A description of work accomplished under contract between the California Institute of Technology and the National Aeronautics and Space Administration for the period January 1 through December 31, 1996. Funding for this publication was provided by the California Institute of Technology.

**Cover**

Photographs by Galileo: Jupiter's ice-covered — and possibly oceanic — moon Europa is contrasted with a photograph of Earth taken earlier in the mission. The Europa image was taken on September 7, 1996, during Galileo's second data-gathering orbit around Jupiter.
The Amazon rain forest appears in purple and blue in this false-color image taken by the NASA Scatterometer (NASCAT), a new tool for land studies. False color helps scientists identify differing vegetation.

Ganymede was "peeled" by scientists using gravity data from Galileo, collected as the spacecraft flew by and felt the tug of the Jovian satellite.

Eerie, pillar-like structures in the Eagle Nebula are a stellar nursery, imaged by the Wide-Field and Planetary Camera 2 aboard the Hubble Space Telescope.

The Great Wall of China was easily detected from space because its steep, smooth sides form a prominent surface for reflection of SAR-C/X-SAR's radar beam. The radar detected two generations (seen in the white box outline) of the Great Wall - one built during the Ming Dynasty, the other built during the Sui Dynasty.

Mars Pathfinder was launched on December 4 on its way to July 4, 1997, landing on Mars.

Fire in the Santa Monica Mountains caused vegetation changes detected by the Airborne Visible and Infrared Imaging Spectrometer. Such information will improve the ability to assess fire risk and predict fire behavior.

Our instruments and spacecraft studied Earth, Jupiter and its moons and a celestial nursery.

ACCOMPLISHMENTS
The National Aeronautics and Space Administration's broad-based program of Solar System exploration received an unexpected boost in 1996 when two scientific findings offered tantalizing — if still preliminary — signs that the conditions for life may not be limited to planet Earth. In early August, at a televised news conference presided over by NASA Administrator Daniel S. Goldin, a team of NASA and university researchers announced that a meteorite known as Allan Hills-84001 (AH84001), which fell to Earth from Mars some 13,000 years ago, bears chemical and possibly fossil evidence of microbial organisms some 3.6 billion years old, dating from a time when Mars appears to have been warmer and wetter — and thus more favorable for the start of biological processes.

Days later, scientists with the Jet Propulsion Laboratory-managed Galileo mission released new images of Jupiter's moon Europa that suggested the presence of slushy ice or liquid water beneath the moon's frozen crust. Water, of course, is the essential component of life on Earth, and Galileo's finding, though less controversial than the claim for the Mars meteorite, must also be viewed with what Administrator Goldin termed "skeptical optimism." Both findings — coming after a year of discovery in which astronomers detected evidence of planets around at least five stars — increased public awareness of our own Solar System, and also coincided with preparations by JPL scientists and engineers to launch two spacecraft to the Red Planet in November and December 1996 as the start of an ambitious 10-year program of exploration.

The Mars and Europa findings, while generating fresh excitement worldwide in old, but fundamental, scientific and philosophical issues — Are we alone? Does life exist elsewhere in the Universe? — served more immediately as a striking illustration of how quickly and creatively a reengineered JPL can respond to new challenges and new opportunities. As part of the planning for the decade-long Mars Surveyor exploration effort, which will send two spacecraft to the planet every 26 months beginning with the late-1996 launches of Mars Global Surveyor and Mars Pathfinder, a JPL-led team determined that Martian samples could be returned to Earth within the first 10 to 20 years of the next century within current Congressional and Administration budgetary constraints. After the Allan Hills meteorite announcement, however, the JPL team reconvened to map out a more focused search for evidence of life on the Martian surface. Working with other JPL
planners, the team developed three strategies — designated as "paced," "accelerated" and "aggressive" — for the collection and return of samples from those areas of Mars to be identified as most conducive (for example, river or lake bottoms) to life. The "paced" option called for a 2005 mission, with samples returned to Earth by 2008; the "accelerated" option for a 2003 mission and sample return by 2006, and the "aggressive" for a 2001 mission with a surface "field geologist" rover and sample return also by 2006. Within months, these proposals had been reviewed by scientists, technologists and engineers throughout NASA and at major American universities, and presented to NASA's Solar System Exploration Committee for its consideration. Proposing such an ambitious series of missions with a compressed time frame would have been unthinkable just a few years ago. But the "faster, better, cheaper" philosophy now pervading the Laboratory's work — with its emphasis on short development cycles, the application of the latest technologies and instrument capabilities and strict cost controls — makes such goals feasible and affordable.

The Mars sample-return mission should also be seen as part of a larger movement at JPL — a second great wave of space exploration. This new wave, capitalizing on the initial reconnaissance of nearly all the planets of the Solar System over the past three decades, is based on landers, penetrators, atmospheric probes and other in situ experiments and sensors all considerably smaller, yet more capable than — and designed specifically to address questions raised by — their predecessors. A prominent example: the 339-kilogram Galileo probe, whose high-speed descent into Jupiter in late 1995 prompted scientists to revise their previous theories about the Jovian atmosphere. Galileo is only the most recent example of this new approach. And in the works are not just Mars sample returns, but missions that will dig deep into planetary soil and ice, embed networks of miniature seismic and meteorological sensors in planetary terrains and catch dust and gas particles from a comet. Nineteen ninety-six was clearly a year of great discovery as well as one of great progress, with the hint of even greater discoveries to come.
The Galileo spacecraft last year successfully completed the first half of its two-year, 11-orbit tour of the miniature solar system that is Jupiter and its moons. After deploying an instrumented probe on a spectacular plunge into the planet's atmosphere on December 7, 1995, the spacecraft's orbiter gathered data during a quick flyby of the satellite Io before going on to close encounters with its sister moons Ganymede (June 27 and September 6), Callisto (November 4) and Europa (December 18).

Galileo's 11 scientific instruments comprise the most comprehensive and capable suite of experiments ever to scan another planet. Galileo's mission is to explore Jupiter in its dual roles as dominant sibling among the planets and substellar companion to the Sun. The planet, its 16 moons and its extended sphere of magnetic influence are a unique laboratory, within which researchers can test their theories of planetary and star formation.

By that measure, scientists got what they bargained for in 1996, as the atmospheric probe (managed by NASA's Ames Research Center) returned findings on composition, wind speed and cloud structure that ran contrary to earlier, prevailing theories on the Jovian atmosphere. And by year's end, scientists had gotten their best looks yet at the four biggest moons of Jupiter — known as the Galilean moons, because they were first discovered in the 17th century by the spacecraft's namesake, Galileo Galilei.

As has become the rule in planetary exploration, a series of surprising results raised as many new questions as it answered old ones. The innermost Galilean moon, volcanic Io — a revelation during the Voyager 1 and 2 encounters of 1979 — proved to be as active today as it probably has ever been, and to possess both an iron core and a dense high-altitude ionosphere. Giant Ganymede, slightly larger than the planet Mercury, appears to have its own magnetosphere, making it the only moon in the Solar System found to have a magnetic field. Remote Callisto showed a mysterious chain of impact craters and unexpected signs of erosion on its ancient surface. And evidence of icy volcanism on Europa kept alive speculation that it may harbor a liquid ocean beneath its cracked and banded crust.

**Chaos at Io**

In May, Galileo scientists announced their first major finding of the orbital mission: the detection of a massive iron core in Io. The discovery came from the December 1995 flyby, when the spacecraft swooped to within 900 kilometers of the small moon on its way into
orbit around Jupiter. Precise measurements of Galileo's radio signal at that time revealed slight deviations in the spacecraft's trajectory — caused by Io's gravitational field — and led Galileo scientists to posit a metallic core about 900 kilometers (coincidentally, almost the same dimension as the flyby altitude) in radius. The core is thought to be iron and iron sulfide, above that is another layer, approximately 900 kilometers thick, of partly molten rock Io undergoes continual distortion in the powerful, complex interplay of the gravitational fields of Jupiter and Io's sister moons, Europa and Ganymede. Their constant pushing and pulling raise "body tides" in Io, similar to oceanic tides on Earth caused by the gravitational distortion of the Sun and Earth's Moon. In Io's case, the ceaseless pumping melts the little moon's subsurface layers and spews lava onto the surface through at least nine active volcanoes. Indeed, Io is the most active body in the Solar System, and though less than a third the size of Earth, it generates twice as much heat.

Data gathered during that first encounter also revealed a large hole in Jupiter's magnetic field. Instead of steadily increasing as the spacecraft neared Jupiter, the field's strength suddenly dropped about 30 percent in the vicinity of Io. That result, which one Galileo scientist termed "astonishing" and "completely unexpected," suggests that something (possibly its own magnetic field) is, in effect, gouging a chunk out of Jupiter's magnetosphere. By year's end, no definitive conclusion had been drawn, however, and the honors for the only known moon with a magnetic field were still with Ganymede. Scientists remained hopeful that future observations of Io would provide more clues.

In October, scientists reported yet another finding at Io from the December 1995 flyby: the detection of a dense ionosphere — a region of electrically charged gases, a feature of some other planetary atmospheres, including Earth's — at an unexpectedly high altitude of 900 kilometers. The layer of ionized oxygen, sulfur and sulfur dioxide is believed to be shot upward by the relentless volcanic activity below. The finding was surprising for two reasons. One, the expectation that any such gases would be swept away by Jupiter's rotating magnetosphere and, two, the belief (based upon data from the two Voyagers and Pioneer spacecraft) that the volcanic plumes rise only a few hundred kilometers at most. The difference between what the earlier missions saw and what Galileo observed indicates that Io's atmosphere and ionosphere are variable and may grow and shrink with greater or lesser cycles of volcanic activity.

During the year, scientists also released images showing other significant changes at Io since the Voyager encounters. Variations in the color and distribution patterns of material on the ground were particularly striking — notably, new deposits of sulfur and sulfur dioxide around the active volcano Masubi in the moon's southern hemisphere. Comparison of Galileo and Voyager images also revealed stark differences at the volcano Ra Patera, where an area the size of New Jersey appears to have been covered by new volcanic deposits. Galileo's images of this volcano show a blue volcanic plume extending about 100 kilometers into space, the blue color is believed to be the result of tiny particles of sulfur dioxide "snow," which condense from the gas as the plume expands and cools.

Galileo detected an iron core in Io, but Ganymede remains the only known moon with a magnetic field.
This close-up of Jupiter's moon Europa — taken by Galileo in December — shows twisted ridges and grooves, indicating that considerable energy was available in Europa's interior. The flat, smooth area is about 3 kilometers across. It resulted from flooding by a liquid that erupted onto the surface, burying the ridges that characterize this area. From evidence gathered by Galileo, scientists believe that aEuropian ocean existed in recent geologic history and may still exist. Other images show broken ice crust that appears to have moved over soft ice or ice-crusted water.
**Dynamism at Ganymede**

Galileo made its first close flyby of Jupiter's largest moon, Ganymede, on June 27, returning stunning close-ups of tectonically deformed terrain and discovering strong evidence of a magnetic field. The spacecraft flew 835 kilometers above the surface of the 5,262-kilometer-diameter moon, coming about 70 times closer than Voyager 2 and 130 times closer than Voyager 1. High-resolution images showed that Ganymede's surface has been extensively reshaped by the same tectonic forces that build mountains and shuffle continents around on Earth. Images of the areas known as Galileo Regio and Uruk Sulcus displayed ancient, cratered ice fields adjacent to, or overlain by, younger features such as plains, ridged ice mountains, deep furrows and smooth broad basins — all indicative of volcanism and tectonic forces at work. These new images have helped scientists better understand this Galilean moon's appearance that seemed so strange when first seen by the Voyagers 17 years earlier.

