1992

Jet Propulsion Laboratory

Annual Report

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Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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< **Cover: After its second Earth flyby** *in December 1992, the Galileo spacecraft looked back from a distance of roughly 6 million kilometers to capture this remarkable view of the Moon in orbit around Earth. Color and contrast in this composite photograph have been computer enhanced.*

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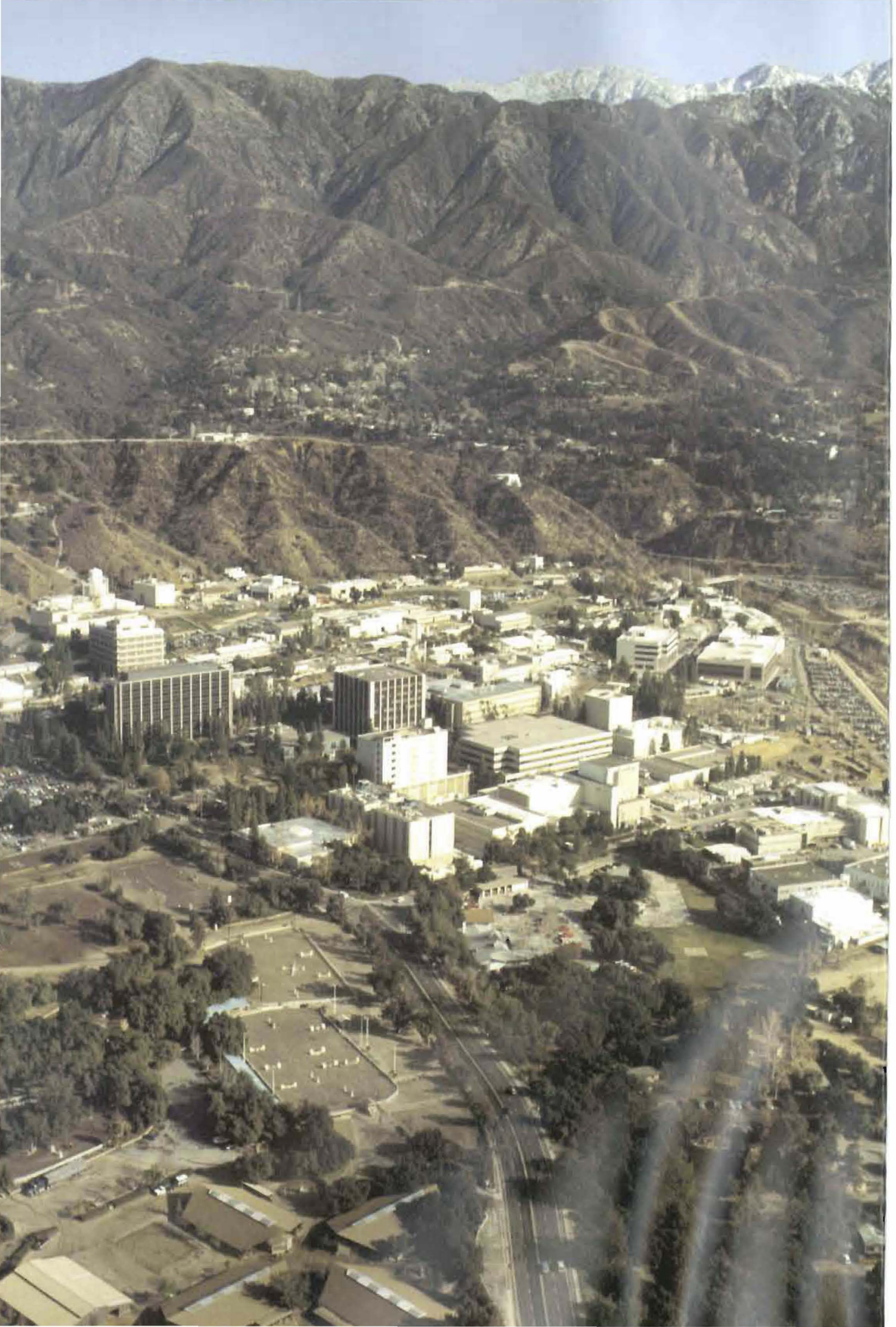


< **Lead center in the nation's robotic** *exploration of space, the Jet Propulsion Laboratory (JPL) occupies 176 acres at the base of the San Gabriel Mountains near Pasadena, California.*

Introduction

The Jet Propulsion Laboratory (JPL), an operating division of the California Institute of Technology (Caltech), performs research, development and related activities for the National Aeronautics and Space Administration (NASA). The people of JPL share a common objective: research and development in the national interest. > The Laboratory's philosophy, missions and goals **incorporate the highest standards of scientific and engineering achievement,** *reflect JPL's lead role in the robotic exploration of the solar system, advance scientific and technical knowledge and endeavor to meet customer needs for high-quality services and products delivered on time and within budget. In keeping with its Caltech heritage and connection, JPL* **strives for excellence, objectivity and integrity** *in all its efforts. > As one of NASA's nine field centers, JPL has been given responsibility for a broad range of major robotic planetary missions and space science instruments. In addition, basic research is conducted and instruments and techniques are created to study Earth and its fragile environment. > As a Federally funded research and development center,* **JPL makes important and innovative contributions** *to the nation's scientific and technological vigor. The Laboratory carries out research not only for NASA, but for the Department of Defense and other Federal agencies as well. Many developments are also being shared with the private sector. > JPL's role has grown significantly from the mid-1930s, when it began as a small university laboratory engaged in basic rocketry, through the 1940s and 1950s, when it played a major role in the development of U.S. Army ballistic missiles. The Laboratory became part of NASA on January 1, 1959, and its various flight projects over the last 33 years have explored every planet in the solar system except Pluto. > Today,* **JPL is an internationally known institution** *with an annual budget of more than $1 billion and a work force of more than 6,400 people. The Laboratory's charter continues to emphasize the robotic exploration of the solar system, but has been expanded to include key roles in astrophysics, Earth sciences and space physics.*

Director's Message

During 1992, JPL enjoyed success in overseeing a broad spectrum of activities for NASA, the Department of Defense, the Federal Aviation Administration and other sponsors. > In flight projects, **two new missions were launched** *— the TOPEX/POSEIDON oceanographic research satellite and the Mars Observer planetary spacecraft — while five other spacecraft continued to operate productively at different locations throughout the solar system. Galileo visited Earth for the last time, gaining a gravity assist on its way to Jupiter. Magellan completed its third Venus mapping cycle and then began measuring the planet's gravitational field. Voyagers 1 and 2 continued* **investigating the outer reaches of the solar system.** *At Jupiter, Ulysses was deflected into an orbit that will take the spacecraft into unexplored regions of the Sun. Also, major restructuring of the Cassini mission to Saturn successfully accommodated new budgetary and programmatic constraints. > In space science, the 70- and 34-meter antennas at the Deep Space Network's Goldstone complex were used to bounce radar pulses off the asteroid Toutatis,* **obtaining remarkable images of an Earth-approaching object.** *> In advanced technology, the space shuttle carried two JPL-designed physics experiments — the Drop Physics Module and the Lambda-Point Experiment — into Earth orbit for studies requiring a microgravity environment. > In applications projects,* **JPL needed only 12 months to develop** *the Miniature Seeker Technology Integration (MSTI) satellite, launched in November for the Strategic Defense Initiative Organization. > The year also saw a major personnel change. Mr. Larry N. Dumas, formerly the Assistant Laboratory Director for Telecommunications and Data Acquisition, became the Deputy Director in July; he succeeded Dr. Peter T. Lyman, who retired after five years in the post and a long, distinguished career at JPL. > In closing, I want to emphasize that JPL's* **many significant achievements in 1992 were due to the dedicated efforts of our people.**

R C Stone

> **JPL's Director and Deputy Director,** *respectively, Dr. Edward C. Stone (right) and Mr. Larry N. Dumas. Dumas, who took over the post in July, was formerly an Assistant Laboratory Director.*

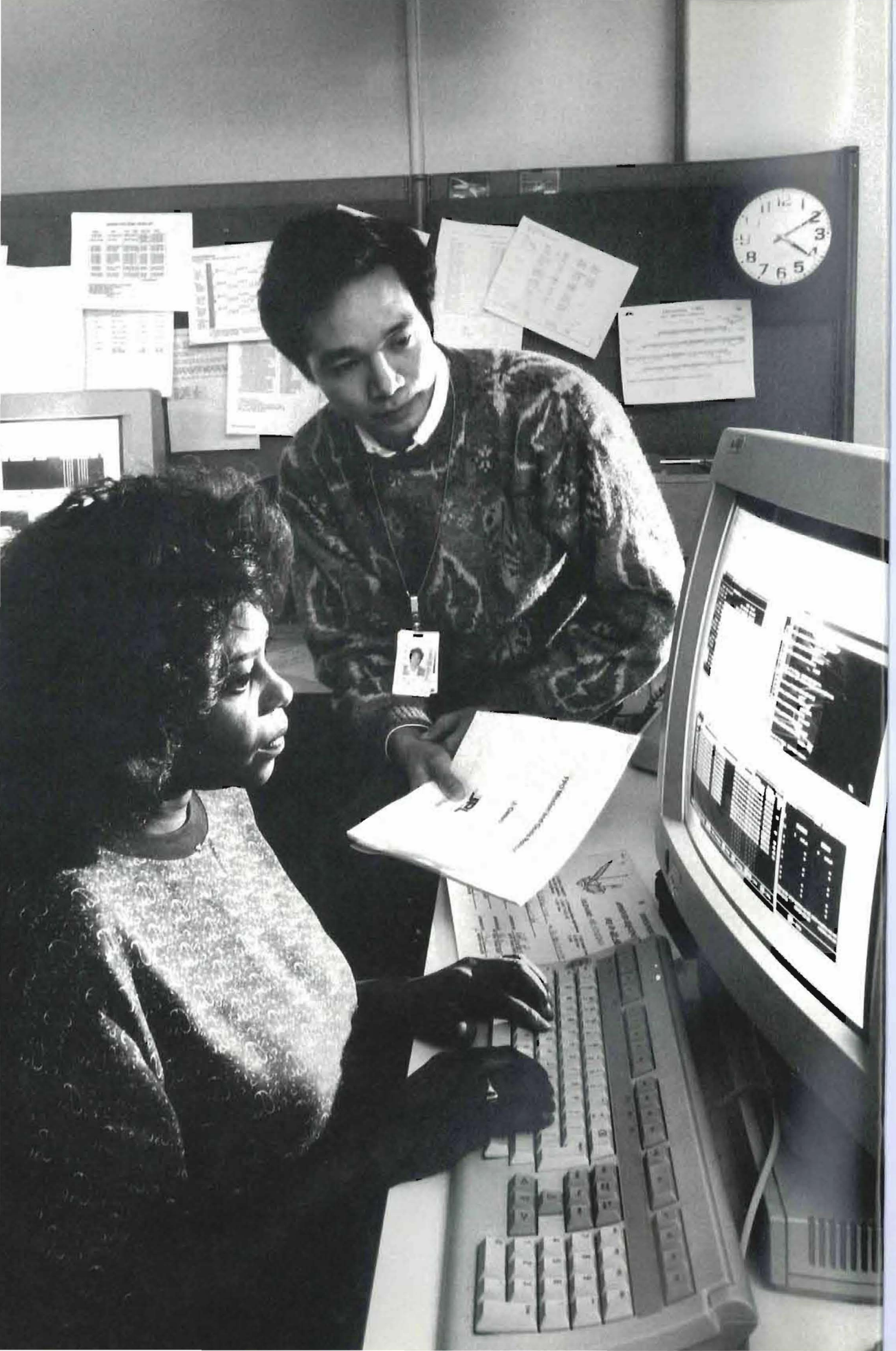
JPL met the challenge of orchestrating *multiple flight missions for NASA in 1992. Galileo performed the last of three gravity-assist maneuvers to send it toward an encounter with Jupiter in 1995. The Magellan spacecraft completed its historic task of radar-mapping the cloud-obscured surface of Venus, then began collecting data for a gravity profile of the planet. The launch of Mars Observer marked the nation's return journey to the alluring Red Planet. The two Voyager spacecraft continued to explore the outer reaches of the solar system. Ulysses, sponsored by NASA and the European Space Agency, used a Jupiter flyby to send it on to a trajectory around the solar poles — and in the process made surprising findings about the giant planet. TOPEX/POSEIDON, the joint U.S.–French satellite, began studying Earth's oceans.*

In development, the international Cassini project was restructured to accommodate new budgetary constraints but remains a promising program to investigate the Saturnian system, including the moon Titan. As part of the trend toward smaller and less expensive missions, the Laboratory is developing a prototype lander to investigate the surface of Mars and is studying the feasibility of a mission to explore Pluto with twin spacecraft. JPL also supported the development of proposals for small, inexpensive and highly focused planetary missions.

Flight Projects

> **The Venusian surface is explored** *by scientists through detailed study of images created from Magellan's radar data. Venusian geology may provide a window into Earth's past.*

Below: Galileo's view of the asteroid Gaspra displays a surface marked by many small craters. Gaspra's irregular shape indicates that it was once part of a larger body.



Galileo

The Galileo spacecraft raced past Earth in December, using our planet's gravity as a final-stage booster to send it on its way to an encounter with Jupiter in December 1995. The flawlessly executed gravity assist culminated a three-year energy-building trajectory known as the Venus-Earth-Earth Gravity Assist (VEEGA), designed to impart sufficient velocity to the spacecraft to reach the giant outer planet. Initial gravity assists from Venus and Earth were accomplished two years ago. Once it reaches Jupiter, Galileo will release an instrumented probe for entry into the planet's atmosphere, then swing into planetary orbit for a two-year mission to explore Jupiter and its satellites.

During its recent Earth gravity-assist maneuver, the spacecraft flew over the Moon's northern polar region at a distance of 110,000 kilometers, providing the first close look at that lunar region. Then Galileo swung by Earth, with its closest approach of 304 kilometers occurring over the South Atlantic Ocean at 34 degrees south latitude and 6 degrees west longitude. The flyby — which increased spacecraft velocity relative to the Sun by 7.65 kilometers per second — was so accurate that a follow-up correction maneuver was not necessary.

As it passed through our system, the spacecraft captured spectroscopic images of the Moon's northern polar regions and the Andes mountains and Antarctic continent on Earth — and also observed Earth's magnetotail. Eight days after the closest approach, Galileo captured multiple images of the Earth-Moon conjunction.

Prior to the Earth encounter, the spacecraft played back data acquired during its October 1991 flyby of the asteroid Gaspra and stored for over a year on onboard tape recorders. The Gaspra science data yielded very high resolution images as well as information on the asteroid's surface composition — affording scientists their best look yet at a main-belt asteroid.

This year, an intensive effort was made to understand and systematically simulate the spacecraft's high-gain antenna deployment problem, producing a final strategy for freeing the antenna's three stuck ribs. Late in December, spacecraft controllers began turning the antenna drive motors on and off in the hope that the resultant jolting, or "hammering," would free the ribs. This technique takes advantage of solar warming during a period when the spacecraft is closer to the Sun than at any time since the beginning of the deployment problem last year. Controllers plan to repeat bursts of motor pulses a number of times over several months or until the ribs are freed.

Even if the high-gain antenna is not successfully deployed, about 70 percent of Galileo's science returns at Jupiter, including all of the probe data, can be recovered using the spacecraft's low-gain antenna.

Magellan

The Magellan spacecraft, orbiting Venus since August 1990, completed its third mapping cycle in September of this year by filling the last significant gap in its radar map of the planet. Each mission cycle comprises one rotation of Earth's closest planetary neighbor — equal to 243 Earth days. After capturing 84 percent of the Venusian surface in the first cycle, Magellan spent the second 243-day period filling data gaps and remapping much of the planet from different viewing angles. Mission scientists devoted most of the third cycle to obtaining stereo coverage of about 22 percent of the cloud-shrouded planet's surface.

In mid-September, Magellan started a fourth cycle by executing an orbit trim maneuver to lower its periapsis, or closest approach to the planet. The

< **To monitor sea surface and wave** *heights along with wind speed, the TOPEX/POSEIDON satellite collects data on Earth's oceans. The data are processed into geophysical data records, which are used by the science community to produce ocean maps and to calibrate ocean models.*

spacecraft then began to characterize Venus' gravity field. Because of the higher frequency of Magellan's telecommunications signal, the resolution of the gravity data obtained during the cycle — which will end in May 1993 — is expected to be four times that of earlier Pioneer 12 data. Precise tracking of the Doppler shift of Magellan's radio signal as the spacecraft orbits close to the surface will enable scientists to map mass variations within Venus and to correlate them with planetary surface features. These gravity data will allow geophysicists to study the dynamics of the planet's upper mantle — the active portion of the structure below the Venusian crust.

