downrange velocity was killed and the vehicle began heading back toward the launch site at sufficient velocity to reach a runway. Afterwards the SSMEs were stopped, the external tank was jettisoned, and the orbiter made a normal gliding landing on the runway at Kennedy Space Center about 25 minutes after lift-off. The CAPCOM would call out the point in the ascent at which an RTLS was no longer possible as "negative return", approximately four minutes after lift-off.

Should all three SSMEs have failed, the shuttle would not have been able to make it back to the runway at KSC, forcing the crew to bail out. While this would have resulted in the loss of the Shuttle, the crew could escape safely and then be recovered by the SRB recovery ships.

This abort mode was never needed in the history of the Shuttle program. Astronaut Mike Mullane referred to the RTLS abort as an "unnatural act of physics," and many pilot astronauts hoped that they would not have to perform such an abort due to its difficulty.

Transoceanic Abort Landing (TAL)

A Transoceanic Abort Landing (TAL) involved landing at a predetermined location in Africa or western Europe about 25 to 30 minutes after lift-off. It was used when velocity, altitude, and distance downrange did not allow return to the launch point via RTLS. It was also used when a less time-critical failure did not require the faster but possibly more stressful RTLS abort.

A TAL abort would be declared between roughly T+2:30 minutes (2 minutes and 30 seconds after liftoff) and Main Engine Cutoff (MECO), about T+8:30 minutes. The

Shuttle would then land at a pre-designated friendly airstrip in Europe. The last four TAL sites until the Shuttle's retirement were Istres Air Base in France, Zaragoza and Morón air bases in Spain, and RAF Fairford in England. Prior to a Shuttle launch, two of them were selected depending on the flight plan, and staffed with standby personnel in case they were used. The list of TAL sites changed over time; most recently Ben Guerir Air Base in Morocco (TAL site from July 1988–June 2002) was eliminated due to terrorist attack concerns. Other previous TAL sites included Lajes Air Base, Terceira, Azores, Mallam Aminu Kano International Airport, Kano, Nigeria; Mataveri International Airport, Easter Island, Chile (for Vandenberg launches); Rota, Spain; Casablanca, Morocco; Banjul, Gambia; and Dakar, Senegal.

Preparations of TAL sites took 4 to 5 days and began a week before a launch with the majority of personnel from NASA, the Department of Defense, and contractors arriving 48 hours before launch. Additionally, two C-130 aircraft from the Manned Space Flight support office from the adjacent Patrick Air Force Base including eight crew members, nine para-rescue men, two flight surgeons, a nurse and medical technician, along with 2,500 pounds of medical equipment were deployed to either Zaragoza, Istres, or both. One or more C-21 or a C-12 aircraft were also deployed to provide weather reconnaissance in the event of an abort with a TALCOM, or astronaut flight controller aboard for communications with the shuttle pilot and commander. This abort mode was never needed during the entire history of the space shuttle program.

Abort Once Around (AOA)

An Abort Once Around (AOA) was available when the shuttle could not reach a stable orbit but had sufficient velocity to circle the earth once and land, about 90 minutes after lift-off. The time window for using the AOA abort was very short – just a few seconds between the TAL and ATO abort opportunities. Therefore, taking this option was very unlikely. This abort mode was never needed during the entire history of the space shuttle program.

Abort to Orbit (ATO)

An Abort to Orbit (ATO) was available when the intended orbit could not be reached but a lower stable orbit was possible. This occurred on mission STS-51-F, which continued despite the abort to a lower orbit. The Mission Control Center in Houston (located at Lyndon B. Johnson Space Center) observed an SSME failure and called "Challenger--Houston, Abort ATO. Abort ATO".

The moment at which an ATO became possible was referred to as the "press to ATO" moment. In an ATO situation, the spacecraft commander rotated the cockpit abort mode switch to the ATO position and depressed the abort push button. This initiated the flight control software routines which handled the abort. In the event of lost communications, the spacecraft commander could have made the abort decision and taken action independently.

A hydrogen fuel leak in one of the SSMEs on STS-93 resulted in a slightly lower orbit than anticipated, but was not an ATO; if the leak had been more severe, it might have necessitated an ATO, RTLS, or TAL abort.

Emergency landing sites

Pre-determined emergency landing sites for the Orbiter were determined on a mission-by-mission basis according to the mission profile, weather and regional political situations.

Chapter 9

Space Stations

Noordung's Space Station Habitat Wheel (1928)

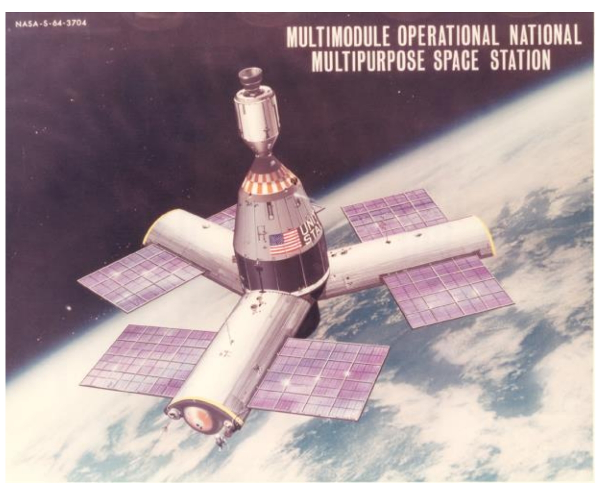
1929 Hermann Noordung depiction of a space station habitat wheel. Hermann Potocnik (1892-1929), also known as Herman Noordung, created the first detailed technical drawings of a space station. Power was generated by collecting sunlight through the concave mirror in the center. This was one of three components of Noordung's space station. The other two were the observatory and the machine room, each connected to the habitat by an umbilical.

Space station from the sci-fi film, 2001: A Space Odyssey (1965)

This the classic space station image from the movie 2001:a Space Odyssey, directed by Stanley Kubrick in 1968. Praised for its special effects, the movie based its space station concept on Wernher Von Braun's model. Kubrick's station in the movie was 900 feet in diameter, orbited 200 miles above Earth, and was home to an international contingent of scientists, passengers, and bureaucrats.

Orbit and Launch Facility Concept (1963)

This is a concept drawing of an orbit and launch facility. It was to use a nuclear SNAP-II nuclear power supply on the end of the long telescoping boom. Nuclear reactors were considered dangerous, which is why in this concept drawing it was located so far away from the habitat part of the station. Creators envisioned the structure being built in orbit to allow assembly of the station in orbit which could be then larger than anything that could be launched from Earth. The two main modules were to be 33 feet in diameter and 40 feet in length. When combined the modules would create a four deck facility, 2 decks to be used for laboratory space and 2 decks for operations and living quarters. The facility also allowed for servicing and launch of a space vehicle. Though the station was designed to operate in micro- gravity, it would also have an artificial gravity capability.

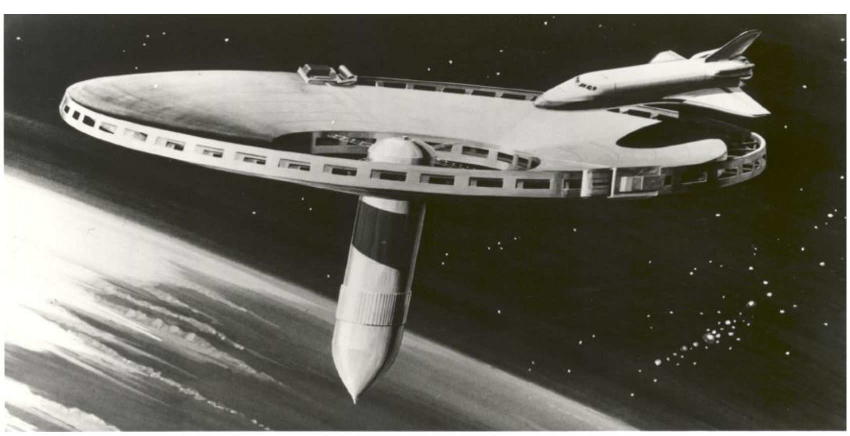


Three Radial Module Space Station Concept (1964)

This three-radial-module space station concept was intended to utilize Apollo hardware to deploy the station and to transfer crews to and from orbit.

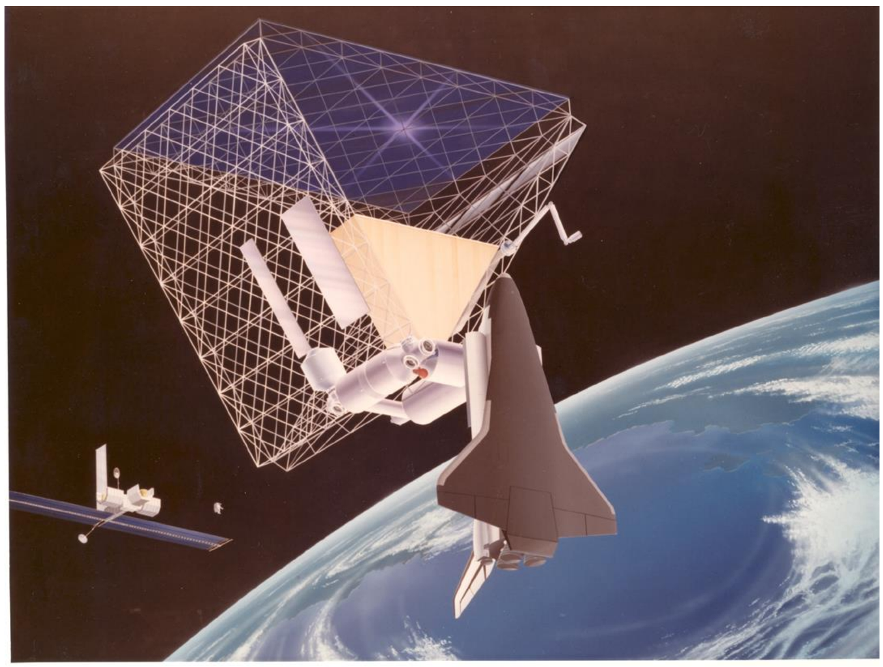
Proposed USAF Manned Orbiting Laboratory (1966)

A 1960 concept image of the United States Air Force's proposed Manned Orbiting Laboratory (MOL) that was intended to test the military usefulness of having humans in orbit. The station's baseline configuration was that of a two-person Gemini B spacecraft that could be attached to a laboratory vehicle. The structure was planned to launch onboard a Titan IIIC rocket. The station would be used for a month and then the astronauts could return to the Gemini capsule for transport back to Earth. The first launch of the MOL was scheduled for December 15, 1969, but was then pushed back to the fall of 1971. The program was cancelled by Defense Secretary Melvin R. Laird in 1969 after the estimated cost of the program had risen in excess of $3 billion, and had already spent $1.3 billion. Some of the military astronauts selected for the program then transferred to NASA and became some of the first people to fly the Space Shuttle, including Richard Truly, who later became the NASA Administrator.



Spider Space Station Concept (1976)

A 1977 concept drawing for a space station, known as the "spider" concept, this station was designed to use Space Shuttle hardware. A solar array was to be unwound from the exhausted main fuel tank. The structure could then be formed and assembled in one operation. The main engine tank would then be used as a space operations control center, a Shuttle astronaut crew habitat, and a space operations focal point for missions to the Moon and Mars.

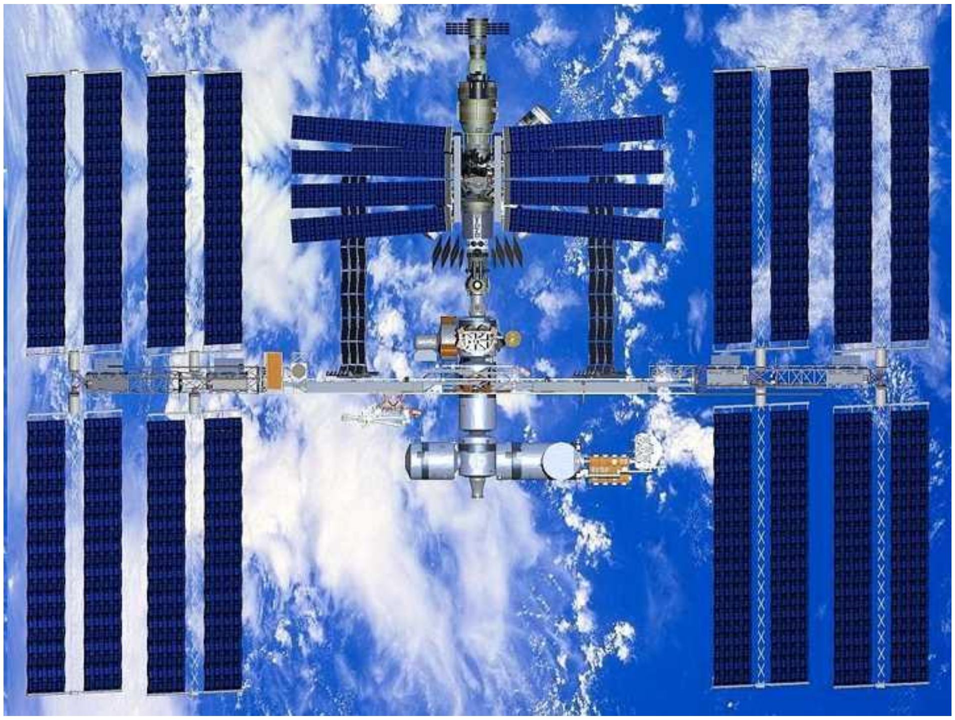


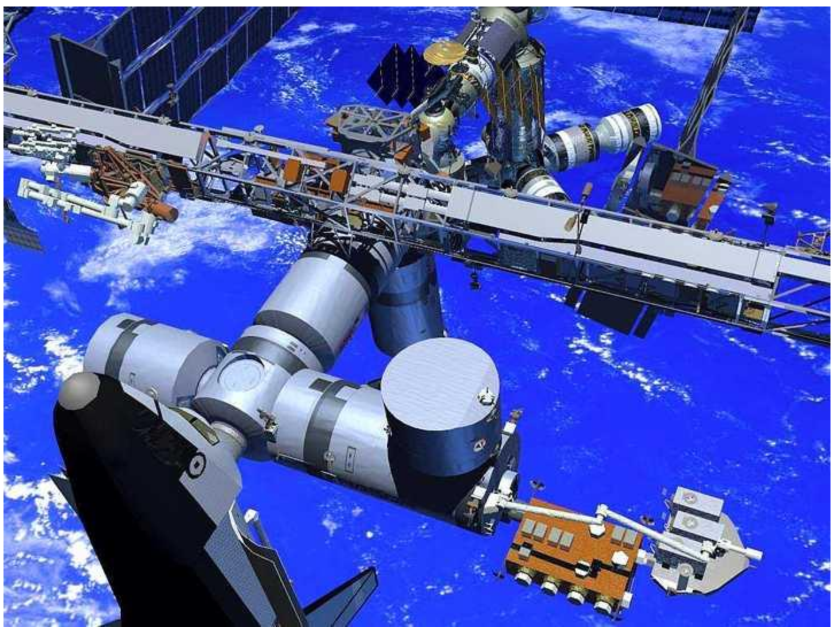
Roof Space Station Concept (1980)

This is the Johnson Space Center's 1984 "roof" concept for a space station. The "roof" was covered with solar array cells that were to generate about 120 kilowatts of electricity. Within the V-shaped beams there would be five modules for living, laboratory space, and external areas for instruments and other facilities.