Scientists also discovered that Ganymede possesses a magnetosphere — a bubble-shaped region of electrically charged particles. Though several planets have surrounding magnetospheres, no moons were previously known to have one, the only other solid bodies in the Solar System known to have magnetic fields before this were Mercury and Earth (and now, in addition to Ganymede, possibly Io as well). Related measurements hinted at the presence of a thin ionosphere and a tenuous oxygen atmosphere.

The second Ganymede encounter, on September 6, brought Galileo just 262 kilometers above that moon's north pole, in what will be the closest flyby of any of the Jovian satellites during the two-year primary mission. This repeat visit allowed the spacecraft to take more pictures of the Galileo Regio and Uruk Sulcus areas, making possible the creation of three-dimensional stereo image pairs, these will help scientists resolve uncertainties about the topography of those icy surfaces. In addition, gravity data obtained from precision tracking of the spacecraft supported the earlier findings indicating a magnetic field. The gravity data indicate that Ganymede has an iron–rocky core approximately 1,300 kilometers in diameter, surrounded by a mantle of ice and rock perhaps another 800 to 1,000 kilometers thick. The boundary between the two could be warm enough to soften the deepest mantle layers, and this differentiated structure could generate the moon's magnetic field in the same way the Earth's is generated — by the dynamo action of a fluid mantle rotating around a metallic core.

**Another Waterworld?**

In August, Galileo returned images of Europa that strongly suggested slushy ice or perhaps even liquid water may once have existed (and perhaps still does) beneath this moon's icy, cracked surface. There were segments with linear features that seem to have been continuous at some distant time, but now are discontinuous, offset, rotated or overlain by other, presumably newer, fractures.
Scientists remarked that these features resembled nothing so much as ice floes here on Earth. Indeed, looking at the “mottled” terrain, parallel grooves and wide, sinuous, smooth bands that could be distinguished on, or between, these crustal segments or floes, there was consensus that underlying material must have gushed up through cracks and periodically replated Europa’s surface.

And when scientists took all these clues together — a brittle surface churned by some energy source, the apparent presence of silicate compounds and possibly liquid water — they had to wonder if Europa might not have environmental “niches” warm enough and wet enough to support some form of primitive life. While the Galileo spacecraft cannot answer this question conclusively, its provocative findings prompted scientists to begin thinking of one or more future missions that would address the issue directly.

**Surprises at Callisto**

Galileo made the first of three planned flybys of Callisto, the outermost Galilean moon, on November 4, passing within 1,100 kilometers of a surface that scientists have characterized as the oldest and most heavily cratered of any yet seen in the Solar System. With data from the encounter, scientists hoped to learn why Callisto seems so much less active than its Jovian siblings.

Orbiter instruments took various measurements of Callisto’s surface to determine its composition and history, to look for evidence of tectonic activity and to search for hints of a magnetic field. This moon seems also to have a rocky core, surrounded by an ice crust — one bearing the scars of tens of thousands of meteoric impacts. In a way, the large number of craters was not surprising, but the comparative absence of small craters was. This suggested to some scientists that small-scale features were being filled in or obliterated. One possible process was the landslide-like movement of debris down the icy, low-friction slopes of these features. As it happens, there are bright slopes visible in some craters where material appears to have slipped downward, exposing fresh, underlying ice strata.

Other Galileo images of Callisto showed a chain of craters that could be the sequential impacts of a shattered object, a discovery reminiscent of the peppering of Jupiter’s atmosphere by the disintegrating Shoemaker-Levy 9 comet in July 1994.

**Advances on the Ground**

The Callisto flyby was notable also as a demonstration of an improved telecommunications capability designed to return as much mission data as possible. The JPL-managed Deep Space Network was augmented by arraying the 70-meter-diameter antenna at Canberra, Australia, with two nearby 34-meter-diameter dishes at the Commonwealth Scientific and Industrial Research Organization (CSIRO) 64-meter Parkes radio astronomy telescope site, some 320 kilometers northwest of Canberra.
Arraying — electronically combining the faint signals received from the spacecraft by several antennas to improve the quality of the transmissions — was the final engineering solution devised by JPL engineers to compensate for the loss of Galileo's original high-speed, large-capacity telecommunications stream. What had been expected to be a flood of data became instead a trickle when the spacecraft's primary 5-meter-diameter, high-gain antenna failed to open fully during the cruise to Jupiter and engineers had to reroute all transmissions to and from the spacecraft over its smaller lower-capacity, low-gain antenna.

Nearing Callisto, Galileo was at its most distant from Earth and its weak radio signals were extremely difficult to capture cleanly and clearly. Earlier modifications to the spacecraft's onboard computer's data-compression processes having provided a factor of 10 improvement to signal clarity and reception, arraying the ground-based Australian tracking stations now yielded an additional 10-fold increase in the quantity of data returned over the low-gain antenna. Everything taken together, these improvements should enable Galileo to meet 70 percent of its original scientific goals.

In 1996, the Deep Space Network, with installations in Goldstone, California, as well as in Spain and Australia — supported some 40 planetary and Earth-orbiting missions in addition to Galileo and provided a better than 98 percent return of scheduled telemetry data. The new hardware, software and operations that made arraying possible represent a major advance that will continue to pay dividends. The effort should prove particularly beneficial to the new generation of "faster, better, cheaper" interplanetary missions under the JPL-managed New Millennium program, allowing spacecraft designers to reduce costs by using smaller onboard antennas and transmitters.

Work progressed in 1996 on the construction of several 34-meter-diameter antennas equipped with beam-waveguide technology. These new antennas will replace their aging counterparts from the 1960s, which not only employ older technology but have become more difficult and more expensive to maintain. When the next-generation spacecraft, with their smaller transmitters and antennas, require a higher downlink data rate, they will rely on fields of these 34-meter antennas, since there are no plans to build any more 70-meter units. Three of the new antennas went on line at Goldstone, when they are equipped with the proper electronics, they can be arrayed with an existing fourth antenna to provide the equivalent performance of a 70-meter apparatus.

In addition, a new antenna has been built at Canberra and is expected to be operational in February 1997, and another is under construction at the Deep Space Network complex near Madrid, with operations expected to begin in time for the October 1997 launch of the Cassini spacecraft to Saturn.
ONWARD TO MARS

The Mars Global Surveyor and Mars Pathfinder spacecraft inaugurated a return to the Red Planet in 1996 with their launches atop McDonnell Douglas Delta II rockets — two decades after the landmark Viking missions. Surveyor was launched November 7 on a 10-month cruise to the planet, where it will map the Martian globe in polar orbit for at least two years. Pathfinder, the first in NASA’s Discovery series of low-cost, highly focused missions, was launched December 4, with the goal of placing a lander and the small (11.5-kilogram) Sojourner rover on the Martian surface on July 4, 1997.

At the end of 1996, both spacecraft were functioning nearly flawlessly, although one of Surveyor’s two solar panels failed to deploy fully. Still, mission engineers concluded that this will not seriously affect the spacecraft’s performance during the cruise and science portions of the mission, nor will it impair the spacecraft’s ability to aerobrake into its mapping orbit. Surveyor conducted a perfect trajectory-correction maneuver on November 21; a few days later, all six of its scientific instruments were powered up for the first time after launch, and the spacecraft camera took a series of test images of Earth and the Moon.

Pathfinder also performed well at the outset of its seven-month, 500-million-kilometer cruise, which will deliver it to Mars about two months earlier than Surveyor despite the later launch. Minor problems with Pathfinder’s Sun sensor, which helps to orient the craft in space, were resolved quickly, and Pathfinder and its rover passenger, Sojourner, were fully checked out for a successful cruise to Mars.

A New Exploration Strategy

Mars Global Surveyor and Mars Pathfinder are the first missions in a decade-long attempt to investigate the evolution of Mars and determine whether or not the planet has, or once had, conditions suitable for life. Besides searching for evidence of past life, these missions will examine the Martian climate and its implications for Earth’s past and future climates; they will also explore the planet’s geology and look for any resources that might support astronaut missions.

A major focus of these and subsequent missions will be the history and possible presence of water, since water is not only an essential requirement for life, but also plays a key role in climatic processes and would be an essential resource for human explorers.
MARS PATHFINDER'S ROVER, NAMED SOJOURNER, WILL BE SEMIAUTONOMOUS IN OPERATION, BUT FUTURE MISSIONS WILL REQUIRE MORE SOPHISTICATED ROBOTS. ROCKY 7, A PROTOTYPE NEXT-GENERATION ROVER, WAS TESTED ON A DRY LAKE BED IN THE CALIFORNIA DESERT. ROCKY 7 DEMONSTRATED ITS ABILITY TO TRAVEL MORE THAN 200 METERS ON ITS OWN, A ROBOTIC ARM THAT CAN DIG INTO SOIL AND AN AGILE MAST WITH AN IMAGING SYSTEM. THE ARM CAN BE USED TO POSITION MINIATURE SCIENCE INSTRUMENTS FOR CLOSE INSPECTION OF ROCKS AND OTHER FEATURES.
Follow-on explorations are to culminate early in the next century with the return to Earth, via a robotic spacecraft, of Martian soil and rock samples. Leading up to that climactic mission, two spacecraft — a lander and an orbiter — will be dispatched to Mars whenever it moves into a favorable position relative to Earth. This alignment occurs about every 26 months, with opportunities in 1998–1999, 2001, 2003 and 2005.

These missions reflect the Laboratory’s commitment to NASA’s “faster, better, cheaper” philosophy. Mars Pathfinder was challenged to meet a start-to-launch cycle of just three years with a development cost cap of $150 million (in fiscal 1992 dollars), and it did so. Mars Global Surveyor cost even less to develop, owing to the use of spare and duplicate parts from the 1993 Mars Observer project.

As still another cost-control measure, JPL established a single Mars Surveyor Operations Project office in March. The Mars Global Surveyor and all subsequent Mars Surveyor missions will be carried out by this six-person unit (Project Manager, Flight Operations Manager, Science Systems Manager, Support and Development Manager, Project Engineer, Project Scientist) instead of a separate operations team for each mission. This consolidated team will use a set of basic processes and procedures to run these missions — some concurrently — and so keep Mars operations costs under an annual cost cap of $20 million.

In a parallel move, the Laboratory announced the formation of the Mars Exploration Directorate in May to coordinate the planning and execution of all JPL missions to the planet. The change recognizes the centrality of Mars exploration in NASA’s planning for the next century, for as the agency’s lead center for robotic planetary exploration, JPL will play a significant part in developing a cohesive, effective Mars program.

**Mars Global Surveyor**

During early 1996, this spacecraft underwent final assembly and testing at the Denver, Colorado, plant of JPL’s industrial partner, Lockheed Martin Astronautics Corporation. With the last of its scientific instruments delivered and installed in the spring, the 1,060-kilogram spacecraft ran through integrated systems and environmental testing and was shipped to the Kennedy Space Center at Cape Canaveral, Florida, in August. Following further tests, the installation of batteries and insulation and the loading of propellants in its propulsion module, the spacecraft was mated to its solid-propellant, upper-stage rocket and the entire assembly was hoisted atop the Delta launch vehicle in late October. The launch that followed on November 7 was flawless.

