The Pioneer Missions

PIONEER 10 SPACECRAFT SENDS LAST SIGNAL - After more than 30 years, it appears the venerable Pioneer 10 spacecraft has sent its last signal to Earth. Pioneer's last, very weak signal was received on 23 January 2003. NASA engineers report that Pioneer 10's radioisotope power source has decayed, and it may not have enough power to send additional transmissions to Earth. NASA's Deep Space Network (DSN) did not detect a signal during a contact attempt on 7 February 2003. The previous three contacts, including the 23 January signal, were very faint, with no telemetry received. The last time a Pioneer 10 contact returned telemetry data was 27 April 2002.

Left: The Pioneer Family (artistic images). Starting on the left, the first is the Pioneer 6, 7, 8,and 9 spacecraft. Next is the Pioneer 10 and 11 spacecraft. Next is the Pioneer Venus Orbiter (Pioneer 12) spacecraft. In the lower right corner is the Pioneer Venus Multiprobe (Pioneer 13) spacecraft.

One final attempt was made to locate Pioneer's 10 signal on March 3-5, 2006 but failed to receive a response detection of a carrier signal from the spacecraft.

Launched on 2 March 1972, Pioneer 10 was the first spacecraft to travel through the Asteroid belt, and the first spacecraft to make direct observations and obtain close-up images of Jupiter. Famed as the most remote object ever made by man through most of its mission, Pioneer 10 is now over 8 billion miles away. (On 17 February 1998, Voyager 1's heliocentric radial distance equaled Pioneer 10 at 69.4 AU and thereafter exceeded Pioneer 10 at the rate of 1.02 AU per year.)

Pioneer 10 made its closest encounter to Jupiter on 3 December 1973, passing within 81,000 miles of the cloudtops. This historic event marked humans' first approach to Jupiter and opened the way for exploration of the outer solar system - for Voyager to tour the outer planets, for Ulysses to break out of the ecliptic, for Galileo to investigate Jupiter and its satellites, and for Cassini to go to Saturn and probe Titan. During its Jupiter encounter, Pioneer 10 imaged the planet and its moons, and took measurements of Jupiter's magnetosphere, radiation belts, magnetic field, atmosphere, and interior. These measurements of the intense radiation environment near Jupiter were crucial in designing the Voyager and Galileo spacecraft.

Pioneer 10 made valuable scientific investigations in the outer regions of our solar system until the end of its science mission on 31 March 1997. The Pioneer 10 weak signal continued to be tracked by the DSN as part of an advanced concept study of communication technology in support of NASA's future interstellar probe mission. The power source on Pioneer 10 finally degraded to the point where the signal to Earth dropped below the threshold for detection in 2003. Pioneer 10 will continue to coast silently as a ghost ship through deep space into interstellar space, heading generally for the red star Aldebaran, which forms the eye of Taurus (The Bull). Aldebaran is about 68 light years away and it will take Pioneer over 2 million years to reach it.

Launched on 5 April 1973, Pioneer 11 followed its sister ship to Jupiter (1974), made the first direct observations of Saturn (1979) and studied energetic particles in the outer heliosphere.

The Pioneer 11 Mission ended on 30 September 1995, when the last transmission from the spacecraft was received. There have been no communications with Pioneer 11 since. The Earth's motion has carried it out of the view of the spacecraft antenna. The spacecraft cannot be maneuvered to point back at the Earth. It is not known whether the spacecraft is still transmitting a signal. No further tracks of Pioneer 11 are scheduled. The spacecraft is headed toward the constellation of Aquila (The Eagle), Northwest of the constellation of Sagittarius. Pioneer 11 will pass near one of the stars in the constellation in about 4 million years.

Pioneer Project History

The Pioneer Spacecraft Missions are a series of eight spacecraft missions managed by the Pioneer Project Office at NASA, Ames Research Center. The following is a brief description of the other Pioneer Missions.

Pioneers 6-9 were launched into Solar orbit between 1965 and 1968. Their prime mission completed years ago, the spacecraft were then tracked only occasionally.

