RETURN TO THE RED PLANET

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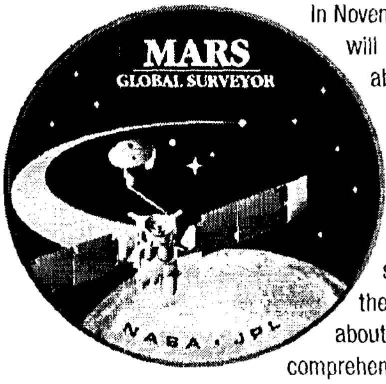

In November 1996, NASA and the Jet Propulsion Laboratory will begin America's return to Mars after a 20-year absence by launching the Mars Global Surveyor (MGS) spacecraft. This mission will usher in a new and exciting era of scientific missions to study the red planet. Over the course of a full Martian year, Surveyor will return an unprecedented amount of data regarding Mars' surface features, atmosphere, and magnetic properties. Scientists will use the data gathered from this mission both to learn about the Earth by comparing it to Mars, and to build a comprehensive data set to aid in planning future missions. This paper will provide an overview of the Surveyor mission, spacecraft, and science instruments. In addition, the use of innovative operational techniques to reduce mission cost, while still delivering comprehensive science, will be discussed,

Nearly sixty years ago cm a chilly evening in October 1938, millions of Americans living on the eastern seaboard believed that the world was about to end. III some alms, national guard troops reported for duty. Many fleet their homes, while others prayed in churches for salva t ion from their soon to be certain deaths.

What caused such mass hysteria? Earlier that evening, audiences listening to the New York CBS radio studio and all of its affiliates around the country heard the apocalyptic announcement. "1 adies and gentlemen," the news broadcaster pronounced, "we interrupt our program of dance music to bring you a special radio bulletin from the Intercontinental Radio News."

Fortunately, the impending apocalypse was fictional. This so-called "special bulletin" was the creation of a young Orson Welles enacting a radio dramatization of 1 I. G. Wells' *War of the Worlds*. At the beginning, Welles announced that the evening's program was fiction. Unfortunately, many tuned in after the initial disclaimer and became convinced that Martians were invading the United States with their flashing ray guns and poison smoke to set fire to the countryside.

110W7CVC1; Welles unknowingly depicted the invasion backward. While no Martian has ever seen Earth, NASA has explored Mars with eight robotic spacecraft since July 1965, but none in the last 20 years. This situation will change in November 1996 as NASA launches the Mars Global Surveyor spacecraft to conduct the most comprehensive scientific study of Mars in the history of space exploration.

The Surveyor spacecraft will launch from the Cape Canaveral Air Station in Florida between 6 November and 25 November 1996 on a Delta 2 rocket. The 1,060-kilogram (2,337-pound) spacecraft, built by Lockheed Martin Astronautics, wilt travel nearly 750 million kilometers (466 million miles) over the course of a 300-day cruise to reach Mars in mid-September 1997.

Upon reaching Mars, Surveyor will fire its main rocket engine for the 25-minute Mars orbit insertion (MO]) burn. This maneuver wilt s1ow the spacecraft and allow the planet's gravity to capture it into orbit. Initially, Surveyor wilt whirl around the reel planet in a highly elliptical orbit that will take 48 hours to complete.

After orbit insertion, Surveyor will perform a series of orbit changes to lower the low point of its orbit into the upper fringes of the Martian atmosphere at an altitude of about 110 kilometers (68 miles). During every atmospheric pass, the spacecraft will slow down by a slight amount because of air resistance. This slowing wilt cause the spacecraft to lose altitude on its next pass through the orbit's high

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View from Above: Photograph taken by NASA's Viking orbiter in 1976 shows the Martian southern hemisphere with the polar ice cap at the bottom.

point. Surveyor will use this innovative "aerobraking" technique over a period of four months to lower the high point of its orbit from 56,000 kilometers (34,800 miles) to altitudes near 400 kilometers (250 miles).

The mapping phase of the mission will begin in mid-March 1998. During mapping operations, the spacecraft will circle Mars once every 118 minutes at an average altitude of 378 kilometers (235 miles). For 687 Earth days, Surveyor will utilize this orbital vantage point to collect scientific data on a continuous basis.

After mapping finishes in late January 2000, the spacecraft will function as a communications satellite to relay data back to Earth from surface landers launched as part of future Mars missions.

Mysterious Planet

Surveyor will conduct mapping operations at Mars more than 30 years after America's first reconnaissance mission reached the mysterious red planet. Since then, an entire generation of scientists have spent their careers attempting to unlock the secrets of Mars by analyzing data transmitted back to Earth by NASA's robotic explorers. These efforts resulted in a tremendous expansion of knowledge compared to what was known on that fateful October evening in 1938 when fictitious Martian invaders declared war on America. However, many questions remain unanswered. The data returned from the Surveyor mission will yield valuable insights into these mysteries.

Unsolved Mysteries. One of the most intriguing, unanswered scientific questions is why do Earth and Mars appear different today? Over one billion years ago, Mars and Earth shared similar conditions. Both planets harbored vast quantities of surface water, thick atmospheres, and temperate climates.

Today, Earth is a lush world filled with a countless number of animal and plant species. In contrast, data gathered from Mars over the last 30 years shows that the planet lies trapped in conditions reminiscent of a global ice age. The dry and seemingly lifeless Martian surface makes the Sahara look like an ocean in comparison, and daily temperatures plummet lower than that found in Antarctica. Comparing the history and evolution of the two planets will yield clues into Earth's past and possibly its future.

Despite its forbidding climate, scientists consider Mars as the prime location in the Solar System to search for extraterrestrial life. Sensors aboard various NASA spacecraft launched to Mars over the last 30 years have shown that advanced life forms almost certainly do not exist on the planet today. However, many feel that the planet may hide bacterial forms of life or their fossil remains.

Optimism regarding the discovery of life on Mars life results in part from the fact that surface temperatures on Mars resemble the Earth's more than any other planet. For example, some locations near the equator may warm up to as high as 25° C (77° F) at noontime during an extremely rare heat wave. This similarity in temperatures results from the fact that Mars orbits the Sun only slightly farther out than the Earth. However, daytime temperatures still average well below freezing, and night temperatures dip much lower.