Mars Global Surveyor will generate a global portrait of Mars, giving scientists their first extensive record of the nature and behavior of the Martian surface, atmosphere and interior. In polar orbit, some 360 kilometers above the surface, the spacecraft will circle Mars every two hours, covering the entire planet every seven days. Its orbital camera, built by Malin Space Science Systems of San Diego, California, will produce a daily wide-angle image of the entire planet, similar to weather photographs of Earth shown on nightly television newscasts, and narrow-angle images of selected areas. The narrow-angle imaging will be able to resolve objects as small as 15 meters across — a 100-fold improvement over most of the Viking pictures of Mars.
Mars Global Surveyor's other instruments are expected to be just as productive. These instruments include a laser altimeter to measure the Martian topography, with its huge volcanic mountains and deep chasms, with great accuracy, a thermal emission spectrometer to look for the characteristic infrared signatures of different mineral types (particularly clays containing carbonate compounds, since these could be evidence of ancient Martian shorelines) in patches as small as 9 square kilometers, as well as studying the clouds and weather in the planet's atmosphere, and a magnetometer that may yield useful information about Mars' interior structure and insight into the history of the geophysical forces that shaped the planet. An analysis of Surveyor's radio signals to Earth will reveal the precise shape of the planet and structure of its atmosphere.

In addition to its scientific mission, the spacecraft will further test the fuel-saving aerobraking technique pioneered by the Magellan spacecraft at Venus in 1994. Aerobraking reduces the amount of fuel a spacecraft requires for trajectory correction, and this translates into a valuable reduction in its weight at launch.

Arriving at Mars in September 1997, Surveyor will enter an elliptical path around the planet, dipping into the top of the Martian atmosphere at the lowest point in each orbit. Over the next five months or so, this atmospheric drag will slow the spacecraft, bringing its orbit to the desired near-circular shape for mapping, to begin in March 1998. The mission is expected to last a full Martian year — about 687 Earth days.

Pathfinder

One of Pathfinder's major goals is to demonstrate an unconventional entry and landing approach. The spacecraft will dive directly into the Martian atmosphere, with its aeroshell absorbing the heat of entry as well as slowing the spacecraft's velocity from 7,500 meters per second to about 400 meters per second. An 8-meter-diameter parachute will be deployed between 5 and 11 kilometers above the surface to further slow the spacecraft to about 65 meters per second, three small retrorockets will help in deceleration and will carry the backshell and parachute away from the landing area. Pathfinder will land encased in three shock-absorbing air bags, each approximately 5.2 meters across.

After a year of rigorous testing of Pathfinder's landing components, the first half of 1996 was devoted to environmental tests in which the frigid conditions of the Martian surface were simulated, and engineering tests of various power, electrical, telecommunications and data-handling systems. These tests were carried out at JPL, where the Pathfinder lander and rover were built, and were completed several weeks ahead of schedule, thereafter, the lander and rover were shipped separately to Cape Canaveral, in mid and late August, respectively.

In Florida, launch teams spent three months on final integration, testing and preparation for flight — securing the rover to one of the lander's four petals, installing the protective aeroshell and attaching the parachute. The assembled entry vehicle, cruise stage and
upper-stage booster were mated to the Delta II rocket on November 21, and launch took place on December 4, the third day of the launch window.

Pathfinder will land at its target site, an ancient basin called Ares Vallis, in the early hours of Martian morning on July 4, 1997. Cushioned inside its voluminous air bags, Pathfinder could bounce along the surface for a kilometer or more before coming to a halt. Over the next three hours, the craft will deflate and retract the air bags, stand itself upright and unfold its petals to uncover Sojourner. Daylight will awaken the tiny solar-powered rover, and it will rise from its stowed configuration to its full height of 30 centimeters and roll down a ramp onto the Martian surface.

Making its way at a snail-like speed of 40 centimeters per minute across the floor of Ares Vallis, a flood plain believed to contain a wide variety of rocks, Sojourner will explore the surface independently for a minimum of some seven sols, or Martian days (each slightly longer than an Earth day), relying on the lander for communication with Earth. The rover will carry an alpha proton X-ray spectrometer (provided by the Max Planck Institute of Chemistry and the University of Chicago) to examine the composition of rocks and soil, as well as a stereo television system that will enable it to navigate around obstacles and to peer close up at interesting surface features.

The nominal mission lifetime of the lander itself is expected to be about 30 sols, during which time it will conduct investigations with a stereo multicolor imager provided by the University of Arizona, with contributions from the Lockheed Martin Group, Max Planck Institute of Aeronomy and Technical University of Braunschweig (these last two in Germany) and the Ørsted Laboratory of the Niels Bohr Institute in Copenhagen, Denmark. Mounted atop an extendible 1.5-meter mast, this imaging system will look out upon the Ares Vallis site, making panoramic views of the landing area as well as following Sojourner’s progress as it moves about the area. An atmospheric structure instrument—meteorology package, developed by JPL with help from San Jose State University, will record the temperatures, pressures, wind speeds and wind directions at the site.

The two U S missions — Mars Global Surveyor and Mars Pathfinder — bracketed the November 16 launch of Mars ‘96, a Russian spacecraft carrying 12 instruments, including a JPL-built soil and atmospheric chemistry experiment named MOX. Unfortunately, the Russian spacecraft plunged into the Pacific Ocean a day later, before it could transfer onto an interplanetary trajectory. The loss was a blow to science because the orbiter, with objectives similar to those of Mars Global Surveyor but also designed to characterize the uppermost atmosphere and its interactions with the solar wind, was to have deployed two landers and two soil penetrators to the Martian surface.
A replacement MOx or similar experiment will be given high priority for inclusion on a future mission, because of the importance of the surface chemistry to an overall understanding of the Martian environment. MOx would have picked up where the two Viking landers left off in the mid-1970s by investigating the effects of a strong oxidizing agent in the soil, whose presence was inferred from the findings of 20 years ago. In their search for past or present life on Mars, scientists will look for traces of organic molecules in the soil. But they must first understand how these compounds, if any, would be destroyed on or near the surface, so that they will know how deep to dig to reach untouched material.

**Mars '98 Missions**

JPL engineers and scientists continued work on two follow-on Mars missions in 1996, with an eye toward the next launch opportunity in late 1998–early 1999. Those two missions, the Mars '98 Surveyor orbiter and Mars '98 Surveyor lander, will continue the current NASA-JPL engineering trend in that they will weigh only half as much as their 1996 counterparts and yet their sensors and onboard systems will be significantly advanced.

The Mars '98 orbiter will carry an improved imaging system — the Mars color imager — weighing only a little more than 1 kilogram (compared to the 21-kilogram mass of the Mars Global Surveyor camera), and a pressure-modulated infrared radiometer, an instrument that will make very detailed vertical profiles of the Martian atmosphere, looking at clouds, dust hazes, water vapor, ozone distribution, high- and low-pressure cells, fronts, dust levels and jet streams, among other phenomena. It will also examine the radiative balance of the reddish surface.

The Mars '98 lander, to be launched a month after the Mars '98 orbiter, will be targeted on a site around 75 to 80 degrees south latitude. This spacecraft will also carry a lightweight camera — the Mars descent imager — that should send back exciting images as it slowly descends under a parachute to the Martian surface.

The lander will have a robotic arm, imaging cameras (including one on the end of the arm), a suite of science instruments known as the Mars volatiles and climate surveyor (MVACS) package, developed by JPL and the University of California at Los Angeles (UCLA), and an upward-looking lidar (light detection and ranging), built by the Space Research Institute (IKI) of the Russian Academy of Sciences. The robotic arm will explore soil types and mineral composition at the site by digging trenches to look for indications of annually deposited layers, since this could provide insights into the climatic cycles of Mars.

The instruments will also search for near-surface ice and characterize physical processes involved in the seasonal cycles of water, carbon dioxide and dust on Mars. Winds, temperatures, pressures, humidity levels, ice fogs, frost or snow and surface ice formation are among the many properties of the polar region to be identified and analyzed.
Still another investigation will be attempted by a pair of identical experiments, each in an aeroshell about the size of a basketball carried piggyback on the lander. These are to crash onto the Martian surface at 200 meters per second and, upon impact, separate into parts joined by a flex cable. The upper segment will remain on the surface, making some measurements of the Martian atmosphere and serving as a communications relay to the Mars '98 orbiter, while its soda can-size microprobe should penetrate the soil to a depth of up to 2 meters.

Sensors in the microprobes will look for any water ice in the Martian subsurface, an important clue to the puzzle of whether life exists, or ever existed, on Mars. The tiny science stations will also measure soil temperature and monitor local Martian weather, passing their findings up through the flex cable to the surface segment for transmission up to the orbiter and from the orbiter back to Earth.

Both Mars '98 spacecraft will be built by Lockheed Martin Astronautics and are expected to benefit from the company's experience in manufacturing the Mars Global Surveyor. The weight reductions achieved will allow the use of a new launch vehicle — the Med-Lite/ Delta 7425, about half the size of the Delta II launchers that carried the 1996 missions aloft.

### Future Rovers

In December, JPL engineers successfully completed three days of navigational tests of a prototype next-generation Mars rover, dubbed Rocky 7 (because it is the seventh in a series of these machines), on a dry lake bed in the California desert that served as a simulacrum of the rubble-strewn Martian surface. The 15-kilogram rover, developed and operated by JPL, should be able to cover much greater distances than Sojourner.

It will also employ such advanced technology as a robotic arm, with which it can dig into the Martian soil, and a stereo imaging system at the end of a 1.4-meter mast. The mast has three degrees of freedom so as to allow the imaging system to take panoramic views of the areas the rover visits, to "reach out and touch" rocks or other features that the rover itself cannot get close to and inspect.

While Sojourner is to be semiautonomous in its operation on Mars (mission controllers at JPL will choose a rock for it to examine and the rover then will determine how to get to it), advanced rovers like Rocky 7 will be programmed with hazard-avoidance software and information on specified location points and targets, so that they can function with little or no human control. Autonomous rovers that can travel long distances, conduct in situ studies of soil and rock and gather samples for return to Earth are central to the goals of the 10-year Mars exploration program.
The largest and most sophisticated planetary spacecraft the United States has ever built, the Cassini mission to Saturn continued its progress toward a planned October 1997 launch atop a Titan IV/Centaur rocket. The mission, a joint effort of NASA, the European Space Agency (ESA) and the Agenzia Spaziale Italiana (ASI), is similar in concept to Galileo and will explore the Saturnian system for four years, after a seven-year cruise to get there.

Saturn — a gas giant, like Jupiter — is, in effect, another miniature solar system. Cassini’s 27 scientific experiments will examine the planet’s atmosphere and interior, its spectacular system of rings, its 18 (at least) highly varied icy moons and its huge magnetosphere.