Pioneer 6 was launched on 16 December 1965. Some time after 15 December 1995 (almost 30 years after it was launched) the primary transmitter (TWT) failed. During a track on 11 July 1996 the spacecraft was commanded to switch to the backup TWT, and the downlink signal was re-acquired. The spacecraft and a few of the science instruments were again functioning.

Pioneer 6 is the oldest NASA spacecraft extant. There was a successful contact of Pioneer 6 for about two hours on 8 December 2000 to commemorate its 35th anniversary.

Pioneer 7 was launched on 17 August 1966. It was last tracked successfully on 31 March 1995. The spacecraft and one of the science instruments were still functioning.

Pioneer 8 was launched on 13 December 1967. Its primary TWT failed several years ago, but on 22 August 1996 the spacecraft was commanded to switch to the backup TWT, and the downlink signal was re-acquired. The spacecraft and one of the science instruments were again functioning.

Pioneer 9 was launched on 8 November 1968. The spacecraft failed in 1983.

Pioneer 10 was launched on 2 March 1972 and Pioneer 11 on 5 April 1973.

The Pioneer Venus Orbiter spacecraft was launched on 20 May 1978. It orbited the planet Venus for 14 years until it entered the Venus atmosphere on 8 October 1992 and burned up by entry heating.

The Pioneer Venus Multiprobe spacecraft was launched on 8 August 1978. Three small probes, one large probe, and the spacecraft bus entered the Venus atmosphere on 9 December 1978.

Pioneer 6-9 Spacecraft

The spacecraft measures 37 inches in diameter by 35 inches high (main body). The horizontal booms are 82 inches long. The antenna mast (pointing down in the picture) is 52 inches long. The weight is approximately 150 pounds. The spacecraft is spin-stabilized at approximately 60 rpm, with the spin axis perpendicular to the ecliptic plane.

Pioneer 6 was launched on a Thor-Delta launch vehicle on 16 December 1965 into a circular solar orbit with a mean distance of 0.8 AU (Astronomical Unit) from the Sun. (The mean distance from the Earth to the Sun is 1.0 AU).

Pioneer 7 was launched on 17 August 1966 into solar orbit with a mean distance of 1.1 AU from the Sun.

Pioneer 8 was launched on 13 December 1967 into solar orbit with a mean distance of 1.1 AU from the Sun.

Pioneer 9 was launched on 8 November 1968 into solar orbit with a mean distance of 0.8 AU from the Sun.

Pioneers 6-9 demonstrated the practicality of spinning a spacecraft to stabilize it and to simplify control of its orientation. Measurements made by these spacecraft greatly increased our knowledge of the interplanetary environment and the effects of solar activity on Earth. New information was gathered about the solar wind, solar cosmic rays, the structure of the Sun's plasma and magnetic fields, the physics of particles in space, and the nature of storms on the Sun which produce solar flares.

Originally designed to operate in space for at least 6 months, the Pioneers proved to be remarkably reliable. Pioneer 9 failed in 1983. Pioneer 8 was last tracked successfully on 22 August 1996, after being commanded to the backup transmitter tube (TWT). Pioneer 7 was last tracked successfully in March 1995. Pioneer 6, the oldest operating spacecraft ever, had a track on the 70 meter Deep Space Station 43 in Australia on 6 October 1997. The spacecraft had been commanded to the backup TWT in July, 1996. The prime TWT apparently had failed some time after December, 1995. Both the MIT and ARC Plasma Analyzers as well as the cosmic ray detector from University of Chicago were turned on and still worked after almost 32 years! Limited availability of NASA's Deep Space Tracking Network antennas and the greater scientific value of newer space missions led to a discontinuance of the tracking of these spacecraft. However, to mark its 35 years in orbit as the oldest extant NASA spacecraft, one last contact was successfully completed on the 70 meter Deep Space Station 14 at Goldstone near Barstow, California on 8 December 2000.