<u>International Space Station (ISS)</u>:

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.

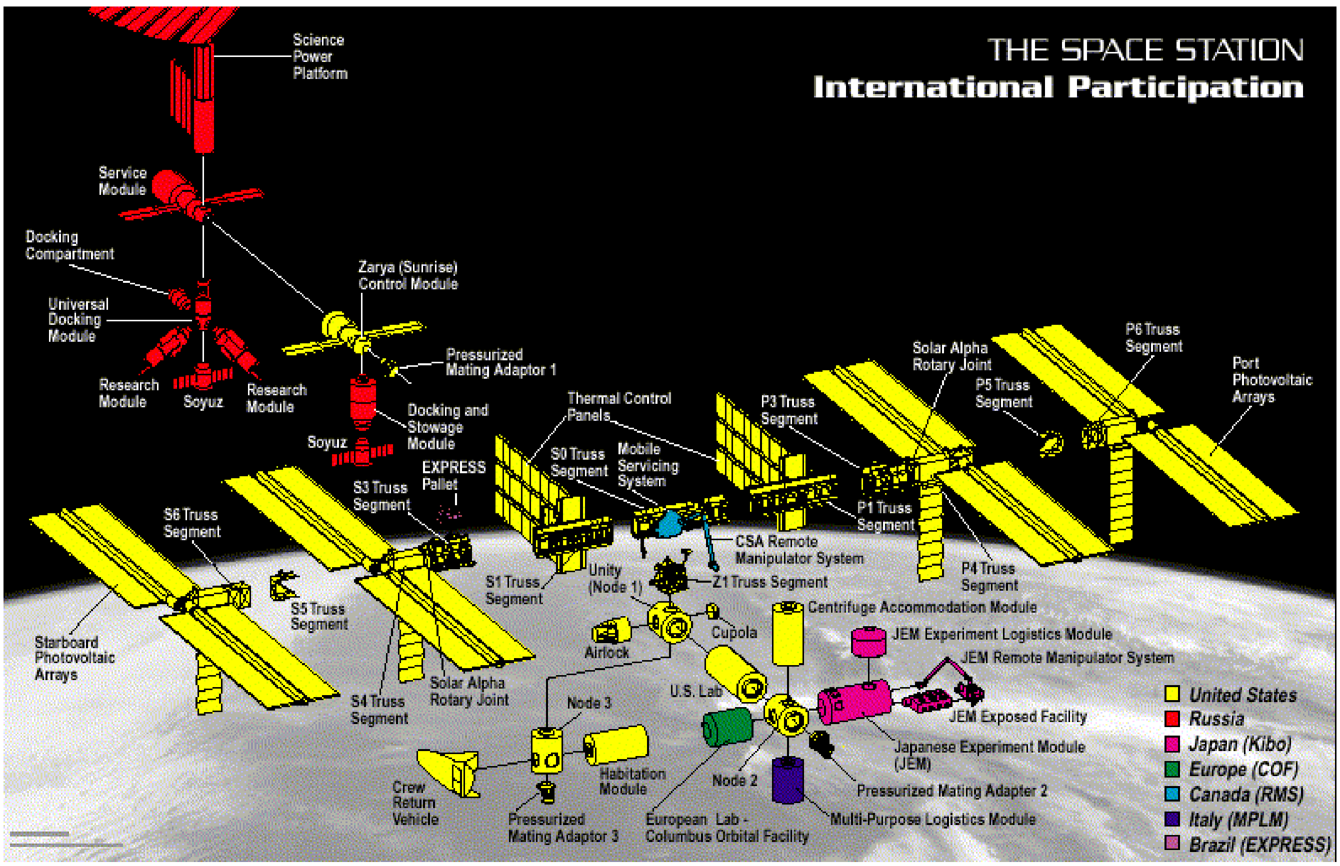




The mission of the International Space Station is to enable long-term exploration of space and provide benefits to people on Earth.

- To create a permanent orbiting science institute in space capable of performing long-duration research in the materials and life sciences areas in a nearly gravity-free environment.

- To conduct medical research in space.
- To develop new materials and processes in collaboration with industry.
- To accelerate breakthroughs in technology and engineering that will have immediate, practical applications for life on Earth and will create jobs and economic opportunities today and in the decades to come.
- To maintain U.S. leadership in space and in global competitiveness, and to serve as a driving force for emerging technologies.
- To forge new partnerships with the nations of the world.
- To inspire our children, foster the next generation of scientists, engineers, and entrepreneurs, and satisfy humanity's ancient need to explore and achieve.
- To invest for today and tomorrow. Every dollar spent on space programs returns at least $2 in direct and indirect benefits.
- To sustain and strengthen the United States strongest export sector aerospace technology which in 1995 exceeded $33 billion



Station Facts:

- Wingspan: 356 feet
- Length: 290 feet
- Mass: 1 million pounds
- Operating Altitude: 220 nautical miles
- Inclination: 51.6 degrees

- Pressurized Volume: 43,000 cubic feet in 6 labs
- Crew Size: 3
- Cost per Year: 2.1 billion dollars (

The pressurized living and working space aboard the completed ISS will be about the size of three average American homes. Its giant solar arrays will generate the electricity needed to power about 50 average American homes. An initial crew of three began living aboard the ISS in late 2000. Inside the ISS its weightless environment will be maintained at shirt sleeve temperatures with atmospheric pressures similar to what we have here on Earth.

Six main laboratories will house research facilities:

- Two U.S. a laboratory module called Destiny and a Centrifuge Accommodations Module (CAM)
- One European Space Agency (ESA) laboratory named Columbus
- One Japanese Experiment Module named Kibo
- Two Russian Research Modules

The central girder, called the truss, will connect the modules and four giant solar arrays making the ISS larger than a football field. The Canadian-built Remote Manipulator System, a 55-foot robot arm and a grappling mechanism called the Special Purpose Dexterous Manipulator (SPDM), will move along the truss on a mobile base transporter to perform assembly and maintenance work.

External sites for mounting experiments intended for looking down at Earth and out into space or for direct exposure to space are provided at four locations on the truss structure, along with 10 on the Japanese Kibo Module s back porch and 4 on the ESA Columbus Module exposed facility. These external experiment sites vary as to the number of payloads that can be accommodated. A three-person Russian Soyuz capsule provides emergency crew return.

More than 40 space flights over five years and at least three space vehicles the space shuttle, the Russian Soyuz rocket and the Russian Proton rocket will deliver the various space station components to Earth orbit. Assembly of the more than 100 components will require a combination of human space walks and robot technologies.

Fifteen flights, which include 11 space shuttle missions, have already occurred in the International Space Station era. The first flight was a Russian Proton rocket that lifted off in November 1998 and placed the Zarya module in orbit. In early December of that same year, the STS-88 mission saw Space Shuttle Endeavour attach the Unity module to Zarya initiating the first ISS assembly sequence. The third ISS mission was STS-96 in June 1999 with Discovery supplying the two modules with tools and cranes.

The fourth flight to the space station was STS-101, which launched May 19, 2000. The seven-member crew of STS-101 performed maintenance tasks and delivered supplies in preparation for the arrival of the Zvezda Service Module and the station's first permanent crew. Zvezda, the fifth flight, docked with the station on July 25 at 7:45 p.m. CDT, or July 26 at 00:45 GMT, and became the third major component of the station. Then, STS-106 visited the station in September to deliver supplies and outfit Zvezda in preparation for the station's first permanent crew, which arrived at the station on Nov. 2. Prior to the Expedition One crew's arrival, STS-92 delivered the Z1 Truss, Pressurized Mating Adapter 3 and four Control Moment Gyros in October.

STS-97 was the last shuttle mission of the 20th century. Space Shuttle Endeavour and its five-member crew installed the first set of U.S. solar arrays onto the station and became the first shuttle crew to visit Expedition One. The solar arrays set the stage for the arrival of the U.S. Destiny Laboratory Module, which arrived at the station in February 2001 on STS-98. The five STS-98 astronauts also relocated Pressurized Mating Adapter 2 from the end of Unity to the end of Destiny to set the stage for future shuttle missions.

In March 2001, the first crew rotation flight arrived. STS-102 delivered the Expedition Two crew to the station and returned Expedition One to Earth. Also, STS-102 carried the first Multi-Purpose Logistics Module, Leonardo, to the station. Logistics modules are reusable cargo carriers built by the Italian Space Agency. Expedition One spent 4.5 months on the station.

STS-100 delivered the station's robot arm, which is also known as the Space Station Remote Manipulator System and the Raffaello Multi-Purpose Logistics Module in April. The delivery of the arm set the stage for the arrival of the station's joint airlock, which was installed during STS-104's visit to the station in July 2001.

Expedition arrived midway between the flights of STS -92 and STS - 97. These two Space Shuttle flights each added segments of the station's Integrated Truss structure, which provided the station with Ku-band communication for US television, additional attitude support needed for the additional mass of the USOS, and substantial solar array supplementing the station's existing 4 solar arrays.

Over the next two years the station continued to expand. A Soyuz U - rocket delivered the *Pirs* docking compartment. The Space Shuttles *Discovery*, Atlantis, and *Endeavour* delivered the Destiny Laboratory and Quest airlock, in addition to the station's main robot arm, the Canada arm 2, and several more segments of the Integrated Truss Structure.

The expansion schedule was interrupted by the destruction of the Space Shuttle Colombia in 2003, with the resulting hiatus in the Space Shuttle Program halting station assembly until the launch of *Discovery* on STS 114 in 2005.

Assembly resumed with the arrival of *Atlantis* on STS-115, which delivered the station's second set of solar arrays. Several more truss segments and a third set of arrays were delivered on STS 116, 117, and 118. As a result of the major expansion of the station's power-generating capabilities, more pressurized modules could be accommodated, and the Harmony node and *Columbus* European laboratory were added. These were followed shortly after by the first two components of *Kibō*. In March 2009, STS - 119 completed the Integrated Truss Structure with the installation of the fourth and final set of solar arrays. The final section of *Kibō* was delivered in July 2009 on STS 127, followed by the Russian Poisk module.

The third node, Tranquility, was delivered in February 2010 during STS - 130 by the Space Shuttle *Endeavour*, alongside the Cupola, closely followed in May 2010 by the penultimate Russian module, Rassvet. Rassvet was delivered by Space Shuttle *Atlantis* on in exchange for the Russian Proton delivery of the Zarya Module in 1998 which had been funded by the United States. The last pressurized module of the USOS, *Leonardo*, was brought to the station by *Discovery* on her final flight, followed by the Alpha Magnetic Spectrometer delivered by *Endeavour.*]

As of June 2011, the station consisted of fifteen pressurized modules and the Integrated Truss Structure. Still to be launched are the Russian Multipurpose Laboratory Module Nauka and a number of external components, including the European Robotic Arm. Assembly is expected to be completed by April 2014 by which point the station will have a mass in excess of 400 tons.