Before the end of the first mapping cycle, Magellan had returned more digital image data than all previous U.S. planetary missions combined. By the end of the third cycle and 4,828 mapping orbits of the planet, the spacecraft had captured approximately 99 percent of the Venusian surface — far exceeding the original goal of 70-percent coverage. The images produced from Magellan data have a resolution of at least 150 meters.

The Magellan Data Management Team has distributed over 200,000 image products to investigators and the broader science community. By combining the image data with Magellan's altimetry returns, the JPL Solar System Visualization project has produced spectacular films and videos of Venus.

Mars Observer

In September, the Mars Observer spacecraft, successfully lofted into space by a Titan III rocket, began an 11-month journey to Mars. Mars Observer is the first U.S. mission to the Red Planet since the launch of the Viking orbiters and landers in 1975. After liftoff from Cape Canaveral, Mars Observer and its powerful transfer orbit stage were inserted into Earth orbit. Then, following a brief coast, the transfer orbit stage ignited, successfully propelling the spacecraft into a trajectory that will deliver it to Mars.

The challenge confronting flight controllers is to direct the spacecraft — traveling at 90,104 kilometers per hour — on a flight path toward a planetary target that is itself moving at a speed of 86,886 kilometers per hour relative to the Sun. To reach its destination, Mars Observer must travel more than 724 million kilometers.

The spacecraft will reach Mars in August 1993, where it will be steered into a near-circular, near-polar orbit 386 kilometers above the surface of the planet. For an entire Martian year (687 Earth days), it will gather data on the planet's atmospheric composition and density, magnetic field and gravitational and surface characteristics. Onboard cameras are expected to capture images of almost the entire surface, including detailed views with a resolution 20 times better than that of any previous images of Mars.

Mars Observer is carrying a suite of instruments for scientific investigations. A laser altimeter will profile the surface to a resolution of about 1 meter; these data will be used to compile topographical maps. A gamma ray spectrometer will help identify the chemical elements present on and near the surface of Mars; this instrument will be complemented by a thermal emission spectrometer designed to determine the mineral content of surface rocks and frosts and the composition of the planet's clouds. Early checkout indicated that all eight of the spacecraft's instruments were operating satisfactorily. Scientists expect the spacecraft to return more Martian data than all previous missions to the planet combined.

Near the end of its mapping mission in late 1995, Mars Observer will participate in the Mars Balloon Relay Experiment, a cooperative venture among the United States, Russia and France. Mars Observer will assist the Russian Mars '94 mission by relaying data from small penetrators and landed packages sent to the Martian surface by the Mars '94 spacecraft. The data will be radioed to the U.S. spacecraft, formatted on board by equipment supplied by the French space agency (Centre National d'Études Spatiales), stored in camera memory and then transmitted to Earth by Mars Observer.

Mars Observer was constructed by the General Electric Astro-Space Division; JPL is responsible for project management, mission design and mission operations.

Cassini

The Cassini spacecraft, scheduled for an October 1997 launch, will use gravitational assists from Venus, Earth and Jupiter to reach Saturn in June 2004. Cassini will orbit the ringed planet and release a probe to parachute into the thick nitrogen-methane atmosphere of Titan, the largest of Saturn's 18 identified satellites. During the four-year mission, the spacecraft will fly past Titan more than 20 times and pierce Saturn's magnetopause about 100 times. Science returns from the mission are expected to exceed by a factor of 10 the data acquired from the Voyager flybys of Saturn.

European nations are contributing significantly to the Cassini project. The European Space Agency is developing the Huygens Probe, named for the Dutch astronomer who discovered Titan. The Italian space agency (Agenzia Spaziale Italiana) is supplying the spacecraft's high-gain antenna and portions of its visual and infrared mapping spectrometer, radio frequency instrument subsystem and radar instrument. The Cassini spacecraft and probe are expected to support 27 investigations, 9 of which are based in foreign countries.

To control Cassini costs, JPL simplified the spacecraft design by mounting the remote-sensing instruments rigidly to the spacecraft body rather than using a more costly scan platform as originally planned. This new approach requires pointing the entire spacecraft at targets when the instruments are in use. The spacecraft-to-probe telecommunications subsystem was redesigned to eliminate a special probe relay antenna on the spacecraft.

The entire project and its major constituents are being designed within strict budgetary guidelines. This "design-to-budget" approach requires initial top-down allocations, with later adjustments from contingency funds as necessary for solving future problems. To accommodate budgetary reductions in the U.S. planetary exploration program, the Comet Rendezvous Asteroid Flyby, a companion project to Cassini, was cancelled by NASA.

Voyager

Fifteen years after launch, and having completed their historic explorations of Jupiter, Saturn, Uranus and Neptune, the Voyager 1 and 2 spacecraft are sailing toward the outer boundary of the solar system. Both spacecraft remain in good health as they seek the heliopause — the region where the Sun's magnetic influence wanes and interstellar space begins. Before reaching the heliopause, the Voyagers will pass through an area, known as the termination shock, where the solar wind abruptly slows.

As part of the Voyager Interstellar Mission — which began two years ago after Voyager 2's successful Neptune encounter — the two spacecraft are studying fields, particles and waves in interplanetary space. Late in the year, the onboard plasma wave science instruments detected radio waves of a type first observed by the Voyagers a decade ago. The source of these waves has not yet been explained.

All instruments relevant to the study of interplanetary space continue to operate satisfactorily; others designed for the earlier planetary encounters were turned off in 1990 to conserve spacecraft power. The ultraviolet spectrometer, the only pointable instrument still being operated, is measuring the light from stars and detecting hydrogen within the heliosphere. The Voyagers have enough electrical power and thruster fuel to operate for another 20 to 25 years.

Voyager 1 is exiting the solar system at a speed of 525 million kilometers a year on a heading 35 degrees above the ecliptic — the plane in which most of the planets orbit the Sun. By late in the year, the intrepid explorer was more than 7.5 billion kilometers from the Sun. At the same time, Voyager 2, diving below the ecliptic plane at a 48-degree angle, was racing along at 465 million kilometers a year and had reached a position more than 5.75 billion kilometers from the Sun.

Launched in September, Mars Observer is cruising on an 11-month journey to the Red Planet, where it will study the Martian atmosphere, surface and magnetic and gravity fields.

Ulysses

The Ulysses spacecraft flew by Jupiter in February, exploiting the gravitational pull of the giant planet to bend its trajectory out of the ecliptic plane and back toward the poles of the Sun Ulysses will make pioneering measurements of the Sun's polar magnetic field, the solar wind and interstellar space at nearly all solar latitudes

During the spacecraft's two-week Jupiter flyby, onboard instruments revealed that the solar wind exerts a much stronger influence on the planet's magnetic field than previously thought Scientists concluded that magnetic field lines are being peeled away from the Jovian magnetosphere by the solar wind, causing high-latitude magnetic field lines to lead out into interplanetary space, rather than return to Jupiter In traversing the previously unexplored dusk sector, Ulysses found that the field lines were being swept toward Jupiter's magnetotail

The magnetic phenomena observed by Ulysses during the Jupiter encounter are similar to those observed in Earth's magnetic field Scientists are now re-examining the long-held belief that the solar wind has less influence on the strongly magnetized, rapidly rotating Jupiter than on Earth's smaller magnetosphere

Ulysses also found that the doughnut-shaped cloud, or torus, of ions circling Jupiter at about the orbital distance of the Jovian moon Io is much less homogeneous than anticipated, the torus exhibited significant variations in density at different latitudes In addition, the spacecraft observed five bright radio sources that were distributed along and rotating with the torus Evidence of a Jovian aurora in the previously unexplored dusk region on the planet was also observed as particle beams streaming along the magnetic field

Ulysses did not sustain any damage from the hostile magnetic environment of Jupiter as had earlier Pioneer and Voyager spacecraft, and as the year ended, the robotic explorer was cruising along at roughly 20 degrees south solar latitude on a trajectory that will take it under the south solar pole in the summer of 1994

NASA and the European Space Agency manage the Ulysses mission jointly. JPL has sole tracking and data acquisition responsibilities, manages the US experiments and shares the mission design and navigation roles with the European Space Agency

TOPEX/POSEIDON

A new era of Earth-monitoring from space was inaugurated in August with the launch of the TOPEX/POSEIDON satellite, a joint effort of NASA and France's Centre National d'Études Spatiales (CNES) to study the world's oceans TOPEX/POSEIDON is designed to measure sea levels, map basin-wide variations in currents and monitor the effects of currents like the Gulf Stream on global climate change

TOPEX/POSEIDON was shipped to the European Space Agency's Guiana Space Center in Kourou, French Guiana, at midyear and boosted by an Ariane 42P launcher into a 66-degree inclined Earth orbit at an altitude of 1,336 kilometers The satellite, which is using the NASA Tracking and Data Relay Satellite system for command operations and data acquisition, was supported by the Deep Space Network for critical launch operations

Earlier in the year, spacecraft environmental testing was completed at the NASA Goddard Space Flight Center by Fairchild Space and Defense Corporation, the satellite system contractor At JPL, which is managing the project for NASA, the command and control center and data processing facilities were completed and the mission operations teams were staffed and trained

The TOPEX/POSEIDON satellite, a modified version of NASA's multimission spacecraft, includes an additional module containing its sensors. Extra propulsion and power capabilities make possible a five-year mission life, including a potential two-year extended mission The satellite carries six instruments. a dual-frequency radar altimeter, a microwave radiometer, a laser retroreflector array, an experimental Global Positioning System demonstration receiver, a single-frequency solid-state altimeter and a dual-Doppler tracking system receiver. The first four instruments were supplied by NASA and the last two by CNES

From orbit, the altimeters measure wave and surface heights for studies of ocean circulation patterns Returns from the satellite's laser retroreflector provide orbital tracking data while the microwave radiometer corrects for atmospheric effects TOPEX/POSEIDON has been returning data for the preparation of preliminary global maps of wave height, water vapor content and sea-surface height variability The NASA verification site (an ocean platform near Point Conception, California) and CNES verification sites (on Lampione and Lampedusa Islands in the Mediterranean Sea) are collecting corroborative data

From TOPEX/POSEIDON data, scientists will create global images of the world's oceans that will show how eddies of ocean currents change over distances of tens to hundreds of kilometers during intervals ranging from weeks to months The currents play an important role in ocean circulation because they transport heat, salt, nutrients and other chemicals throughout the ocean TOPEX/POSEIDON is expected to contribute to the assessment of global change and improve long-range weather forecasting and pollution control The satellite will also help in monitoring environmental conditions of offshore and coastal areas throughout the world

Advanced Mission Studies

Mars Environmental Survey

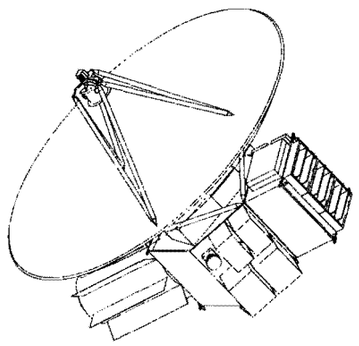
JPL has lead responsibility for NASA's Mars Environmental Survey (MESUR) activity The MESUR baseline mission would involve placing a network of 16 small landers at widely separated sites on the Martian surface The purpose of the mission is to study global atmospheric circulation; the planet's interior, and local rock, soil and surface characteristics. Plans call for launching these spacecraft over a six-year period, beginning in January 1999.

Early in 1992, JPL was given the additional assignment of producing an engineering prototype lander for Mars surface exploration, to be launched in 1996 This new project, called MESUR Pathfinder, is a precursor to the 16-lander network of the baseline mission MESUR Pathfinder is expected to return science data from surface investigations and could possibly deploy a small mobile instrument on Mars. Its objectives, however, must be achieved within a firm cost cap of $150 million Thus, the mission will provide project management with an opportunity to develop techniques for accomplishing smaller planetary flight projects at a faster pace

Most of the work in 1992 was devoted to developing the Pathfinder lander concept — including the crucial entry, descent and landing designs The evolving design features an aeroshell, parachutes to brake the lander's descent and an airbag to cushion the actual landing Once the lander is on the surface, petals deploy to expose the instruments and solar panels before operations begin

Pluto Flyby

Pluto is the only planet in the solar system that has not yet been explored by spacecraft JPL is examining the feasibility of sending twin spacecraft on a flyby of Pluto and its moon Charon,



with launches suggested for 1998 or 1999. The main science goals of the proposed mission are to characterize Pluto and Charon's global geology and geomorphology, map their surface compositions and determine Pluto's neutral atmosphere. The small spacecraft, each weighing well under 200 kilograms, would arrive at Pluto in six to eight years — before the planet's atmosphere collapses again in the farther reaches of its solar orbit.

Fiscal year 1992 culminated in the delivery of an end-to-end mission concept and cost estimate.

Discovery Program

The Discovery program, announced by NASA in the spring, calls for small planetary missions with highly focused science objectives and budgets of less than $150 million each. These missions would be under the direction of the principal investigators, who would be encouraged to form teams with representation from universities, industry and Government agencies.

In November, NASA conducted a workshop to review 72 mission concepts proposed by principal investigators; JPL supported the development of 35 of these proposals, for which review is still pending.

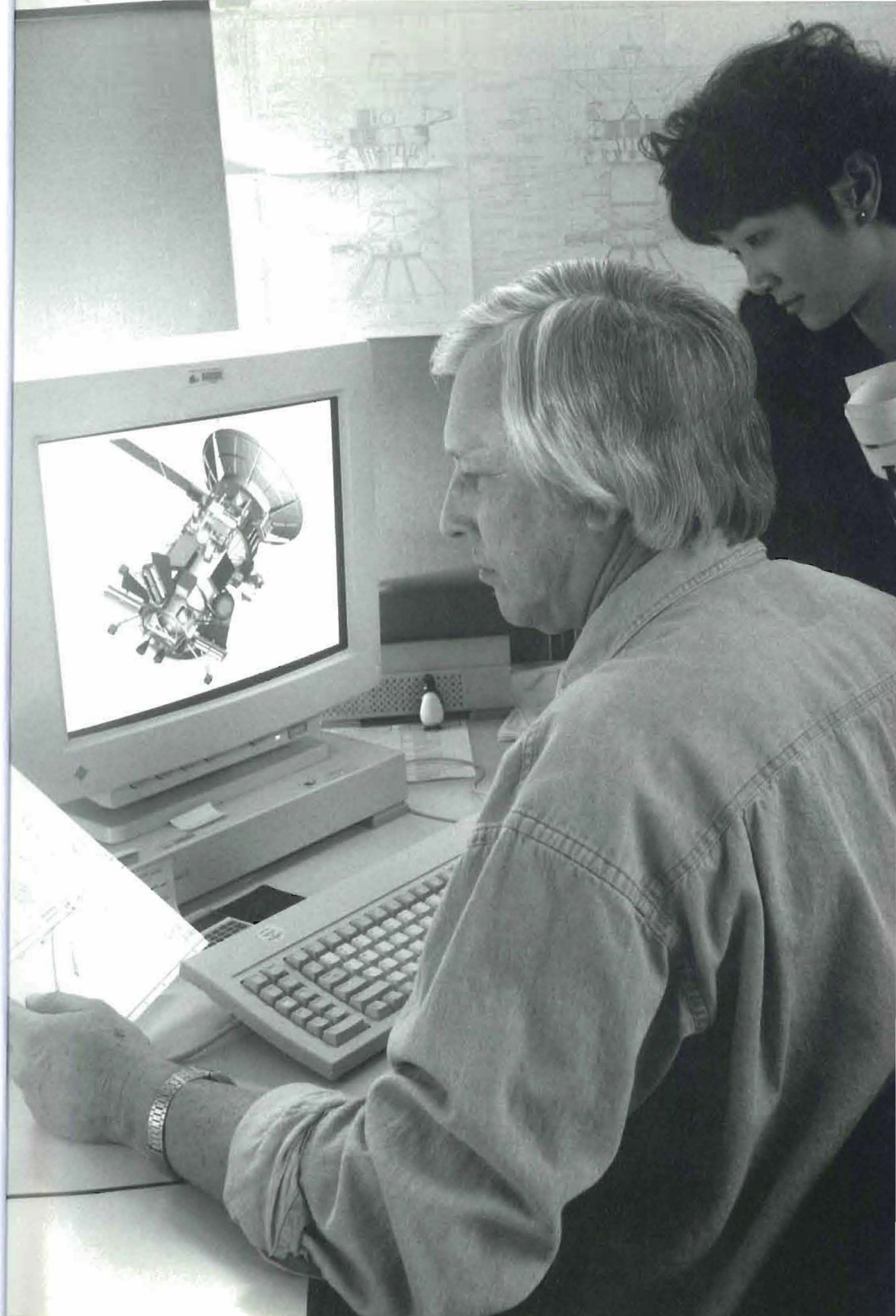
Multimission Operations

JPL has expanded its multimission operations support concept and its ability to manage additional ground data systems capabilities for flight projects. Previously, each flight project built and operated its own ground system; now, the Multimission Operations Systems Office (MOSO) provides substantial portions of a shared system. During 1992, MOSO supported the Magellan project using the new Advanced Multimission Operations System. The office continued to provide support to the Voyager, Galileo and Ulysses projects with the old ground data system and accomplished the transition of the Voyager and Ulysses projects to the new system with no interruption of service.