The Pioneer 10 & 11 Spacecraft

The Pioneers are managed by NASA's Ames Research Center in Moffett Field, California, for NASA's Office of Space Science. The spacecraft were built by TRW Space & Technology Group, Redondo Beach, Calif. under contract with Ames.

Mission History

Pioneer 10 was launched on 2 March 1972 on top of an Atlas/Centaur/TE364-4 launch vehicle. The launch marked the first use of the Atlas-Centaur as a three-stage launch vehicle. The third stage was required to rocket Pioneer 10 to the speed of 52,000 kilometers per hour (32,400 mph) needed for the flight to Jupiter. This made Pioneer the fastest manmade object to leave the Earth, fast enough to pass the Moon in 11 hours and to cross the Mars orbit, about 80 million kilometers (50 million miles) away, in just 12 weeks.

On 15 July 1972 Pioneer 10 entered the Asteroid Belt, a doughnut shaped area, which measures some 280 million kilometers wide and 80 million kilometers thick. The material in the belts travels at speed about 20 km/sec. and ranges in size from dust particles to rock chunks as big as Alaska. After safely traversing the Asteroid Belt, Pioneer 10 headed toward Jupiter. Accelerated by the massive giant to a speed of 132,000 km/hr (82,000 mph), Pioneer 10 passed by Jupiter within 130,000 km (81,000 miles) of the cloudtops on December 3, 1973. During the passage by Jupiter, Pioneer 10 obtained the first close-up images of the planet, charted Jupiter's intense radiation belts, located the planet's magnetic field, and discovered that Jupiter is predominantly a liquid planet.

Following its encounter with Jupiter, Pioneer 10 explored the outer regions of the Solar system, studying energetic particles from the Sun (Solar Wind), and cosmic rays entering our portion of the Milky Way. The spacecraft continued to make valuable scientific investigations in the outer regions of the solar system until its science mission ended on March 31, 1997. Since that time, Pioneer 10's weak signal has been tracked by the DSN as part of an advanced concept study of communication technology in support of NASA's future interstellar probe mission. The spacecraft had also been used to help train flight controllers how to acquire radio signals from space during the Lunar Prospector mission. The power source on Pioneer 10 finally degraded to the point where the signal to Earth dropped below the threshold for detection in its contact attempts on 7 February 2003 and 3 March 2006. The previous three contacts had very faint signals with no telemetry received. The last time a Pioneer 10 contact returned telemetry data was on 27 April 2002.

Pioneer 11 was launched on 5 April 1973, like Pioneer 10, on top of an Atlas/Centaur/TE364-4 launch vehicle. After safe passage through the Asteroid belt on 19 April 1974, the Pioneer 11 thrusters were fired to add another 64 m/sec (210 ft/sec) to the spacecraft's velocity. This adjusted the aiming point at Jupiter to 43,000 km (26,700 miles) above the cloudtops. The close approach also allowed the spacecraft to be accelerated by Jupiter to a velocity 55 times that of the muzzle velocity of a high speed rifle bullet - 175,000 km/hr (110,000 mph) - so that it would be carried across the Solar System some 2.4 billion kilometers (1.5 billion miles) to Saturn.

During its flyby of Jupiter on 2 December 1974, Pioneer 11 obtained dramatic images of the Great Red Spot, made the first observation of the immense polar regions, and determined the mass of Jupiter's moon, Callisto.

Looping high above the ecliptic plane and across the Solar System, Pioneer 11 raced toward its appointment with Saturn on 1 September 1979. Pioneer 11 flew to within 13,000 miles of Saturn and took the first close-up pictures of the planet. Instruments located two previously undiscovered small moons and an additional ring, charted Saturn's magnetosphere and magnetic field and found its planet-size moon, Titan, to be too cold for life. Hurtling underneath the ring plane, Pioneer 11 sent back amazing pictures of Saturn's rings. (http://quest.nasa.gov/sso/cool/pioneer10/graphics/lasher/slide4.html) The rings, which normally seem bright when observed from Earth, appeared dark in the Pioneer pictures, and the dark gaps in the rings seen from Earth appeared as bright rings.