The Air Up There. Martian conditions may seem almost inviting to the seasoned outdoors explorer, but the composition of the atmosphere leaves much to be desired from a human perspective. Most of the Martian air consists of carbon dioxide (CO_2), similar to conditions on Venus. If breathing carbon dioxide seems uninviting, the density of the air will appear worse. Average barometric pressures on Mars plummet to a level lower than that found at Earth's sea level by a factor of more than 125. In other words, the air at the surface of Mars is thinner than that found on Earth at an altitude 19 times higher than Denver, Colorado.

The extremely thin Martian air directly impacts the mystery of potential life on Mars, either in the past or present. The reason is that almost all of the water lies trapped in the southern polar ice cap or frozen beneath the surface. Liquid water cannot exist on the surface because the thin atmosphere will cause melting ice to evaporate directly into water vapor. Scientists call this process "sublimation."

Water World? Although liquid water on Mars will instantly evaporate, photographs transmitted back to Earth by previous NASA missions to the planet reveal a countless number of giant flood channels, dry river beds, and flood plains on the surface. The evidence of past water on Mars suggests that the planet's distant past supported more temperate conditions with a thicker atmosphere and possibly deep oceans filled with water.

Scientists theorize that if Marx once possessed a thicker atmosphere and vast quantities of surface water billions of years ago, then the planet may have harbored conditions favorable to the formation of life. Although Surveyor will not conduct a direct search for life on Mars, the spacecraft will gather detailed data that will help in understanding the mystery of the missing water. This type of study will provide important background data that will help scientists in their search for Martian life on future missions.

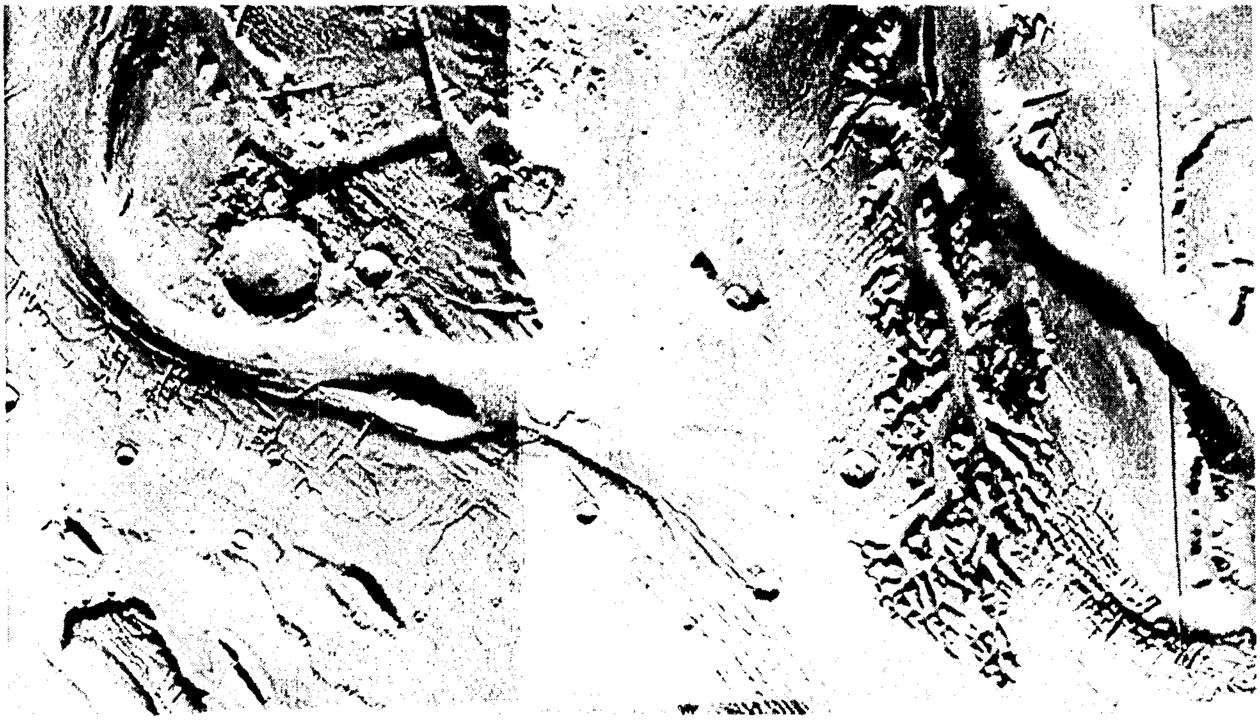
Natural Wonders. Geologically, Mars is also one of the most interesting planets in the Solar System. This small, reef-cololecl, rocky planet ranks in size as twice as large as the Moon, but only half as large as Earth. Despite the planet's small size, it contains large ice caps at each pole, a canyon much deeper than the Grand Canyon and longer than the United States, crater valleys as large as terrestrial continents, and four possibly extinct, monstrous volcanoes that make Mount Everest appear tiny in comparison.

Some Assembly Required

Designing a robust machine to gather data that will yield clues into the mystery of Mars is not an easy task. Consider the fact that from launch in November 1996 to the completion of mapping in January 2000, Surveyor must operate without major malfunctions. If a component on the spacecraft breaks, no means exist to send a repair crew to Mars.