MOSO's Navigation and Multimission Image Processing support to the Galileo project yielded unprecedented images of the asteroid Gaspra. MOSO provided the Ulysses project and its science investigators with a timely supply of data products on the Jupiter flyby; quick-look experiment data records were supplied hourly during the period of closest approach. MOSO developed, tested and implemented major new Multimission Ground Data System capabilities for the Mars Observer launch.

The multimission concept is designed to reduce overall operations costs to the flight projects. During 1992, MOSO took many steps to initiate or enhance cost savings and to increase the efficiency of flight project support. The Multimission Control Team became fully established and is now supporting three projects, allowing an overall reduction in support personnel. Also, the Project Data Base technology was developed to provide a secure repository for flight project data — one accessible to both JPL users and remotely located principal investigators, who can remain at their home facilities while still interacting effectively with day-to-day planning and mission operations activities.

In other efforts, MOSO redefined multimission spacecraft analysis tools — already under development — to be more cost effective. In addition, the multimission Navigation Computing Facility became operational and is supporting the Mars Observer and Galileo projects and the Navigation Software Development Group, allowing a substantial reduction in personnel and more efficient use of computing capabilities.



> **Using a computer-aided design (CAD)** *system, engineers design the Cassini spacecraft. This system allows them to create and exchange three-dimensional drawings electronically. Through a network-linked data base, detail designs are integrated into the overall spacecraft configuration.*

The Laboratory conducts basic research *and develops instruments and techniques for space exploration and the study of Earth and its environment. These activities add significantly to our knowledge of the planets, solar physics and astronomy and provide insight into Earth and the processes that change it. Large quantities of data are generated that must be processed, analyzed and archived, then made available to scientists, educators and the public. Work in 1992 shed new light on the structure of the ozone layer and its depletion by chemical processes, expanded our ability to analyze earthquakes and locate faults and helped validate geophysical data from spaceborne Earth-sensing radar over remote polar areas. Ground-based radar observations of Saturn's rings and the asteroid Toutatis were made. The Laboratory logged significant progress toward completion of several complex flight instruments, including a radar to measure Earth's biomass and soil moisture globally and a planetary camera to compensate for the distortion in the Hubble Space Telescope's primary mirror. Advances were achieved in preliminary technology development for an Earth-orbiting infrared telescope. JPL continues to develop scientific visualization techniques that combine and present data sets in graphical displays for analysis of the large volumes of information returned by instruments in space.*

Earth and Space Science

> **The massive antenna flight** *structure of the Spaceborne Imaging Radar-C/X-band Synthetic Aperture Radar (SIR-C/X-SAR) is prepared prior to modal testing.*

Below: A micro-machined pressure sensor, shown being calibrated, can be used in a micro-weather station to be deployed both on Mars and in Earth's atmosphere.

Earth Science

As part of NASA's Mission to Planet Earth, JPL is investigating the biological, chemical and physical features of Earth's atmosphere, oceans, land surface and crust — and studying aspects of the interfaces between them. To address key global problems such as ozone depletion, climate change, volcanism and tectonism, JPL scientists acquire data from remote-sensing instruments carried by aircraft, balloons and satellites; insights are also gained through laboratory experimentation, field work and theoretical modeling. While research is becoming largely interdisciplinary in nature, JPL is building on strengths in traditional areas of expertise, such as atmospheric chemistry, oceanography, geology and geodynamics.

Microwave Limb Sounder

Since its launch aboard NASA's Upper Atmosphere Research Satellite in September 1991, the Microwave Limb Sounder has gathered data on the composition, chemistry and dynamics of Earth's stratosphere. These data will help scientists understand the variability of Earth's protective ozone shield and the chemical processes affecting it.

The Microwave Limb Sounder — the precursor of the planned Earth Observing System instrument — is making daily observations of ozone, chlorine monoxide, water vapor, temperature and pressure over nearly the entire globe. Stratospheric chlorine monoxide, derived primarily from industrial chlorofluorocarbons, is a factor in the destruction of atmospheric ozone.

The wintertime polar increase in stratospheric chlorine monoxide, which had been sampled only occasionally before the launch of the Upper Atmosphere Research Satellite, has now been monitored and mapped in both the northern and southern hemispheres. Over Antarctica, the concentration of chlorine monoxide is increased in the presence of polar stratospheric clouds, leading to the formation of the ozone hole.

The instrument has monitored the structure of ozone during its annual depletion. Results indicate that the depletion process known to peak in October begins as early as June. Surprisingly, during winter in the northern hemisphere, elevated levels of chlorine monoxide were found to be as extensive as in the south. Yet the formation of a springtime Arctic ozone hole was forestalled in late January by the warming and dissipation of the polar stratospheric clouds necessary for maintaining the higher levels of chlorine monoxide.

Data from the equatorial and mid-latitudes are also providing new insights into the threat of global ozone depletion and the impact of sulfur dioxide and aerosols injected into the stratosphere by the 1991 eruption of Mt. Pinatubo in the Philippines.

During its first year of operation, the Microwave Limb Sounder operated flawlessly and is expected to continue collecting data for several more years. Research groups from Heriot-Watt University, the University of Edinburgh and the Rutherford Appleton Laboratory in the United Kingdom are collaborating with JPL in this experiment.

NASA Scatterometer

Winds near the surface of the world's oceans play a pivotal role in global weather. As part of NASA's efforts to apply advanced space technology to understanding Earth and its climate, JPL scientists and engineers are designing and building the NASA Scatterometer, a satellite instrument to measure near-surface ocean winds. The scatterometer, scheduled for a 1996 launch on Japan's Advanced Earth Observing Satellite, will help scientists understand ocean circulation and the role of air–sea interactions in the global ecosystem, thereby facilitating predictions of climate changes and improving weather forecasting.

During the year, the instrument's major engineering subsystems, including radio frequency and digital subsystems, were assembled and successfully tested. The scatterometer's six stick-like antennas were calibrated. Engineers assembled a

< **The lost city of Ubar may have** *been found in Oman, on the Arabian Peninsula, based on satellite data. In this satellite-derived image, ancient tracks (faint lines from the lower right) converge at the contemporary village of Shisr, which is surrounded by a triangle of modern roads. Shisr is believed to be the site of Ubar.*

The Microwave Limb Sounder, aboard NASA's Upper Atmosphere Research Satellite, is gathering data on the chemical processes of Earth's stratosphere relating to ozone depletion.

mock-up of the spacecraft's antenna support structure, allowing electrical cable and radio frequency waveguides to be laid out in preparation for fabricating flight versions. A mechanism for deploying the antenna passed performance and environmental tests. Engineers also completed a model to simulate the instrument's electrical performance for spacecraft compatibility testing by the National Space Development Agency of Japan.

Spaceborne Imaging Radar

A giant multiple-frequency sensor known as the Spaceborne Imaging Radar-C and X-band Synthetic Aperture Radar (SIR-C/X-SAR) progressed to the hardware assembly and integration stage in anticipation of the first of a series of flights aboard the space shuttle late next year or early in 1994. In orbit, the SIR-C/X-SAR imaging sensor will make observations that will shed light on Earth's carbon, water and energy cycles and the continuing human impact on these cycles

The project is a joint venture of NASA, the German space agency (Deutsche Agentur für Raumfahrtangelegenheiten GmbH) and the Italian space agency (Agenzia Spaziale Italiana), with 52 science investigators from around the world The sensor integrates the NASA-developed SIR-C — an electronically scanned radar operating at C- and L-band frequencies, each vertically and horizontally polarized — and a German-made, mechanically scanned, vertically polarized X-band radar This combination of frequencies and polarizations, the equivalent of five separate and complementary radars, makes possible far more detailed assessments of global phenomena from space than were possible with earlier single-frequency, single-polarization spaceborne radars

JPL built the SIR-C instrument electronics, while Ball Communication Systems Division supplied the radar's active phased-array antenna panels, which are mounted on a JPL-fabricated antenna structure In 1992, the antenna mechanical structure progressed from an engineering design on paper to an integrated and tested flight hardware assembly The digital and C- and L-band radio frequency electronics were completed, tested and integrated. The X-band radar, which arrived at JPL in October, is being integrated with the SIR-C hardware at the Laboratory's Spacecraft Assembly Facility

At 10,500 kilograms, the SIR-C/X-SAR antenna assembly is the largest flight hardware ever assembled at JPL The antenna structure — 12 meters long by 4 meters high — fills most of the space shuttle payload bay. The radar electronics are carried on a Spacelab pallet mounted in the space shuttle bay under the center section of the antenna.

The precursor of the planned Earth Observing System SAR, SIR-C/X-SAR will collect data on the carbon cycle from the Amazon basin and other sites in the United States and Canada Additional studies will focus on the water cycle in the Amazon basin, Italy and Austria, as well as on the geology and paleoclimatology of North Africa, the southwestern United States, the Galápagos Islands and the Andes mountains Oceanography experiments will be conducted over the Atlantic and Pacific Oceans.

Most of the key mission sites will have been imaged by NASA's DC-8 aircraft SAR prior to the first flight of SIR-C/X-SAR, allowing investigators to develop preliminary algorithms for analysis of the new sensor's data. In addition, the DC-8 is expected to gather radar data at the sites during the SIR-C/X-SAR space shuttle mission. The combination of flight data, ground measurements at the sites and flight crew observations will allow scientists to extract quantitative information from SIR-C/X-SAR returns as the basis for developing better models for assessing global change

Alaska Radar Processing Facility

The Alaska Synthetic Aperture Radar Facility began receiving and processing radar data from Japan's Earth Resources Satellite (JERS-1) this year, adding to data it had already gathered from the European Space Agency's Earth Remote-Sensing Satellite (EERS-1) Radar images from satellite passes over the Arctic revealed features such as river valleys, tundra lakes, wind roughening over open water, internal waves, pack ice, ice floes and ice cracks called "leads"

The facility — a joint effort by NASA and the University of Alaska, Fairbanks — processes and distributes data from European and Japanese remote-sensing satellites and will support the planned Canadian Radarsat satellite It provides data processing services to support research in sea-ice studies, polar oceanography, glaciology and vegetation studies.

Analysis of radar imagery has derived ice motion vectors from overlapping pairs of images The ice geophysical products are important in examining the heat fluxes in the polar oceans and understanding the effects of global warming Using the Alaska Radar Processing Facility, scientists hope to glean important information about global change from environmental monitoring of forest health, seasonal conditions, glacial and volcanic changes and methane emission from tundra

Polar Oceanography

JPL contributed to innovative oceanographic investigations at the South Pole in an effort to validate geophysical data generated by the European Space Agency's EERS-1 satellite From February to June, JPL participated in the first joint U.S.-Russian staffed drifting scientific ice station in the Antarctic The station, located in the western Weddell Sea, was supported by synthetic aperture radar data from EERS-1

From May to August, a complementary shipborne experiment was conducted in the eastern and central Weddell Sea aboard the German icebreaker Polarstern Radar data from EERS-1 were downlinked to a German receiving station on the Antarctic Peninsula, then processed and relayed to investigators. JPL personnel aboard the Polarstern acquired shipborne radar scatterometer data at the same frequency as the satellite radar as a way of confirming contrasts between principal types of winter sea-ice

The combination of radar data, scatterometer returns and on-site sea-ice data provided critical information for monitoring the motion response of the winter ice cover to climatic and oceanic forces. Oceanographic and meteorological data, together with the sea-ice information, will yield insights into the fundamental role of the Weddell Sea in the ventilation of the ocean and in the cycling of heat, nutrients and chemicals

Lost City of Ubar

What are believed to be the remains of the legendary city of Ubar were found in Oman, in the southern part of the Arabian Peninsula, partially as a result of data gathered by JPL space experiments and analytical techniques developed at the Laboratory. The site was located by the application of an unusual combination of space technology, historical research and traditional archaeology

According to legend, Ubar was an important center for the frankincense trade that flourished in the region from about 2000 BC to 300 AD. The fortified city was said to have been buried in a sandstorm as divine punishment Actually, much of the city apparently collapsed into a sinkhole, perhaps undermined by extensive groundwater withdrawal.

Remote-sensing data — from JPL's Shuttle Imaging Radar, the space shuttle-based Large Format Camera and the Landsat and French Satellite Pour Observation Terrestre (SPOT) Earth-sensing satellites — were enhanced and analyzed. Through analysis based on JPL-developed methods, the images revealed a network of tracks that converge at the modern village of Shisr Some of the tracks are demonstrably ancient because they lead directly under large sand dunes. Although no ruins are visible in the images, they enabled researchers to eliminate large regions of the desert from consideration and indicated where to look for probable sites for the lost city.

The quest for Ubar benefited from three significant advantages of satellite data First, satellite observations cover vast areas, permitting a survey of the desert expanse that would otherwise have been impossible Second, digital satellite data permit computer image enhancement. Finally, satellite instruments record information at nonvisible wavelengths at which many terrain features are more distinctive Principal support for the expedition came from the Sultanate of Oman and many Omani, British and American businesses.

nium detectors doped with gallium that could simplify procedures for building the two-dimensional arrays needed for the telescope Sensitive at wavelengths between 40 and 120 microns, these arrays will make possible studies of the luminosity function of infrared galaxies and will allow spectroscopic exploration of the chemical and physical conditions in interstellar clouds

In addition to detector investigations, the JPL team weighed the feasibility of a new mission concept for the orbital instrument Studies showed that an Atlas IIAS rocket could launch a 2,500-kilogram telescope into a heliocentric orbit with significant cryogenic and operational benefits. The spacecraft, telescope and instruments could be reduced in size to accommodate the mass and volume constraints of the rocket while preserving a major part of the telescope's core scientific capabilities As a result of these studies, the Atlas configuration has become the new mission baseline

Satellite Test of the Equivalence Principle

A preliminary study of an ambitious space experiment to investigate the nature of gravity and its relationship to other fundamental laws of physics was completed by JPL scientists The experiment, called the Satellite Test of the Equivalence Principle, is a candidate for the European Space Agency's (ESA's) next medium-sized space mission, scheduled for launch in 2000 If selected, the experiment would be conducted jointly by ESA and NASA; NASA sponsored the JPL study.

The equivalence principle relates inertial mass and gravitational mass Inertial mass, defined by Newton's second law of motion, involves the acceleration, inertia and momentum of physical objects Gravitational mass, defined by Newton's universal law of gravitation, involves the force of attraction, at a distance, between physical objects These two different kinds of mass play fundamentally different roles in the equations describing the motion of matter.

The satellite test of equivalence is a modern version of the physicist Galileo's experiment in which any difference in the rate of fall of two test objects indicates that each object has a different ratio of gravitational to inertial mass. Unlike Galileo's experiment, in which the test objects fell for only a few seconds, the satellite experiment's test objects — supported by superconducting bearings — would fall virtually forever in orbit, allowing any difference in acceleration to build up indefinitely. The satellite experiment could increase the accuracy over similar ground-based experiments by a factor of one million.

ESA would provide the drag-free spacecraft for the proposed experiment while NASA plans to supply the booster, launch services and mission operations. The payload would be a joint effort of the two space agencies

Capturing Cosmic Dust in Space

Cosmic dust contains the historical record of ancient processes, including invaluable clues to the early history of the solar system Dust samples obtained in the stratosphere and on Earth's surface have given us some insight into cosmic processes But these samples have been altered by heating, weather erosion and contamination To obtain unaltered samples, JPL has developed a technique for capturing cosmic dust traveling at hypervelocities in space; the technique has been successfully demonstrated in laboratory simulations and on a space shuttle flight using silica aerogel cells, a highly porous type of glass

Gathering cosmic dust requires the use of a capture medium having a microcellular foam-like structure and a lower density than the material from which it is made. Since cosmic dust is so small, a capture medium ideally should be transparent to help researchers locate and extract captured particles A JPL researcher was the first to prove that transparent silica aerogel, the lowest density solid material known, would be a desirable medium for capturing hypervelocity cosmic dust

Space shuttle flight experiments have successfully captured two atomized particles and one intact, 10-micron cosmic dust particle using the silica aerogel. Researchers from the Caltech Campus and the University of Washington will analyze the captured particle and other samples to determine their geochemistry and dust structures Analysis should supply valuable information on solar system formation. Additional attempts to capture cosmic dust particles with aerogel cells are planned.