The gross mass of the station changes over time. The total launch mass of the modules on orbit is about 417,289 kg (919,965 lb) (as of 03/09/2011).] The mass of experiments, spare parts, personal effects, crew, foodstuff, clothing, propellants, water supplies, gas supplies, docked spacecraft, and other items add to the total mass of the station. Hydrogen gas is constantly vented overboard by the oxygen generators.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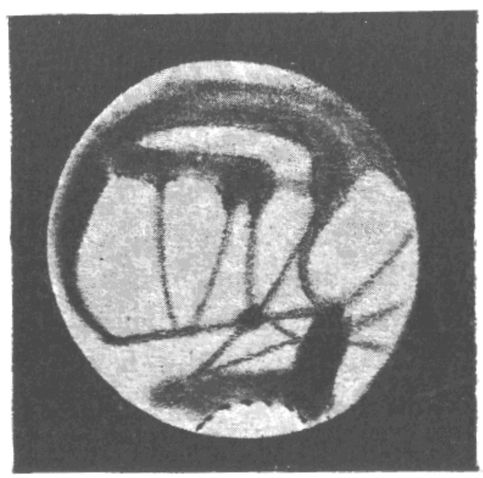
Chapter 10

Mission to Mars

Since the 16th century, learned men have recognized Mars for what it is-a relatively nearby planet not so unlike our own. The fourth planet from the sun and Earth's closest neighbor, Mars has been the subject of modern scientists' careful scrutiny with powerful telescopes, deep space probes, and orbiting spacecraft. In 1976, Earth-bound scientists were brought significantly closer to their subject of investigation when two Viking landers touched down on that red soil. The possibility of life on Mars, clues to the evolution of the solar system, fascination with the chemistry, geology, and meteorology of another planet-these were considerations that led NASA to Mars. Project Viking's goal, after making a soft landing on Mars, was to execute a set of scientific investigations that would not only provide data on the physical nature of the planet but also make a first attempt at determining if detectable life forms were present.



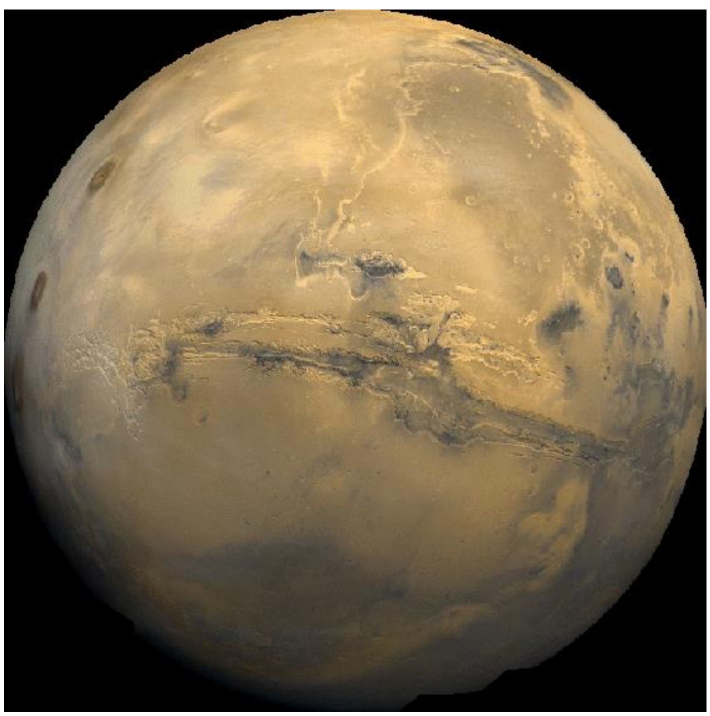
Landing a payload of scientific instruments on the Red Planet had been a major NASA goal for more than 15 years. Two related projects-Mariner B and Voyager-preceded Viking's origin in 1968. Mariner B, aimed at placing a capsule on Mars in 1964, and Voyager, which would have landed a series of sophisticated spacecraft on the planet in the late 1960s, never got off the ground. But they did lead directly to Viking and influenced that successful project in many ways.

When the space agency was established in 1958, planetary exploration was but one of the many projects called for by scientists, spacecraft designers, and politicians. Among the conflicting demands made on the NASA leadership during the early months were proposals for Earth-orbiting satellites and lunar and planetary spacecraft. But man in space, particularly under President John F. Kennedy's mandate to land an American on the moon before the end of the 1960s, took a more than generous share of NASA's money and enthusiasm. Ranger, Surveyor, and Lunar Orbiter-spacecraft headed for the moon-grew in immediate significance at NASA because they could contribute directly to the success of crewed Apollo operations. Proponents of planetary investigation were forced to be content with relatively constrained budgets, limited personnel, and little publicity. But by 1960 examining the closer planets with rocket-propelled probes was technologically feasible, and this possibility kept enthusiasts loyal to the cause of planetary exploration.

Viking Mission:

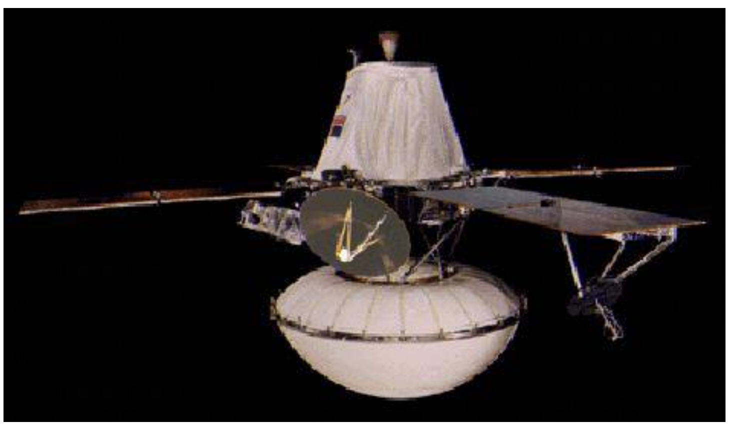
NASA's Viking Mission to Mars was composed of two spacecraft, Viking 1 and Viking 2, each consisting of an orbiter and a lander. The primary mission objectives were to obtain high resolution images of the Martian surface, characterize the structure and composition of the atmosphere and surface, and search for evidence of life.

The Viking Landers transmitted images of the surface, took surface samples and analyzed them for composition and signs of life, studied atmospheric composition and meteorology, and deployed seismometers. The Viking 2 Lander ended communications on April 11, 1980, and the Viking 1 Lander on November 13, 1982, after transmitting over 1400 images of the two sites.



The results from the Viking experiments gave our most complete view of Mars. Volcanoes, lava plains, immense canyons, cratered areas, wind-formed features, and evidence of surface water are apparent in the Orbiter images. The planet appears to be divisible into two main regions, northern low plains and southern cratered highlands. Superimposed on these regions are the Tharsis and Elysium bulges, which are high-standing volcanic areas, and Valles Marineris, a system of giant canyons near the equator. The surface material at both landing sites can best be characterized as iron-rich clay. Measured temperatures at the landing sites ranged from 150 to 250 K (what is this in Fahrenheit? , with a variation over a given day of 35 to 50 K. Seasonal dust storms, pressure changes, and transport of atmospheric gases between the polar caps were observed. The biology experiment produced no evidence of life at either landing site.

The Viking mission represented a careful melding of the demands imposed by the scientific mission and the high degree of reliability required of the spacecraft subsystems. Weight and volume considerations affected the size of each subsystem. After the Voyager program with plans for an 11,500-kilogram spacecraft was abandoned in 1967, a follow-on study concluded that a spacecraft weighing 3700 kilograms could he transported to Mars by a Titan-Centaur-class launch vehicle. The lander and its flight capsule would account for more than a third of this weight (1195 kilograms). At the start of the mission, the orbiter and lander would be housed in a 4.3-meter shroud atop the Titan-Centaur. The landed spacecraft would be 3 meters at its widest point and 2 meters tall from the footpads to the tip of the large disk S-band high-gain antenna. While weight and volume limitations helped to shape the Viking lander, data about Martian atmospheric pressure obtained during the Mariner 9 mission were also influential.



Viking 1 was launched on August 20, 1975 and arrived at Mars on June 19, 1976 after a 10 month cruise to Mars. The orbiter began returning global images of Mars about 5 days before orbit insertion. The Viking 1 Orbiter was inserted into Mars orbit on 19 June 1976 and trimmed to a 1513 x 33,000 km, 24.66 hr site certification orbit on 21 June. Imaging of candidate sites was begun and the landing site was selected based on these pictures. The lander separated from the orbiter on 20 July 08:51 UT and landed at Chryse Planitia at 11:56:06 UT. The orbiter primary mission ended at the beginning of solar conjunction on 5 November 1976.

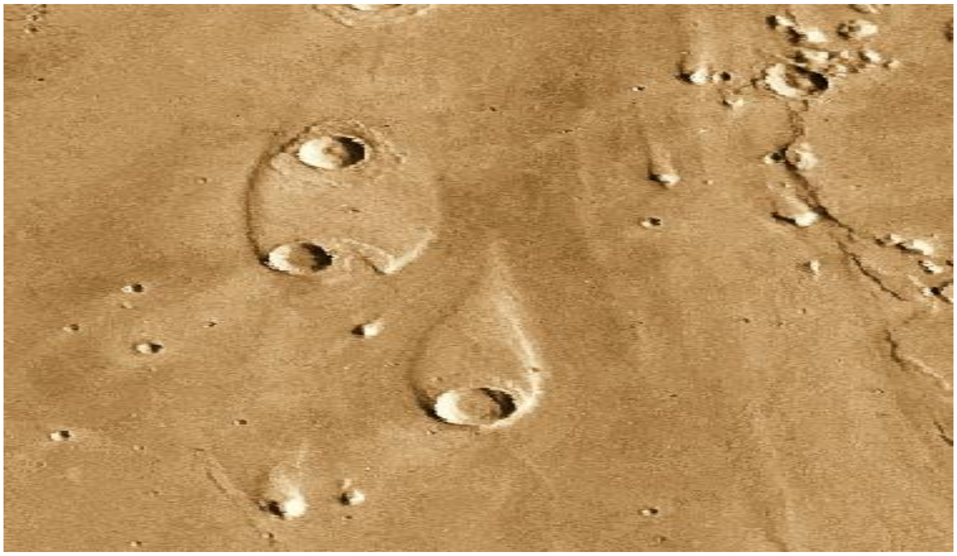
The extended mission commenced on 14 December 1976 after solar conjunction. Operations included close approaches to Phobos in February 1977. The periapsis was reduced to 300 km on 11 March 1977. Minor orbit adjustments were done occasionally over the course of the mission, primarily to change the walk rate - the rate at which the planetocentric longitude changed with each orbit, and the periapsis was raised to 357 km on 20 July 1979. On 7 August 1980 Viking 1 Orbiter was running low on attitude control gas and its orbit was raised from 357 x 33943 km to 320 x 56000 km to prevent impact with Mars and possible contamination until the year 2019. Operations were terminated on 17 August 1980 after 1485 orbits. The total cost of the Viking project was roughly one billion dollars.

Viking 2 was launched September 9, 1975 and entered Mars orbit on August 7, 1976 after a 333 day cruise to Mars. The Viking 2 Orbiter began returning global images of Mars prior to orbit insertion. The orbiter was inserted into a 1500 x 33,000 km, 24.6 hr Mars orbit on 7 August 1976 and trimmed to a 27.3 hr site certification orbit with a periapsis of 1499 km and an inclination of 55.2 degrees on 9 August. Imaging of candidate sites was begun and the landing site was selected based on these pictures and the images returned by the Viking 1 Orbiter. The lander separated from the orbiter on 3 September 1976 and landed at Utopia Planitia at 22:37:50 UT.

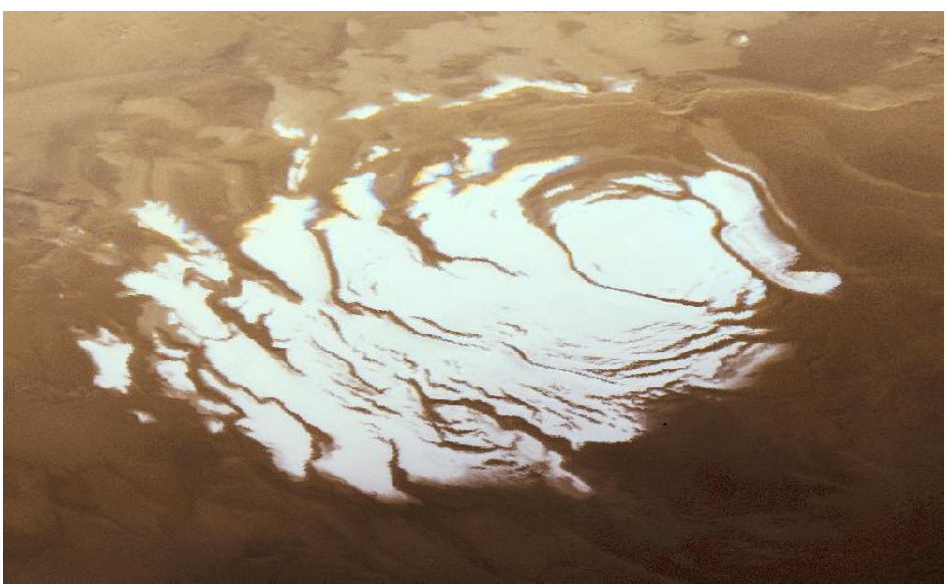
Normal operations called for the structure connecting the orbiter and lander (the bioshield) to be ejected after separation, but because of problems with the separation the bioshield was left attached to the orbiter. The orbit inclination was raised to 75 degrees on 30 September 1976. The orbiter primary mission ended at the beginning of solar conjunction on 8 November 1976. The extended mission commenced on 14 December 1976 after solar conjunction. On 20 December 1976 the periapsis was lowered to 778 km and the inclination raised to 80 degrees. Operations included close approaches to Deimos in October 1977 and the periapsis was lowered to 300 km and the period changed to 24 hours on 23 October 1977. The orbiter developed a leak in its propulsion system that vented its attitude control gas. It was placed in a 302 x 33176 km orbit and turned off on 25 July 1978 after returning almost 16,000 images in 706 orbits around Mars.