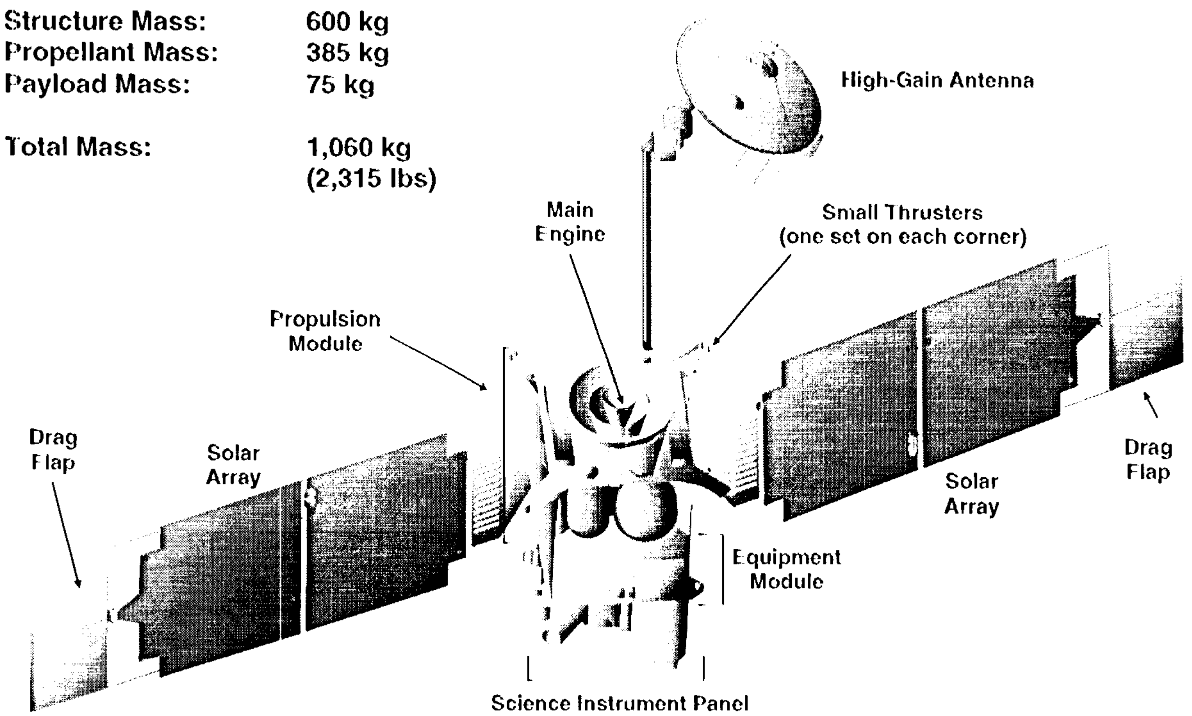
No Flying Saucers. The Surveyor spacecraft, fabricated at the Lockheed Marlin Astronautics plant in Denver, appears nothing like the Space Shuttle or the saucer-shaped UFOs depicted by Hollywood over the last half century. Instead, Surveyor looks like a rectangular-shaped box with wing-like projections extending from opposite sides.

When fully loaded with propellant al the time of launch, the spacecraft will weigh only 1,060-kilograms (2,337 pounds). Most of Surveyor's mass lies in



High Water: Large channels mark the site of a catastrophic flood long ago in Martian history. The crater on the left side of the picture is ?5 km wide

A Mapping Machine: Computer generated drawing shows the Mars Global Surveyor spacecraft in mapping configuration.



the box-shaped module occupying the center portion of the spacecraft. In reality, this center module is made of two smaller rectangular modules stacked on top of each other. One of the two smaller modules, called the equipment module, holds all of the spacecraft's electronics and science instruments. The other, called the propulsion module, houses Surveyor's rocket engines and propellant tanks.

Electronic Parts. Not including items attached on the outside, the equipment module measures approximately 80 centimeters (2.6 feet) tall. Most of the electronics that run the spacecraft lie inside the module, while the science instruments are bolted outside on the end opposite the propulsion module.

Inside, two identical computers will orchestrate almost all of the spacecraft's flight activities. Although only one of the two units will control Surveyor at any one time, identical software will run concurrently in the backup unit in case of an emergency. Each computer control until consists of a Marconi 1750A microprocessor, 128 Kbytes of RAM for storing programs to control the spacecraft, and 20 Kbytes of ROM that contain code to run basic survival routines in the event that the computers experience a reset,

Additional storage space for science and spacecraft health data will be provided by two solid-state recorders with a combined capacity of 375 megabytes. Surveyor will be America's first spacecraft sent to another planet to exclusively use computer RAM instead of a tape recorder for mass data storage. This technological improvement will dramatically reduce operational complexity, thereby reducing mission planning costs during flight.

The equipment module also houses three "reaction wheels" mounted in directions at right angles to each other. Surveyor's flight computers can control the spin of each one of these disks. By spinning different sets of disks at fast speeds, the spacecraft will be able to rotate its body and point its rocket engine or science instruments in any direction. Engineers refer to this concept of spinning disks to change pointing directions as "attitude control, "

Rocket Science. Surveyor's main rocket engine nozzle sits outside the propulsion module on the end opposite the equipment module, When fired during major maneuvers, this engine will provide a thrust of 659 Newtons. If applied at sea level, that amount of force would be strong enough to suspend a 148 pound person in mid-air.

The main engine derives its power by burning a combination of nitrogen tetroxide (N_2O_4) and hydrazine (a derivative of N_2H_4). Engineers working on the project call this chemical combination "hypergolic." This term refers to the fact that the two chemicals will spontaneously combust when they come into contact with each other. In other words, no spark is needed to ignite the engine.

In addition to the main engine, Surveyor also carries small "attitude control" thrusters attached to each corner of the propulsion module. Each one of these tiny rocket engines only provides 4.45 Newtons of thrust. Their main purpose involves performing small course correction changes and keeping the spacecraft from wobbling out of control during main engine burns.

In total, Surveyor will carry 385 kilograms (849 pounds) of propellant. Nearly 75% of that amount will be expended during the MOI burn to allow the spacecraft to slow down and enter orbit around Mars.

Power From the Sun. Two solar arrays, each 3.53 meters (11.6 feet) long by 1.85 meters (6.1 feet) wide will gather power from the Sun to generate electricity. Each array mounts to the main body of the spacecraft close to the attachment point between the equipment and propulsion modules. Rectangular-shaped, metal flaps attached at the ends of both arrays add another 81.3 centimeters (32 inches) to the overall structure. These "drag flaps" serve no purpose other than to increase the spacecraft's susceptibility to air resistance when it flies through the Martian atmosphere to lower its orbit.