Following its encounter with Saturn, Pioneer 11 explored the outer regions of our Solar system, studying energetic particles from our Sun (Solar Wind) and cosmic rays entering our portion of the Milky Way. In September 1995, Pioneer 11 was at a distance of 6.5 billion km (4 billion miles) from Earth. At that distance, it takes over 6 hours for the radio signal (which is traveling at the speed of light) to reach Earth. However, by September 1995, Pioneer 11 could no longer make any scientific observations. On 30 September 1995, routine daily mission operations were stopped. Intermittent contact continued until November 1995, at which time the last communication with Pioneer 11 took place. There have been no communications with Pioneer 11 since. The Earth's motion has carried it out of the view of the spacecraft antenna. The spacecraft cannot be maneuvered to point back at the Earth. It is not known whether the spacecraft is still transmitting a signal. No further tracks of Pioneer 11 were scheduled.

Description of the Spacecraft

Measured from its farthest ends, from the horn of the medium-gain antenna to the tip of the omnidirectional antenna, the Pioneer spacecraft is 2.9 meters (9 1/2 feet) long. Its widest cross-wise dimension, exclusive of the booms, is the 2.7-meter (9-foot) diameter high gain antenna. Pioneer weighs 270 kilograms (570 pounds). The spacecraft is spin-stabilized, spinning about the axis of the high gain dish antenna at approximately 5 rpm. Six Hydrazine thrusters provide velocity, attitude and spin-rate control.

Electrical power is provided by four radioisotope thermoelectric generators (RTG), each providing 40 watts of power at launch. Two three-rod trusses, 120 degrees apart, project from the equipment compartment to deploy the RTG power sources about 10 feet from the center of the spacecraft. A third boom, 120 degrees from the others, projects from the experiments compartment and positions the helium vector magnetometer sensor 20 feet from the spacecraft center.

Pioneer 10 carries 11 instruments, and Pioneer 11 carries 12.

As the first two spacecraft to leave our planetary solar system (in 1983 and 1990, respectively) Pioneer 10 & 11 carry a graphic message in the form of a 6- by 9-inch gold anodized plaque bolted to the spacecraft's main frame.

About the Launch Vehicle

Launch of Pioneer 10

The Atlas vehicle has a total thrust of 410,000 pounds, consisting of two 175,000-pound-thrust booster engines; one 60,000-pound thrust sustainer engine, and two vernier engines, each developing 675 pounds thrust. Propellants are liquid oxygen and RP1.

The Centaur second stage has two engines having a total thrust of 29,200 pounds. This engine carries insulation panels which are jettisoned just before the vehicle leaves the Earth's atmosphere and are used to prevent heat or air friction from causing boil-off of liquid hydrogen during flight through the atmosphere. Propellant is liquid hydrogen and liquid oxygen.

The solid-fueled TE364-4 third stage develops approximately 15,000 pounds of thrust. This stage also spins the spacecraft up to 60 rpm.

For further launch information, see NASA Lewis Pioneer 10 Silver Anniversary.

Scientific Instruments

The following is a list of scientific instruments on board the Pioneer 10 & 11 spacecraft. Some instruments eventually failed (F) or were only used during Jupiter or Saturn encounter (ENC).

Pioneer 10 Instruments
Helium Vector Magnetometer (F)
Plasma Analyzer
Charged Particle Instrument
Cosmic Ray Telescope
Geiger Tube Telescope
Trapped Radiation Detector
Meteoroid Detector (ENC)(F)
Asteroid-Meteoroid Experiment (ENC)(F)
Ultraviolet Photometer
Imaging Photopolarimeter (ENC)
Infrared Radiometer (F)
Pioneer 11 Instruments

The Pioneer 11 instruments are the same as the Pioneer 10 instruments, except that a Flux-Gate Magnetometer was added. As the spacecraft power continued to decline, instruments had to be turned off. By October 1995, none of the instruments could be operated, and the scientific investigations by Pioneer 11 came to an end. Sometime in late 1996, its transmitter will fall silent altogether, and Pioneer 11 will travel forever as a ghost ship in our galaxy.