Shortly before its arrival at Saturn in July 2004, Cassini will fly past Titan, the planet’s largest moon, and send an instrumented probe — called Huygens, after Titan’s discoverer, the 17th-century Dutch astronomer Christiaan Huygens — through the satellite’s nitrogen-rich atmosphere to its shrouded surface. The complex organic chemistry of Titan — like Jupiter’s Ganymede, roughly the size of the planet Mercury — appears similar to conditions on primitive Earth and could provide clues about how life formed on our planet.

A key scientific payload aboard Cassini is its imaging radar. Peering through Titan’s atmospheric haze, it will create photograph-like images that should reveal if oceans exist on Titan, and, if so, their distribution, as well as the geologic features and topography of this moon’s solid surface. The microwave radar will also acquire data on other Saturnian targets such as the ring system and the icy satellites.

Another Cassini instrument, provided by the Applied Physics Laboratory at Johns Hopkins University, will carry out the first imaging of a planetary magnetic field. Indeed, advanced technology throughout the spacecraft will set new standards for deep-space missions. Solid-state recorders, powerful computer chips, gyroscopes with no moving parts and solid-state power switches are among Cassini’s many technological innovations.

The mission achieved several milestones in 1996. Among them were the delivery of scientific instruments starting in February, the arrival of the propulsion module subsystem in August and the mating of the engineering model of the Huygens probe with the orbiter flight model in October, thus completing the assembly of the spacecraft’s major components for the first time.
The spacecraft and its various subsystems underwent testing at JPL throughout the year under conditions simulating the vibrational and thermal stresses of launch and interplanetary travel. At the same time, teams were busy readying ground systems and preparing for mission operations, including the development of sequences for compatibility testing between Cassini and the Deep Space Network Assembly and testing will continue at JPL through mid-1997, at which time the spacecraft will be shipped to Cape Canaveral for final launch preparations.

Since early 1995, JPL has had responsibility for overall Cassini program management — spacecraft, science, operations and launch vehicle. Throughout the mission, costs are to be contained and efficiency enhanced by streamlined operations, including the use of simplified organizational groups to make decisions. The program finished the year on schedule and within budget, earning high marks in its third annual review by a team of outside evaluators.

**New Millennium**

Cassini is the last of the large flagship projects — Viking, Voyager and Galileo — that have added so much to our knowledge of the Solar System while advancing the state of the art in space exploration. With its launch, the Saturn-bound omnibus will pass the torch to a new generation of spacecraft — missions that hold as much potential for delivering revolutionary science and engineering as did their predecessors, while adhering to NASA’s new “faster, better, cheaper” philosophy.

Much of the promise of this next generation is to be found in the JPL-managed New Millennium program. Chief among the program’s significant achievements during the year were the start-ups of the Mars microprobe effort and an Earth-orbiting project, and the continuing progress of the program’s first mission, an asteroid-comet flyby, toward launch in the summer of 1998.

The New Millennium program was inaugurated in the fall of 1995 with the goal of validating the advanced technologies, scientific instruments and operations systems needed to fulfill NASA’s vision for 21st-century Earth science and space science missions. The program will develop a succession of engineering flights to demonstrate critical technologies in space, so that future missions can employ them without assuming the costs and risks inherent in their first use. These flights will also collect meaningful scientific data from a broad range of targets, as evidenced by the first three announced missions — Deep Space 1, Deep Space 2 and Earth Orbiter 1.

**Ion propulsion, surface-penetrating microprobes and miniaturized subsystems are among the technologies planned for flight testing**
**Deep Space 1.** The first New Millennium mission — Deep Space 1 — will rendezvous in July 1998 with asteroid McAuliffe (named in remembrance of schoolteacher Christa McAuliffe, who was on board the fatal flight of Space Shuttle Challenger) and comet West-Kohoutek-Ikemura. Deep Space 1 will employ solar electric ion propulsion, the first use of this technology in interplanetary space travel.

Solar electric ion propulsion converts sunlight gathered by solar panels into electric power and then uses that power to ionize a gaseous fuel — xenon, in this case. The ion propulsion engine provides a small but lengthy thrust (about 90 microneewtons, roughly 1/50th of a pound). Because it can run continuously for long stretches, the engine can accelerate a spacecraft, initially very slowly, but over time to the very high speeds (35,000 kilometers per hour) necessary to catch up to a comet.

A prototype of the ion engine began a nearly yearlong endurance test at JPL in April. In flight, the spacecraft’s engine will be powered by more than 2,000 watts from large solar arrays provided by the U.S. Ballistic Missile Defense Organization.

In addition to solar electric propulsion, the mission will demonstrate a number of other technologies — in particular, miniaturized components that will help keep total spacecraft weight to only 100 kilograms. The scientific payload will include a 5-kilogram, miniaturized sensor system that will perform the functions of spacecraft instruments that would weigh 85 kilograms if using 1970s Voyager technology.

In 1996, Deep Space 1 completed mission- and system-design reviews with Spectrum Astro Inc., of Gilbert, Arizona, JPL’s primary industrial partner in this project.

**Deep Space 2.** Two Mars microprobes, to be flown on the Mars ’98 lander, constitute the Deep Space 2 mission. If successful, the probes could validate an evolving concept called “network science” — the serial emplacement of seismic and meteorological networks across the landscape of a body such as Mars. Networks would focus on a complex, dynamic area — a planet’s atmosphere or climate, or its internal structure — enabling scientists to extend and deepen their knowledge about that planet. Surface-penetrating microprobes might also be the most effective way of obtaining soil samples and making subsurface measurements.

Among the new technologies proposed for the Deep Space 2 mission are a lightweight, single-stage entry aeroshell, a miniature, programmable telecommunication subsystem, an ultralow-temperature lithium battery, power microelectronics with mixed digital–analog integrated circuits, a microcontroller, and flexible connections for system cabling.

**Earth Orbiting 1.** In April, NASA announced the selection of the first New Millennium flight dedicated to the agency’s Mission to Planet Earth. The Advanced Land Imager mission — dubbed EO1, for Earth Orbiting 1— will be launched in late 1998 and will carry a lightweight sensor to produce high-resolution images, in both visible and infrared light, of Earth’s land surfaces.
CATCHING UP TO A COMET

The New Millennium Program's first deep space flight heralds a new way of traveling through the solar system. The Deep Space 1 ion propulsion system will get its power from newly developed solar panels. Sunlight converted to electric power will ionize a gaseous fuel, yielding a small but steady thrust to eventually accelerate the spacecraft to the high speed required to reach asteroid McAuliffe in 1999 and Comet West-Kohoutek-Ikenura in 2000.
The mission will gather measurements consistent with data collected since 1972 by the Landsat series of satellites, information that has been a boon to farmers, foresters, geologists, economists, hydrologists, environmental researchers and city planners. Like other New Millennium missions, EO1 will also flight test new technologies and designs — in this case, with the aim of developing less costly and more compact land-imaging systems.

The Advanced Land Imager is to be seven times lighter than the current Landsat 5 multispectral instrument and will require only a seventh as much electrical power. This novel wide-field observing system will incorporate an advanced, high-resolution hyperspectral imaging "spectrometer on a chip." In addition, the EO1 imaging system does not require a scan mirror, will be built around a lightweight integrated silicon carbide structure and optical system, and will feature an innovative inflight calibration system.

Technologies validated by New Millennium flights will be infused into the smaller, lighter spacecraft and Earth orbiters of the 21st century.

The EO1 project is managed by NASA's Goddard Space Flight Center in Greenbelt, Maryland. The Advanced Land Imager will be developed from instrument technologies proposed by members of the New Millennium Integrated Product Development Teams. The Massachusetts Institute of Technology's Lincoln Laboratory, a federally funded research and development center like JPL, will expedite the transfer of the resulting new technology to the commercial sector.

After 2000, technologies validated by New Millennium will allow frequent launches of lightweight and less costly spacecraft to address sharply drawn scientific questions. Such missions will be able to use smaller launch vehicles as a result of the development of miniaturized spacecraft and instruments. Mission operations will be similarly streamlined, through the use of autonomous flight and ground systems.

NASA's Integrated Product Development Teams — with representatives from other government agencies, the private sector and academia — are responsible for developing and delivering the technologies necessary for validating missions. The engineers and scientists on these teams will be involved in all aspects of the New Millennium program, ranging from identifying and developing technologies to analyzing scientific data returned by the various missions.

The teams have created "road maps" setting development priorities in six vital technology areas — autonomy, communications, in situ instruments and microelectromechanical systems, instrument technologies and architectures, microelectronics and modular and multi-functional systems.
Stardust

A Discovery-class mission — part of a NASA program to launch many smaller missions with focused science goals, fast turnaround times and costs under $183 million to build — Stardust is an ambitious endeavor to gather samples of cometary dust and return them to Earth for analysis. It is the second of three comet missions in which JPL is playing a major role, the others are NASA’s New Millennium Deep Space 1 and the European Space Agency’s Rosetta mission. The latter is to rendezvous with comet Wirtanen in 2012, JPL will build a tiny probe that will land on the comet’s nucleus.

Stardust completed its preliminary design review and proceeded on to the development phase. NASA is committing nearly $118 million for Stardust development and an additional $37 million for mission operations.

After launch in February 1999, the 380-kilogram spacecraft is to loop twice around the Sun, gathering interstellar dust particles before going on to comet Wild 2 for an encounter in early 2004. Stardust will fly through the comet’s extended coma, or tail, collecting dust and other materials to be returned inside a 1-meter-diameter capsule that will hurtle back to Earth for a 2006 landing in Utah. If successful, Stardust will become the first mission to return material from a Solar System object other than the Moon.

The mission will employ a novel material known as aerogel (a sponglike silica compound, the volume of which is 99 percent empty space) to capture the speeding dust particles. The aerogel, in a grid-like plate mounted on the end of an extendible arm, will be deployed from the open capsule, capturing interstellar dust on one side and cometary grains on the other. When the specks of dust collide with the aerogel, they will slow down gradually, eventually lodging in the material. Because aerogel is largely transparent, scientists will be able to trace the tracks made by the dust particles in order to retrieve them, a technique already tested in JPL-designed space shuttle experiments.

As with other Discovery missions, Stardust is the product of a collaboration among NASA, industry (Lockheed Martin) and academia (the principal investigator is Don Brownlee, University of Washington). JPL will manage the project.

Scientists have long been fascinated by comets, primitive bodies that may have been the building blocks of the outer planets and are also thought to have been a significant source of the water and organic materials in the early atmosphere and oceans of Earth. The investigators expect the captured material to provide data that may resolve many long-standing questions about planetary evolution.
Pluto, the only planet in the Solar System yet to be reconnoitered by an interplanetary spacecraft, could lose that distinction sometime in the next decade as JPL continues to develop an innovative mission to Pluto and its large moon, Charon.

As the first "sciencecraft," Pluto Express will be built according to a new philosophy in which the design of the spacecraft, instruments and, most importantly, mission operations will be carried out concurrently by the instrument builders and the spacecraft designers and manufacturers.

To illustrate this philosophy, consider the cameras to be flown on this mission. Their focal lengths would be determined in a way that would provide the required spatial resolution of features to be scanned on Pluto, while also taking into account the impact of those choices on all the other instruments in terms of power, data rates, pointing requirements, thermal loading, etc. This approach is essentially the inverse of the customary one wherein the spacecraft and each of many instruments are designed separately, with decisions about specific measurements made after the spacecraft is under construction — or sometimes en route to its destination.