Each array consists of two panels, an inner and outer panel comprised of gallium arsenide and silicon solar cells, respectively. During mapping operations at Mars, the amount of power produced by the arrays will vary from a high of 980 Watts when Mars is closest to the Sun, to a low of about 660 Watts when Mars is farthest from the Sun. In order to understand the difficulty of designing and operating an interplanetary spacecraft, consider the fact that 980 Watts is less power than that used by an ordinary hair dryer.

While in orbit around Mars, the solar arrays will provide power as Surveyor flies over the day side of the planet. When the spacecraft passes over the night side, energy will flow from two nickel-hydrogen (NiH_2) batteries to compensate for the temporary loss of power from the solar arrays. These two batteries can provide power for over an hour before requiring a recharge from the solar arrays.

Keeping in Touch. In order to communicate with the Earth, Surveyor will use a 1.5 meter (59 inch) diameter high-gain antenna dish that sits at the end of a 2.0 meter (6.6 foot) long boom attached to the propulsion module. Two rotating joints, called gimbals, hold the antenna to the boom. The gimbals will allow the antenna to automatically track and point at the Earth while the science instruments observe Mars.

One of the high-gain antenna's two main functions will involve receiving command programs sent by the flight operations team on Earth. These programs, called command sequences, will contain instructions to tell Surveyor what functions to perform for time periods up to seven weeks in duration. During commanding periods, data will flow to Surveyor at a rate up to 750 commands per minute (500 bits per second).

The antenna's other main function involves sending data back to Earth. All transmissions broadcast by Surveyor will utilize X-band radio signals near 8.4 gigahertz. That frequency would be equivalent to 8,400 on an FM receiver if ordinary radio dials reached that high. To complicate matters, Surveyor's radio transmitter will broadcast with a power of only 25 Watts. By the time the signal crosses millions of kilometers of space to reach the Earth, the signal strength will diminish to less than one millionth of one billionth of a Watt. How small is that number? If one could gather energy at that rate to charge a battery, it would take 30 million years to store enough charge to run a wrist watch for one second.

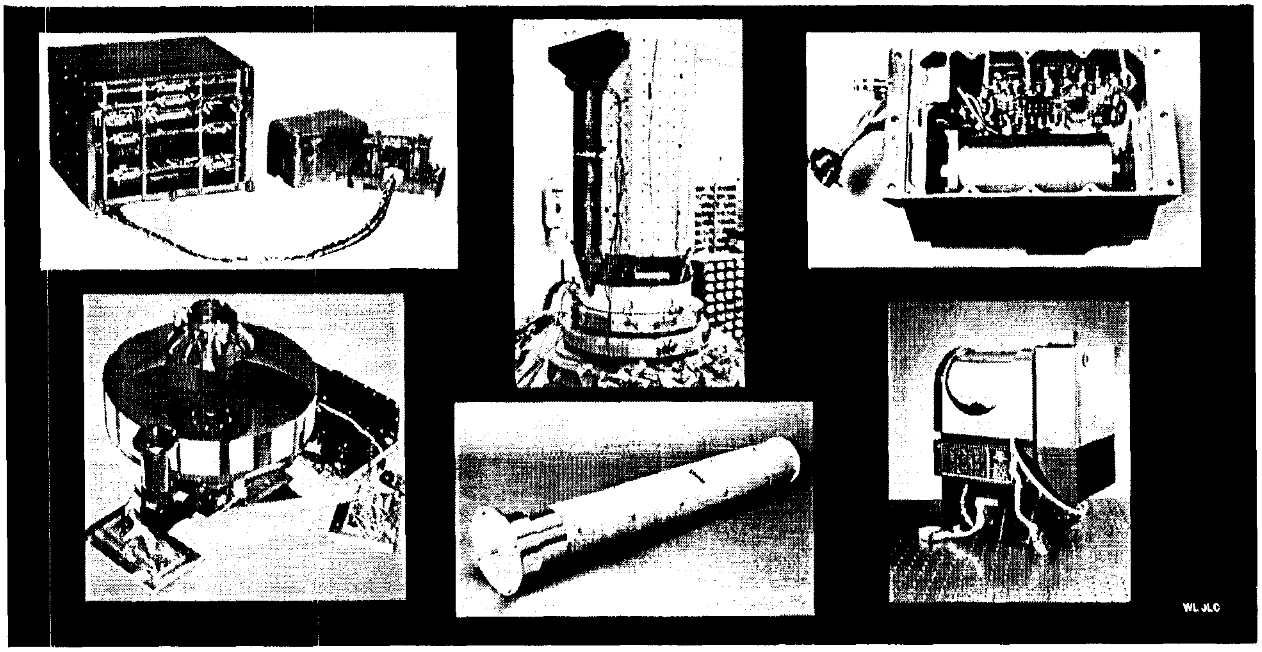
In order to receive the faint signal transmissions sent from Mars by Surveyor, NASA will utilize the gigantic tracking antennas of the Deep Space Network. These 34-meter (11 ?-foot) diameter antennas are located in the Mojave desert, Spain, and Australia. The large size of these Earth-based tracking antennas will allow Surveyor to transmit scientific data at rates up to 85,333 bits per second. In contrast, the average home computer modem functions at 14,400 bits per second.

Tools for Surveying

Transmission rates as fast as 85,333 bits per second will allow Surveyor's six main scientific instruments to send nearly 83 gigabytes of data back to Earth over the course of 687 days of mapping operations. The enormous amount of data, enough to fill over 130 CD-ROMs, will contribute to an extremely comprehensive study of the Martian atmosphere, surface features, mineral distribution, and magnetic properties.

Mars Orbiter Camera (MOC). Most of the data volume from Surveyor will be generated by a dual-mode camera called the MOC. This device works like a television camera, but will takes still images instead of motion video. In narrow-angle mode, MOC's black and white, high-resolution telephoto lens will spot Martian rocks and other objects as small as 1.4 meters

Surveyor's Instruments: Counterclockwise from top left: magnetometer, laser, relay antenna, thermal emission spectrometer, radio science, camera.