Radio Astronomy Experiments

The 70-meter antennas at Goldstone and Madrid joined with the U.S. Very Long Baseline Interferometer Network to make highly accurate observations of the supernova SN1986J in the galaxy NGC 891 The findings indicate that this distant star exploded around 1982 The Deep Space Network (DSN) antennas measured transverse velocities as high as 18,000 kilometers per second — about one-fifteenth the speed of light

In another investigation, the DSN antennas combined with the Very Long Baseline Interferometer Network to observe the naturally occurring water vapor maser emission in the nucleus of the Seyfert galaxy NGC 1068 The position of the maser source was coincident with the nucleus to within 0 1 arc second. The findings indicate that the maser source may be a torus, or doughnut-shaped cloud, of gas and dust surrounding the nucleus and that the nucleus may have a mass equivalent to that of four billion suns — comparable to that of a supermassive black hole

Information Systems

Scientific Visualization

Interactive analysis of large, complex data sets requires powerful software as well as hardware. Several activities at JPL are developing software tools that allow users to visualize complex data

The Linked Windows Interactive Data System, or LinkWinds, provides analysts with the capability to combine interactively and manipulate displays of data. The links, made at the analyst's discretion, enable the detection of trends, correlations and anomalies The LinkWinds data visualization system was developed and tested using atmospheric, oceanographic and geologic data The system produces results that are rapidly understood and readily communicated to others. Copies of an early test version have been installed at a variety of sites, including the San Diego Supercomputer Center, the NASA Marshall Space Flight Center, the Oregon State University College of Oceanography and the University of Colorado.

Software specialists are enhancing LinkWinds with mathematical analysis tools, animation features and other capabilities and are applying the system to new computers. They also added a real-time data mode to support Galileo's plasma wave spectrometer during the spacecraft's second Earth encounter

Another software program developed at JPL was chosen as a computer interface for one of five national testbeds of the High-Performance Computing and Communications Initiative, an interagency research and development venture to extend U.S leadership in computers and networks The software program permits analysis and visualization of multidimensional, multivariate data and imagery. These capabilities are expected to be portable to many computing environments and should be compatible with low-cost, general-capability workstations. Researchers in the Earth sciences are using this software program to analyze spectral and seismic data in evaluating earthquake faults and other geologic information

A third software development effort, called the Planetary Analysis Tool, has integrated an object-oriented systematic data processing package with a newly developed program for dynamic data base selection The integration allows a scientist to interactively describe desired data sets and process them automatically using entire Planetary Data System compact disk-read-only memory (CD-ROM) data sets

New visualization capabilities developed at JPL provide previously unavailable science analysis techniques One software package processes image data from CD-ROMs generated by the Planetary Data System The software package encompasses science products and the original digital data set from which other products can be made In addition, the software can simulate spacecraft flybys using actual trajectory data These new techniques support the analysis and long-range planning capabilities required by scientists

Solar System Visualization

The Solar System Visualization project seeks to apply visual analytical tools to the re-exploration of the planets based on data from previous NASA planetary missions and to create new techniques and materials for science, education and public information Its major products include science analysis and visualization tools and technologies

along with a series of science videotape products and CD-ROM perspective maps for each planet in the solar system.

In collaboration with the Ulysses flight team, the Solar System Visualization project developed a model of the Ulysses spacecraft, created computer graphics representations of the Ulysses and earlier Pioneer and Voyager trajectories and simulated the Ulysses encounter with Jupiter. These products helped the flight team to visualize and plan the Jupiter encounter.

In June, an animation product showing a series of simulated, three-dimensional perspective views of the asteroid Gaspra was released by the visualization project. The animation was based on a digital elevation map of the asteroid developed by Cornell University and the U.S. Geological Survey from data acquired by the Galileo spacecraft during its Gaspra encounter.

Two images of the Venus surface were produced by the visualization project in collaboration with the Magellan science team using the Intel Touchstone Delta supercomputer. The images provide three-dimensional perspective views of Maat Mons and Sapas Mons, two volcanoes located on the western edge of the Venusian highland area called Atla Regio.

Using tools developed by the visualization project, a research team this year produced a videotape compilation, "From Surveyor to Galileo and Beyond," for the 25th anniversary of the Surveyor lunar lander. In another activity, the visualization project helped create a 10-minute videotape presentation entitled "A Voyage to the Planets" for the inaugural ceremony of the World Space Congress in Washington, D.C., in August; two collections of science visualizations prepared by the project were on display during the Congress.

Excerpts from another videotape, "Global Ozone Concentration Movies, 1980–1990," were shown at the United Nations Conference on Environment and Development. The videotape provides five views of global ozone concentrations derived from data acquired by the Total Ozone Mapping Spectrometer aboard the Nimbus-7 satellite.

Planetary Data System

The Planetary Data System has become a primary source of planetary information, responding to over 6,000 orders from the scientific community and providing more than 20,000 gigabytes of data since it began operation in 1991. In 1992, in its capacity as the curator of NASA's planetary data sets, the system archived more than 100 Magellan CD-ROMs and distributed them to scientists within a month of their release by the project office.

The Planetary Data System, which leads the science community in the development of standards for documenting and preparing data sets for archiving, has recently released a comprehensive set of standards for planetary missions. These standards, which assure uniformity of data products for the planetary community, enable users to search broadly across missions, target bodies and disciplines.

Based on these standards, the Planetary Data System developed a powerful set of software tools for creating, validating and manipulating archival data sets. The tools were distributed to planetary missions to help them create archival products. The Planetary Data System also continues to refine its on-line system capabilities. This year, the Central Node Catalog was upgraded to include a more user-friendly interface, better "help" features and an improved order system.

While pioneering the use of CD-ROMs for distributing large volumes of digital data products, the Planetary Data System is also investigating new technologies in archival media, such as optical carousels that will make large quantities of data available to on-line users.

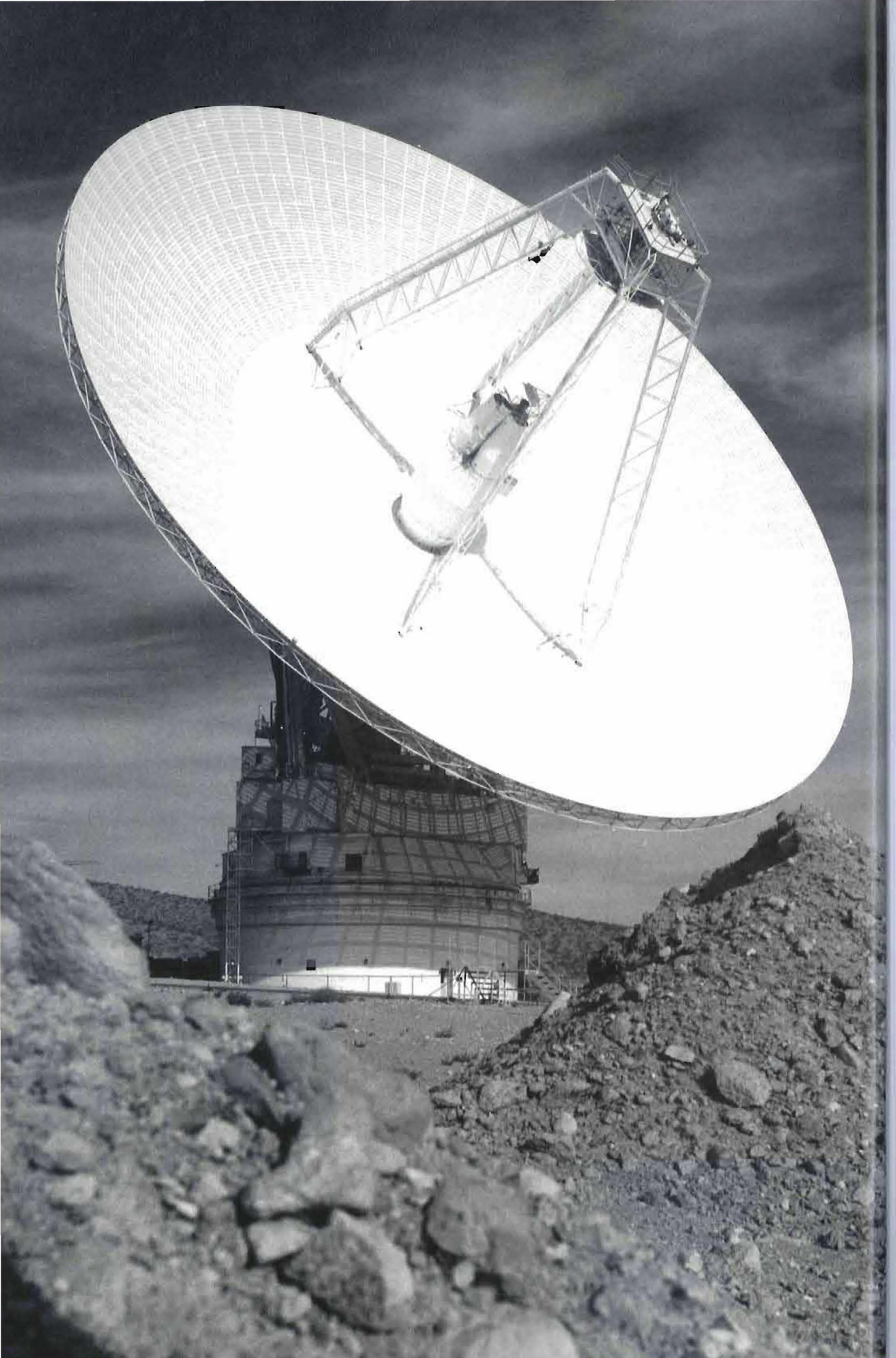
> **Wide Field/Planetary Camera 2** — *being assembled for the Hubble Space Telescope — incorporates changes that enable the camera to correct for the spherical aberration in the telescope's main mirror. Astronauts will substitute the new camera for the original instrument in a space shuttle mission.*

In 1992, the Deep Space Network (DSN) *supported 31 deep space and near-Earth missions, including Galileo; Ulysses; Magellan; Voyagers 1 and 2; Pioneers 10, 11 and 12; the International Cometary Explorer; the European Giotto and Hipparcos; the Geostationary Operational Environmental Satellite (GOES-7); Nimbus; the German-U.S. Roentgensatellit (ROSAT); the Japanese Yohkoh, and the space shuttle. Launch and early orbit support were provided for Mars Observer, TOPEX/POSEIDON, the Extreme Ultraviolet Explorer, the Solar Anomalous and Magnetospheric Particle Explorer (SAMPEX), the Japanese Geotail, the U.S.-Italian Laser Geodesic Satellite (LAGEOS II) and four foreign reimbursable missions. The DSN also participated in radio astronomy observations at all Deep Space Communications Complexes and made radar astronomy observations from Goldstone — including joint efforts with the National Radio Astronomy Observatory's Very Large Array in Socorro, New Mexico. To meet the challenges of current and prospective space missions, the DSN's facilities were significantly upgraded and enhanced. The Laboratory continued to pursue innovations in telecommunications. In an experiment involving Galileo as it flew by Earth, JPL successfully demonstrated the use of laser beams to communicate with distant spacecraft.*

Telecommunications Systems

> **Perched on a girder, a worker** *is dwarfed by the massive support structure of the DSN's 34-meter beam waveguide antenna at the Goldstone research and development site.*

Below: The Goldstone complex's radar observations of the asteroid Toutatis revealed that it is two irregularly shaped bodies — one with a 700-meter-diameter crater.



DSN Overview

The Deep Space Network (DSN), NASA's worldwide system for communicating with spacecraft above low Earth orbit (above 10,000 to 15,000 kilometers), is managed by JPL through the Telecommunications and Data Acquisition Office. The DSN's three Deep Space Communications Complexes — at Goldstone in Southern California's Mojave Desert, near Madrid, Spain, and near Canberra, Australia — are separated by approximately 120 degrees of longitude so that a distant spacecraft is normally in view of one of the stations. The Network Operations Control Center at JPL monitors the operations of each complex; a spacecraft compatibility test facility at JPL and a launch support facility at the NASA Kennedy Space Center in Florida are also part of the DSN.

Mission Support

Galileo

Late in January, the Galileo spacecraft experienced its first solar conjunction; communication with the spacecraft became more complicated as the Sun–Earth–Probe angle, or angle between the Sun and the spacecraft as observed from Earth, dropped to 5 degrees. A command sequence for cooling Galileo's high-gain antenna tower was uplinked in mid-January via Goldstone's 70-meter antenna at about 5.36 degrees Sun–Earth–Probe angle, using 100 kilowatts of transmitter power. Neither this attempt, nor a subsequent one at the same power level from the Canberra 70-meter antenna, was entirely successful because of Galileo's close angular proximity to the Sun. Finally, controllers resorted to emergency high power, uplinking commands via Madrid's largest antenna at the rarely used 400-kilowatt power level — the highest power level used by anyone for commanding spacecraft. This time, controllers were able to verify Galileo's receipt of the command sequence.

The DSN aided attempts to free Galileo's high-gain antenna by uplinking commands to warm or cool the stubborn antenna by turning the spacecraft toward or away from the Sun, respectively; in the final few days of the year, additional commands — to turn on and off the antenna drive motors — were uplinked. Because of Galileo's distance from Earth and the availability of only the low-gain antenna, the spacecraft could only downlink data at 10 bits per second until late April. A 40-bit-per-second data rate was achieved when the Gaspra imagery was played back in May and June. The low-gain antenna's full data-rate capability of 1200 bits per second was restored in early October as Galileo approached Earth.

Mars Observer

The DSN initially acquired the Mars Observer spacecraft at X-band (8.5 gigahertz), the first application of the narrower beam signal for acquisition. Within 40 seconds of activating the spacecraft's transmitter, the DSN Canberra complex successfully acquired the spacecraft's X-band signal with its 26-meter antenna and 34-meter high-efficiency antenna. The challenge of introducing a new X-band command frequency was increased by the unexpected absence of a real-time S-band downlink signal from the spacecraft's transfer orbit stage.

The DSN compatibility test station at the NASA Kennedy Space Center had provided excellent compatibility testing and spacecraft end-to-end data flow during the Mars Observer launch. The DSN's 34-meter high-efficiency subnetwork continuously tracked the spacecraft for 30 days after the September launch and is supplying daily uplink and downlink services during the cruise phase.

< **Deep space links with spacecraft** *as well as radio and radar astronomy observations are the primary functions of the Goldstone 70-meter antenna. In 1992, the antenna provided support to Galileo and maintained contact with Ulysses during the Jupiter encounter.*

Ulysses

To accurately determine Ulysses' orbit during the Jupiter flyby in February, the DSN relied on a new navigation method called Delta Differenced One-Way Ranging — a way to quickly make precise distance measurements without degradation by charged particles. Controllers effectively navigated the spacecraft by using a quasar angularly close to Ulysses as a known reference. The DSN had developed the technique to ensure high Ulysses target accuracy at Jupiter during a period when the DSN was expected to be busy supporting the Magellan, Pioneer 12 and Galileo spacecraft

Continuous telecommunications were maintained with Ulysses during the Jupiter encounter The DSN supplied dual simultaneous coverage using the 70- and 34-meter antennas at both the Goldstone and Canberra complexes when Ulysses made its closest approach to Jupiter, at a distance of about 675 million kilometers from Earth During this period, the DSN recovered 100 percent of the spacecraft's telemetry data.

Ulysses' gravity-assist trajectory around Jupiter, which carried it out of the ecliptic plane, created a unique radio path geometry The spacecraft's radio signal passed through both sides of the torus plasma ring around Jupiter before being received by the DSN. Nonetheless, all the radio science data transmitted through the torus were successfully acquired

Following the Jupiter encounter, the DSN continued to record radio science data for the Ulysses gravitational wave experiment during the second solar opposition of the spacecraft in February and March.

Magellan

In January, the Magellan spacecraft's primary transmitter failed because of the loss of all X-band telemetry subcarriers The backup transmitter, which had a history of erratic performance, was reactivated to relay radar data, but at a lower telemetry rate To maintain radar-mapping operations, the transmitter was operated at higher temperature "plateaus."

By late April, the ability of the DSN's 34-meter antennas to acquire even the lower rate telemetry had become marginal In response, the DSN implemented a procedure in which the receiver phase shifters were manually adjusted before each acquisition period. This technique consistently improved signal detection by 70 to 100 percent

Giotto

The European Space Agency's Giotto spacecraft was successfully reactivated and its signal acquired by the DSN in May, after commands originating from the European Space Operations Centre in Darmstadt, Germany, were transmitted by the 70-meter antenna at the DSN Madrid complex. At the time, Giotto — one of five spacecraft encountering Halley's Comet in March 1986 — was 219 million kilometers from Earth. Telecommunications and data acquisition assistance to the European Space Operations Centre continued during May and June for spacecraft engineering tests, science instrument calibration and checkout, navigational ranging and trajectory correction maneuvers

During Ulysses' Jupiter flyby in February, DSN controllers effectively navigated the spacecraft by using a quasar angularly close to the spacecraft as a known reference.

Pioneer Venus Orbiter

In September, after nearly 14 years in orbit around Venus, NASA's Pioneer Venus Orbiter spacecraft was about to descend to a periapsis altitude so low as to cause atmospheric entry and termination of its extended mission. The spacecraft's power and propellant would be exhausted by this final low-altitude science phase, after which the orbiter would be destroyed by friction-induced heat.