Pioneer Plaque

On the plaque a man and woman stand before an outline of the spacecraft. The man's hand is raised in a gesture of good will. The physical makeup of the man and woman were determined from results of a computerized analysis of the average person in our civilization.

The key to translating the plaque lies in understanding the breakdown of the most common element in the universe - hydrogen. This element is illustrated in the left-hand corner of the plaque in schematic form showing the hyperfine transition of neutral atomic hydrogen. Anyone from a scientifically educated civilization having enough knowledge of hydrogen would be able to translate the message. The plaque was designed by Dr. Carl Sagan and Dr. Frank Drake and drawn by Linda Salzman Sagan.

Pioneer Venus

The Orbiter was launched on 20 May 1978 on an Atlas-Centaur launch vehicle. On 4 December 1978, the orbiter was injected into a highly elliptical orbit around Venus. The periapsis, or low orbital point, of the orbit was about 150 km (93 miles) above the surface of the planet. The apoapsis, or highest orbital point, was 66,000 km (41,00 miles) from the planet. The orbital period was 23 hours 11 minutes.

The orbit permitted global mapping of the clouds, atmosphere and ionosphere; measurement of upper atmosphere, ionosphere, and solar wind-ionosphere interaction; and mapping of the planet's surface by radar. For the first 19 months of the mission, the periapsis was maintained at about 150 km by periodic maneuvers. As propellant began to run low, the maneuvers were discontinued, and Solar gravitational effects caused the periapsis to rise to about 2,300 km. By 1986, the gravitational effects caused the periapsis to start falling again, and the orbiter instruments could again make direct measurement within the main ionosphere.

During the Orbiter's mission, opportunities arose to make systematic observations of several comets with the Ultraviolet Spectrometer (OUVS). The comets and their date of observation were: Encke April 13 through April 16, 1984; Giacobini-Zinner, September 8 through 15, 1985; Halley, December 27, 1985 to March 9, 1986; Wilson, March 13 to May 2, 1987; NTT, April 8, 1987; and McNaught, November 19 through 24, 1987. For Halley, the results showed that, near perihelion, the water evaporation rate was about 40 tons per second.

Pioneer Venus entry Starting in September 1992, controllers used the remaining fuel in a series of maneuvers to keep raising periapsis altitude for as long as possible. On 8 October 1992, its fuel supply exhausted, the Orbiter ended its mission as a meteor flaming through the dense atmosphere of Venus.

As the Pioneer Venus Orbiter entered the Venusian atmosphere, it produced a glowing tail like a large meteorite.

Spacecraft Description

The main body of the spacecraft was a flat cylinder 2.5 m (8.2 ft) in diameter and 1.2 m (4 ft) high. In the upper or forward end of the cylinder was a circular equipment shelf. All the spacecraft's scientific instruments and electronic subsystems were on this shelf. Below the shelf, 15 thermal louvers controlled heat radiation from an equipment compartment that was between the shelf and the top of the spacecraft. On top of the spacecraft was a 1.1 m (3.6 ft) diameter, despun, high gain, parabolic dish antenna. The despun design allowed the antenna to me mechanically directed to continuously face the Earth from the spinning spacecraft.

The spacecraft also carried a solid-propellant rocket motor with 18,000 N (4045 lb) of thrust. This thrust would decelerate the spacecraft by 3800 km/hr (2400 mph) and place it into an orbit around Venus. The spacecraft's launch weight of 550 kg (1220 lbs) included 45 kg (100 lb) of scientific instruments and 180 kg (400 lb) of rocket propellant.

Beneath the equipment compartment were two conical hemispheric propellant tanks. These tanks stored 32 kg (70 lb) of hydrazine propellant for three axial and four radial thrusters. These thrusters were used to change the attitude, velocity, or orbital period and spin rate during the mission.