(4.6 feet) across from orbit. These pictures will be sharp enough to help scientists conduct detailed geological studies without setting foot on the planet.

In contrast to the detailed surface images, MOC's wide-angle, global monitoring mode will use a "fish-eye" lens to generate spectacular panoramic images in color spanning from horizon to horizon. The line pictures will resemble weather photos of Earth commonly shown on late-night news broadcasts. NASA will release many of these images on a public access, "information super-highway" called the Internet almost as soon the radio signals carrying the pictures reach the Earth.

Using hundreds of these panoramic photographs, scientists all over the world will be able to play them like a motion "flip-book" or a film. This ability will allow them to see the life history of Martian weather phenomena such as dust storms, cloud formations, and the growth and contraction of the polar ice caps. In addition, these time-lapse animations will allow scientists to keep track of surface features that get blown by the wind, such as dust streaks and sand dunes.

Mars Orbiter Laser Altimeter (MOLA). Unlike spacecraft portrayed in science fiction stories, Surveyor's laser was not designed to fend off hostile aliens waiting in ambush. Instead, scientists will use the laser altimeter, known as MOLA, to gather data that will enable them to calculate the height of surface features.

This altitude determination process works by measuring the time that a pulse of light takes to leave the spacecraft, reflect off of the ground, and return to MOLA's collecting mirror. By multiplying the reflection time by the speed of light, scientists will be able to calculate Surveyor's altitude above the local terrain to within 30 meters (98 feet) or better.

As the spacecraft flies above hills, valleys, craters, and other surface features, its altitude above the ground will constantly change. A combination of MOLA data with images from the camera will allow Scientists to construct a detailed topographical atlas of the planet. Such maps will help in the understanding of the geological forces that shaped Mars.

Thermal Emission Spectrometer (TES). Although scientists will depend heavily on visual images for their Martian studies, a third instrument on Surveyor will image the planet in regions of the energy spectrum that humans cannot see. This instrument, called TES, will conduct infrared scans of the planet. On a color chart, infrared represents the region that would take on an extremely deep red hue if the human eye could see it. Scientists frequently refer to infrared emissions as heat or thermal energy.

TES works on the concept that different types of compounds will take on different temperatures when exposed to the same amount of sunlight. For example, water in the ocean always remains cooler than the hot sand on the beach. The thermal data radioed back to Earth from TES will allow scientists to determine the general mineral composition of patches of ground as small as 9.0 square kilometers (3.5 square miles) in area. Scientists will gather this type of data over many days in order to conduct a planet-wide mineral survey of Mars. In addition, TES will also scan the Martian atmosphere to provide data for the study of the clouds and weather.

Many scientists hope that TES will ultimately yield clues into the location of clays containing carbonate minerals. Although no liquid water exists on Mars today, carbonate deposits might indicate areas that could have been shorelines long ago in Martian history. Future missions to Mars might begin their search for fossil remains of life in areas identified by TES data.

Magnetometer (MAG). This instrument will attempt to measure the poorly understood global magnetic properties of Mars. On Earth, an extremely powerful magnetic field surrounds the planet. The magnetism results from an enormous amount of molten iron churning at the center of the Earth.

In comparison, data returned from previous Mars missions indicates that the Martian magnetic field is extremely weak and almost ncm-existent. By looking at data from Surveyor's magnetometer, scientists hope to learn about the interim composition of Mars. Such a study will also yield insight into the history of the geophysical forces that shaped Mars. Scientists hope to learn how those forces differed from those that shaped the Earth.

Giant Volcano: Olympus Mons, as shown in a Viking orbiter photograph, will be one of many sites imaged by Surveyor's instruments. 1 his VOl cano is ?7 km tall and covers a surface area larger than Arizona.

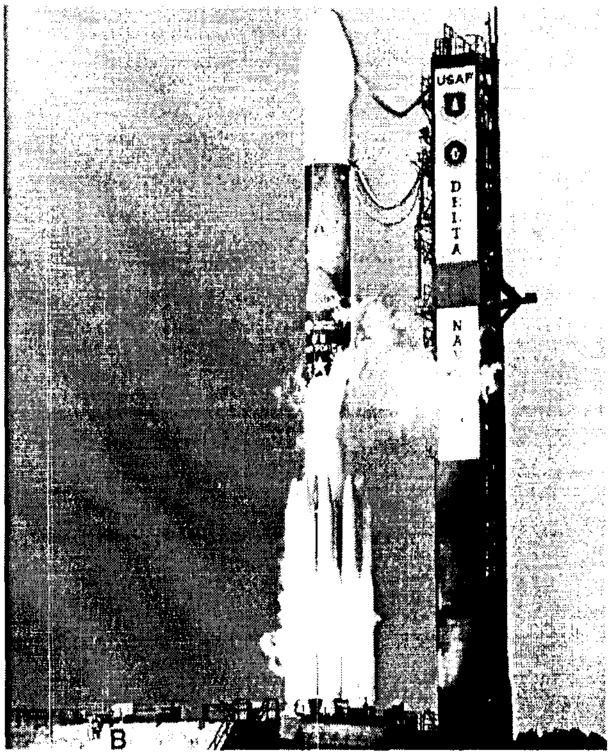
Radio Science (USO). All of the data collected by the four instruments arrives at Earth by way of radio signals transmitted from the spacecraft. A special group of scientists will use sophisticated computers to analyze these signals. They ate interested not in the data contained in the signals, but in the electrical strength and "tone" of the transmissions. The reason for this immense interest is that Surveyor carries a tiny device called the ultrastable oscillator (11 S()), This unit acts as an electronic clock that will allow the spacecraft's radio to broadcast signals at an extremely precise frequency.