Viking Orbiter:

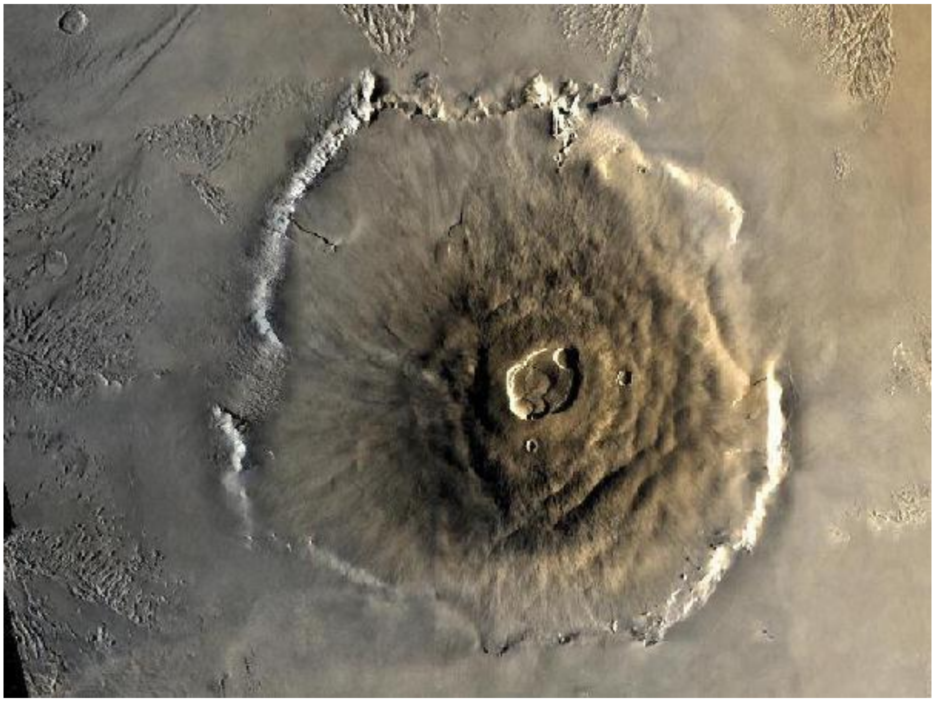
The primary objectives of the Viking orbiters were to transport the landers to Mars, perform reconnaissance to locate and certify landing sites, act as a communications relays for the landers, and to perform their own scientific investigations. The orbiter, based on the earlier Mariner 9 spacecraft, was an octagon approximately 2.5 m across. The total launch mass was 2328 kg, of which 1445 kg were propellant and attitude control gas. The eight faces of the ring-like structure were .4572 m high and were alternately 1.397 and 0.508 m wide. The overall height was 3.29 m from the lander attachment points on the bottom to the launch vehicle attachment points on top. There were 16 modular compartments, 3 on each of the 4 long faces and one on each short face. Four solar panel wings extended from the axis of the orbiter, the distance from tip to tip of two oppositely extended solar panels was 9.75 m. The power was provided by eight 1.57 x 1.23 m solar panels, two on each wing. The solar panels were made up of a total of 34,800 solar cells and produced 620 W of power at Mars. Power was also stored in 2 nickel-cadmium 30-amp-hr batteries.



The main propulsion unit was mounted above the orbiter bus. Propulsion was furnished by a bipropellant (monomethyl hydrazine and nitrogen tetroxide) liquid-fueled rocket engine which could be gimballed up to 9 degrees. The engine was capable of 1323 N thrust, translating to a delta-V of 1480 m/s. Attitude control was achieved by 12 small compressed-nitrogen jets. An acquisition Sun sensor, a cruise Sun sensor, a Canopus star tracker and an inertial reference unit consisting of 6 gyroscopes allowed three-axis stabilization. Two accelerometers were also on board. Communications were accomplished through a 20-W S-band (2.3 GHz) transmitter and 2 20-W TWTA's. An X-band (8.4 GHz) downlink was also added specifically for radio science and to conduct communications experiments. Uplink was via S-band (2.1 GHz). A 2-axis steerable high-gain parabolic dish antenna with a diameter of approximately 1.5 m was attached at one edge of the orbiter base, and a fixed low-gain antenna extended from the top of the bus. Two tape recorders were each capable of storing 1280 Mbits. A 381 MHz relay radio was also available.

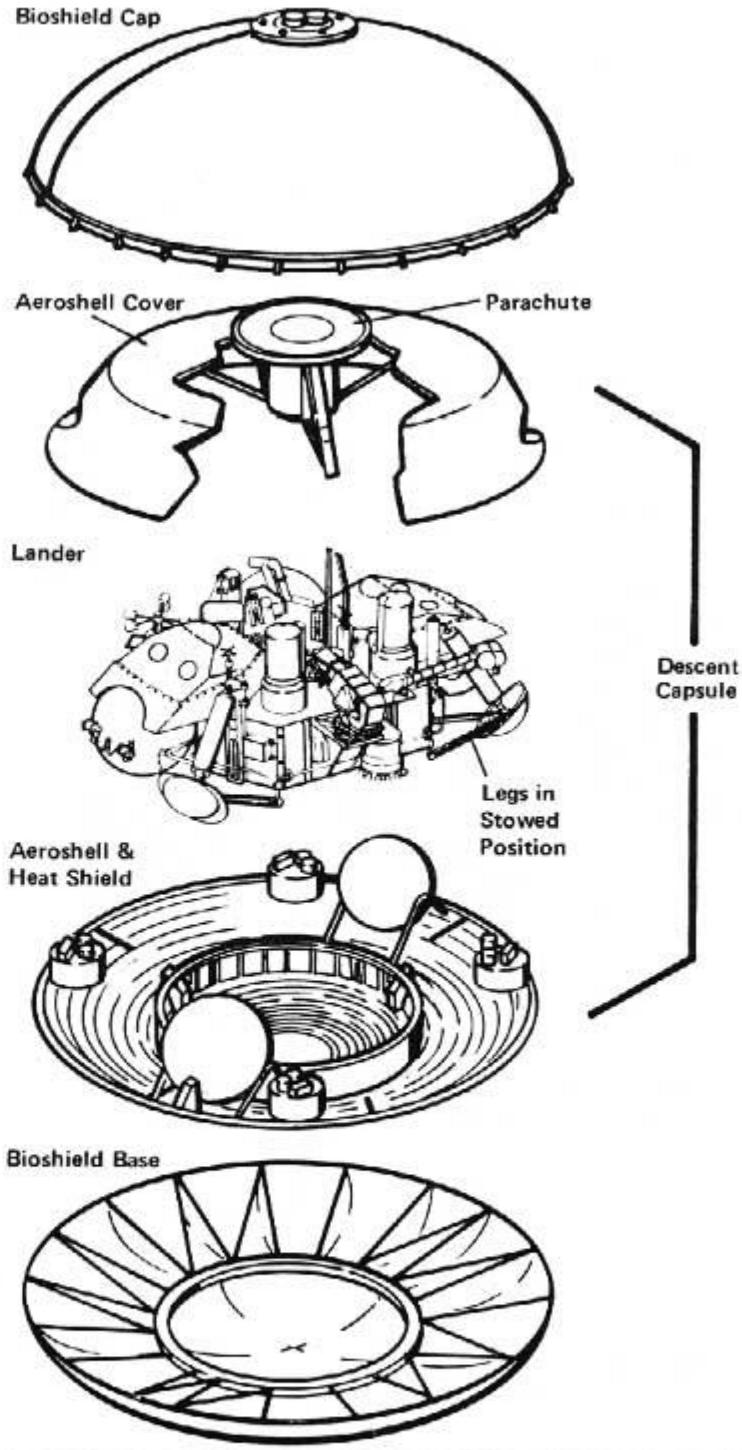


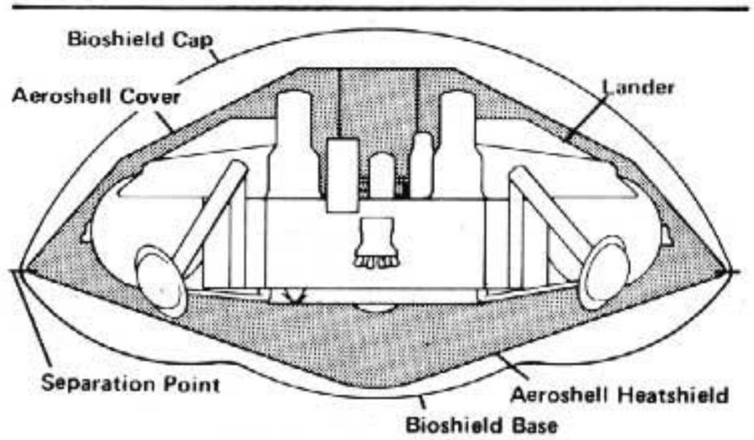
Scientific instruments for conducting imaging, atmospheric water vapor, and infrared thermal mapping were enclosed in a temperature controlled, point able scan platform extending from the base of the orbiter. The scientific instrumentation had a total mass of approximately 72 kg. Radio science investigations were also done using the spacecraft transmitter. Command processing was done by two identical and independent data processors, each with a 4096-word memory for storing uplink command sequences and acquired data.



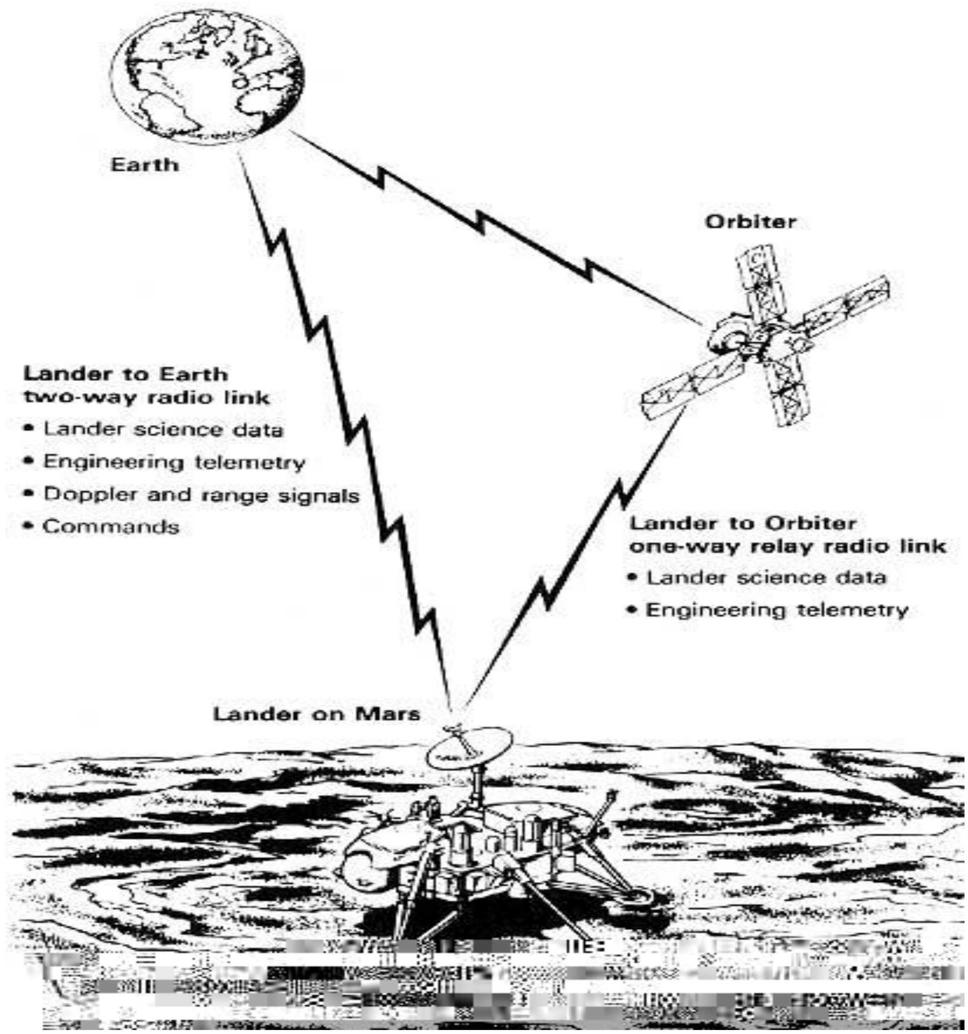
Viking Lander:

Mariner 9's occultation experiment indicated that the atmospheric pressure at the surface of Mars ranged from 4 to 20 millibars, rather than 80 millibars as estimated earlier. This information had a definite impact on the aerodynamic shape of the Mars entry vehicle being designed, since weight and diameter would influence the craft's braking ability. Langley engineers had determined that aerodynamic braking was the only practical method for slowing down a lander as large as Viking for a soft touchdown. The entry vehicle would have a diameter of 3.5 meters, an acceptable ballistic coefficient that would help ensure Viking's safe landing on Mars.