The National Space Science Data Center (NSSDC) has a description of the Pioneer Venus missions and science data sets. The Center for Space Research at MIT has a science data set from the Radar Mapper instrument on the Orbiter.

On 8 August 1978, slightly less than three months after the Orbiter left Earth, the Multiprobe spacecraft was launched from the Kennedy Space Center on an Atlas-Centaur launch vehicle. On 16 November 1978, the Large Probe was released from the Bus toward an entry near the equator on the day side of Venus. Four days later, on 20 November 1978, the three Small Probes were released from the bus. Two of the probes were targeted to enter on the night side and one was targeted to enter on the Venus day side. On 9 December 1978 the bus with its instruments was retargeted to enter Venus' day side.

When the probes separated from the Multiprobe bus, they went "off the air" because they did not have sufficient on-board power or solar cells to replenish their batteries. Preprogrammed instructions were wired into them and their timers had been set before they separated from the bus. The on-board countdown timers were scheduled to bring each probe into operation again three hours before the probes began their descent through the Venusian atmosphere. On 9 December 1978, just 22 minutes before entry, the Large Probe began to transmit radio signals to Earth. Only 17 minutes before hurtling into the Venusian atmosphere at almost 42,000 km/hr (26,100 mph), all the Small Probes started transmitting.

All four probes were designed for a descent time of approximately 55 minutes before impacting the surface. None were designed to withstand the impact. However one Small Probe (the Day Probe) did survive and sent data from the surface for 67 minutes. Engineering data radioed back from the Day Probe showed that its internal temperature climbed steadily to a high of 126 degrees C (260 degrees F). Then its batteries were depleted, and its radio became silent.

The Bus

The Pioneer Venus Multiprobe (Pioneer 13) spacecraft consisted of a basic Bus similar to the Orbiter's, a Large Probe and three identical Small Probes. It did not carry a despun, high-gain antenna. The weight of the Multiprobe was 875 kg (1930 lb), including 32 kg (70 lb) of hydrazine. The Multiprobe used this propellant to correct its trajectory and orient its spin axis. The total weight of the four probes it carried was 585 kg (1290 lb). The Bus itself weighed 290 kg (640 lb). The Multiprobe's basic Bus design was similar to the Orbiter's design. It also used a number of common subsystem designs. The spacecraft diameter was 2.5 m (8.3 ft). From the bottom of the Bus to the top of the Large Probe mounted on it, the Multiprobe measured 2.9 m (9.5 ft).

During their flight to Venus, the four probes were carried on a large inverted cone structure and three equally spaced circular clamps surrounded the cone. Bolts held these attachment structures to the control thrust tube. This thrust tube formed the structural link to the launch vehicle. The Large Probe was centered on the spin axis. A pyrotechnic-spring separation system launched the probe from the Bus toward Venus. The ring support clamps that attached the Small Probes were hinged. To launch the Small Probes, the Multiprobe first spun up to 45 rpm. Then explosive nuts fired to open the clamps on their hinges. This sequence allowed the probes to spin off the Bus tangentially.

The Probes

The probes' designers faced a number of tremendous challenges: the high pressure in the lower regions of Venus' atmosphere, which is 100 times greater than the pressure on Earth; the high temperature of about 480 degrees C (900 degrees F) at the surface (hot enough to melt lead); and corrosive constituents of the clouds, such as sulfuric acid. Moreover, the probes had to enter the atmosphere at a speed of about 41,600 km/hr (25,850 mph). The Large and Small Probes were similar in shape. The main component of each probe was a spherical pressure vessel. Machined from titanium, the vessels were sealed against the vacuum of space and the high pressure of Venus' atmosphere. A conical aeroshell deceleration module and heat shield protected the probes from the heat of high speed atmospheric entry.