When in orbit, tiny variations in the strength of the Martian gravity caused by small "blemishes" in the planet's shape will bump the spacecraft slightly from its anticipated path, During these bumps, the "tone" of Surveyor's radio signal will vary by a slight amount. By analyzing these tiny changes, scientists will be able to determine Mars' shape more accurately than ever before, This data will also be combined with the laser altimeter (MOLA) data to improve on the accuracy of the topographical maps.

in addition, this team of "radio scientists" will also conduct occultation experiments. As Surveyor passes over the day side of Mars and approaches the night side, the planet will block radio signals from reaching Earth. Engineers refer to this blockage as an occultation. During the few minutes just before the spacecraft flies behind Mars, and during the few minutes after it reappears, Surveyor's radio signal will pass through the thin Martian atmospher, on its way to Earth. An analysis of the distortion of the signal's strength and tone as it fades and reappears will enable scientists to determine the atmospheric pressure at a specific location on Mars.

During 687 days of mapping operations, the orientation of Earth relative to the spacecraft's orbit will gradually change and allow the radio science team to gather data about the Martian atmosphere all over the planet. When combined with data from the thermal emission spectrometer (TES), scientists will be able to gain a greater understanding of the Martian atmosphere than ever before.

Mars Relay (MR). Of the six main instruments that will fly to Mars on Surveyor, the Mars Relay is the only one not designed to take scientific measurements. Instead, this cylindrical-shaped antenna will focus its efforts on collecting data transmitted to Surveyor from landers on the Martian surface. After collecting the data, Surveyor will transmit the data back to Earth.



Reliable Power: 1 he three stage Delta **2 is one of the** most **dependable** rockets **in** America's arsenal. At the time of **launch,** urveyor will **sit in the white colored nose cone at** the **top of the Delta.**

Martian **landers** that **Surveyor's** relay may support include a **Russian** spacecraft scheduled for **launch** in mid-November 1996, and American probes scheduled for launch in late 1998 and 2001.

Lighting the Fuse

Before **Surveyor's sophisticated** group **of** scientific instruments can begin to **collect data** about **Mars,** the **spacecraft** must **first** survive the long journey from **the** Earth. The **first step** in this **trip will** begin sometime in **November** 1996 with **a** launch on **a** Delta **?** rocket from the **Atlantic seacoast** in Florida.

An Economy Fare. The Delta **?, manufactured by** McDonnell Douglas Aerospace, **consists** of three stages. In other words, the Delta rocket **is a** conglomeration of three smaller rockets stacked on top of each other **with** the **Surveyor spacecraft** at **the** top. Including Surveyor, the Delta **will** weigh 231,325 kilograms **(51 0,OOO** pounds) **at** the **time** of launch and **will** stand nearly 37 meters (121 feet) **tall.** Most of the **rocket's mass** resides **in** the enormous amount of propellant needed to boost Surveyor into **space.**

In the past, Delta rockets have primarily been used **by NASA, the** Air Force, and commercial organizations to **launch small** to medium-sized **satellites** **into** Earth orbit. The **Surveyor** mission **will represent** the **first** use **of the low-cost** Delta to send **a** spacecraft **t[]at~c)tl~cr}~lal-let.** By using the Delta, **NASA will** save nearly $300 **minim as** compared to the Titan launch vehicles used by previous Mars missions.

Open Windows. NASA's decision to launch Surveyor **in** November 1996 was **not** an arbitrary **choice,** nor **was it based** on **when management** thought the spacecraft would be **ready for** flight. Instead, **the** November choice depended on the exact positions of the Earth and Mars **relative** to **the** Sun.

The reason for **this geometrical** dependence **is** that in spaceflight, **straight-line** paths do **not exist, All** planets move in long, curved paths around the Sun that **take the shape** of **circular and elliptical orbits.** In order to reach **Mars, Surveyor must** depart Earth and **then coast** in an elliptical orbit around the Sun **that** will **eventually intersect** the orbit of Mars.

The tricky **part** involves timing **the** launch to **allow** Surveyor and Mars to arrive **at the same** point **in** space **at** the **same time.** Engineers on **the flight** team **refer** to the **dates when Mars** and Earth are aligned in **the** right position **for** launch **as** the **"launch window"** or **"launch** period." Surveyor's launch period opens on 6 November 1996 and **c1oscs** on 25 **November** 1996.

Golden Opportunities. On Surveyor's launch day, the Delta must lift-off at **a** precise moment during the day called **the "launch opportunity."** This **time will** occur **at the exact** moment when the Earth rotates into **a** position where the launch pad is directly aligned with **an** imaginary line along **the** flight path to Mars. **('hanging** the flight path to **Mars will** change the launch time. In **other** words, **Calculating,** the **lift-off time works** like jumping **off of a carousel** and timing the jump so **that** you land **exactly where** you want.

One **additional** complication **is that** the **exact** flight path from Earth to Mars **will** depend on the **specific** flight path **that the 1** Delta rocket takes **from** the launch pad **into** space. Consequently, changing the Delta's **flight path into** space **will result in a** slightly different **launch time.** For **launch** attempts from November 6th through November 15th, the **1** Delta **will** utilize one **of** two **slightly** different flight paths **with** launch **times** about one hour apart.

For example, **the first lift-off** opportunity on November 6th **will occur at** 12:11:17 **P.in.** EST. **If** the launch **does** not occur **at that time** due to bad **weather** or minor **mechanical difficulties,** the launch team can attempt **a lift-off** on **the** second opportunity **at 1:15:44** p.m. EST. **As the days move forward in** the launch period, the **lift-off** times **will move backward until** they reach 9:29:58 a.m. and 10:47:27 a.m. (S) for a launch attempt on November 15th.

Because of budget limitations, the Delta will only fly one flight path and utilize only one launch opportunity per day from November 16th through November 25th. For a launch attempt on November 16th, lift-

We Have Lift-Off. The first stage is the largest and most powerful of the three stages on the Delta rocket. At the time of lift-off, the engines on this stage will ignite to push the rest of the rocket off of the launch pad and then up past the thick portions of the lower atmosphere.

For the first two minutes of flight, a set of nine smaller rockets attached in a ring formation around the outside of stage one will help it accelerate. McDonnell Douglas refers to these nine "helper" rockets as solid-rocket motors because they burn a solid putty-like material instead of liquid propellant.