To minimize costs and risks, the Pluto mission will employ a pair of small, identical spacecraft — each equipped with an integrated array of sensors to examine the planet's atmosphere and surface, as well as Charon's surface. Among several flyby trajectories being considered, the primary one is to have the two Pluto-bound craft loop around Venus three times, building momentum with each passage, and then get a final gravitational boost at Jupiter to the outer Solar System. This path would provide an opportunity to launch in March 2001, with arrival at Pluto and Charon in 2013.

Pluto, the smallest planet in the Solar System, has remained an enigma since its discovery by astronomer Clyde Tombaugh in 1930. Given its distance from the Sun and its size, it continues to challenge planetary astronomers. Images acquired by the Hubble Space Telescope and released in March were the first ever to show surface details of the planet. Encompassing nearly all of Pluto's surface, the images showed it to be a complex object, with more large-scale contrast than any other planet except Earth. Significantly, the images displayed almost a dozen distinctive albedo features, or provinces, none of which have ever been seen before, and confirmed the previously inferred presence of icy-bright polar caps.

The recent confirmation of a vast swarm of objects — ranging from small particles to cometary bodies hundreds of kilometers across — orbiting in the Edgeworth-Kuiper Belt just beyond the planets raises the exciting possibility of extending the Pluto Express mission for a flyby glimpse of one or two of those bodies. An extended mission would allow scientists to compare the properties of Pluto and Charon with these objects.
The Laboratory plays a significant role in NASA's Mission to Planet Earth, a comprehensive effort to study our planet's land, oceans, atmosphere, ice and life-forms from the all-encompassing vantage point of Earth orbit. It is only from space that researchers can piece together all these elements of the environment to solve their complex interactions.

JPL scientists and engineers work closely with NASA's Goddard Space Flight Center in seeking innovative means of applying advanced Space Age technology to this major NASA enterprise. Current JPL-led efforts — such as the NASA Scatterometer, TOPEX/Poseidon and the Spaceborne Imaging Radar flight series — are providing new insights into large-scale environmental processes. Data from these projects and from several instruments that JPL is contributing to NASA's forthcoming series of Earth Observing System (EOS) satellites will enable researchers not just to identify human-made changes in the global environment but to learn more about Earth's origins and consider its possible future.

The NASA Scatterometer

A JPL-managed radar instrument designed to study global ocean surface winds was launched into Earth orbit on August 16 aboard Japan's Advanced Earth Observing Satellite (ADEOS), an ambitious three-year international climate research mission. The instrument, called the NASA Scatterometer, or NSCAT, was developed and built at the Laboratory. From orbit, NSCAT is making 190,000 measurements per day of the speed and direction of winds blowing just a few centimeters above the ocean surface, by beaming radar pulses to Earth and measuring their natural reflection — or "backscattering" (hence the instrument's name) — by wind-driven ripples in ocean waves.

The surface winds directly affect the turbulent exchange of heat, moisture and greenhouse gases between the oceans and the atmosphere. The sea-air exchanges, in turn, help to determine regional weather patterns and shape global climate. Examining and characterizing this interface is critical to a better understanding of global warming, the El Niño phenomenon and other aspects of Earth's dynamic systems.

Covering more than 90 percent of the globe's ice-free oceans every two days from an altitude of 800 kilometers, NSCAT is providing more than 100 times the amount of ocean wind information than can be derived from ship reports. And since NSCAT is a radar instrument, it is capable of gathering data day and night, regardless of weather conditions. The
STUDYING EARTH'S MAJOR ICE MASSES IS IMPORTANT FOR UNDERSTANDING GLOBAL CLIMATE CHANGES. THE NASA SCATTEROMETER — WHICH MAKES HIGH-RESOLUTION MEASUREMENTS OF NEAR-SURFACE WIND SPEED AND DIRECTION OVER THE OCEAN — IS UNIQUELY SUITED FOR MAPPING THE POLAR REGIONS BECAUSE IT IS AN ALL-WEATHER, ALL-YEAR MONITORING SYSTEM. THE DARK CIRCLE REPRESENTS "NO DATA" Owing to the orbit of the Japanese satellite carrying the Scatterometer.
Instrument's measurements of ocean-surface winds will be used in numerical models to help weather forecasters more accurately predict the path and intensity of hurricanes, winter storms and other weather systems that form over the oceans. In addition, ships that transport goods and passengers across the oceans can use NSCAT data to select the safest and most economical routes.

The instrument quickly proved itself, with the release in October of the first radar images assembled from its measurements. The images, from data gathered in September, showed two typhoons in the northwest Pacific Ocean — “Violet,” which struck the coast of Japan, killing three people and causing extensive property damage, and “Tom,” which churned the most heavily used sea lanes in the Pacific.

NSCAT measured winds in the storms of about 100 kilometers per hour. Preliminary analysis of that first set of scatterometer data demonstrated that the instrument’s high resolution can improve the monitoring of severe storms. It also showed that repeated global coverage provides a better description of atmospheric circulation over the oceans, a phenomenon not adequately sampled until now.

Although the scatterometer’s primary function is to study winds over the oceans, an NSCAT team member from Brigham Young University has developed a way of enhancing the resolution of the instrument’s radar backscatter to take detailed looks at land and ice surfaces as well. Images released in November detailed the extent of the Antarctic ice sheet and the Amazon rain forest, providing valuable new views in both cases as well as demonstrating the scatterometer’s versatility.

TOPEX/Poseidon

Four years into its mission, the NASA-Centre National d’Études Spatiales TOPEX/Poseidon satellite continued to deliver new, valuable data about Earth’s oceans. The mission’s primary goal is to improve understanding of how the oceans circulate by measuring sea level relative to Earth’s center — that is, measuring ocean topography (the “top” in TOPEX).

As the satellite orbits Earth, two of its suite of six instruments — altimeters — bounce radar pulses off the ocean surface and time the return signals, thus measuring precisely the distance between satellite and sea surface. From these and other data gathered by its instruments, scientists can construct a global map of ocean topography every 10 days to an accuracy of 4 centimeters.

In April, TOPEX/Poseidon scientists released data that challenged a fundamental oceanographic theory about the speed of Rossby waves (named after Swedish-American meteorologist Carl-Gustav Rossby, who first identified them in the 1930s). These large-scale, nearly imperceptible undulations, which stretch hundreds of miles from one crest to the next, carry across the ocean a “memory” of weather changes that have occurred at distant locations.
The TOPEX/ Poseidon measurements disclosed that these waves travel two to three times faster at midlatitudes than scientists had thought, a finding that will lead to the revision of textbooks and improved global weather forecasting.

The findings from the satellite's US-supplied dual-frequency altimeter suggested that Earth's sea surface had been rising about 1 millimeter annually for the previous two years. The measurements agree closely with Earth-based tide gauges and also with the single-frequency French altimeter (1 to 3 millimeters).

In any case, TOPEX/ Poseidon, expected to exceed its original three-year mission lifetime by four years, continues to provide the most precise measurements ever made of global average sea-level change. The continuation of such measurements by the planned US-French Jason-1 mission, set for launch in 2000, is considered essential to identifying long-term trends in sea levels and their relationship to climate change.

**Spaceborne Imaging Radar**

The Spaceborne Imaging Radar (SIR) program, one of the more successful JPL efforts of the space shuttle era, made some important advances last year with the release of new results from two 1994 shuttle flights, the announcement of a follow-on, joint NASA-Department of Defense shuttle mission and the start of a new, low-cost radar-mapping satellite.

In March, scientists announced the discovery — from analysis of images taken in 1994 by the Spaceborne Imaging Radar-C/X-band Synthetic Aperture Radar (SIR-C/X-SAR) aboard Space Shuttle Endeavour — of what appears to be a chain of three 12-kilometer-diameter craters in the Sahara desert in northern Chad in North Africa. The craters are thought to have been caused by the impact of a fragmented 1- to 3-kilometer comet or asteroid some 360 million years ago. The finding is reminiscent of the fate of comet Shoemaker-Levy 9, which broke up and slammed into Jupiter in 1994.

One of these craters was already known: Aorounga. The radar images revealed faint traces of two other impact craters trailing off from the first, if confirmed by on-site inspections, these three craters would represent only the second chain of large impact craters known on Earth. Similar chains have been found on Jupiter's moon Callisto.

In another interesting find, announced in April, a SIR-C/X-SAR science team member from the Chinese Academy of Sciences in Beijing used radar images to locate and study two lost sections of the Great Wall of China — one built by the Sui Dynasty more than 1,000 years ago and the other by the Ming Dynasty about 600 years ago — which had been eroded and buried by centuries of blowing sand. Although archeology was not an original objective of the SIR flight series, the radar data have proved useful for studies of such ancient sites as Angkor in Cambodia, the Lost City of Ubar in Oman and the Silk Road of northwestern China.
In July, NASA and the Defense Mapping Agency of the U.S. Department of Defense signed a formal memorandum of understanding to develop and conduct the Shuttle Radar Topography Mission (SRTM). The mission is tentatively manifested for an 11-day flight in 2000 and will collect three-dimensional measurements of nearly 80 percent of Earth's land surface to an accuracy of better than 16 meters, the regions to be mapped are home to about 95 percent of the world's population.

SRTM will employ the same radar instrument used by the joint U.S.-German-Italian SIR-C/X-SAR in 1994, but engineers will add a mast almost 60 meters long, two additional antennas and improved tracking and navigational devices. The mast, which resembles the truss structure developed for the international space station, will extend sideways from the orbiter's cargo bay. The two new antennas will be mounted at the tip of the mast and allow the system to acquire stereo radar images of Earth's surface using techniques successfully tested during SIR-C/X-SAR’s October 1994 flight.

Information produced by SRTM could have a variety of potential commercial uses, such as the development of more realistic flight simulators for pilot training, siting optimal locations for cellular phone towers and improved maps of wilderness recreation areas, among others. Topographic maps have been generated from stereo pairs of photographs taken by high-altitude aircraft and satellites, such optical systems, however, cannot penetrate the cloud cover that obscures so much of Earth's surface at any given time. In some tropical regions, the cloud cover is virtually constant and thus significant portions of the globe have never been mapped in detail. SRTM is expected to generate a topographical image of Earth that is 30 times more precise than anything now existing.

JPL and NASA embarked on the next stage in synthetic aperture radar mapping with the October start of LightSAR — the Lightweight Synthetic Aperture Radar mission. This proposed satellite would provide high-resolution images of Earth on a nearly continuous basis. It would also demonstrate that radar missions can be much less expensive (costs will be held to less than $150 million, including launch vehicle), while still producing uniquely valuable data for use in scientific research, commercial remote sensing and emergency management.

New spaceborne radars will provide high-resolution images for improved topographic maps, earthquake fault monitoring and commercial purposes.
Potential commercial users include federal and state governments, as well as companies involved in forestry, agriculture and the extraction of oil, gas and other natural resources. For their part, scientists will use LightSAR data to measure surface deformation of earthquake faults, to monitor biomass change in deforestation studies and to map the extent of floods and the regrowth of vegetation in those affected areas.

JPL engineers are looking at ways to reduce the weight of spaceborne radar and obtain improved performance through lightweight structures and miniaturized electronics. On the management side, JPL is exploring new approaches to government and industry teaming and cost-sharing as a means of maximizing the private sector's investment in LightSAR.