A series of nine altitude-raising maneuvers planned by the Pioneer project at NASA's Ames Research Center began in September The DSN's 70-meter antennas at Madrid and Canberra supported the first six maneuvers, which raised the periapsis altitude from 132 to 145 kilometers Throughout this period, the DSN's 70- and 34-meter antennas collected low-altitude atmospheric data on the cloud-veiled planet

But early in October, during the seventh maneuver, the orbiter's supply of hydrazine fuel expired. A few days later, all communications abruptly ended after the spacecraft dropped to within 127 kilometers of Venus.

SAMPEX Project

In July, the first of a series of small explorer missions — designed to be highly focused and inexpensive — got under way with the launch of the NASA Goddard Space Flight Center's Solar Anomalous and Magnetospheric Particle Explorer (SAMPEX) satellite. SAMPEX's primary scientific objectives are to measure the elemental and isotopic composition of solar energetic particles, anomalous cosmic rays and galactic rays.

The DSN's 26-meter subnetwork station at Madrid initially acquired the satellite Since launch and the early orbital period, the subnetwork has executed command, tracking and data acquisition functions for a minimum of two satellite passes a day — acquiring data at a capture rate of 98.5 percent.

Network Upgrades

Goldstone Antenna Construction

In April, the DSN began construction of a new 34-meter deep space communications antenna at Goldstone — the first of a subnetwork that will contain two other identical antennas

In the new antenna design, a beam waveguide system transfers microwave energy from the usual Cassegrain focus, above the main reflector, to an accessible point within the antenna pedestal. This design permits housing several sets of electronics operating at multiple frequencies. The antenna's microwave optics, precise enough to support both Ka-band (32 gigahertz) and X-band (8.5 gigahertz), will ensure compatibility with prospective small Ka-band-utilizing spacecraft and with Cassini's radio and gravitational science experiments

Signal Processing Center

Newly upgraded equipment located at the signal processing center of each DSN complex began operational support this year. Each signal processing center provides the telemetry, command, tracking, test support and monitor and control functions for all of its complex's antennas. The upgrade will increase availability for flight project support, integrate operation of the inherited 26-meter subnetwork into the signal processing centers and meet requirements for ongoing and upcoming flight projects supported by the DSN.

Network Operations

In 1992, the efficiency and response time of controllers directing the operations of each DSN complex from the Network Operations Control Center at JPL were improved significantly by hardware and software upgrades. An open architecture with industry-standard hardware and networks was substituted for obsolescent systems. By employing the open architecture, the DSN will be able to upgrade the Center's software economically, based on future needs

The new hardware and software included controller workstations with three-screen, high-resolution color graphics monitors, a significant amount of commercial off-the-shelf software and more than 200,000 lines of JPL-developed applications software.

Goldstone Earthquake Damage

The DSN's 70-meter antenna subreflector at Goldstone returned to service a little over three weeks after being severely damaged by the Landers

earthquake in June. Despite extensive damage, the antenna resumed operations with only a temporary loss of approximately 30 percent in performance above 60 degrees elevation at X-band, the frequency used for high-rate telemetry. A plan has been adopted to protect against future earthquakes by replacing the subreflector structures of the 70-meter antennas, starting in 1995.

Architecture Studies

Mission communications strategies were developed this year for the exploration of Mars. One approach involves direct links between small landers on the Red Planet and Earth-based DSN stations; another calls for a communications relay satellite in Martian orbit as an intervening terminal between the landers and Earth stations. These alternatives are being explored in anticipation of DSN support of NASA's Mars Environmental Survey (MESUR) and the European Space Agency's MarsNet missions, which together would place up to 20 simple landers on the Martian surface between 2000 and 2004.

The missions require a relatively modest data throughput of 10 megabits per day for each lander over a full Martian year, during which the distance between Mars and Earth ranges from 70 million to 400 million kilometers. The landers' communications capability requirement is equivalent to just a few minutes of the daily traffic of a larger spacecraft like Mars Observer.

Direct links would eliminate the cost of a relay satellite and avoid a single point of failure. But they would increase lander power, weight and cost. Using a phased-array antenna in combination with the DSN's 70-meter antennas, along with suppressed carrier modulation and medium-rate coding developed at JPL, each lander could return half the data required.

A Mars relay satellite with onboard storage and playback in combination with the DSN's 34-meter antennas could meet the 10-megabit-per-day throughput requirement for each lander while reducing lander power, weight and cost. Acting as a beacon, the relay would also help in more precisely locating the positions of the landers and in targeting subsequent landers.

Communications Technology

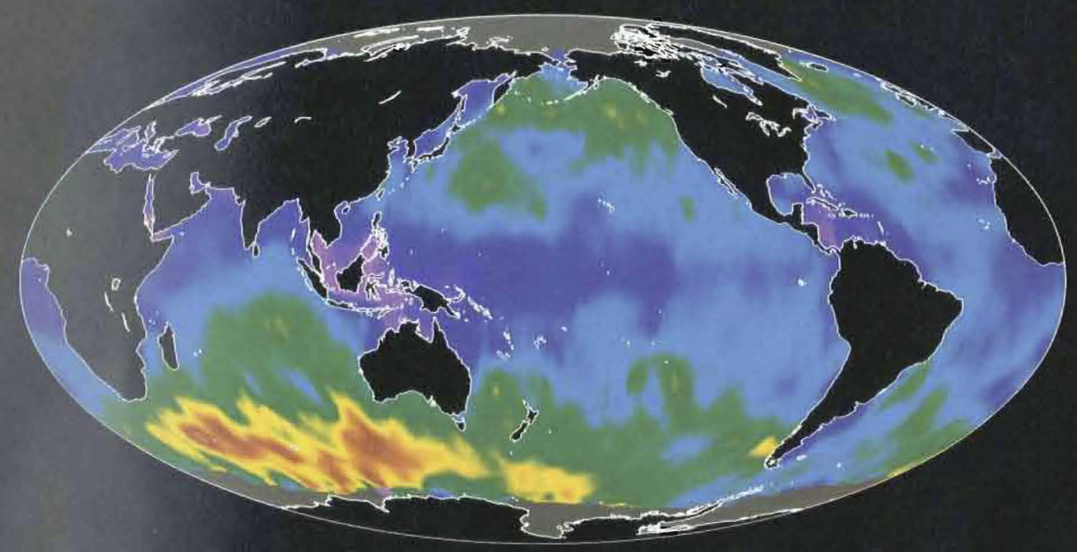
Navigation by Two-Way Ranging

The DSN demonstrated two-way ranging using a new range data filtering technique for both Galileo and Ulysses navigation that enhances spacecraft navigational accuracy by factors of four to seven. The technique was employed to detect and simultaneously compensate for spacecraft nongravitational forces in the navigation process, the effects of residual station calibration errors and uncalibrated effects due to solar plasma. Post-encounter orbit solutions using the data filtering technique were computed in 1992 for the Galileo spacecraft's first Earth encounter in December 1990 and for the Ulysses spacecraft prior to its Jupiter encounter in February of this year. In both cases, the two-way ranging data were successfully used at accuracies of 2 to 10 meters. These improved navigational accuracies will translate into lower mission operations costs or more encounters for the same mass of expendables.

Satellite Determination of DSN Coordinates

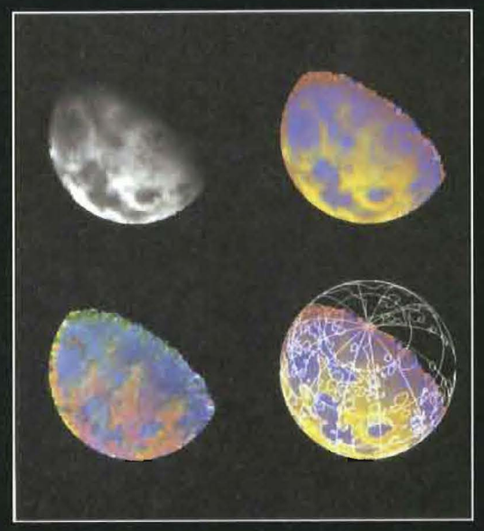
Precise tracking of Earth-orbiting and interplanetary spacecraft requires that DSN antenna locations be known accurately to within 3 centimeters. While accurate relative coordinates have been found from extragalactic radio measurements, coordinates calibrated to Earth's center of mass require very precise tracking data from Earth-orbiting satellites.

In the absence of such precise Earth orbiter data, the DSN geocentric coordinates until recently had significant geocentric biases of 50 to 100 centimeters. New data from Global Positioning System satellites have enabled coordinates to be directly measured and calibrated to an accuracy of better than 3 centimeters in the X- and Y-coordinates and better than 7 centimeters in the component parallel to the axis of rotation. The calculation incorporated corrections for numerous potential



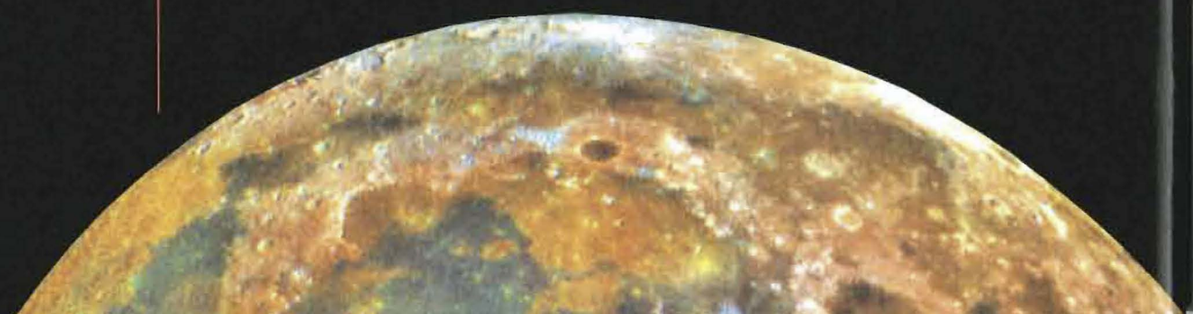
^ **This global map of wave heights was** *created from initial measurements made by the TOPEX/POSEIDON satellite. The colors indicate approximate wave heights ranging from red (8 meters), through green (5 meters) and light blue (3 meters), to pink (1 meter). Waves 8 meters high were observed in the Southern Ocean south of Australia and South Africa. The small pink square on Antarctica's shoreline is an artifact of processing. Continents appear black in the image; gray indicates an absence of valid data.*

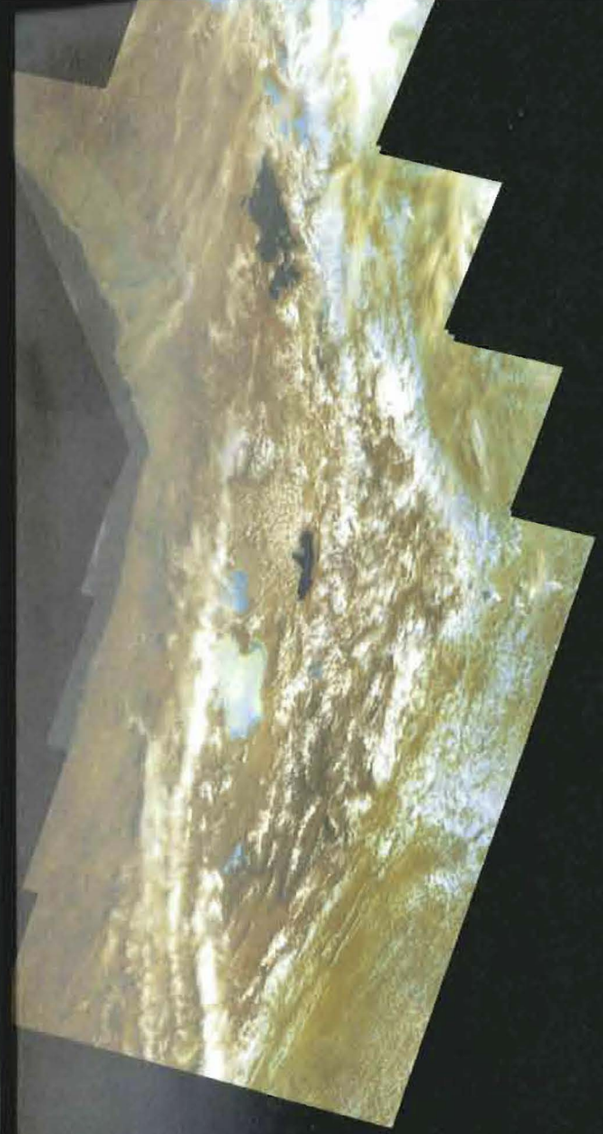
< **This false-color lunar mosaic was** *constructed from images taken by the Galileo spacecraft in December as it flew by the Moon on the way to Earth. Pink areas represent lunar highland materials, such as those surrounding the oval, lava-filled Crisium impact basin at the bottom of the mosiac. Blue to orange shades indicate volcanic lava flows.*



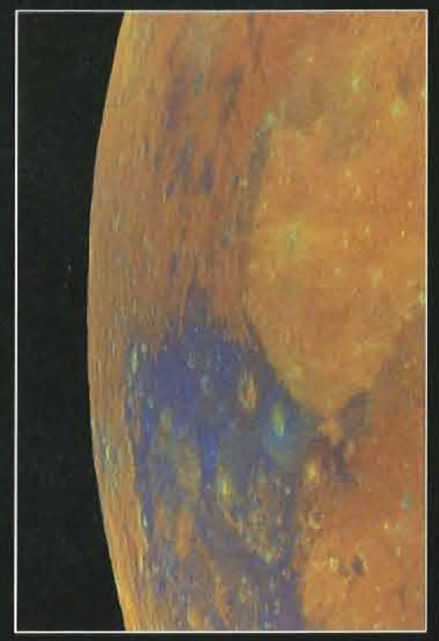
^ **Data obtained by Galileo's near-Earth** *mapping spectrometer during the December Moon–Earth flybys were the basis of these four lunar images. The black-and-white image shows lunar maria and highlands; the false-color maps, one with superimposed geological features, indicate mineralogical variations.*

v **Images acquired by Galileo from a** *distance of 425,000 kilometers were used to assemble this false-color composite of the Moon. The spacecraft was 69,000 kilometers from Earth when the onboard solid-state imaging system captured these images through three color filters. Image processing was used to aid in the analysis of the lunar surface. Pink regions are lunar highlands, while blue and orange areas represent ancient lava flows.*





v **Multiple observations by Galileo as it** *raced by on a trajectory toward Earth contributed to this false-color mosaic of part of the Moon. The images were processed to exaggerate the colors of the lunar surface for scientific analysis. Titanium-rich soils, typical of the Apollo II landing site, appear blue; the large blue region is Mare Tranquillitatis. Light orange areas contain less titanium. Most of the lunar highlands appear a darker orange, indicating that their soils have little titanium or iron.*



^ **From an altitude of 25,000 kilometers,** *Galileo captured 42 images to make up this false-color mosaic of the central part of South America's Andes mountains. Filters were used to separate regions with distinct vegetation and soil types. The mosaic shows the area where Chile, Peru and Bolivia meet. To the left is the Pacific Coast. The dark blue patches at the top and center are large lakes that lie between the western and eastern Andes. Vegetation-bearing plains to the right appear pale green.*

^ **Looking back from 1.9 million kilometers** *away, Galileo's solid-state imaging system took this photograph of Earth. In the image, Antarctica is visible at the bottom of the planet and daylight is spreading over the Pacific Ocean. Galileo is now speeding toward a 1995 encounter with Jupiter. When it reaches the giant outer planet, the spacecraft will release a probe for entry into the Jovian atmosphere; Galileo will then swing into planetary orbit for a two-year mission to explore Jupiter and its satellites.*

Optical communications systems in development at JPL will permit a spacecraft to transmit large volumes of data by aiming narrow laser beams at Earth-based receivers.

errors stemming from such factors as Earth rotation and orientation, atmospheric distortion of the satellites' radio signals and gravitational and nongravitational forces acting on the satellites, as well as various geophysical effects.

The new Global Positioning System-based estimates for DSN antenna coordinates provide a geocentric calibration more than an order of magnitude more accurate than was previously possible. Repeated over a period of months, the measurements are consistent at the centimeter level.

Antenna Phase Stability

The stability of the round-trip radio signal path between DSN stations and distant spacecraft can be a significant factor in detecting gravitational waves. A milestone in measuring this stability was reached during the year when the DSN's prototype 34-meter beam waveguide antenna was characterized to a level that is important for gravitational wave experiments.

With its reflector at 46.5- and 37-degree elevation angles, the antenna's stability at 12.2 gigahertz was measured between 1.3 and 2.2 parts in 10^{15} for measurement intervals of 1,024 seconds in fair weather. These frequency stability values apply to the entire microwave optics portion of the antenna, including the main reflector, subreflector, tripod legs and the six internal beam waveguide mirrors. The test results are the first successful measurements of the stability of the microwave optics portion of a large antenna to this level of accuracy.