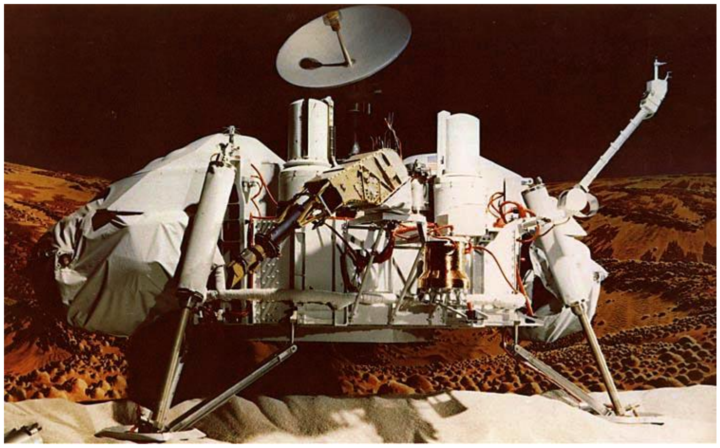

Bioshield Cap
Aeroshell Cover
Parachute
Lander
Descent
Capsule
Legs in
Stowed
Position
Aeroshell &
Heat Shield
Bioshield Base


Bioshield Cap
Aeroshell Cover
Lander
Separation Point
Aeroshell Heatshield
Bioshield Base

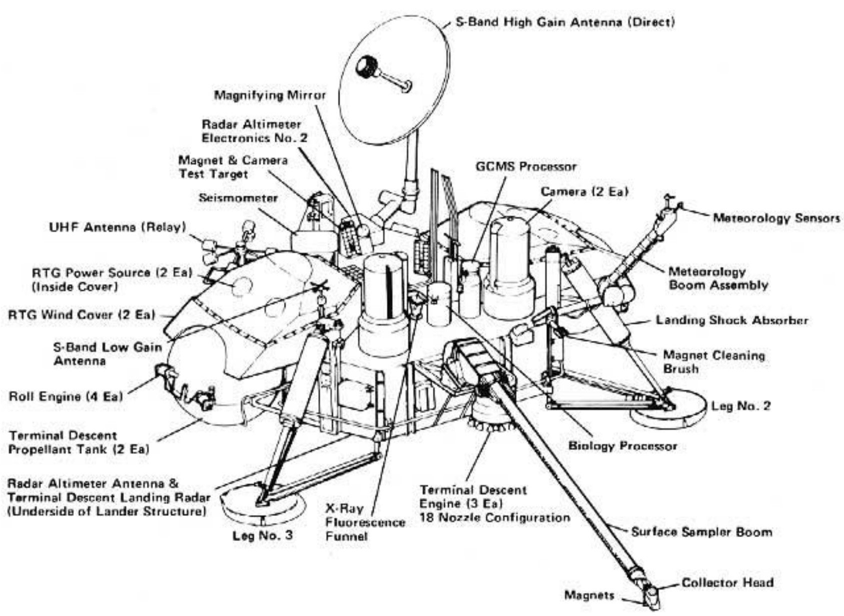
Since electrical power requirements were thought of in terms of the weight that the power apparatus would add to the spacecraft, the design engineers sought creative means for getting maximum results from a minimum amount of power. Low-power integrated circuits were used extensively both to conserve energy and to keep the package small. In addition, power switching techniques were devised to reduce energy requirements. As John D. Goodlette, deputy project director at Martin Marietta, noted, the design rule was "turn off unneeded consumers." When power had to be used, the equipment was designed with multiple power levels, or states, so [that only the minimum power required to achieve the immediate function would he consumed.



Once separated from the orbiter with its 700-watt solar panels, only 70 watts of radioisotope-thermoelectric-generated power would support the long mission on the surface. Because of this limitation on landed power, the radio transmitters could be used only sparingly, a factor that in turn controlled the amount of data that could be sent to Earth.



The Viking lander was a highly automated spacecraft for a number of reasons. Since there was only a 20-minute one-way communications opportunity between Earth and Mars during the landings, control of the lander from Earth from separation to touchdown was not practical. The entire function of navigation-from obtaining an inertial reference to locating a local surface reference-had to be accomplished by the onboard computer. After landing, the spacecraft would be out of direct communication with Earth for about half of each Martian day. And because of electrical power limits, the communications between lander and mission control in California would amount to only a short time each day. The lander, therefore, had to be capable of carrying out its mission unattended by Earth. Mission specialists could send the lander new assignments or modify preprogrammed ones, but for the most part the craft was on its own as it did its day-to-day work.

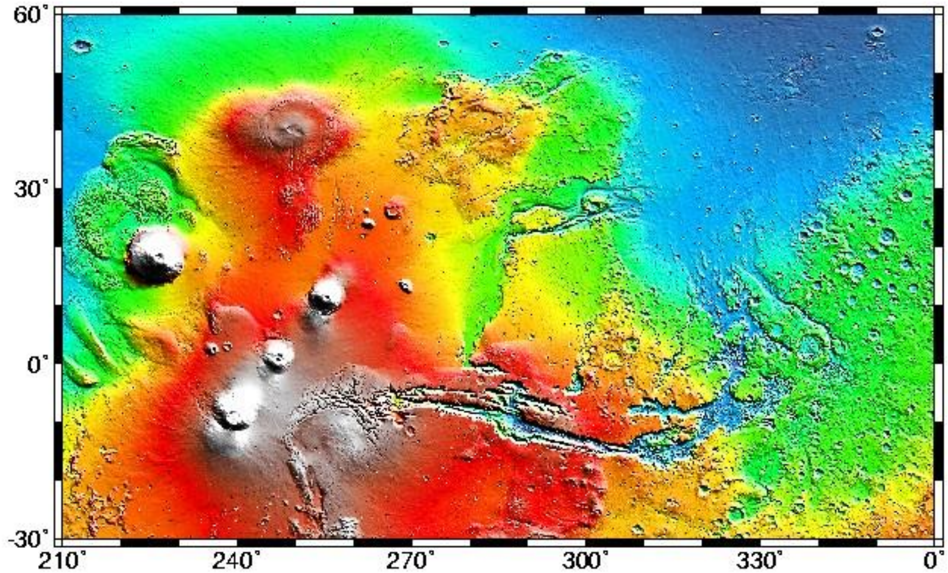


The lander consisted of a 6-sided aluminum base with alternate 1.09 m and 0.56 m long sides, supported on three extended legs attached to the shorter sides. The leg footpads formed the vertices of an equilateral triangle with 2.21 m sides when viewed from above, with the long sides of the base forming a straight line with the two adjoining footpads. Instrumentation was attached to the top of the base, elevated above the surface by the extended legs. Power was provided by two radioisotope thermal generator (RTG) units containing plutonium 238 affixed to opposite sides of the lander base and covered by wind screens. Each generator was 28 cm tall, 58 cm in diameter, had a mass of 13.6 kg and provided 30 W continuous power at 4.4 volts. Four wet-cell sealed nickel-cadmium 8-amp-hour, 28 volt rechargeable batteries were also onboard to handle peak power loads.

Propulsion was provided for deorbit by a monopropellant hydrazine (N2H4) rocket with 12 nozzles arranged in four clusters of three that provided 32 N thrust, giving a delta-V of 180 m/s. These nozzles also acted as the control thrusters for translation and rotation of the lander. Terminal descent and landing was achieved by three (one affixed on each long side of the base, separated by 120 degress) monopropellant hydrazine engines. The engines had 18 nozzles to disperse the exhaust and minimize effects on the ground and were throttleable from 276 N to 2667 N. The hydrazine was purified to prevent contamination of the martian surface. The lander carried 85 kg of propellant at launch, contained in two spherical titanium tanks mounted on opposite sides of the lander beneath the RTG windscreens, giving a total launch mass of 657 kg. Control was achieved through the use of an inertial reference unit, four gyros, an aerodecelerator, a radar altimeter, a terminal descent and landing radar, and the control thrusters.

Communications were accomplished through a 20 W S-band transmitter and two 20 W TWTA's. A 2-axis steerable high-gain parabolic antenna was mounted on a boom near one edge of the lander base. An omnidirectional low-gain S-band antenna also extends from the base. Both these antennae allowed for communication directly with the Earth. A UHF (381 MHz) antenna provided a one-way relay to the orbiter using a 30 W relay radio. Data storage was on a 40 Mbit tape recorder, and the lander computer had a 6000 word memory for command instructions.

The lander carried instruments to achieve the primary scientific objectives of the lander mission: to study the biology, chemical composition (organic and inorganic), meteorology, seismology, magnetic properties, appearance, and physical properties of the martian surface and atmosphere. Two 360-degree cylindrical scan cameras were mounted near one long side of the base. From the center of this side extended the sampler arm, with a collector head, temperature sensor, and magnet on the end. A meteorology boom, holding temperature, wind direction, and wind velocity sensors extended out and up from the top of one of the lander legs. A seismometer, magnet and camera test targets, and magnifying mirror are mounted opposite the cameras, near the high-gain antenna. An interior environmentally controlled compartment held the biology experiment and the gas chromatograph mass spectrometer. The X-ray flourescence spectrometer was also mounted within the structure. A pressure sensor was attached under the lander body. The scientific payload had a total mass of approximately 91 kg.



Cylindrical projection of topography in the Tharsis rise (left) and Chryse region (right). The spatial resolution of the grid is about 3.75 km and the vertical accuracy is approximately 5 m.

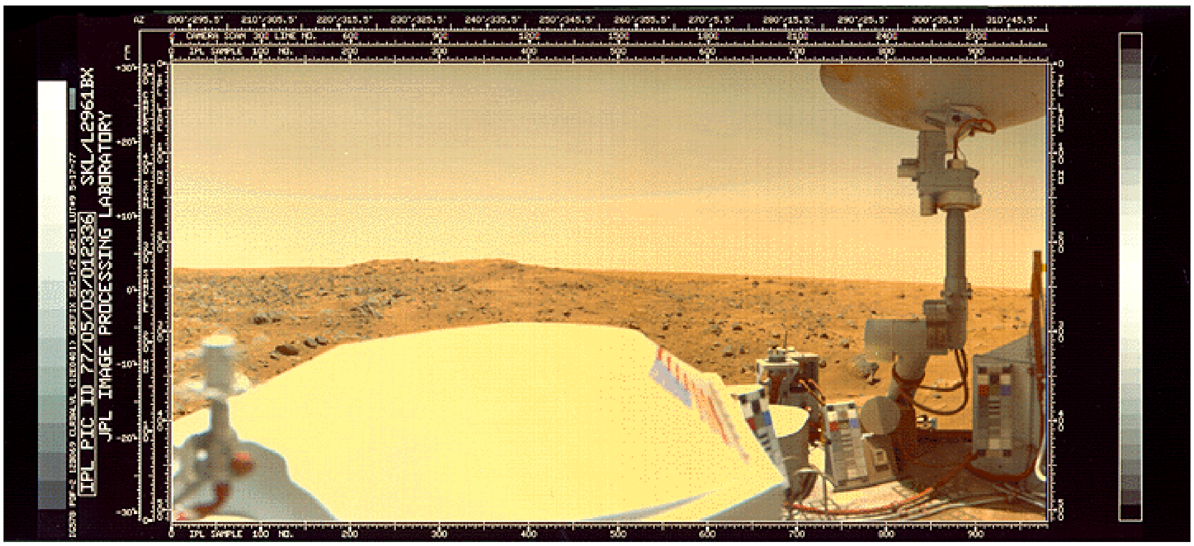
Obvious on the map are the major Tharsis volcanoes: Olympus Mons (18 N, 228 E), Alba Patera (40 N, 250 E) and the volcanic chain consisting of Ascraeus, Pavonis and Arsia montes. Note that Olympus Mons sits off to the west of the Tharsis rise and Alba Patera is separated from the main dome that contains the Tharsis montes. Note that at the high elevations of the volcanoes the color scale saturates -- those are NOT snow-capped peaks!

The grid also shows improved detail in Valles Marineris (in the center) and verifies our earlier observation that the eastern part of the canyon is about a kilometer in elevation below the mouth of the Chryse outflow channels. The westward dip of the eastern part of the canyon seems to be controlled by the intersection of pre-existing Noachian (old!) terrain with the canyon at a longitude of about 300 E. The fact that this structural control is older than the canyon suggests that the westward dip was not due to a late-stage tectonic uplift.

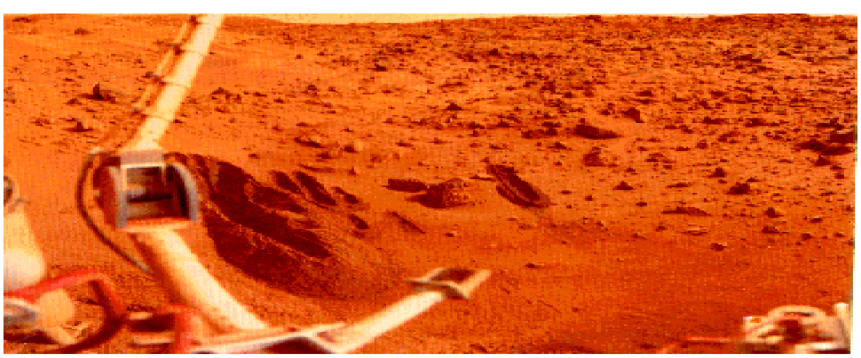
The map also clarifies aspects of early water transport on Mars. In the Chryse region (330 E) there is detailed structure where outflow channels debouch into the northern plains that indicates that water flowed well beyond the channel mouths into what previously appeared to be relatively featureless (from a topographic standpoint) plains. The map also shows considerable detail regarding past flow out of the Hebes Chasma (2 S, 282 E) and into the Kasei Valles (25 N, 290 E).