**Earth Observing System**

JPL is a major supplier of instruments for the Earth Observing System (EOS), the cornerstone of NASA's Mission to Planet Earth. The program, managed by the Goddard Space Flight Center, is based on a fleet of orbiting platforms that, starting in 1998, will provide continuous observations of global climate change.

The first in the series is EOS-AM1 — the satellite is designated “AM” because in its polar orbit, it will always be crossing the equator in the morning — to be launched in June 1998. It will carry aloft the JPL-built Multi-Angle Imaging Spectro-Radiometer and the U.S.-Japan Advanced Spaceborne Thermal Emission and Reflection Radiometer.

The former instrument is to measure how much sunlight is scattered in different directions under natural conditions — by atmospheric particles, the planet’s surface and clouds — and so help quantify the amount of solar energy heating Earth’s surface and atmosphere. These data are expected to contribute significantly to studies of the effects of land-use changes, air pollution and volcanic eruptions, as well as processes such as desertification, deforestation and soil erosion.

**JPL instruments will study Earth’s dynamic systems — the atmosphere, climate and surface**

The latter instrument, a collaboration between JPL and Japan’s Ministry of International Trade and Industry, will create high-spatial-resolution maps of surface feature temperatures, emissivities, reflectance and elevation, from data gathered in 14 channels encompassing wavelength regions from the visible through the thermal infrared.

EOS-PM1, the second platform in this program (called “PM” because it will overfly the equator in the afternoon), is to carry the Atmospheric Infrared Sounder — developed by the Loral Corporation and managed by JPL — and five other instruments into polar orbit.
In 2000, the Infrared sounder will collect observations both of the atmosphere and of clouds, to help scientists unravel the role of clouds in the greenhouse effect.

**Earthquake Research**

In the fall, a consortium of scientists from JPL and other institutions began enlarging a network of Global Positioning System receivers, called the Southern California Integrated GPS Network, that continuously measures the movements of the Southern California crust. This information, much of which is to be gathered and analyzed with the help of local students, will substantially aid attempts to forecast earthquakes in the Greater Los Angeles area.

The project is designed to track ever-so-slight geologic strains and stresses in the faults crisscrossing the landscape. It relies on data from a constellation of 24 Earth-orbiting GPS navigation satellites under the joint aegis of the U.S. Defense and Transportation Departments. Several of the satellites are accessible via GPS radio receiver at any given time from any point on the surface of the planet, the precise location of a GPS receiver on the ground can be determined by coordinating their signals. The earthquake network, which began in 1990 with four GPS receivers as a prototype project funded by NASA, will grow to 250 receivers over the next three years, and will monitor movements of Earth's crust as small as 1 millimeter a year. This, it is hoped, will tell scientists where strain is building up and will help in emergency preparedness and in planning measures, such as retrofitting key structures like freeway overpasses.

The network, grown to 40 GPS receivers by October 1996, demonstrated its potential usefulness by detecting very small motions in the crust in Southern California after the 1992 Landers and 1994 Northridge earthquakes. The GPS measurements disclosed that the Granada Hills immediately to the north of the Northridge epicenter rose, in a “quiet slip,” by about 16 centimeters as a result of that tremor.

This finding raises the possibility that tectonic stress may be partially relieved through crustal deformation instead of fault slippage. If this is true, the Southern California region's overall seismic hazard may have to be reevaluated downward. The reasoning is that some fraction of the strain caused by the opposed movement of the Pacific and North American plates is absorbed by this aseismic motion in the crust, instead of simply being transferred to other nearby fault zones.

In addition to possibly aiding earthquake forecasts, GPS data could be useful in characterizing damage following a temblor. Receivers placed on or near dams, bridges, and buildings would allow remote detection of probable structural damage. Toward that end, the earthquake network is collaborating with Los Angeles County in a pilot study of continuous GPS monitoring of Pacoima Dam.
How did the Universe come into being? How are galaxies and stars born? Are there planets like Earth orbiting nearby stars? Might some form of life have arisen on any of these planets? Obtaining answers to such time-honored, fundamental questions is the goal of NASA's Origins program. The program's announcement in late 1995, followed by the August 1996 revelations of tantalizing signs of microbial life on meteorite ALH84001 and liquid water on the Jovian moon Europa, has fostered a sense of urgency among scientists working in this area at JPL and throughout the space science community.

The Origins program will combine a variety of space- and ground-based observing systems, leading to the ultimate goal of a Terrestrial Planet Finder to be launched in 2010. In the near term, ambitious new missions are moving toward launch in the next century, including the JPL-managed Space Infrared Telescope Facility (SIRTF) and the Space Interferometry Mission. These instruments will look farther into the Universe, and therefore deeper into the early stages of its existence, than any observatories before them.

JPL is also working with other organizations in an effort to link the world's two largest telescopes — the Keck I and Keck II, on Mauna Kea, Hawaii — to create a powerful ground-based interferometer capable of detecting Jupiter-size planets around nearby stars. With interferometry, a technology underpinning many of the Origins projects, the light gathered by several widely separated mirrors is combined so that the mirrors perform as if they were a single, much larger collecting surface — for example, two 5-meter collecting surfaces spaced 50 meters apart can duplicate the resolution of a telescope 50 meters in diameter.

The Space Infrared Telescope Facility

SIRTF is an astrophysics mission to explore the birth and evolution of the Universe. It will collect infrared images and spectra of the birth of stars and galaxies; study objects ranging from comets and asteroids to distant quasars, and search for planetary systems. SIRTF will build on the results of the highly successful 1983 Infrared Astronomical Satellite, which was also managed by JPL. The new observatory, set for launch in 2001 or 2002, will measure the faint heat radiated by these celestial objects, using cryogenically cooled instruments to keep its own heat from distorting the data.
The National Academy of Sciences has called the mission the highest-priority, major new American astronomy undertaking. SIRTF is expected to offer a view of the early Universe that predates even the youngest galaxies observed at optical wavelengths by the Hubble Space Telescope.

The project, which completed one phase (preliminary analysis of its scientific objectives) and entered a second (preliminary design) last year, is another example of how the Laboratory's "faster, better, cheaper" approach can significantly reduce costs — in this case, from more than $2 billion to $450 million.

One major cost-reduction step was to shift SIRTF from Earth orbit, as originally proposed, to a cooler orbit around the Sun, trailing well behind Earth. This allows project engineers to cut the amount of cryogenic coolant to be used at launch and in orbit, thus achieving mass and cost savings without sacrificing scientific capabilities.

In keeping with the new method of operation, NASA and JPL chose to award the SIRTF contracts in three specialized areas, employing the new concept of integrated project teams rather than relying on the traditional systems-contractor approach. The three contracts were awarded in June. Lockheed Martin Missiles & Space, of Sunnyvale, California, and Ball Aerospace & Technologies Corporation, of Boulder, Colorado, were chosen to team with JPL to design, develop, test, and integrate SIRTF. Under the agreement, Ball will design and develop the cryogenic telescope assembly, and Lockheed Martin will provide the SIRTF spacecraft and under a separate contract will perform system-level integration and testing. Plans call for carrying out SIRTF's initial development at JPL, with representatives from each of the contractor teams in residence from the early systems-definition period through completion of the project's requirements review.

**Ground-Based Interferometry**

NASA researchers also embarked on a project to use the giant twin 10-meter telescopes of the W M. Keck Observatory, atop Hawaii's Mauna Kea, as a single, high-powered instrument to search for Jupiter-class planets around nearby stars. The just-completed Keck II Telescope was dedicated in May, at which time the NASA project was formally announced.

The use of interferometry, in which the two Keck telescopes will make concurrent observations of the same object in space, will provide a dramatic increase in their individual light-gathering and resolution capabilities. These studies are an essential preparation for the coming spaceborne elements of the Origins program, enabling researchers to test the techniques on the ground before building large interferometers in space. In turn, the discovery of Jupiter-class planets will identify prime locations for seeking out smaller, Earth-like planets with the more sensitive spaceborne instruments going on line in the next century.

The two Keck telescopes, connected along a baseline of 85 meters, will be assisted by four smaller "outrigger" telescopes spread over an area not quite the size of a football.
field. The resulting interferometric system — which should be operating within the next three years — will be capable of detecting regular perturbations in nearby stars presumably caused by the gravitational influence of orbiting planets. NASA will provide a total of $44 million for construction and $2 million a year for operating costs as part of a cooperative effort between the space agency, Caltech, JPL and the California Association for Research in Astronomy (CARA). JPL is managing the agency’s participation in the Keck Observatory for NASA’s Office of Space Science.

**Space-Based Interferometry**

The Space Interferometry Mission (SIM), now in the planning stages at JPL, will define the position of stars with an accuracy of a few millionths of an arc second, a measurement more than 250 times as precise as that in the best-available star catalogs (and comparable to the observation, from Earth’s surface, of a person standing on the Moon and switching a flashlight from hand to hand).

SIM will be launched into Earth orbit early in the next decade, and will be the first space mission with an optical interferometer as its primary instrument. As with the Keck interferometer, the system will map the wobbles of stars in their paths across the sky — wobbles that provide indirect evidence of orbiting planets — and its data should allow astronomers to deduce the presence of planets as small as Earth.

The spacecraft will also triangulate the positions of individual stars in the Milky Way and in some nearby galaxies, from these data, scientists will be able to infer more accurate distances to other objects in the Universe.

SIM is seen as a technological stepping-stone to a larger JPL-managed interferometer dubbed the Terrestrial Planet Finder. This instrument, with a baseline of between 75 and 100 meters, would be capable of detecting Earth-size planets up to 50 light-years away, and will also look for the chemical signature of planets that might harbor life. To ensure maximum sensitivity, the craft will be sent into deep space — perhaps as far as the orbit of Jupiter, where it will escape the haze of glowing dust in the inner Solar System. The Planet Finder is currently envisioned as a suite of four infrared telescopes, each about 2 meters across, mounted on a 75-meter truss, the telescopes would beam their light to a common focus. The infrared light collected by each telescope will be combined with that of the others in such a way that the starlight will be rejected and only the emissions from planets will be collected and analyzed.
IN PURSUIT OF PLANETS

WITH THE COMPLETION OF THE SECOND 10-METER KECK TELESCOPE ATOP HAWAII’S MAUNA KEA, NASA RESEARCHERS ANNOUNCED A PROJECT TO LOOK FOR JUPITER-SIZE PLANETS AROUND NEARBY STARS. THE TWO TELESCOPES WILL OBSERVE CELESTIAL OBJECTS CONCURRENTLY; THEIR COMBINED MEASUREMENTS WILL RESULT IN IMAGES AS SHARP AS IF THE TWO INSTRUMENTS WERE ONE LARGE TELESCOPE. THE SYSTEM WILL LOOK FOR SUBTLE STAR PERTURBATIONS CAUSED BY THE GRAVITATIONAL INFLUENCE OF ORBITING PLANETS.
As a federally funded research and development center, JPL recognizes its obligation to advance technologies within its charter and apply them on behalf of vital national interests. Indeed, the Laboratory is not just a world leader in robotic space exploration, but through the years has been in the forefront in developing a variety of other technologies. To promote a steady stream of innovations, the Laboratory uses such programs as the Director's Discretionary Fund to support selected staff proposals, covering a broad spectrum of scientific disciplines and technologies. Last year, the Fund — operating with $3.5 million from NASA and $156,000 from other sponsors — started 26 new research tasks and provided continuing funds for four ongoing tasks.