Space Optical Communications

The trend toward smaller and lighter spacecraft will greatly constrain the allowable size, weight and power consumption of spacecraft systems. To meet these needs, JPL is developing component and systems technologies for optical communications that promise to be smaller, less complex and less expensive than existing technologies. The new optical systems will transmit large volumes of data using very narrow laser beams that must be precisely pointed at an Earth-based receiver by a transmitter on board the spacecraft.

To achieve the necessary pointing precision, JPL engineers are developing techniques to enable a spacecraft to acquire from deep space either a laser beacon signal radiated from an Earth ground terminal or, at great distances, Earth's image illuminated by the Sun as a natural beacon.

During Galileo's second Earth flyby, JPL succeeded in simultaneously transmitting laser signals to the spacecraft from telescopes at Table Mountain Observatory and the Air Force's Starfire Optical Range. Detection of the signals by Galileo's imaging camera was confirmed by telemetry from the spacecraft during each of the seven days of the experiment, when the distance to the spacecraft varied from 600,000 to 8 million kilometers. The experiment was still another demonstration of the feasibility of laser-based communications for deep space missions.

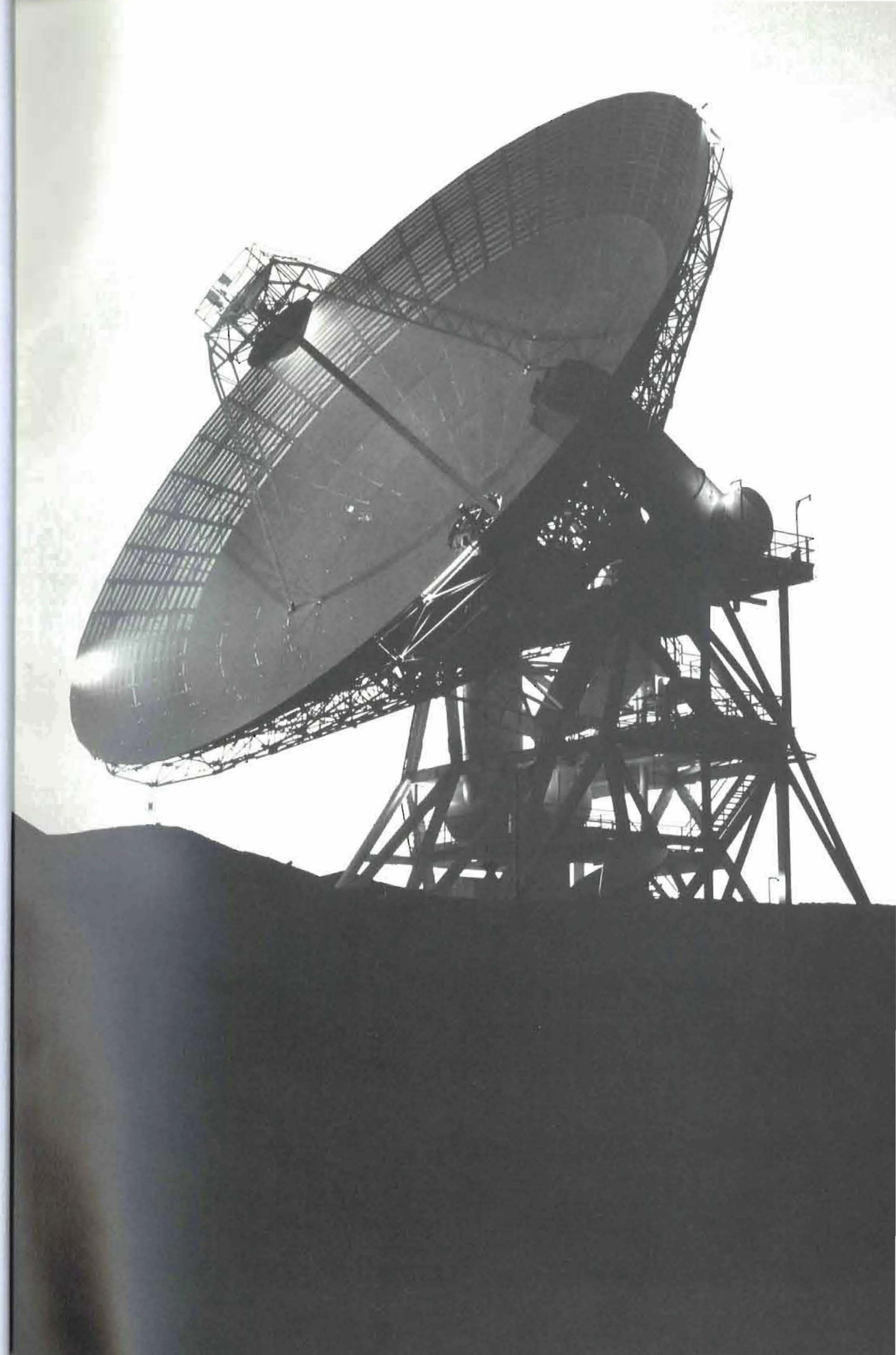
Separate component technologies are also being assembled into an integrated system that will lead to a flight experiment on the space shuttle. Slightly larger than a 2-pound coffee can, the demonstration system can transmit hundreds of millions of data bits per second to a ground receiver from an orbiting space shuttle. Innovative optical reception techniques will permit communications signals to be detected despite interference from background light as strong as the Sun's.

Link Monitor and Control Prototype

The Link Monitor and Control Operator Assistant, an artificial intelligence-based prototype intended to assist DSN operators with semi-automated closed-loop control, was tested at the Goldstone

Deep Space Communications Complex from September through November. The prototype is designed to automatically define plans for equipment setup, send messages to configure and calibrate equipment, monitor the state of a communications link, detect anomalies and assist in failure recovery.

During the Goldstone tests, the Link Monitor and Control Operator Assistant demonstrated semi-automated control of the 70-meter antenna and other equipment necessary to support very long baseline interferometry. The demonstration showed that the Assistant could reduce the amount of time required for setting up DSN antennas, thus increasing antenna availability to support a greater number of spacecraft.



> **Sky scans conducted by the** *Goldstone 34-meter research and development antenna search for possible signals from extraterrestrials. As part of the NASA High-Resolution Microwave Survey, millions of frequencies in the microwave band are being sampled using a new wideband spectrum analyzer.*

JPL's many technology developments

are directed toward increasing the capabilities and reliability of future space missions while concurrently reducing their cost. Ongoing refinements in automation, propulsion systems, microelectronics and optical techniques continue to limit mission costs and enhance science returns. For example, a rover capable of autonomous navigation is being developed to explore the surface of Mars. Also, microsensors and microinstruments that are smaller, lighter and less costly than conventional versions are being designed and built to meet space mission requirements. During 1992, progress was made in technology development for observatory-class spacecraft in such areas as vibration control, optics fabrication and control of segmented mirror shapes. The Laboratory continues to explore advanced concepts for future spacecraft, including a more efficient thermoelectric converter for producing power and navigation sensors capable of autonomously recognizing and tracking sky features like star patterns. To increase spacecraft safety and longevity, JPL conducted both flight and laboratory studies to understand the ways in which atomic oxygen causes spacecraft surface materials to degrade. In addition, space-related radiation effects that can damage onboard microelectronic components were successfully simulated employing a method considerably less expensive than traditional testing.

Advanced Technology

> **A 7-meter collimating mirror** *is being refinished with a three-axis grinding/polishing machine as part of the refurbishment of the JPL Large Space Simulator.*

Below: In a microdevices fabrication process called silicon micromachining, silicon wafers are chemically etched after patterning to create tiny structures.

Space Automation and Robotics

Through its Automation and Robotics Program, JPL contributes to the development and application of technologies in knowledge-based systems, telerobotics and roving vehicles. These technologies make possible innovative missions, provide tools for reducing costs of mission operations and data analysis and lead to improvements in safety.

Artificial Intelligence Tool

JPL is developing a new generation of intelligent, trainable systems for dealing with the huge volumes of scientific data collected by modern instruments. Such systems help to enhance, and reduce the costs of, mission operations and data analysis.

In 1992, the Laboratory collaborated with the Caltech Campus in the development of an artificial intelligence system, called the Sky Image Cataloging and Analysis Tool, to assist in classifying objects in a photographic survey of the northern sky conducted by the Caltech Campus. From this survey, astronomers hope to generate a comprehensive catalog of sky objects like stars and galaxies. The survey has yielded 2,000 digitized images containing over 100 million sky objects — a forbidding task of visual classification.

The tool permits analytical tasks that once would have taken several years to be accomplished in a few hours. Through the application of learning algorithms to astronomer-created training data sets, the system generates robust classification rules. Its object classification efficiency of 94 percent matches that of a human. Also, using training data obtained from high-quality images in a small portion of the survey coverage, the system can classify objects in the survey images that are at least one visual magnitude fainter than humans can recognize. This heightened perception yields roughly triple the number of cataloged sky objects that would be available through traditional means.

Telerobotics

JPL develops telerobotic systems to perform remote operations under the surveillance and command of human controllers. This year, the Laboratory demonstrated the feasibility of a ground-controlled telerobot performing surface inspections on Space Station Freedom. By automatically comparing new images to previously stored ones, the telerobot can discover any flaws or differences appearing in the space station's surface. It can automatically scan known surfaces, or a ground-based operator can guide the sensor-bearing, 7-degrees-of-freedom robot arm to take a closer look at potential defects from different angles and under varied lighting. In tests, astronauts have found the system easy to learn and operate.

The ground-based operator uses a high-level command interface to help plan and graphically simulate telerobot movements. The operator can also update the telerobot's knowledge of the worksite and calibrate its location by video feedback. Once movements are planned and simulated, commands are sent to the remote site where the telerobot executes the task while its behavior is monitored and controlled by an operator through sensor feedback.

In another telerobotics demonstration, JPL established the feasibility of installing a robotic system to inspect satellites in large vacuum chambers. Under development is the Satellite Test Assistant Robot for use in JPL's 7.6-meter space simulator. Able to acquire stereo images using a platform-mounted camera with pan, tilt and zoom capability, the system will allow operators to view test articles from all directions, provide infrared images from any view angle and automatically map the simulated solar radiation intensity over the entire work volume of the chamber.

Rover

At midyear, a rover maneuvered about a simulated Martian terrain in the Arroyo Seco, an area adjacent to JPL, to demonstrate how rover technology

< **In the Microdevices Laboratory,** *patterns are developed in photoresist after it has been deposited on a silicon wafer. Through electron-beam lithography, electrons are used to "expose" the photoresist, thereby creating microdevice structures as narrow as 10 nanometers in width.*

could perform on a Mars science mission The small 10-kilogram robot, named Rocky IV, was released from a simulated landing vehicle Navigating by sensors and algorithms that allow it to avoid obstacles, the six-wheeled rover moved from one point to another as instructed by an operator.

When Rocky IV reached a rock of interest, its onboard spectrometer obtained a spectrum of light reflected from the rock to determine its composition; the rover then chipped off the rock's outer layer and obtained a spectrum of the freshly exposed surface. As part of the test, the rover scooped up a soil sample and returned it to the landing vehicle. This demonstration showcased most of the capabilities for robotic autonomy desired on a Mars mission given the long time delays and narrow bandwidth of communications signals from Earth.

Center for Space Microelectronics Technology

The Laboratory's Center for Space Microelectronics Technology, a joint enterprise of NASA and the Department of Defense, conducts research and development in space microelectronics The Center concentrates on innovative, high-risk and high-payoff concepts and devices with the potential for significantly enhancing both current and future space missions Following proof-of-concept demonstrations, technologies are turned over to engineering development areas at JPL, to Government laboratories or to industry

Because several of the Center's inventions have significant commercial potential on Earth, the Undersecretary for Technology of the Department of Commerce recently joined the Center's governing board to help develop new ways to work with industry in an effort to boost U.S industrial competitiveness Additionally, the Director of the Department of Energy (DOE) Office of Space was added to the board to accelerate technology transfer as outlined this year in the National Technology Initiative Partnership between JPL and three DOE laboratories

In entering into the partnership with the three DOE facilities — Lawrence Berkeley Laboratory, Lawrence Livermore National Laboratory and Sandia National Laboratories — JPL is participating in the effort to help U.S. industry meet the challenges of technology-driven competitiveness in the 1990s and beyond. The partners will pool resources and facilities to work with U.S. industry in such areas as new products, materials and processes, accelerated design and production cycles, work force productivity and skills and environmentally sensitive manufacturing processes

Microsensors and Microinstruments

The Laboratory has become a leader in research in microsensors and microinstruments, including microseismometers, tunneling infrared sensors, microscale weather stations, hygrometers and microscale optics

Conventional seismometers, which detect ground motion, are too large and too heavy to use in upcoming space missions, such as the Mars Environmental Survey (MESUR) To meet space mission requirements, JPL developed the first microseismometer that utilizes a silicon mechanical system and a unique high-resolution capacitive position sensor. Prototypes of this sensitive device exhibit performance exceeding that of conventional seismometers of more than 50 times greater mass

In a test this year, a capacitive microseismometer was buried in a borehole 2,286 meters below the ground surface at China Lake Naval Weapons Station The device's performance was superior to that of other seismometers installed at great depths (i e, greater than about 300 meters)

JPL is developing sensors for a microscale weather station intended for use on the surface of Mars as part of the prospective MESUR mission — and for use in the upper atmosphere of Earth A new hygrometer, developed for the Mars mission but suitable for commercial and industrial applications as well, rapidly measures dew point with high accuracy and low sensitivity to contamination

In addition, a micromachined pressure sensor is being developed for long-term atmospheric pressure measurements on Mars. The sensor will feature high-pressure and low-temperature sensitivity, low mass and low power consumption.

A miniature temperature sensor is also being developed based on a micromachined, low-mass structure supporting a platinum wire resistance thermometer.

A new program aimed at fabricating novel binary optical elements — devices that make use of diffractive optics within a thin film — employs electron-beam lithography to repeatedly expose a polymer film. A chemical-developing process then removes polymer from the film surface in proportion to the amount of each electron-beam exposure With four separate exposure patterns, researchers were able to fabricate and subsequently test optical structures such as a Fresnel lens with 16 levels of etching. Planar optical elements are important for miniature optical systems in imaging and spectroscopy

Electronic Neural Networks

Fine-grain, massively parallel computing and information processing based on models of biological neural networks are research areas of great interest to JPL Conventional digital computers primarily use a single processor to serially execute logical steps of a given task. By contrast, artificial neural networks consist of many nonlinear processors (neurons) operating asynchronously and simultaneously, interacting with each other through complex networks of interconnections (synapses). Such networks mimic the way the human brain operates

The unique properties of these networks are ideally suited to solving a variety of complex processing problems that involve unclear information or distorted situations, for which conventional processing methods are often time consuming, cumbersome or simply nonexistent The "neuro-processing" approach is particularly attractive when a near-optimal solution is acceptable, instead of the most accurate solution available after a long calculation process

In collaboration with Caltech Campus researchers, JPL is actively investigating a broad range of neural network applications of interest to NASA and the Department of Defense. The applications include multispectral data classification, robotic control, resource allocation, planetary rover path planning, weapon target assignment and multi-target tracking.

JPL is transferring its neural network hardware technology to U.S industry For example, the Charles Stark Draper Laboratory and McDonnell Douglas acquired JPL-developed technology during the year, discussions with other companies are under way

Ultraviolet and X-Ray Charge-Coupled Device Imaging Sensors

A new technology for enhancing the quantum efficiency of silicon charge-coupled device imaging sensors in the ultraviolet and low-energy X-ray wavelength regimes has been demonstrated at the Laboratory Without special treatment, imaging sensors do not respond to light at these wavelengths. In 1992, JPL modified such a charge-coupled device by adding a very thin layer of crystalline silicon containing a monolayer sheet of boron atoms.

The modified device exhibits a quantum efficiency corresponding to the theoretical limit imposed by the reflection of light at the silicon surface With the addition of an antireflection coating, the new charge-coupled device more than doubles the stable efficiencies of existing devices at ultraviolet wavelengths. This advance permits the use of this device for low-energy X-ray imaging — a wavelength regime to which previous charge-coupled device surface treatments could not be extended.

Astronomers believe emissions at these short wavelengths could offer insights into the structure of the universe and of its galaxies and stellar systems, as well as illuminate many fundamental physical processes governing these systems.

Advanced Optical Systems Technology

JPL is actively developing technology for advanced optical systems such as large ultraviolet and visible light telescopes, cryogenically cooled infrared telescopes, submillimeter wavelength receivers and long baseline optical interferometers. This technology, required by NASA's long-range plan, is applicable to new observatories in space and perhaps on Earth's Moon, where performance is not re-

stricted by atmospheric effects as it is on Earth or in lower Earth orbits The program also seeks affordable technical solutions adaptable to the special requirements of space operations.