Lander Site #1:

The Viking 1 Lander touched down in western Chryse Planitia at 22.697 deg N latitude and 48.222 deg W longitude at a reference altitude of -2.69 km relative to a reference ellipsoid with an equatorial radius of 3397.2 km and a flatness of 0.0105 (22.480 deg N, 47.967 deg W planetographic) at 11:53:06 UT (4:13 p.m. local Mars time). Approximately 22 kg of propellants were left at landing. Transmission of the first surface image began 25 seconds after landing. The seismometer failed to uncage, and a sampler arm locking pin was stuck and took 5 days to shake out. Otherwise, all experiments functioned nominally. The Viking 1 Lander was named the Thomas Mutch Memorial Station in January 1982 in honor of the leader of the Viking imaging team. It operated until 13 November 1982 when a faulty command sent by ground control resulted in loss of contact.



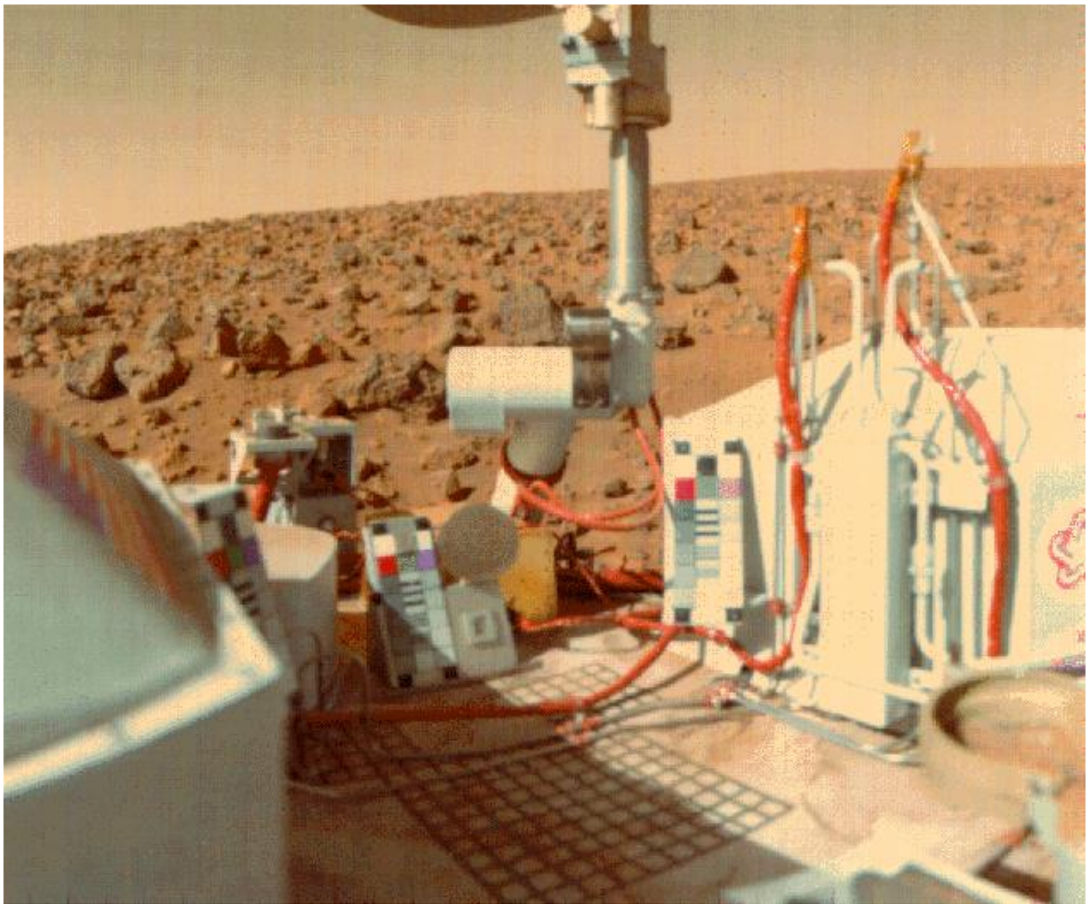
The above is a Viking 1 Lander image of Chryse Planitia looking over the lander. The large white object at lower left and center, with the American flag on the side, is the radiothermal generator (RTG) cover. The high-gain S-band antenna is at upper right. The view, from 22 N, 50 W, is to the northwest. Chryse Planitia is a wide, low plain covered with large rocks and loose sand and dust. The image was taken on 30 August 1976, a little over a month after landing.



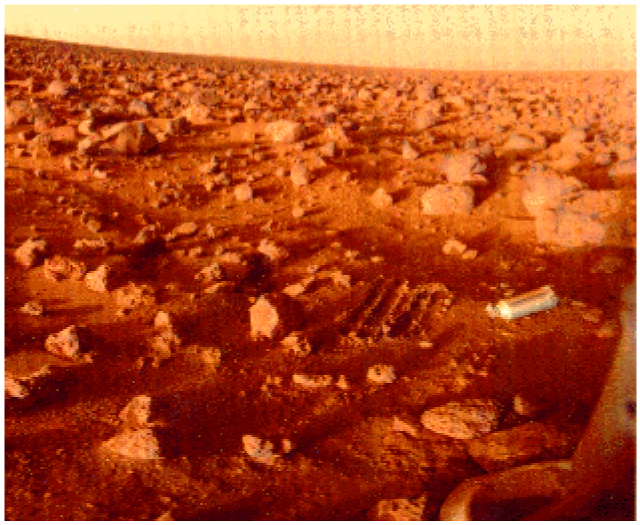
The Viking 1 Lander sampling arm created a number of deep trenches as part of the surface composition and biology experiments on Mars. The digging tool on the sampling arm (at lower center) could scoop up samples of material and deposit them into the appropriate experiment. Some holes were dug deeper to study soil which was not affected by solar radiation and weathering. The trenches in this ESE looking image are in the "Sandy Flats" area of the landing site at Chryse Planitia. The boom holding the meteorology sensors is at left.

Lander Site #2:

The Viking 2 Lander touched down about 200 km west of the crater Mie in Utopia Planitia at 48.269 deg N latitude and 225.990 deg W longitude at a reference altitude of 4.23 km relative to a reference ellipsoid with an equatorial radius of 3397.2 km and a flatness of 0.0105 (47.967 deg N, 225.737 deg W planetographic) at 22:58:20 UT (9:49:05 a.m. local Mars time). Approximately 22 kg of propellants were left at landing. Due to radar misidentification of a rock or highly reflective surface, the thrusters fired an extra time 0.4 seconds before landing, cracking the surface and raising dust. The lander settled down with one leg on a rock, tilted at 8.2 degrees. The cameras began taking images immediately after landing. The Viking 2 Lander operated on the surface for 1281 Mars days and was turned off on April 11, 1980 when its batteries failed.



Viking 2 Lander image of the spacecraft and Utopia Planitia looking SSW. At the center of the image is the pole for the S-band high gain antenna. In the foreground left is the radiothermal generator (RTG) and to the right is the other. The camera test target grids are visible near the center. Note the dark gray rocks littering the plain are partly covered with orange dust. The image covers about 70 degrees azimuth and was taken at 9:29 local time.



Viking 2 Lander close-up of the surface of Mars. The metal cylinder at right is the shroud for the surface sampler instrument, which was ejected after landing. To the left of it are trenches dug by the sampling arm, and at lower right part of a footpad can be seen. Note the holes in the rocks, which appear to be vesicles produced by gas bubbles when the rocks first solidified from lava. The camera is looking due east and local time is 19:47. The shroud is about 30 cm long.

<u>Viking Search for Life</u>:

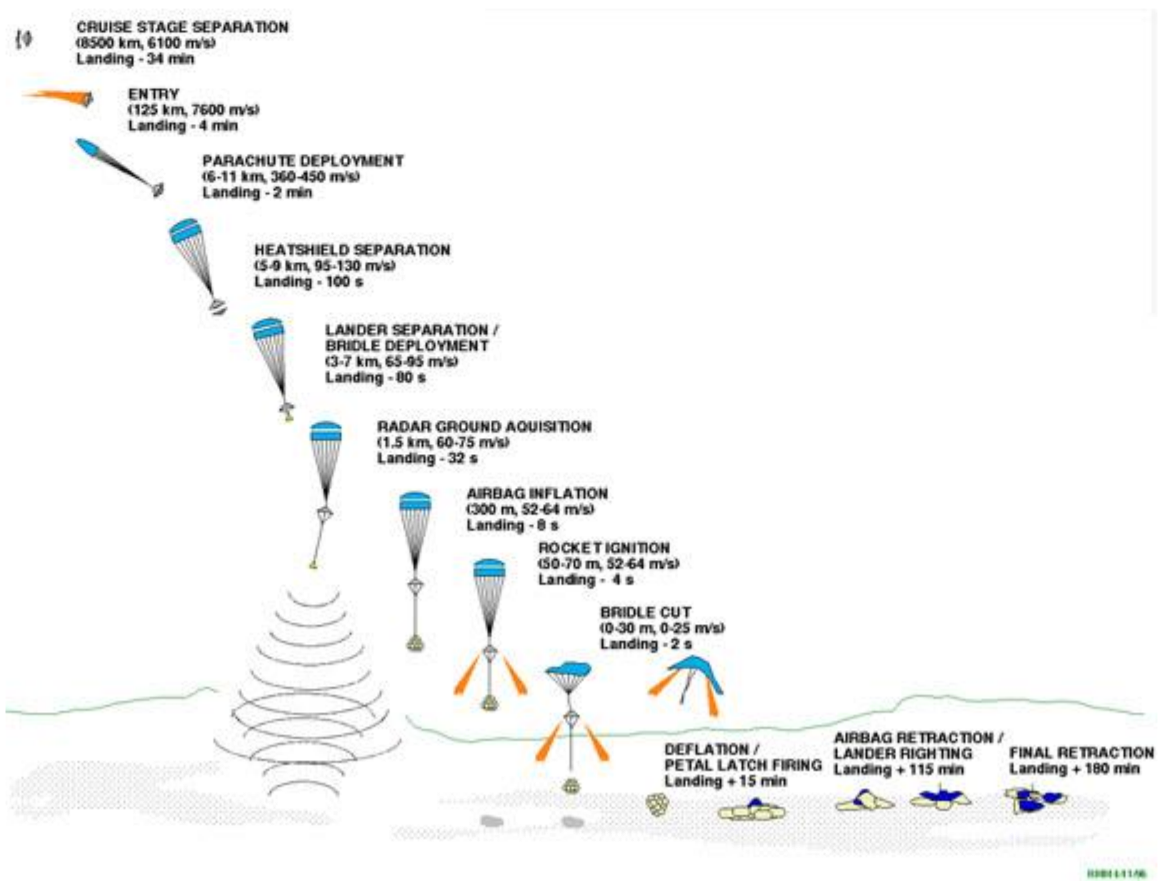
The Viking landers each contain three experiments to search for life:

1. Pyrolytic release - an experiment to test for photosynthesis, where a small amount of Martian soil was placed in a CO_2 gas, using carbon -14, illuminated for a time, then baked. If living organisms ingest the CO_2, then the soil would contain traces of the isotope.
2. Label release - an experiment to look for metabolism, where a small amount of Martian soil is moistened with nutrients tagged with carbon-14. If living organisms exist they would release the carbon-14 as waste.
3. Gas exchange - an experiment to test for respiration, where a sample of soil is given nutrients in a controlled atmosphere. The atmosphere is monitored for changes.

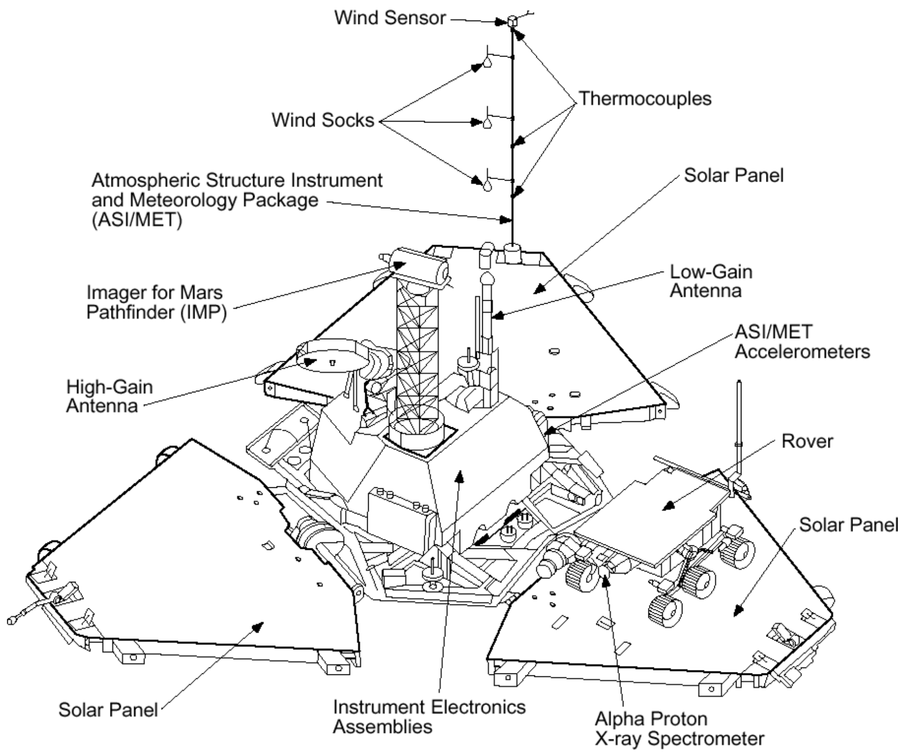
The first two experiments showed rapid changes in the Martian soil, but too fast for most living processes. The Martian soil is rich in oxides, and the reactions seen where chemical in nature.