JPL's Technology and Applications Program (TAP) Directorate funds new research and oversees JPL's technology transfer and commercialization activities. NASA recognized this Directorate's key role with a $15-million increase in its budget for fiscal 1996, during a period of overall decline in NASA funding. At the same time, reimbursable research and development for non-NASA customers stabilized, representing about half of TAP's budget.

**Technology Highlights**

A space shuttle flight in May carried aloft two examples of TAP-sponsored research for tests in the microgravity environment of Earth orbit: the Brilliant Eyes Sorption Cryocooler, an instrument that can quickly cool sensors to near absolute zero; and the Inflatable Antenna Experiment, a test structure intended as a prototype of future inflatable telescopes and other space structures. So-called sorption coolers of the Brilliant Eyes type are essentially vibration-free and can operate reliably and efficiently for more than 10 years — all necessary qualities for use with infrared telescopes, which require cooling but must be able to maintain precise pointing.

As an indicator of things to come, the Laboratory and its industrial partner, L'Garde, Inc., of Tustin, California, carried out one of the more interesting experiments in space: the successful deployment of an inflatable structure — a 14-meter-diameter antenna reflector (made of aluminized Mylar) with tripod-like, 28-meter-long struts (of neoprene-coated Kevlar).
Inflatable structures hold out the promise of significant cost savings for future missions because of their low mass (this complete unit weighed just 60 kilograms), low cost (JPL engineers estimated that a traditional mechanical antenna would have run upwards of $50 million, compared to about $1 million for this L'Garde unit) and small, stowed volume (this antenna occupied the space of an ordinary kitchen table).

The unit was flown during a May space shuttle mission, in NASA Goddard Space Flight Center’s “Spartan” recoverable spacecraft. Spartan is an omnibus vehicle that can accept a wide range of scientific sensors and support systems, carried into space in a space shuttle’s cargo bay, it is released into Earth orbit for a few days to two weeks and then recovered by the shuttle crew for return to Earth and later reuse.

In another success story, a TAP-funded demonstration of Global Positioning System applications software led quickly to commercial and U.S. government licensing agreements. The JPL system, which completed development in July, provides real-time, differential-positioning data derived from the array of two dozen GPS Earth-orbiting satellites. SATLOC Inc., a commercial provider, signed a license to sell the software, with expected delivery of the final version in early 1997, several other providers of wide-area differential GPS data worldwide were also in negotiations to license the system.

Last summer, the Federal Aviation Administration and its contractor, the Hughes Aircraft Company, selected the JPL software for use in that federal agency’s Wide Area Augmentation System (WAAS), a critical component to safe commercial airline operations within the United States. The software will enable the Global Positioning System to meet the Federal Aviation Administration navigation-performance requirements for domestic en route, terminal, nonprecision approach and precision approach phases of flight.

Among key hardware technology developments in 1996 were two hand-held infrared cameras developed by JPL in partnership with industry. The cameras use highly sensitive, quantum-well infrared photodetectors, or QWIPs — arrays of detectors that are sensitive to wavelengths from 8 to 12 micrometers, 20 times longer than the wavelengths of visible light and therefore considerably weaker. Although not apparent to the naked eye or to any human sensory systems, objects do give off heat at these long wavelengths, and it is this low energy that the QWIP cameras can detect.

Developers foresee applications in situations wherever heat is a factor — for example, maintaining product quality control by detecting overheated parts or faulty welds on a manufacturing line. The cameras may also be useful in such fields as surveillance, night vision and medical imaging. The first camera, developed in collaboration with Amber, a Raytheon company, was used by a Los Angeles television news crew in October to monitor brush fires in Malibu, the camera could “see” through smoke and pinpoint lingering hot spots. A later camera, announced in December, is four times lighter, five times smaller in volume and uses 10 times less power than the earlier model, it was developed by JPL and Inframetrics, of Billerica, Massachusetts.
The QWIP research originated in JPL’s Center for Space Microelectronics Technology, the first of a group of Laboratory-based “Centers of Excellence,” which are basically science-technology and/or science-engineering fields that are critical to fulfilling the JPL Strategic Plan. Other Centers of Excellence, either existing or soon to be established, include Space Interferometry, In Situ Exploration and Sample Return, Space Mission Architecture and Design, Autonomous Advanced Spacecraft, Deep Space Navigation, Deep Space Communications, Active Microwave Advanced Spacecraft, Deep Space Navigation, Deep Space Communications, Active Microwave Remote Sensing, Optical/Submillimeter/Infrared Remote Sensing and finally, Space Mission Information and Computing Technology.

Through these centers — led by men and women with well-recognized technical expertise and proven leadership abilities — JPL will meld the science, technology, engineering and staff to carry out the challenging planetary, space science and Earth science missions of the future.

**Commercial Technology Program**

The Laboratory is committed to sharing with American industry the fruits of technology developed for NASA and federally sponsored projects by disseminating information, distributing software, entering into affiliation agreements, funding small-business innovation research, issuing patent licenses and promoting cooperative ventures.

Information on available JPL technology is set out in NASA Tech Briefs. The Laboratory produced 268 (37.5 percent) of the 714 Tech Briefs published at NASA field centers in 1996. Interested parties can request Technical Support Packages about any of these items, last year, JPL sent out nearly 33,000 such packages.

The Laboratory’s Technology Affiliates program provides American firms with access to JPL technological resources. Any U.S. company with a technical problem can contact the Laboratory, describe the difficulty and ask for an evaluation. If JPL determines that there is technology available and appropriate to the problem, it will enter into an agreement with the firm. Under this program — in which more than 110 firms were participating at the end of 1996 — the company funds the research and its employees work closely with JPL engineers in applying the Laboratory’s technology to the firm’s needs.

The Targeted Commercialization Office works with U.S. industry to maximize the transfer and commercialization of JPL mission technologies through opportunities in growth and emerging markets. This office looks to the private sector as the major source of million-dollar-level funding for commercial technology applications and is developing programs in remotely sensed imagery, telecommunications and health care.

JPL’s Technology Reporting and Communications Team submitted 187 new reports on inventions or technical innovations to NASA and concluded dozens of licenses for both the Laboratory and the California Institute of Technology in 1996. Additionally, the U.S. Patent and Trademark Office issued numerous patents on inventions developed at JPL in 1996.
Through its Small Business Innovation Research program, the Laboratory encourages small companies to develop promising "dual-use" technologies — those that have both NASA and commercial applications. The program, which typically receives close to 500 proposals each year, awarded 69 such contracts in 1996, with a total value of $17 million.

Technology Cooperation Agreements are yet another vehicle for furthering technology to the mutual benefit of NASA and industry. These collaborative ventures, in which no funds are exchanged, allow private firms to participate in the early stages of research and development projects. The goal is to ensure that emerging technologies prove useful both to government agencies and to commercial interests. In 1996, JPL and its technology partners signed six new agreements; 26 other agreements were active during the year.

INSTITUTIONAL ACTIVITIES

Change continued to be a major goal for JPL in 1996, as the Laboratory moved on several fronts to transform itself into a more flexible, responsive, and customer-focused organization. For the near future, JPL will have to steer a difficult course through a rapidly changing political, economic and international landscape — a landscape in which the only predictable constant will be change itself. Only by reengineering to meet these new circumstances will the Laboratory succeed in advancing its long tradition of space exploration and technology development on behalf of the nation.

The Laboratory has steadily progressed in its reengineering efforts from Phase A (preliminary analysis), with the establishment of a Total Quality Management initiative in 1992, to Phase B (definition) with the completion of the JPL Strategic Plan in mid-1995. JPL is now engaged in Phases C and D (design and development), with five reengineering teams looking at major changes and the implementation of process-based management principles throughout the Laboratory.

With all this activity, JPL is striving to become a process-oriented organization. "Process" refers to a group of tasks that, taken together, create value — and is concerned with the ways that work gets done, rather than with organizational structure. Since most organizations have traditionally organized themselves around functions, a process orientation
requires a major shift in perspective from the vertical (hierarchical) to the horizontal (cutting across departments and functions, where the actual work of an organization is carried out) and from boss to customer. For the process-oriented organization that JPL intends to become, the top priorities are "customer" and "results."

The Strategic Plan

The philosophical foundation for the Laboratory's change initiatives can be found in the Strategic Plan, a statement of JPL's vision, mission, values and strategies. It is an essential guide to the Laboratory's work force as it strives for success in a new era of economic constraints, redefined national goals and revised priorities for the national space program.

JPL's vision is to expand the frontiers of space in order to enrich knowledge and benefit humanity. Its mission is to carry out activities to fulfill that vision — in particular, to mount challenging robotic space ventures to explore the Solar System, the Universe and Earth, while applying the Laboratory's special capabilities to problems of national importance.

JPL's values — the characteristics its workforce brings to its missions — are openness (of people and processes), integrity (of both the individual and the institution), quality (a commitment to excellence in everything done) and innovation (employee creativity).

The strategies are 10 actions that JPL has vowed to take to better serve customer needs:

- Focus science, technology and engineering resources to carry out those missions that no other organization can carry out.

- Establish a presence throughout the Solar System and enhance understanding of Earth's environment and the Universe through small, frequent, low-cost missions.

- Combine JPL's strengths with those of other NASA field centers, other federal laboratories, industry, academia and other nations to build robotic space science and Earth-observing missions of the highest value.

- Broaden and deepen the Laboratory's capabilities to execute successful robotic space science and Earth-observing programs.

- Act as a scientific and technological bridge between NASA and other federal agencies to help the latter achieve important national goals.

- Routinely use the best business practices in carrying out the Laboratory's work and continually verify their effectiveness and appropriateness.
• Infuse new technologies into flight and ground systems and capture the benefits for the commercial sector through technology transfer programs

• Inspire the public with the wonder of space science and enhance science and engineering education

• Promote individual and organizational excellence through employee training and growth and by creating a work environment based on mutual trust and respect

• Contribute to the nation as a socially responsible organization

Reengineering Teams

Four reengineering teams were set up in the previous year to develop and implement fundamental improvements to the processes JPL uses to make rules, nurture and assign people, develop products and deliver administrative support. The teams' successes in the first full year of operation served both to validate the Strategic Plan and to underscore JPL's commitment to carrying it out. It also inspired the formation of a fifth team (the Enterprise Information System Project), in September 1996, to set up a state-of-the-art information system to support and enable all Laboratory work. By year's end, two of the teams — concerned chiefly with development — were on schedule to finish their work by the end of fiscal 1997, the other three are aiming for completion dates in 1998.

The Define and Maintain the Institutional Environment team was created to make JPL's administrative rules simpler to access, easier to understand and less voluminous. In its first year, the team transferred all paper-based administrative rules to an electronic format, so that JPL no longer needs to print its 14 administrative manuals in bulky 3-ring binders, developed the Institutional Environment Navigator program for accessing the rules electronically, spearheaded efforts to translate all rules into processes, and held several Laboratory-wide training and communications events, including a roundup and recycling of 2.5 tons of the old paper manuals. The team is expected to complete its work by the fall of 1997.