JPL made progress this year in the development of optical-system design tools and specialized submillimeter mirror materials; the fabrication of ultra-smooth, low-scatter optics, the suppression of vibration in precision space structures, and the control of segmented mirror shapes. Some of these technologies, which have been applied in new instruments to correct optical flaws in the Hubble Space Telescope, promise expanded capability, improved performance and reduced cost for NASA missions

Control-Structures Interaction

Studies of future NASA missions requiring precision optical systems indicate the need for optical alignment stability on the order of one-billionth of a meter — 1,000 times that of current technology To achieve such stringent stabilities, researchers are developing active and passive design and control techniques to reduce vibrations in the optical train by factors of 1,000 to 10,000.

Recent experiments demonstrate that a novel approach developed at JPL, named Control-Structures Interaction Multilayer Architecture, can meet these goals. A dedicated ground test facility is investigating the blending of control layers, or feedback loops, for achieving greater stability Current investigations use three such layers — vibration isolation, active/passive structural quieting and optical element compensation.

Disturbance energy is intercepted at the source via vibration isolation, along the transmission path via structural quieting and at the destination via high-bandwidth optical compensation Each layer of control is tested in operation independently as well as successively. Experiments with all layers in operation simultaneously have demonstrated a vibration attenuation factor exceeding 5,000.

Equally important is the level of operational jitter stability, which is critical for optical systems Preliminary results show that the optical pathlength can be stabilized to a very impressive level of five-billionths of a meter root-mean-square — far exceeding original expectations for the initial experiments. These unprecedented levels of precision and stability will eliminate vibration-induced image distortion in lightweight space optical systems such as interferometers, which must maintain the distance between widely separated optical elements to within a few billionths of a meter

A flexible, flight-like test structure, measuring 7 by 6.8 by 55 meters and weighing only 200 kilograms, is being developed for integration of the multilayer architecture techniques with interferometer technologies; the goal is to demonstrate the applicability of the vibration reduction techniques to space missions These techniques could then be applied to specific space-based interferometric missions or other projects having similar challenging requirements.

Telescope Technology

Future NASA astrophysical missions will require large, lightweight, multisegmented reflector systems for deployment in space or on Earth's Moon JPL is developing the materials, structures, optics and controls technologies to make such systems possible. For lighter reflectors, the Laboratory will switch from glass optics to composite materials in new systems. In 1992, significant advances were made in composite materials, structures, fabrication techniques, optical test methods and mirror segment position sensing and control.

In a significant demonstration, the Laboratory used a new cyanate-based composite material in manufacturing 1-meter mirror panels with thermal and dimensional stability in the range of one part in a million — even at temperatures as low as 100 kelvin and at radiation levels as high as 1 billion rads. Yet the panels weigh only one-half to one-third as much as comparable glass optics. The new composite materials are also easier to process, have better moisture resistance and are virtually free of microcracking at cryogenic temperatures All of these properties are critical for achieving long-term dimensional stability and optical performance in a space environment.

Ten years of research have led to the routine manufacturing of 1-meter composite mirror panels with highly curved surfaces (3-meter radius-of-curvature). One manufactured unit displayed a root-mean-square surface figure error of less than four-millionths of a meter. In addition, a technique for polishing the panel surface reduced the as-manufactured figure errors by as much as two and a half times.

A complete alignment system architecture controls the very precise alignment of the segmented panels relative to one another once they are mounted in a telescope structure. For segmented mirror systems to achieve optical performance similar to that of monolithic mirrors, they must be actively aligned to extreme levels of precision JPL has developed a system architecture designed around a two-stage process· The alignment is first initialized using a natural reference target, such as an unresolved star, and then it is maintained with onboard laser metrology. JPL also demonstrated the feasibility of using science instruments for initialization, thereby eliminating the need for special-purpose figure-sensing hardware

During the year, an alignment technique using the system architecture achieved an optical performance of 99.96 percent with respect to the ideal telescope segment alignment, even with disturbances due to actuator and sensor noises in the positioning system Between initializations, alignment was maintained at 99 percent of the initialized optical performance using a sophisticated laser metrology system. In related work, a fiber-optic-based sensor, integrated into an actuator proof-of-concept breadboard, demonstrated the feasibility of detecting panel motions as small as ten-billionths of a meter in an alignment-maintenance subsystem configuration

These technologies and techniques are being developed primarily for submillimeter-telescope use but will be fully extendable to segmented telescopes for any wavelength

Optical systems technology being created at JPL is applicable to new observatories in space and perhaps on Earth's Moon, where performance is not restricted by atmospheric effects.

Advanced Spacecraft Technologies

Ongoing research at the Laboratory is producing new technologies for less costly and more capable, reliable and efficient spacecraft for future space missions throughout and beyond the solar system Advances in such areas as spacecraft power, propulsion, communications, computing and data systems, pointing control and materials will increase by a factor of 10 to 1,000 the potential science returns from future NASA space missions.

Alkali Metal Thermoelectric Converter

A novel technology is under development at JPL that can convert heat in the range of 700 to 1,000 degrees Celsius into electricity. This advanced energy conversion system, called the Alkali Metal Thermoelectric Converter, will greatly reduce the weight of spacecraft power systems or provide significantly more power for the same weight, depending on how this technology is applied.

The converter is a continuously operable electrochemical cell that uses sodium as the working fluid Sodium ions are conducted across a solid electrolyte from a high-temperature, high-pressure source to a low-temperature sink, generating electricity in the process. In long-term tests begun last year, a prototype cell has operated nearly 2,000 hours, producing power at better than twice the efficiency of thermoelectric converters aboard current spacecraft Further testing is expected to demonstrate the feasibility of using this technology for long-duration deep space missions

Electric Propulsion Ion Engine

Future solar system exploration missions will emphasize shorter trip times, smaller launch vehicles and reduced cost. These needs will be met using the electric propulsion technology currently under development at JPL.

Ion engines produce thrust when electrically charged propellant — such as xenon — is accelerated through a nozzle to a typical velocity of 50,000 meters per second. These engines use much less propellant than even the most advanced chemical engines, their high efficiencies will be the key to more ambitious deep space exploration missions

This year, JPL successfully applied an innovative test technique to substantially reduce the cost of life-testing ion engines for the 5,000 to 10,000 hours typically required to perform a planetary mission with electric propulsion. A 900-hour trial of a xenon-fueled ion engine measured the wear rates of the engine's ion-accelerating electrodes The test was the longest ever run at input power levels greater than 5 kilowatts Additional engine tests of 5,000 to 10,000 hours are scheduled to start next year. A new ion engine test chamber, 3 meters in diameter by 5 meters in length, with a pumping speed of 180,000 liters per second, was constructed at the Laboratory to perform these tests

Autonomous Star Tracker

As a leader in image-based pointing technology, JPL is pioneering in the development of opto-electronic tracking and pointing sensors capable of autonomously identifying and subsequently tracking sky features such as star patterns or unusual planetary features. The Laboratory has already successfully flown a solid-state star tracker on the space shuttle and is now expanding the sensor's capabilities

In 1992, Laboratory scientists demonstrated autonomous star pattern identification with new star tracker hardware and software at the Table Mountain Observatory Patterns in observed star fields were identified in real time, without the sensor system having prior knowledge of the targets

When completely developed, this technology will have a dramatic impact on the basic operation of spacecraft and space-based instruments Autonomous identification of guide stars will provide more efficient, robust and independent modes of attitude determination and recovery from loss of attitude information Although attitude determination is a recurring problem with today's spacecraft, future trackers will allow scientific instruments to track points of interest easily and will eliminate the need for tedious mosaicking and overlap matching of scientific target images.

Other Technological Advances

Drop Physics Module

The Drop Physics Module flew on board the space shuttle in June as part of the first US Microgravity Laboratory (USML-1) The module supported a series of fluid dynamics experiments performed in the nearly gravity-free conditions of space This research will lead to more sophisticated fluid science experiments and eventually may enable the development of important new materials in space. Studies made possible by the module will also provide research data that may be applied to the development of fuel-containing pellets for nuclear fusion reactors, the design of time-release medicines and the manufacturing of food, drugs, chemicals and plastics that go through liquid stages in their production cycles.

Lambda-Point Experiment

In October, the space shuttle carried the Lambda-Point Experiment into orbit as part of the first U.S. microgravity payload. The experiment tested the Nobel Prize-winning theory of physicist Kenneth G Wilson as the theory applies to the behavior of helium at its critical temperature. In the experiment, the heat capacity of liquid helium was measured as it changed from a superfluid to a normal fluid near 2 degrees above absolute zero This transition from the superfluid phase is called the lambda transition because the shape of helium's specific heat curve near the transition point resembles the Greek letter lambda (λ).

The experiment enabled scientists to measure the dramatic increase in heat capacity predicted by the theory with an accuracy 100 times that of an Earth-based experiment. Employed in the experiment were Stanford University-developed thermometers sensitive to billionths of a degree and JPL-developed, 2-kelvin cryogenics technology. Initial science results will be available in early 1993 Extremely accurate demonstration of the theory is important in determining the scope of its application to similar critical-point questions in condensed-matter physics, particle physics and lattice-gauge theory

JPL was responsible for the overall management, integration and environmental testing of the experiment This was the second in a series of fundamental physics investigations using the Laboratory's space-qualified, low-temperature research facility. New experiments are planned for 1995 and 1999.

Atomic Oxygen Testing

Many spacecraft materials, reacting to conditions in space, can be degraded Since the earliest flights of the space shuttle, NASA has studied the effects of atomic oxygen on spacecraft materials. Several JPL flight experiments have investigated reaction mechanisms in space and the degrading effects of atomic oxygen on various materials

The experiment called Evaluation of Oxygen Interactions With Materials, conducted aboard the space shuttle in August, offered the latest evidence substantiating the models of atomic oxygen interaction developed by JPL researchers. Flight data contained conclusive proof of a stepwise oxidation mechanism for kapton and other materials in low Earth orbit. A JPL-developed model identified two reaction mechanisms accounting for the direct reaction of atomic oxygen with elemental carbon

Collisions of atomic oxygen with surfaces of the space shuttle and other spacecraft at orbital velocities not only degrade materials but cause surface glow and gas-phase collisions, leading to glowing clouds that follow spacecraft To study these phenomena, JPL has the world's only facility capable of simulating the atomic oxygen found in low Earth orbit

Recent Laboratory results confirm that atomic oxygen reacts with adsorbed gases — nitric oxide, hydrazine and hydrogen cyanide — on surfaces to produce excited states of nitrogen dioxide, nitrogen hydride radicals and cyanide radicals, respectively Emissions from these molecules were confirmed by observations from the space shuttle. Researchers are studying the oxidation and reaction of silver, kapton and polyethylene and observing non-light-emitting reaction products

These oxidation and reaction studies have direct bearing on the expected design lifetime of spacecraft and satellite components in low Earth orbit A data base of atomic oxygen effects is now available for use by spacecraft designers in selecting degradation-resistant materials The knowledge of how atomic oxygen interacts with spacecraft materials has already been applied to ongoing missions such as Magellan to identify vulnerable spacecraft components.

Single-Event Effects Simulator

In 1992, the Laboratory introduced an inexpensive technique for simulating and pinpointing specific sources of certain deleterious effects of radiation on spacecraft electronics. The sensitivity of microelectronic parts to the group of space radiation effects collectively known as "single-event effects" has long been a major concern for NASA flight projects. These effects can cause problems ranging from minor data acquisition errors to catastrophic failures

Traditional testing for these effects is very expensive, requiring the use of energetic, heavy ions produced at large nuclear particle accelerators to simulate galactic cosmic rays found in the space environment JPL's alternative to traditional testing employs the radioactive isotope californium-252 (Cf-252), which fissions spontaneously, as a source of relatively energetic fission fragments that produce single-event effects in microelectronic chips. The Cf-252 simulator system is relatively simple, requiring only a vacuum chamber and appropriate electronics plus the radiation source

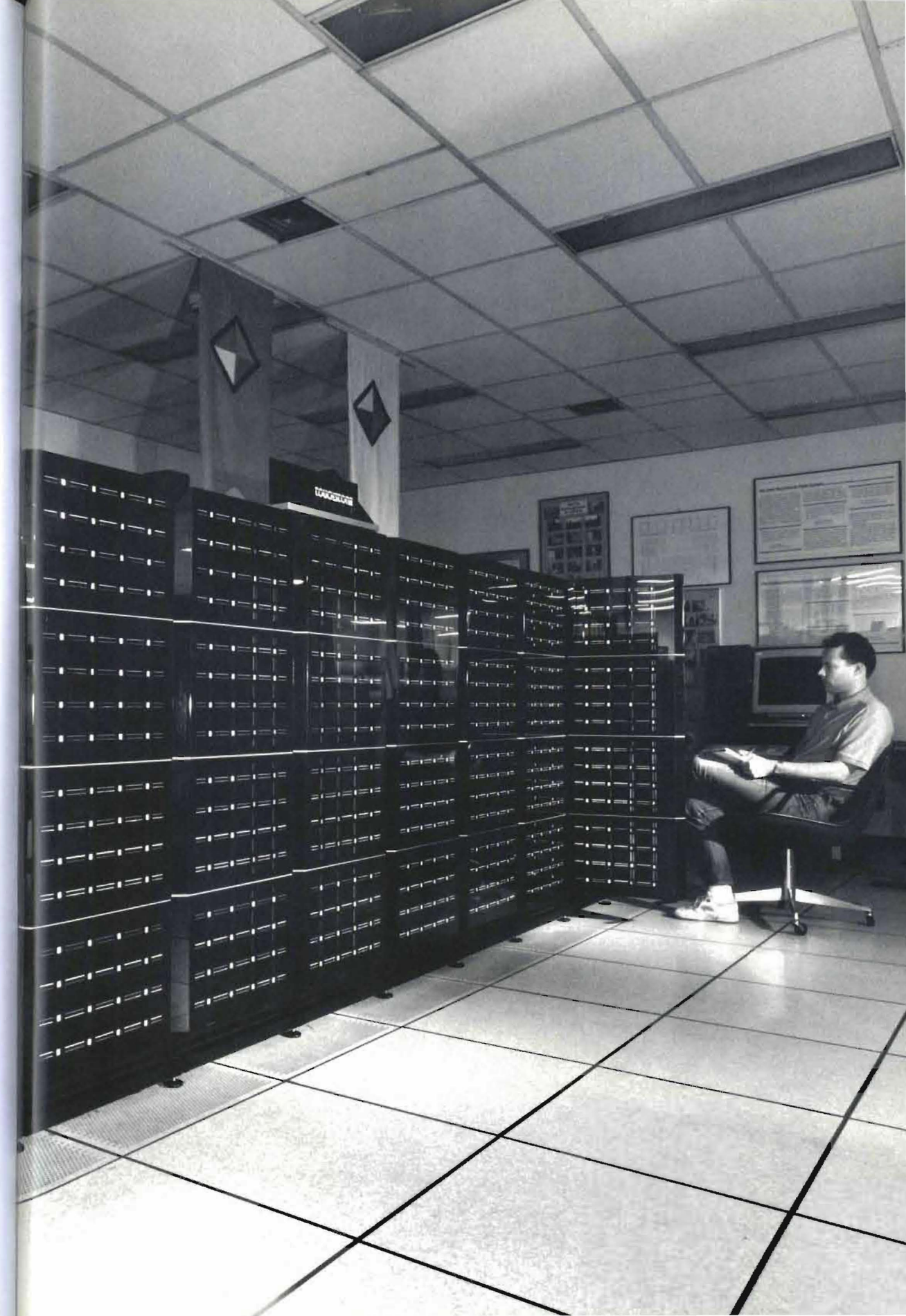
Because the fission process produces many isotopes with different masses and energies, JPL has added a capability to the Cf-252 apparatus that permits measurement between two detectors of the flight time of each fission fragment. From this additional information, the specific isotope causing a single-event effect can be identified JPL is the first laboratory to successfully use this time-of-flight technique to perform tests of single-event

effects. In the short time it has been operational, the Cf-252 simulator system has reduced costs for flight projects by eliminating the need for more costly accelerator testing of radiation-vulnerable parts.

High-Speed Spacecraft Simulation

The simulation of data operations on a bit-for-bit basis to test and validate planned sequences of flight events for advanced spacecraft has become feasible with the emergence of supercomputers. In a demonstration of this prospect, JPL has programmed a Silicon Graphics 4D/480 multiprocessor computer to host the simulation of the Galileo Command and Data Subsystem.

Through the use of reduced instruction set computing technology and parallel processing architecture, along with the Galileo flight software, the test system simulates the six microprocessors and two buses of the spacecraft data system 10 times faster than the spacecraft's system itself. Thus, the simulation system can test planned spacecraft command sequences before they are executed in space. The system is intended to support the development of flight software for the Galileo mission and sequence validation for the Cassini mission.