Pathfinder:

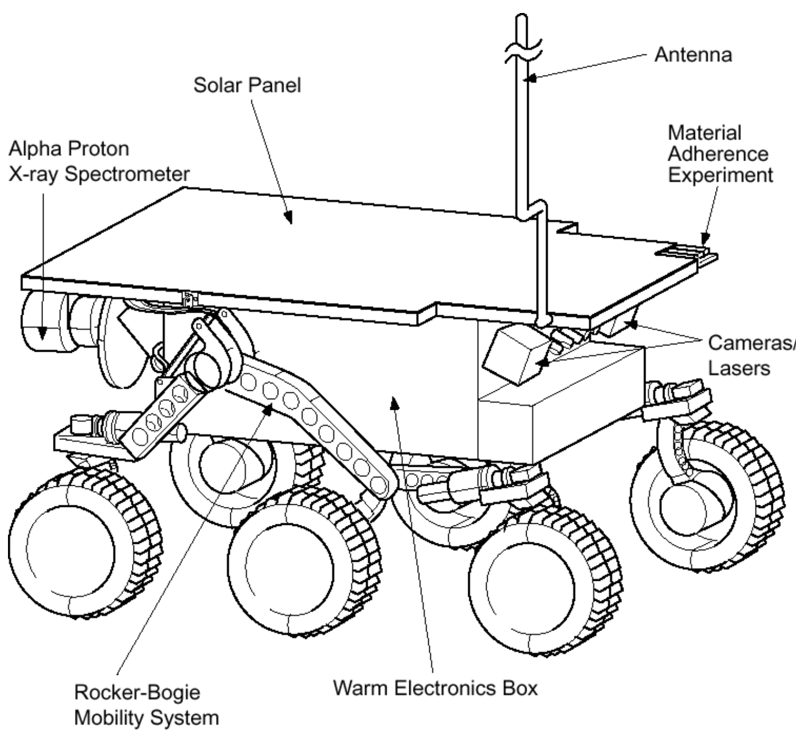
Mars Pathfinder was originally designed as a technology demonstration of a way to deliver an instrumented lander and a free-ranging robotic rover to the surface of the red planet. Pathfinder not only accomplished this goal but also returned an unprecedented amount of data and outlived its primary design life.



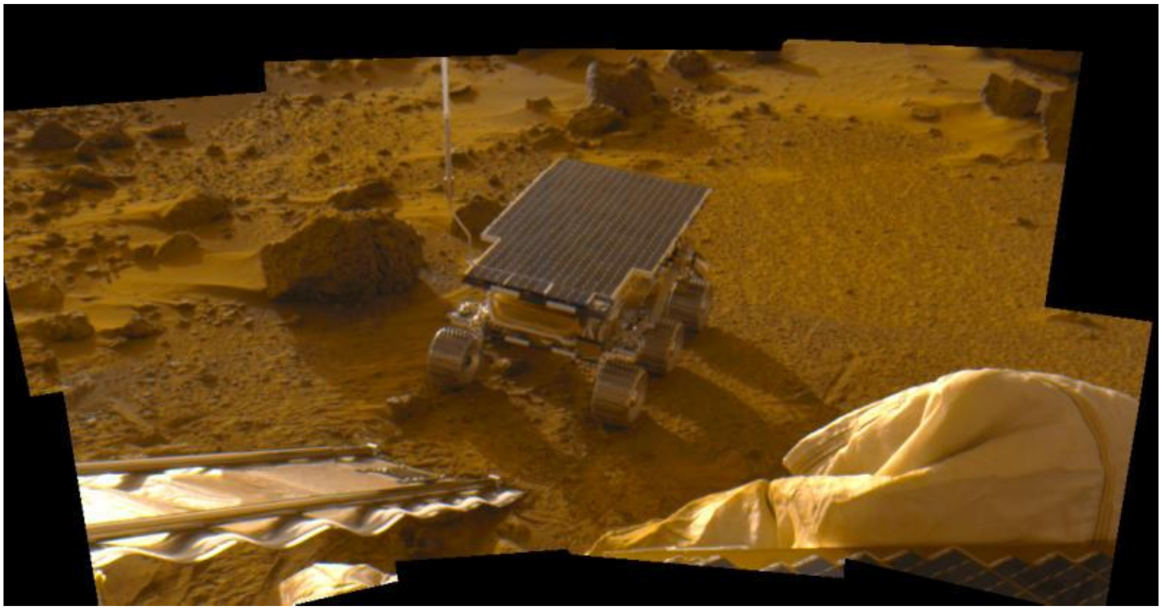
Mars Pathfinder used an innovative method of directly entering the Martian atmosphere, assisted by a parachute to slow its descent through the thin Martian atmosphere and a giant system of airbags to cushion the impact. The landing site, an ancient flood plain in Mars northern hemisphere known as Ares Vallis, is among the rockiest parts of Mars. It was chosen because scientists believed it to be a relatively safe surface to land on and one which contained a wide variety of rocks deposited during a catastrophic flood.



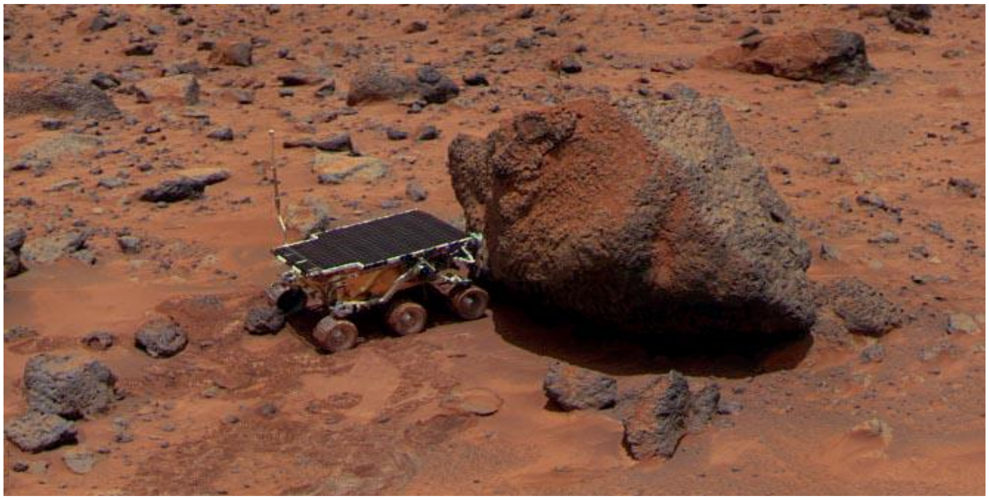
The lander, formally named the Carl Sagan Memorial Station following its successful touchdown, and the rover, named Sojourner after American civil rights crusader Sojourner Truth, both outlived their design lives the lander by nearly three times, and the rover by 12 times.



From landing until the final data transmission on September 27, 1997, Mars Pathfinder returned 2.3 billion bits of information, including more than 16,500 images from the lander and 550 images from the rover, as well as more than 15 chemical analyses of rocks and soil and extensive data on winds and other weather factors. Findings from the investigations carried out by scientific instruments on both the lander and the rover suggest that Mars was at one time in its past warm and wet, with water existing in its liquid state and a thicker atmosphere.



The entry, descent and landing (EDL) process for Mars Pathfinder began days before landing when controllers at JPL sent commands to the spacecraft to tell it precisely when and how to begin the complex autonomous series of steps necessary to safely land on the surface of Mars. These commands are sent periodically right up to a few hours before landing, when controllers on the Earth had the most precise knowledge of where the spacecraft is relative to Mars (the effect of Mars' gravity well is not felt until the spacecraft is less than 48 hours away).



Landing was at about 3:00 am local time on Mars, which is 10:00 am PDT on Friday, July 4, 1997. From an hour and a half before landing until about 3 and a half hours later, the spacecraft is under control of autonomous on-board software that precisely controls the many events that must occur. The fast-paced approach of Pathfinder at Mars begins with venting of the heat rejection system's cooling fluid about 90 minutes prior to landing. This fluid is circulated around the cruise stage perimeter and into the lander to keep the lander and rover cool during the 7 month cruise phase of the mission.

Its mission fulfilled, the cruise stage is then jettisoned from the entry vehicle about one-half hour prior to landing at a distance of 8500 km from the surface of Mars. Several minutes before landing, the spacecraft begins to enter the outer fringes of the atmosphere about 125 km. (80 mi.) above the surface. Spin stabilized at 2 rpm, and traveling at 7.5 km/sec, the vehicle enters the atmosphere at a shallow 14.8 deg angle. A shallower entry angle would result in the vehicle skipping off the atmosphere, while a steeper entry would not provide sufficient time to accomplish all of the entry, descent and landing tasks. A Viking-derived aeroshell (including the heatshield) protects the lander from the intense heat of entry. At the point of peak heating the heatshield absorbs more than 100 megawatts of thermal energy. The Martian atmosphere slows the vehicle from 7.5 km/sec to only 400 m/sec (900 mph).

Then entry deceleration of up to 20 gees, detected by on-board accelerometers, sets in motion a sequence of preprogrammed events that are completed in relatively quick succession. Deployment of the single, 24-ft. diameter parachute occurs 2-3 min. after atmospheric entry at an altitude of 5-11 km. (3-7 mi.) above the surface, eventually slowing the vehicle down to 65 meters/sec. The parachute is similar in design to those used for the Viking program but has a wider band around the perimeter which helps minimize swinging.

The heatshield is pyrotechnically separated from the lander 20 sec. later and drops away at an altitude of 2-9 km. (3-6 mi.). The lander soon begins to separate from the backshell and "rappels" down a metal tape on a centrifugal braking system built into one of the lander petals. The slow descent down the metal tape places the lander into position at the end of a braided Kevlar tether, or bridle, without off-loading the parachute or placing excessive loads on the backshell. The 20 m bridle provides space for airbag deployment, distance from the solid rocket motor exhaust stream and increased stability. Once the lander has been lowered into position at the end of the bridle, the radar altimeter is activated and aids in the timing sequence for airbag inflation, backshell rocket firing and the cutting of the Kevlar bridle.

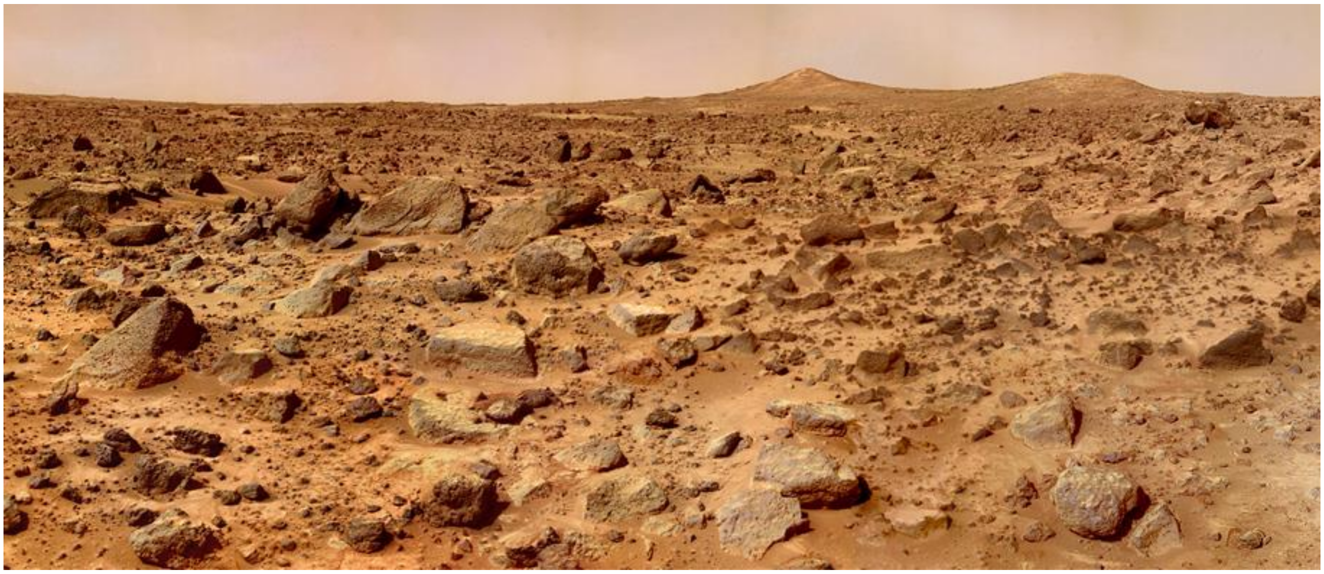
The lander's Honeywell radar altimeter is expected to acquire the surface about 32 sec. prior to landing at an altitude of about 1.5 km. The airbags are inflated about 8 sec. before landing at an altitude of 300 meters above the surface. The airbags have two pyro firings, the first of which cuts the tie cords and loosens the bags. The second, 0.25 sec. later, and 4 sec. before the rockets fire, ignites three gas generators that inflate the three 5.2 m (17-ft) dia. bags to a little less than 1 psi. in less than 0.3 sec. The conical backshell above the lander contains three solid rocket motors each providing about a ton of force for over 2 seconds. They are activated by the computer in the lander. Electrical wires that run up the bridle close relays in the backshell which ignite the three rockets at the same instant.

The brief firing of the solid rocket motors at an altitude of 80-100 meters is intended to essentially bring the downward movement of the lander to a halt some 12 meters (10 m) above the surface. The bridle separating the lander and heatshield is then cut in the lander, resulting in the backshell driving up and into the parachute under the residual impulse of the rockets, while the lander, encased in airbags, falls to the surface. Because it is possible that the backshell could be at a small angle at the moment that the rockets fire, the rocket impulse may impart a large lateral velocity to the lander/airbag combination. In fact the impact could be as high as 25 m/sec (56 mph) at a 30 deg grazing angle with the terrain.