Six of the nine solids will ignite along with stage one at the time of lift-off. Approximately 60 seconds into the flight, those six will burn out and be jettisoned. When the six fall away, their exhaust trails will form a brilliant star-like pattern radiating away from the Delta. Then, the remaining three solids will ignite and burn for the next 60 seconds before falling away.

After the last of the solid rockets drop away, stage one will continue thrusting until its propellant runs out. At the time of stage one jettison, four minutes and 20 seconds after lift-off, the Delta will have reached a velocity of 6,200 meters per second (13,870 miles per hour) and climbed to an altitude of 115 kilometers (71 miles).

Stage two will ignite several seconds after jettison of the first stage. Nine minutes and 37 seconds after lift-off, its engine will shut down to place the Delta into a circular orbit around the Earth at an altitude of 185 kilometers (115 miles). Orbit insertion will occur 2,524 kilometers (1,568 miles) southeast of Cape Canaveral with the rocket traveling at 7,793 meters per second (17,432 miles per hour).

For the next half hour, the Delta will coast around the Earth until it reaches a position over the mid-Indian Ocean. Then, the second stage engine will restart and perform a two minute burn to boost the Delta's velocity to 8,766 meter per second (19,608 miles per hour). Jettison of stage two will follow moments after the completion of the two-minute engine firing.

The third stage engine will ignite roughly half a minute after the second stage falls away. This stage will thrust for 87 seconds to perform what the flight team calls the TMI or "trans-Mars injection" burn. After the completion of TMI, Surveyor will be moving at 11,449 meters per second (25,611 miles per hour), a speed equivalent to 34 times faster than a speeding bullet.

The enormous velocity provided by the Delta's three stages will allow the spacecraft to escape the pull of the Earth's gravity and never return. Shortly after TMI, stage three will separate itself from Surveyor and allow the spacecraft to begin its long journey to Mars.

Destination Mars

Engineers working on Surveyor's flight operations team refer to the 750 million kilometer (466 million mile) journey from Earth to Mars as the "cruise" phase of the mission. During this time period, Surveyor will coast around the Sun in an orbit that will intercept Mars 10 months after launch. The flight team will conduct few operations in cruise other than monitoring the spacecraft to ensure that all systems function normally, and sending commands that will refine Surveyor's flight path to Mars.

Course Corrections. These minor changes in the spacecraft's flight path are called trajectory correction maneuvers (TCMs). Each correction will involve a short firing of Surveyor's rocket engine to gently change the spacecraft's speed and direction of travel.

The first of four scheduled TCMs will occur 14 days after launch with the goal of adjusting the spacecraft's velocity by about 25 meters per second (56 miles per hour). This maneuver will correct most of the velocity errors accumulated during the launch. Although the Delta's computer control systems are extremely accurate, the rocket's powerful engines lack the finesse needed to push the spacecraft to an exact velocity.

According to the flight plan, the remaining TCMs will occur in March, April, and late August 1997. All of the final three correction maneuvers will involve a velocity change much smaller than the first. Consequently, the calculations from Surveyor's navigation team will require extreme precision. The reason is that a velocity error as small as one meter per second (2.2 miles per hour) may result in missing Mars by thousands of kilometers after a 10-month journey.

The combination of the four TCMs will allow the navigation team to aim the spacecraft for a point barely 300 kilometers (186 miles) in front of Mars.

Achieving this accuracy after a 750-million-mile journey is equivalent to throwing a baseball from San Francisco to New York and hitting the torch on the Statue of Liberty.

Arrival Day. Surveyor will complete its cruise to Mars and arrive at the point of closest approach to the planet sometime in mid-September 1997. At that time, the ground team will command the main engine to fire for 25 minutes to slow the spacecraft by about 980 meter per second (2,192 miles per hour). The slow down, called the Mars orbit insertion (MOI) burn, will allow Surveyor to be captured into orbit by Mars' gravity. Without the burn, the spacecraft will fly past Mars and never return.

MOI will occur between 301 and 309 days after launch. A lift-off at the open of the launch period on 6 November 1996 will result in a 11 September 1997 insertion, while a lift-off at the close cm 25 November 1996 will result in an insertion on 22 September 1997.

Inward Spiral. After the MOI burn, Surveyor will whirl around Mars cmcc every 48 hours in a highly elliptical orbit with high point of 56,000 kilometers (34,800 miles) and a low point of 300 kilometers (186 miles). Before mapping operations can begin, the flight team must find a way to lower the orbit's high point to an altitude near 400 kilometers (250 miles).

The traditional method of lowering a highly elliptical orbit involves using the rocket engine to slow the spacecraft at the orbit's low point. In the business of orbital mechanics, if a spacecraft slows down at the low point in the orbit, the next pass through the high point will be at a lower altitude. Unfortunately, the small Delta 2 rocket that will launch Surveyor from Earth lacks the punch needed to lift both the spacecraft and the propellant needed to slow down in Mars orbit.