The focus of the Growth and Assignment of Our People team is to improve opportunities for employees' career growth, advancement and job rotation, and to better the Laboratory's projections of staffing needs. During its first year, the team formed the Education and Training Providers Consortium (in partnership with the Laboratory's Professional Development staff) to establish an online interactive college resource center and an online unified course catalog, created an informal mentoring program and worked to promote the mentoring concept across the Laboratory, and developed and tested prototype online business operations and tools to forecast the kinds of skills that will be needed in the future. This team, too, expects to wrap up its work by next year, and was instrumental in JPL's decision to establish a Human Resources Directorate.
JPL has committed itself to transformation of the laboratory into a more flexible and responsive organization. The JPL milieu is evolving toward a customer-oriented, process-based environment — one in which openness, integrity, quality and innovation continue as our canonical values. The laboratory's strategic plan is the touchstone for our reengineering and streamlining activities.
More focused on work than workers, the Develop New Products team is seeking ways to cut the development time of products in half and to reduce average project development costs by 30 percent. Among other first-year accomplishments, the team reviewed JPL (and other) space missions and so identified early simulations and modeling as two key ways to bring the design phase of new products along faster and more efficiently. The team also worked with JPL's technical divisions to standardize a design process for future projects, and designed and built an integrated mission testbed facility with connections to the Deep Space Network and the Multimission Ground Systems Office. The team, now operating as an implementation project, is expected to continue its work through early 1998.

The New Business Solutions Project, which evolved from the original Team Élan, is charged with reengineering JPL's business systems and administrative processes. The team identified finance, acquisition and human resources as the most important business processes to be reengineered, and set out to select a vendor to provide the best off-the-shelf, online business system for the Laboratory's needs in those areas.

In August, after separate week-long software-system demonstrations by three prospective vendors, team leaders selected the Oracle Corporation as the winning company. The New Business Solutions Project is expected to complete its work on installing the Oracle-based system and realigning JPL business practices in April 1998.

The fifth reengineering effort, the Enterprise Information System Project, will have turned the Laboratory's computer infrastructure into a user-friendly, secure, state-of-the-art, always-on-duty system by September 1998. As envisioned, the new system will allow users to log on from anywhere in the world at any time and access files from, or share them with, any other valid user. The system will offer improved electronic mail, replacing a costly hodgepodge of sometimes incompatible systems, and also allow users to search all 73,000 Internet and intranet pages at JPL.

**Outsourcing**

As part of its reengineering efforts, the Laboratory is reviewing all its activities to identify that work to be retained in-house and that which can be "outsourced" to industry and commercial suppliers. Outsourcing will enable JPL to achieve significant workforce reductions — as mandated by NASA's "zero-base" review of 1995 — from 6,100 employees and contractors in fiscal 1997 and 5,400 in fiscal 1998 to approximately 4,780 in fiscal 2000. The increased reliance on subcontracting and outsourcing is also in keeping with JPL's strategy of focusing its science, technology and engineering resources on those missions that no other organization can carry out.
During 1996, a number of special honors, NASA Honor Awards and Laboratory honors were presented to JPL personnel in recognition of their exceptional achievements and service. Special honors were awarded to individuals and to groups by a variety of organizations and professional societies. The annual NASA Honor Awards are presented to JPL personnel by NASA in recognition of outstanding individual or group achievements. Finally, through special appointments, Caltech Campus and the Laboratory recognize the accomplishments of individuals and promote the exchange of information in areas of research.

**Special Honors**

- **Aerospace Laurels 1996, Aviation Week and Space Technology**
  - John R. Casani and William J. O’Neil
- **Aerospace Power Systems Award, American Institute of Aeronautics and Astronautics**
  - Vincent C. Truscello
- **Dwight D. Eisenhower Award for Excellence, U.S. Small Business Administration**
  - Jet Propulsion Laboratory
- **Elected Fellow, Institute of Electrical and Electronics Engineers**
  - Fuk K. Li
- **International von Kármán Wings Award of Excellence**
  - Edward C. Stone
- **NASA Software of the Year Award**
  - Allan S. Jacobson
- **National Safety Council Award for Injury Prevention**
  - Jet Propulsion Laboratory
- **Nordberg Medal, Committee on Space Research**
  - Charles Elachi
- **Presidential Early Career Award for Scientists and Engineers, U.S. Government**
  - Andrea Donnellan and Ellen R. Stofan
- **Rolex Award for Enterprise in Applied Science and Invention**
  - Gilbert A. Clark
- **William T. Pecora Award, NASA and the U.S. Department of the Interior**
  - Crofton B. Farmer

**NASA Honor Awards**

- **Distinguished Service Medal**
  - William J. O’Neil
- **Outstanding Leadership Medal**
  - Neal E. Ausman, Jr.
  - Robert C. Barry
  - E. Kane Casani
  - Leslie J. Deutsch
  - James A. Evans*
  - Joseph A. Gleason
  - Ralph J. Reichert
- **Exceptional Achievement Medal**
  - Olen Adams
  - Arthur V. Amador
  - Robert Angelino
  - Arturo Avila
  - Todd Barber
  - David M. Bates
  - Gilbert A. Clark
  - Cynthia L. Compton
  - Arvid P. Croonquist
  - Louis A. D’Amario
  - Kauser S. Dar
  - James K. Erickson
  - Charlayne J. Fliege
  - Eric Fossum
  - Kenneth H. Friberg
  - Robert B. Gounley
  - Robert O. Green
  - Gregory S. Harrison
  - Kathryn B. Hilbert
  - Maynard G. Hine
  - Jennie R. Johannesen
  - Michael Robert Johnson
  - William E. Kirchofer
  - Wayne Kohl
  - Alexander S. Konopliv
  - Gary R. Kunzmann
  - Hamid Kuri
  - Gregory R. LaBorde
  - Matthew R. Landano
  - Greg G. Levaras
  - Gerald W. Lilienthal
  - Tom Loesch
  - Saturnino Lopez
  - Jan M. Ludwinski
  - Kevin R. Maguire
  - Howard P. Marderness
  - Elihu H. McMahon
  - Robert M. Metzger
  - Jerry Millard
  - Edward A. Miller
  - Alex Moncada
  - Arthur J. Murphy, Jr.
  - Tracey A. Neilson
  - Francis T. Nicholson
  - Allen Nikora
  - Sharon E. Okonek
  - Mary B. Oldham
  - Christopher L. Potts
  - William G. Read
  - John H. Reimer
  - Dare Sabahi
  - Choon-Foo Shih
  - Robert Shishko
  - R. Wayne Sible
  - Stephen M. Spohn
  - William H. Spuck III
  - Reid C. Thomas
  - William C. Tibbitts
  - Michael J. Tickner
  - Vallerie D. Wagner
  - Alison N. Weisbin
  - Robert L. White
  - Michael G. Wilson
  - Donald L. Young
**Exceptional Scientific Achievement Medal**
Lee-Lueng Fu

**Exceptional Engineering Achievement Medal**
Dennis V Byrnes
Darrush Divsalar
Siamak Forouhar
Sarah D Gunapala
Allan S Jacobson

**Exceptional Service Medal**
Edward J Adams
Anil K Agrawal
Ken Bartos
Stephen W Benskin
Jeff B Berner
Jeffery J Cornish
Rebecca J Custer
Susan Foster de Quintana
Gloria C Gerhard
Gene L Goitz
Edward Greenberg
Fred Y Hadaegh
Jeanne M Holm
John A Hultberg
William J Hurd
Edward H Kieckhefer
Alfonso F Klasius
Esther C Knox
Richard W Kuberry
Mary F Kunstler
Beatrice C Lathrop-Pino
Paul D Maker
Patrick Murphy

Ralph C Ouellet
Joon H Ouellet
Lynn M Patterson
Robert Ruchter
Audrey V Riethle
James A Rooney
William E Ruhland
Casper S Sagoian
Fred W Sanders
Carl G Sauer, Jr
Edward B Schneider
Samuel W Sirlin
Kenneth S Smith
Clara Sneed
E Myles Standish, Jr
Jerry T Swanson
David L Trowbridge
Ronald T Welch
Steven J Wells
Edward C Wong

**JPL Adaptive Recognition Tool Development Team**

**Main Electrical Substation Replacement Project Team**

**Mars Surveyor Exploration Program Procurement Team**

**Multimission Image Processing System Design Team**

**Project Galileo Team**

**Sky Image Cataloging and Analysis Tool Team**

**Small Disadvantaged Business Subcontracting Team**

**Spaceborne Imaging Radar-C Outreach Team**

**Telescopes in Education Team**

**TOPEX/Poseidon Mission Operations Team**

**Special Appointments**

**Distinguished Visiting Scientist**
- Kevin C A Burke
  Global studies of tectonics — University of Houston, Houston, Texas
- Crofton B Farmer
  Stratospheric spectroscopy — Jet Propulsion Laboratory (Retired)
- James McWilliams
  Oceanography-ocean circulation modeling — University of California, Los Angeles, California
- Marcia M Neugebauer
  Space physics — Jet Propulsion Laboratory (Retired)
- John B Rundle
  Radar interferometry — University of Colorado, Boulder, Colorado
- Donald E Shemansky
  Aerospace engineering — University of Southern California, Los Angeles, California
- Fredric W Taylor

**Senior Research Scientist**
- Joseph M Ajello
  Ultraviolet emission spectroscopy
- William A Imbriale
  Synthesis, analysis and design — reflector antennas
- Stanley P Sander
  Chemical kinetics and atmospheric science
- Homayoun Seraji
  Robotics
JPL's annual budget for the fiscal year ending in September 1996 was $1.09 billion. Research and development costs amounted to $1.06 billion; facilities construction costs accounted for the remainder. Costs for NASA-funded and non-NASA-funded activities remained essentially constant at $990 million and $70 million, respectively, from fiscal year 1995 to fiscal year 1996. The Laboratory's workforce decreased again during 1996, to 5,444 employees. The workforce had been 5,692 in 1995 and 5,875 in 1994. The following charts show financial and personnel statistics for the 1992–1996 period.

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### Total Personnel

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Consulting Members

R. Stanton Avery
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Ruben F. Mettler
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Volcanoes on Io create a variegated, distressed landscape. Ash plumes and flowing lava color the surface red and black, and frozen sulfur dioxide gas forms white frost. Blankets of yellow sulfur complete the tapestry. The Galileo spacecraft captured this dramatic image during its second orbit around Jupiter.

Galileo successfully completed the first half of a two-year, 11-orbit tour of the Jupiter system.

The Cassini spacecraft was tested at JPL throughout 1996, as ground systems and mission operations teams prepared for an October 1997 launch to the Saturn system. After a seven-year journey, the spacecraft will spend four years carrying out a multitude of experiments in studying Saturn, its magnificent rings and its numerous moons.

The Keck I and II telescopes atop Hawaii's Mauna Kea will be used as an interferometer, making concurrent observations to look for evidence of planets orbiting nearby stars.

Radar images revealed a chain of ancient craters in North Africa. The 12-kilometer-diameter craters are thought to have been created by a comet or asteroid impact perhaps 300 million years ago.
In all, 1996 was another major stride forward in JPL's continuing transition from an organization focused on large flagship missions — taking a decade or more to develop and another decade to implement — to one committed to the development of smaller, less-expensive missions flown more frequently to a wider range of bodies.