It is expected that the lander may bounce at least 12 m about the ground and soar 100-200 m between bounces. (Tests of the airbag system verified that it was capable of much higher impacts and longer bounces.) Once the lander has settled on the surface, pyrotechnic devices in the lander petal latches are blown to allow the petals to be opened. The latches locking the sturdy side petals in place are necessary because of the pulling forces exerted on the lander petals by the deployed airbag system. In parallel with the petal latch release, a retraction system will begin slowly dragging the airbags toward the lander, breaching vent ports on the side of each bag, in the process deflating the bags through a cloth filter. The airbags are drawn toward the petals by internal lines extending between attachments within the airbags and small winches on each of the lander sides. It takes about 64 minutes to deflate and fully retract the bags.

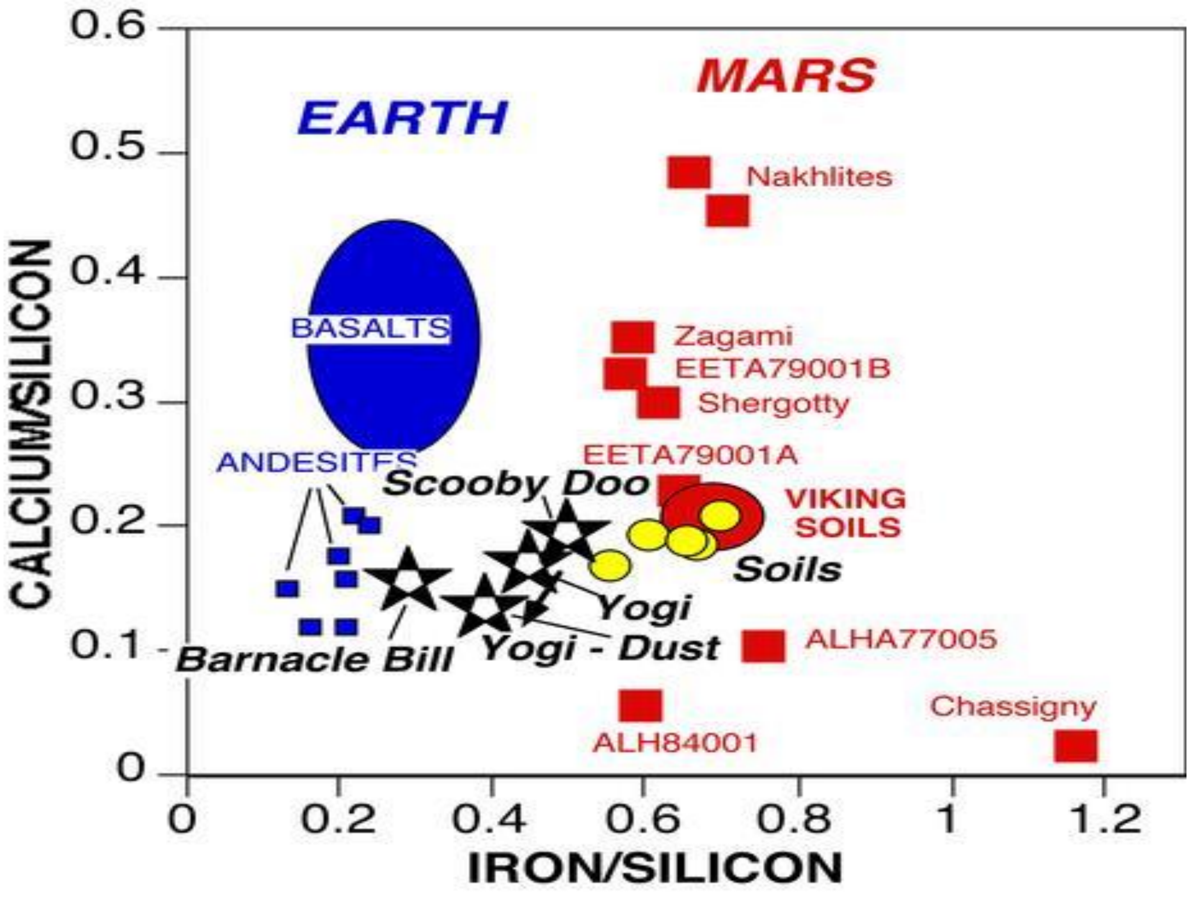
There is one high-torque motor on each of the three petal hinges. If the lander comes to rest on its side, it will be righted by opening a side petal with a motor drive to place the lander in an upright position. Once upright, the other two petals are opened. About 3 hours is allotted to retract the airbags and deploy the lander petals. In the meantime, the lander's X-band radio transmitter will be turned off for the first time since before launch on December 4, 1996. This saves battery power and will allow the transmitter electronics to cool down from being warmed up during entry without the cooling system. It also allows time for the Earth to rise well above the local horizon and be in a better position for communications with the lander's low-gain antenna later in the morning.

Normal digital data transmissions will cease near the time of cruise stage separation due to the dynamics of EDL. Instead, the transmitter's carrier signal and sidebands will be recorded by the Deep Space Network's Madrid station so that the effects of the many events on the signal may be discerned. The digital data downlink will automatically resume 3.5 hours after landing, long after the airbags have been retracted and the petals opened.



The mosaic of the landscape constructed from the first images revealed a rocky plain (about 20 percent of which was covered by rocks) that appears to have been deposited and shaped by catastrophic floods. This was what we had predicted based on remote-sensing data and the location of the landing site (19.13 degrees north, 33.22 degrees west), which is downstream from the mouth of Ares Vallis in the low area known as Chryse Planitia. In Viking orbiter images, the area appears analogous to the Channeled Scabland in eastern and central Washington state. This analogy suggests that Ares

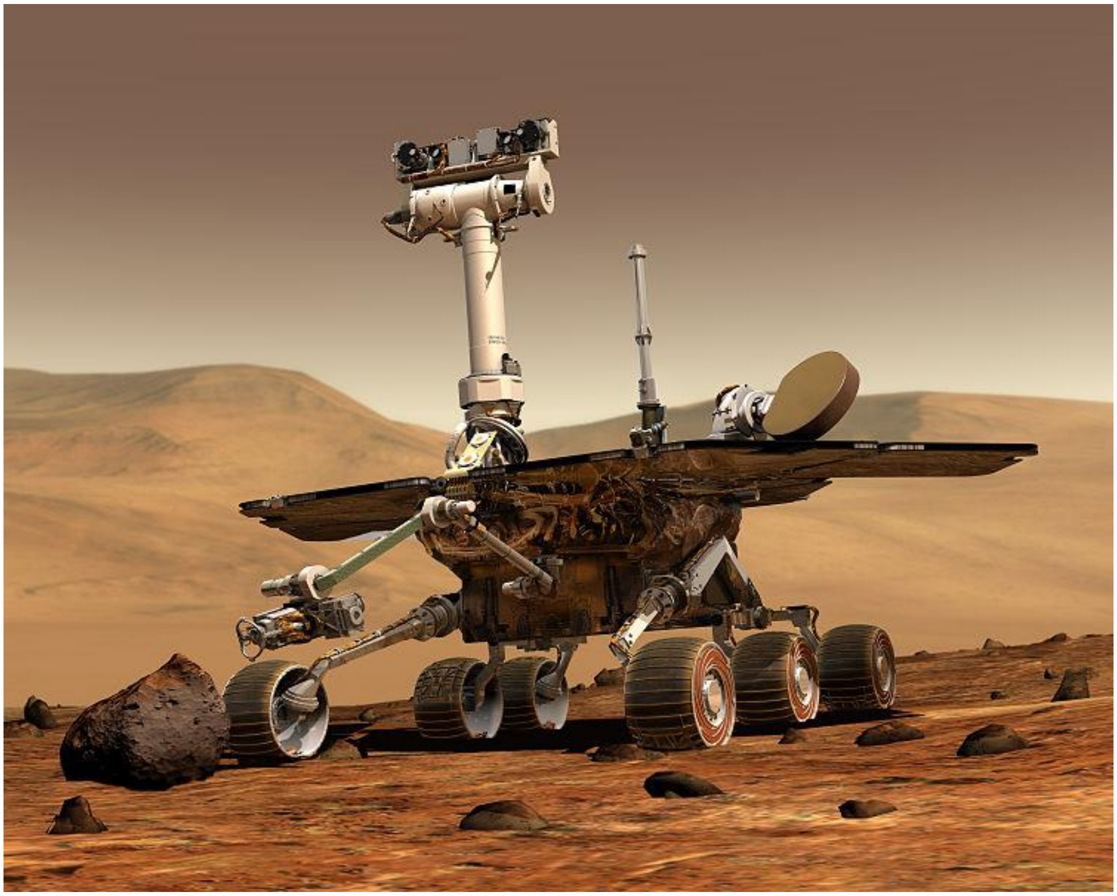
Vallis formed when roughly the same volume of water as in the Great Lakes (hundreds of cubic kilometers) was catastrophically released, carving the observed channel in a few weeks. The density of impact craters in the region indicates it formed at an intermediate time in Mars' history, somewhere between 1.8 and 3.5 billion years ago. The Pathfinder images support this interpretation. They show semi-rounded pebbles, cobbles and boulders similar to those deposited by terrestrial catastrophic floods. Rocks in what we dubbed the Rock Garden a collection of rocks to the southwest of the lander, with the names Shark, Half Dome, and Moe are inclined and stacked, as if deposited by rapidly flowing water. Large rocks in the images (0.5 meters or larger) are flat-topped and often perched, also consistent with deposition by a flood. The Twin Peaks, a pair of hills on the southwestern horizon, are streamlined. Viking images suggest that the lander is on the flank of a broad, gentle ridge trending northeast from Twin Peaks; this ridge may be a debris tail deposited in the wake of the peaks. Small channels throughout the scene resemble those in the Channeled Scabland, where drainage in the last stage of the flood preferentially removed fine-grained materials.



Taking all the results together, scientists have deduced that Mars was once more Earth-like than previously appreciated. Some crustal materials on Mars resemble, in silicon content, continental crust on Earth. Moreover, the rounded pebbles and the possible conglomerate, as well as the abundant sand- and dust-sized particles, argue for a previously water-rich planet. The earlier environment seems to have been warmer and wetter, perhaps similar to that of the early Earth. In contrast, since the time that floods produced the landing site 1.8 to 3.5 billion years ago, Mars has been a very un-Earth-like place. The site appears almost unaltered since it was deposited, indicating very low erosion rates and therefore no water in relatively recent times.

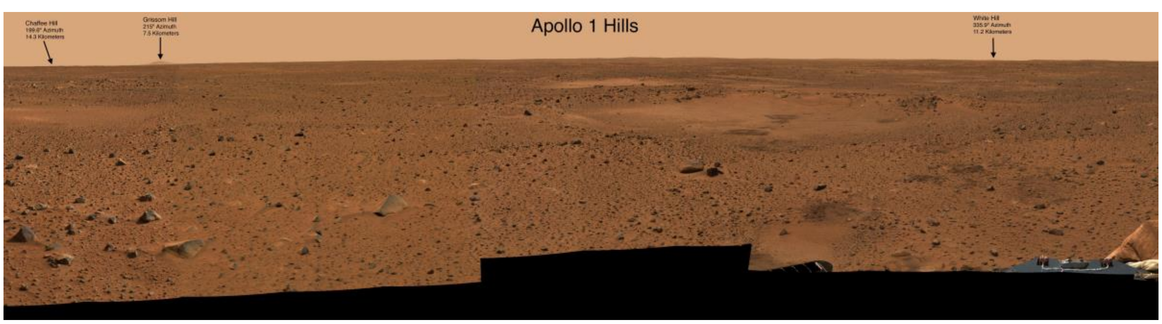
Spirit/Opportunity/Curiosity:

NASA's Mars Exploration Rover Mission (MER) is an ongoing robotic space mission involving three rovers, Spirit, Opportunity and Curiosity, exploring the planet Mars. It began in 2003 with the sending of the two rovers: MER-A Spirit and MER-B Opportunity to explore the Martian surface and geology.



The mission's scientific objective was to search for and characterize a wide range of rocks and soils that hold clues to past water activity on Mars. The mission is part of NASA's Mars Exploration Program, which includes three previous successful landers: the two Viking program landers in 1976 and Mars Pathfinder probe in 1997.

Curiosity is a car-sized robotic rover exploring Gale Crater on Mars as part of NASA's Mars Science Laboratory mission (MSL). Curiosity was launched from Cape Canaveral on November 26, 2011, at 10:02 EST aboard the MSL spacecraft and successfully landed on Aeolis Palus in Gale Crater on Mars on August 6, 2012, 05:17 UTC. The Bradbury Landing site was less than 2.4 km (1.5 mi) from the center of the rover's touchdown target after a 563,000,000 km (350,000,000 mi) journey.



The rover's goals include: investigation of the Martian climate and geology; assessment of whether the selected field site inside Gale Crater has ever offered environmental conditions favorable for microbial life, including investigation of the role of water; and planetary habitability studies in preparation for future human exploration.

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 - 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, they 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.

EGT – APU Exhaust Gas Temperature

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.

H_2 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.

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

MECO - Main Engine Cut Off point 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 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 planets rotation.

RCS – The reaction control system is a subsystem of a spacecraft whose purpose is attitude control and steering by the use of thrusters. An RCS system is capable of providing 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 planets 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 waste water 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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