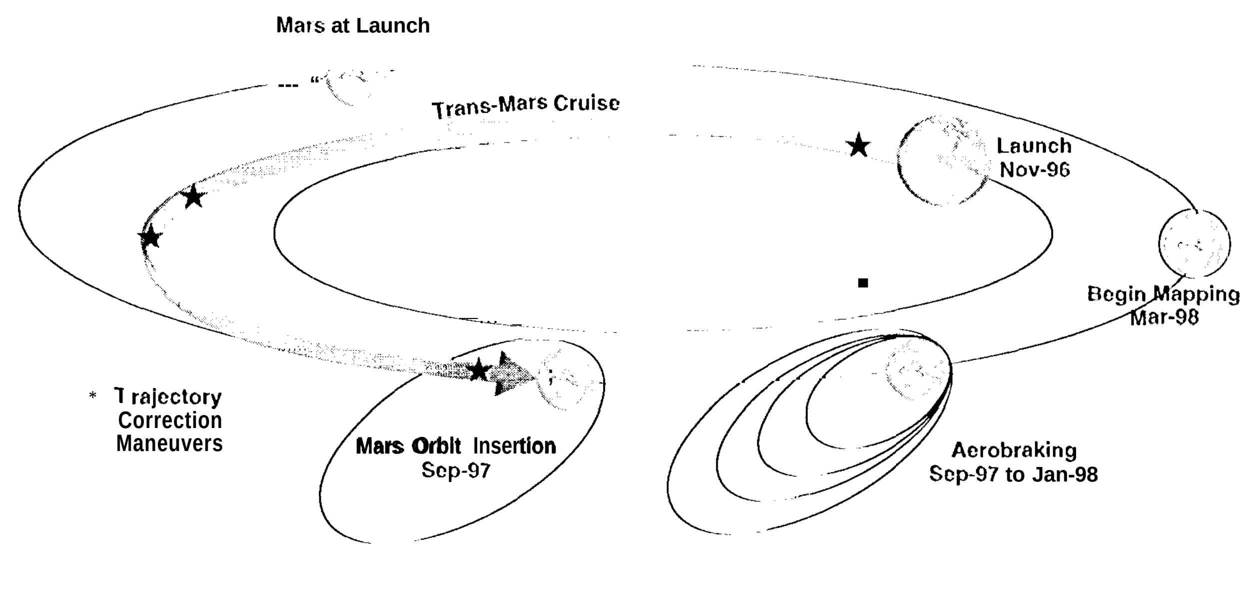
Fortunately, the mission design engineers at the Jet Propulsion Laboratory have developed an innovative technique to lower the orbit without using Surveyor's rocket engine. They call this new idea "aerobraking." Essentially, the solution works in the same way that children slow down and lower how high they swing on a playground swingset by dragging their feel through the sand as they swing pass the bottom.

In order to begin the aerobraking process, the flight team will command the spacecraft to lower the low point of its orbit into the upper fringes of the Martian atmosphere. During every subsequent pass through the orbit's low point, Surveyor will encounter air resistance and will slow slightly. Consequently, the spacecraft will not climb as high on its next pass through the orbit's high point.

Safety Margins. Initial calculations show that the low point of Surveyor's orbit must lie in a corridor between 105 kilometers (65 miles) and 110 kilometers (68 miles) above the Martian surface. If the spacecraft flies lower, it will encounter too much air resistance and burn up like a shooting star. Conversely, if the spacecraft flies higher, it will not encounter enough air resistance to slow down appreciably.

Despite all of the pre-planning, the flight team will need to made rapid, minor adjustments to the spacecraft's orbit to successfully carry out aerobrak-

Mission to Mars: This diagram illustrates the major phases of Surveyor's mission from launch to the start of mapping operations *(not to scale)*



ing. The main problem is that scientists only have a limited amount of knowledge regarding the thickness of the air in the upper Martian atmosphere. Because the air thickness will determine the exact altitude of the safely corridor, the flight team will need to alter the orbit's 10w7 point if Martian weather conditions alter the conditions in the atmosphere.

Aerobraking will take until mid-January 1998 to complete. At that time, the orbit will lie at the correct altitude for mapping operations, but not in the correct geometrical orientation. Over tile next two months, small irregularities in the shape of Mats and its gravitational pull will automatically nudge Surveyor's orbit into the correct geometrical orientation.

An Orbit Made for Mapping, The intensive period of scientific data collection will begin in mitt-Malch 1998 and will last for one Martian year (687 days). During this Mats mapping phase of the mission, the spacecraft will circle the Planet once every 117 minutes and 39 seconds at an average altitude of 378 kilometers (235 miles). In addition, the mapping orbit will lie tilted at nearly a right angle to the Martian equator. Consequently, Surveyor will pass over both the north and south polar regions of Mars on every revolution around the planet.

This polar orientation will allow the scientific instruments to image the entire Martian surface once every 7.2 Earth days as Mars rotates under the orbit. Surveyor will repeat this cycle of global observation many times over to allow scientists the chance to observe changes due to short-term or seasonal weather.

Throughout mapping, Surveyor will always travel southward over the clay side of Mars and northward over the night side. The orbit is designed so that every time the spacecraft flies over the equator on the day side, the local Mars time on the ground will always be 2:00 p.m. Engineers refer to this orbit characteristic as "Sun synchronous."

The "afternoon orientation" of the orbit will ensure that the shadows, lighting conditions, and heat properties of the ground and air will remain constant throughout the course of the mission. Such a characteristic will provide a common frame of reference for scientists to compare data from different parts of the planet.

Looking Ahead

After Surveyor completes its mapping operations in late January 2000, it will remain in orbit around Mars and will continue to gather data as long as the spacecraft's components remain functional. Most of the data collection activities will involve listening to broadcast signals from landers on the Martian surface, and then relaying that data back to Earth. in addition, NASA scientists may occasionally call on Surveyor's instruments to conduct further measurements to corroborate data collected by other missions to Mars.

These missions are all part of NASA's Mars Exploration Program. Every 25 months when Mars and Earth move into the proper alignment to conduct a launch, NASA is planning to send two spacecraft to the red planet. For example, the Mars Pathfinder spacecraft will launch in December 1996 to join Surveyor at Mars in 1997. Pathfinder is an innovative mission that will land a six-wheeled micro-rover on the surface. This rover will land on Independence Day in 1997 and will roam the surface of Mars to collect data on the soil and rocks.

At the end of 1998, NASA will launch another orbiter and lander. The orbiter will carry a camera and another instrument dedicated to examining the properties and dynamics of the Martian atmosphere. Meanwhile, the lander will touch down near the South Pole to conduct a detailed study of the role of atmospheric gasses and water in the climate of Mars.

Other scientific missions will follow in '2001, 2003, and 2005. One of those missions, launched in 2003 or 2005, may land cm the surface, gather rocks, and then return the sample to Earth for detailed analysis. Some of those rocks may yield clues into the mystery of life on Mars.

As important as the search for life, the data collected by Surveyor and the future missions will allow scientists to gain insight into the geology, history, and climate of Mars. Over one billion years ago, Mars and Earth shared similar conditions despite the fact that they appear different today. A comparison of Mars and Earth will help scientists to better understand Earth's history and possibly its future.

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