The Large Probe weighed about 315 kg (695 lb) and was about 1.5 m (5 ft) in diameter. The probe was equipped with a parachute to slow its entry into the atmosphere. The forward heat shield and aft cover of the deceleration module were designed to separate form the pressure vessel. There were a total of seven scientific instruments on the Large Probe. Four scientific instruments used nine observation windows through pressure vessel penetrations. Eight of the windows were sapphire and one was a diamond. There were three pressure vessel penetrations as inlets for direct atmospheric sampling by a mass spectrometer, a gas chromatograph, and an atmospheric structure instrument.

The three Small Probes were identical. In contrast to the Large Probe, they did not carry parachutes. Aerodynamic braking slowed them down. Like the Large Probe, each Small Probe consisted of a forward heat shield, a pressure vessel, and an afterbody. The heat shield and the afterbody remained attached to the pressure vessel all the way to the surface. Each probe was 0.8 m (30 in.) in diameter and weighed 90 kg (200 lb). The Small Probes were equipped with a mechanism that deployed two 2.4-m (8- ft) cables and weights as a yo-yo despin system five minutes before atmospheric entry. The cables and weights reduced the spin rate of the probes from 48 to 15 rpm. The weights and cables were then jettisoned. Each Small Probe carried three scientific instruments.

ANOMALOUS GRAVITATIONAL FORCE

A discussion of this phenomenon appears in the 4 October 1999 issue of Newsweek magazine (See also the December 1998 issue of Scientific American.) The mystery of the tiny acceleration towards the sun in the motion of the Pioneer 10, Pioneer 11 and Ulysses spacecraft remains unexplained as of 2006. A team of planetary scientists and physicists led by John Anderson (Pioneer 10 Principal Investigator for Celestial Mechanics) has identified a tiny unexplained acceleration towards the sun in the motion of the Pioneer 10, Pioneer 11, and Ulysses spacecraft. The anomalous acceleration - about 10 billion times smaller than the acceleration we feel from Earth's gravitational pull - was identified after detailed analyses of radio data from the spacecraft. A variety of possible causes were considered including: perturbations from the gravitational attraction of planets and smaller bodies in the solar system; radiation pressure, the tiny transfer of momentum when photons impact the spacecraft; general relativity; interactions between the solar wind and the spacecraft; possible corruption to the radio Doppler data; wobbles and other changes in Earth's rotation; outgassing or thermal radiation from the spacecraft; and the possible influence of non-ordinary or dark matter. After exhausting the list of explanations deemed most plausible, the researchers examined possible modification to the force of gravity as explained by Newton's law with the sun being the dominant gravitational force. "Clearly, more analysis, observation, and theoretical work are called for," the researchers concluded. The scientists expect the explanation when found will involve conventional physics.

PROJECT MANAGEMENT

Charles Hall, the original Project Manager from 1962 to 1980, is the manager most responsible for the immense success of Pioneer. He was Project Manager from conception through successful implementation of the primary missions of Pioneer 6 through 13. Charlie retired after the encounter of Pioneer 11 with Saturn in 1979. The space community was saddened to learn of the death of Charles Hall on 26 August 1999. Over a period of 13 years, 8 Pioneer spacecraft were successfully launched by the Pioneer Project Office under Mr. Hall's management and direction. NASA Administrator Daniel Goldin has this to say of Charlie Hall: "The entire NASA family mourns the loss of Charlie Hall. His intelligence, persistence and leadership throughout his career at NASA, and particularly as the original program manager for the Pioneer Project, continue to inspire us to reach the stars and beyond. Charlie Hall's Pioneer 10 craft may be over 6.8 billion miles from Earth, but his spirit will always be with us at NASA." Richard Fimmel successfully managed Pioneer 6 through 12 through their extended missions. Fred Wirth was the third Project Manager and is responsible for the design of this Web document. Larry Lasher, the present project manager, organized the 25th anniversary celebration of Pioneer 10 and presided over the retirement of the Pioneer Mission program. He instituted the training program and then arranged for support of an advanced technology program investigating chaos theory on the Pioneer 10 signal that allowed us to continue following Pioneer 10 until loss of signal in 2003. Dr. Lasher is the primary point of contact for information about the Pioneer Missions.