> **Among the fastest supercomputers** *in the world, the Intel Touchstone Delta is used by JPL and Caltech to carry out computationally intensive science and engineering applications. The 568-node Delta system is operated by Caltech for the Concurrent Supercomputing Consortium.*

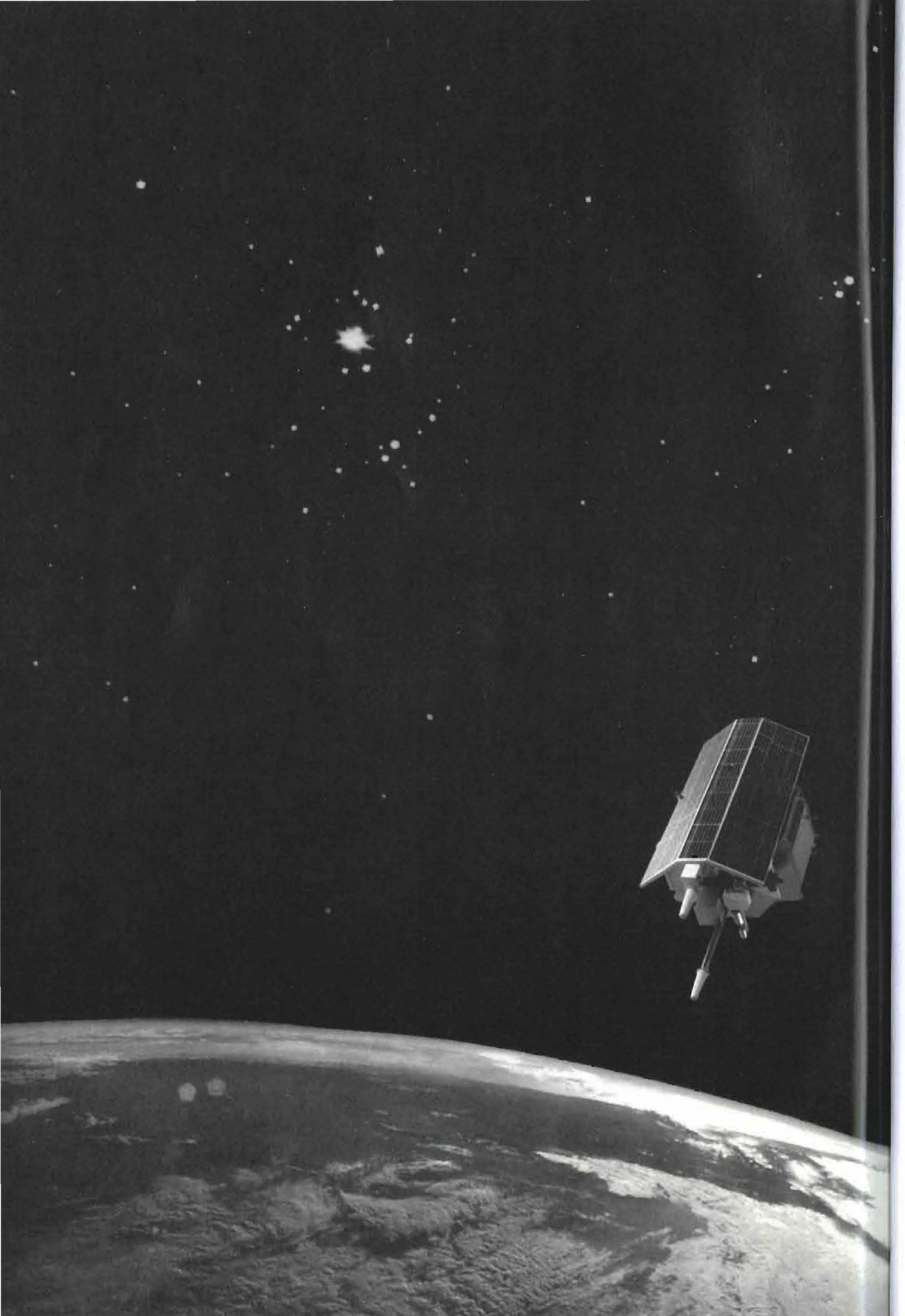
JPL's technical applications projects

make important contributions to the national interest and assist industry in developing advanced scientific and engineering technology for commercial use. In 1992, JPL's unique mix of technical and project-management skills were applied in work for sponsors such as the Department of Defense, the Department of Energy and the Federal Aviation Administration; at the same time, technology commercialization activities were expanded significantly. As part of the Strategic Defense Initiative, JPL and its subcontractors developed a low-cost satellite in only 12 months. A spacecraft nuclear power project was reoriented to accelerate development and reduce cost. After Army certification, a computer-based system for analyzing battlefield intelligence was deployed for operation in the field. In programs to improve the nation's air traffic system, a weather-data processor passed user testing and JPL developed enhancements to the simulation unit for evaluating a voice switching and control system designed for aircraft controllers. Using a rapid deployment approach, the Laboratory made its fourth delivery of elements of a command and control system to the U.S. European Command. In a delivery of remote-sensing technology, the U.S. Forest Service received an infrared system for detecting and mapping wildland fires.

Applications Projects

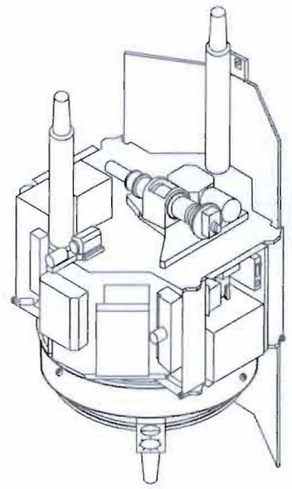
> **A nondestructive optical thin-film** *measurement system allows researchers during microdevice processing to determine the thickness of photoresist layers at specific locations on wafers.*

Below: In the interest of U.S. industrial strength, JPL is giving increasing attention to adapting microelectronics technology and techniques to commercial uses.



Miniature Seeker Technology

The November launch of the first Miniature Seeker Technology Integration (MSTI) satellite aboard a Scout solid-propellant rocket from Vandenberg Air Force Base signaled the success of new management practices that could be applied to other low-cost flight projects at JPL. The satellite mission was the first in a proposed series of flights intended to place miniature cameras in Earth orbit to detect missile launches. After orbit insertion, the small satellite began mission activities; data returned from the payload were processed by the Laboratory. All objectives were met and the mission was considered a success.



< **Low-cost, rapidly developed missions,** *such as the Miniature Seeker Technology Integration (MSTI) satellite, control costs by using existing designs as well as new technologies. Successful management of the MSTI project demonstrated JPL's capabilities in this area.*

Sponsored by the Department of Defense's Strategic Defense Initiative Organization, the project was an innovative attempt to apply managerial and technical approaches to develop better spacecraft more quickly and at lower cost. Only a year elapsed between contract initiation and launch. JPL and its subcontractors — Spectrum Astro, Inc., and Integrated Systems, Inc. — procured and assembled the spacecraft components and delivered them to the Air Force Phillips Laboratory for systems integration and testing.

The project rigorously adhered to aggressive schedule milestones. Use of existing hardware to reduce nonrecurring design costs was encouraged, and suppliers were allowed to use their own processes and procedures to reduce overall procurement costs. As a result, 83 percent of the hardware procured did not require modification and was delivered and accepted using the developers' processes and reliability standards. In addition, the project mandated clean subsystem interfaces and froze the design early in the development cycle. The use of engineering time was strictly controlled. By adopting these procedures, JPL delivered the satellite under budget.

Space Nuclear Power

The Space Power-100 (SP-100) project, which is developing key components of a nuclear reactor power system for planet- and asteroid-exploring spacecraft, was reoriented this year toward a goal of producing a less expensive system sooner than previously planned. The system uses a thermoelectric converter to transform heat — generated by a nuclear reactor — into electricity. An array of thermoelectric cells in the converter produces approximately 25 times the power of a radioisotope device aboard the Galileo spacecraft.

Sponsored by the Department of Energy and NASA, the reoriented project provides an opportunity to use first-generation technology — expected to be ready in 1994 — to support a mission as early as

Innovative techniques allowed JPL to develop the Miniature Seeker Technology Integration (MSTI) satellite in only 12 months for the Strategic Defense Initiative Organization.

1998, six years sooner than originally planned. The first-generation technology will be heavier and have a shorter operational life than the second-generation technology originally used as a guideline. Besides supporting an earlier flight, the reoriented project will save an estimated $17 billion by combining qualification and acceptance tests, deleting a nuclear ground test, reducing the size of the reactor and completing the program in less time than previously allotted.

During 1992, the project finished most of the reactor development, including testing the fuel pins in an environment approximating end-of-mission conditions, fabricating all uranium nitride fuel pellets and testing niobium-zirconium material in a flowing lithium test loop for over 4,000 hours. The latter testing is a significant accomplishment given the difficulty of transporting the lithium working fluid at extremely high temperatures in refractory metal tubes containing many welded joints.

NASA is investigating a number of potential missions late in the decade as candidate applications for the space power system.

All Source Analysis System

The All Source Analysis System is a tactical Army intelligence system employing computer and communications technology to automate intelligence analysis processes that were previously performed manually A test version of the JPL-developed system was delivered to the Army in late 1991 for formal evaluation by military specialists at Fort Hood, Texas

This year, JPL assisted the Army in performing two critical tests of the system: the Force Development Testing and Experimentation, a process of developing and refining operational and maintenance concepts, followed by the Initial Operational Test and Evaluation The All Source Analysis System passed these tests successfully and was then placed in the field with specific Army units. Plans for continued deployment of the intelligence system remain on schedule.

JPL will continue to train Army field personnel in the system's use and instruct the Army's new-equipment training teams in assuming most of the anticipated military training duties. JPL is also helping the Army to take over operation and maintenance of both system hardware and software as the Laboratory phases itself out of the program over the next few years

Voice Switching and Control System

JPL is assisting the Federal Aviation Administration (FAA) in the development of the Voice Switching and Control System, a vital communications link for the agency's planned air traffic controllers workstation complex. This complex assesses the position and safety of sensors by which controllers establish air traffic flow and control The telephonic links of the Voice Switching and Control System allow the controllers to communicate with one another and with pilots in flight in an effort to increase the efficiency and reliability of the National Air Traffic Control System.

Prior to 1992, JPL and the FAA jointly developed the original voice system specification along with the complete proposal request package. JPL defined the original touch-entry display concept for the FAA's two prototype contractors and also helped the agency with technical assessment in the source selection for both the prototype and production phases of the project The Laboratory monitored the contractors' technical progress and developed an independent test system called the Traffic Simulator Unit This unit simulates air traffic controllers to exercise the Voice Switching and Control System at rates up to double its intended usage and provides near-real-time analyses of the results.

In 1992, JPL supported the FAA in monitoring the production contractor's performance and developed the final enhancements to the Traffic Simulator Unit for testing performance of the production version of the Voice Switching and Control System

Real-Time Weather Processor

In January, the FAA successfully completed a formal systems acceptance test of the prototype Real-Time Weather Processor developed by JPL. The processor is an integral part of the National Airspace System Plan to upgrade the U.S. air traffic system A month later, FAA meteorologists and air traffic controllers tested and evaluated the prototype at JPL, thereby completing, on schedule and under budget, all milestones in a five-year development of the processor's hardware and software.

The FAA has asked JPL to deliver the prototype to the National Center for Atmospheric Research in Boulder, Colorado. The Center and JPL will jointly evaluate advanced weather products using the processor, which will be connected to advanced weather radars being deployed in the field by the National Weather Service and the FAA

The Real-Time Weather Processor, comprising 14 interconnected Digital Equipment Corporation computers, is to be deployed at each of the FAA's 23 Air Traffic Control Centers. Using this advanced technology, air traffic controllers will be able to view, in near-real time, a mosaic of weather data from up to 27 advanced radars, which detect clear-air turbulence for en route flights

EUCOM Command Center

JPL has been developing for the U.S European Command (EUCOM) a command and control system that integrates information from approximately 100 communications and automation systems for use by a commander and staff. Located at EUCOM's headquarters at Patch Barracks near Stuttgart, Germany, the system contains numerous servers and workstations and offers features such as automated message handling, map and text manipulation and data base management; briefing and display equipment are interconnected by high-speed local area networks. The Command — which is responsible for managing humanitarian relief efforts, treaty monitoring, military activities and European troop reduction operations — will use the automated system to distribute messages, generate briefings and prepare, coordinate, and release situation reports

During 1992, JPL completed the fourth hardware and software delivery to EUCOM, thus providing users with an evolutionary growth in system capability The four deliveries have successively increased the system's functions and equipment, which are currently supporting relief efforts in Somalia and Nigeria.

Command and Control Support Agency

The Laboratory is modernizing and automating a large and complex command and control center system for the Army Command and Control Support Agency in the Pentagon. The system is part of a facility that continuously monitors worldwide political, military and economic events and tracks and responds to national emergencies. The command and control system, which provides 24-hour-a-day support to the agency's critical missions, integrates many functions including automated message handling, map graphics, briefing and display data, communications with the World Wide Military Command and Control System, data management and office automation.

After getting under way last year, the JPL project has combined a previously disparate array of networks into a single information network with a common set of user application programs. This year, the project successfully installed two additional components — a briefing and display system and a map graphics unit. These new capabilities found unexpected application during the Los Angeles civil disturbance in April and again during disaster relief activities in the aftermath of Hurricane Andrew in southern Florida during September

Analysis and Training Systems

In previous years, JPL supplied a Corps Battle Simulation system to the Army as a corps- and division-level battle trainer simulating 800 ground units. The system allows corps, division and brigade commanders and their staffs to exercise wartime duties in simulated battle drills

As part of a Department of Defense initiative to develop simulation interface standards, the Army, JPL and other organizations linked the Corps Battle Simulation system with the Air Force's training simulation system This year, while coupled with the Air Force's simulator, the JPL-developed system supported three joint and combined forces exercises — two in Europe and one in Korea

In 1992, JPL twice extended the system's capabilities — first to manage over 7,000 units and then to manage between 15,000 and 20,000 units, or six corps. Plans call for linking the Corps Battle Simulation system with additional military training systems in 1993 and beyond.

Advanced Computer Simulation

The Advanced Laboratory for Parallel High-Performance Applications, an outgrowth of JPL's former Hypercube Computer project, specializes in developing solutions to large-scale simulation problems by the application of advanced network computing and parallel processing.

Under Air Force sponsorship, the laboratory is investigating the innovative design and implementation of an advanced simulation framework to support highly complex, parallel, discrete-event simulations. The laboratory is also developing aircraft and ballistic missile tracking algorithms for future use in command center operations. In a cooperative arrangement with the Defense Advanced Research Projects Agency, the laboratory is designing a type of simulation architecture called virtual reality — one that conveys a sense of real presence in an environment — for the agency's large, geographically distributed Critical Moveable Targets Simulation.

This year, a prototype aircraft tracker was completed and delivered to a transition contractor in Colorado Springs, Colorado The prototype is scheduled to be adapted and installed experimentally in a workstation environment in the Air Defense Operations Center at Cheyenne Mountain, Colorado

Wildland Fire Detection and Mapping

Culminating an effort that began with a feasibility study almost a decade ago, JPL officially delivered an infrared imaging system for detecting and mapping wildland fires to the U.S Forest Service in October. Called Firefly, the system uses an airborne infrared sensor, similar to those employed for remote sensing from space, to provide near-real-time wildland fire information for fire management and suppression.

Firefly incorporates several technological advances, including automatic onboard signal and data processors, a telecommunications link and a ground data terminal in addition to the airborne sensor. The system, which is reliable and maintainable, offers superior performance in terms of timely data delivery, quantifiable accuracy and data consistency. Operational units are expected to form the next-generation wildland fire mapping and detection system used by the Forest Service.

Technology Commercialization

Technology transfer and commercialization activities expanded significantly at the Laboratory in 1992. Responding to the Government's desire to move technology from Federal laboratories to private industry, JPL established a Commercial Program Office within the Office of Technology and Applications Programs.

The cornerstone of the Laboratory's commercialization activity is the Technology Affiliates Program, which gives U.S. companies ready access to JPL's technology base. During 1992, the program grew from 22 to 30 participating companies. Nearly 100 individual tasks have been performed for client companies in the four years since the program's inception.

In the program, corporate technical personnel are encouraged to interact directly with Laboratory experts to define and solve problems. As an example, the California Construction Technology Transfer Consortium, one of this year's enrollees in the program, is trying to hasten the transfer of current and recently completed research to commercial products and services for the architecture, engineering and construction industry. JPL's first task for the consortium was to develop a portable, easy-to-use instrument to detect the presence of asbestos in structures. In developing the instrument, the Laboratory drew upon planetary geology and spectroscopic techniques.

In another project, JPL adapted a novel technique for deep refrigeration of space instruments that was perfected only last year. Under sponsorship of The Gas Company of Southern California, JPL applied this cryogenic refrigeration technology to domestic heat pumps and discovered a very efficient means of powering the refrigeration cycle by reusing waste heat normally discarded in the cycle. Compared to conventional vapor compression refrigeration systems, the JPL Regenerative Sorption Heat Pump can significantly reduce air conditioning costs and operate with environmentally safe refrigerants. Since the system uses natural gas instead of electricity, there are significant decreases in effluent pollution, reliance on foreign oil and electrical utility peak load requirements experienced during summer months.

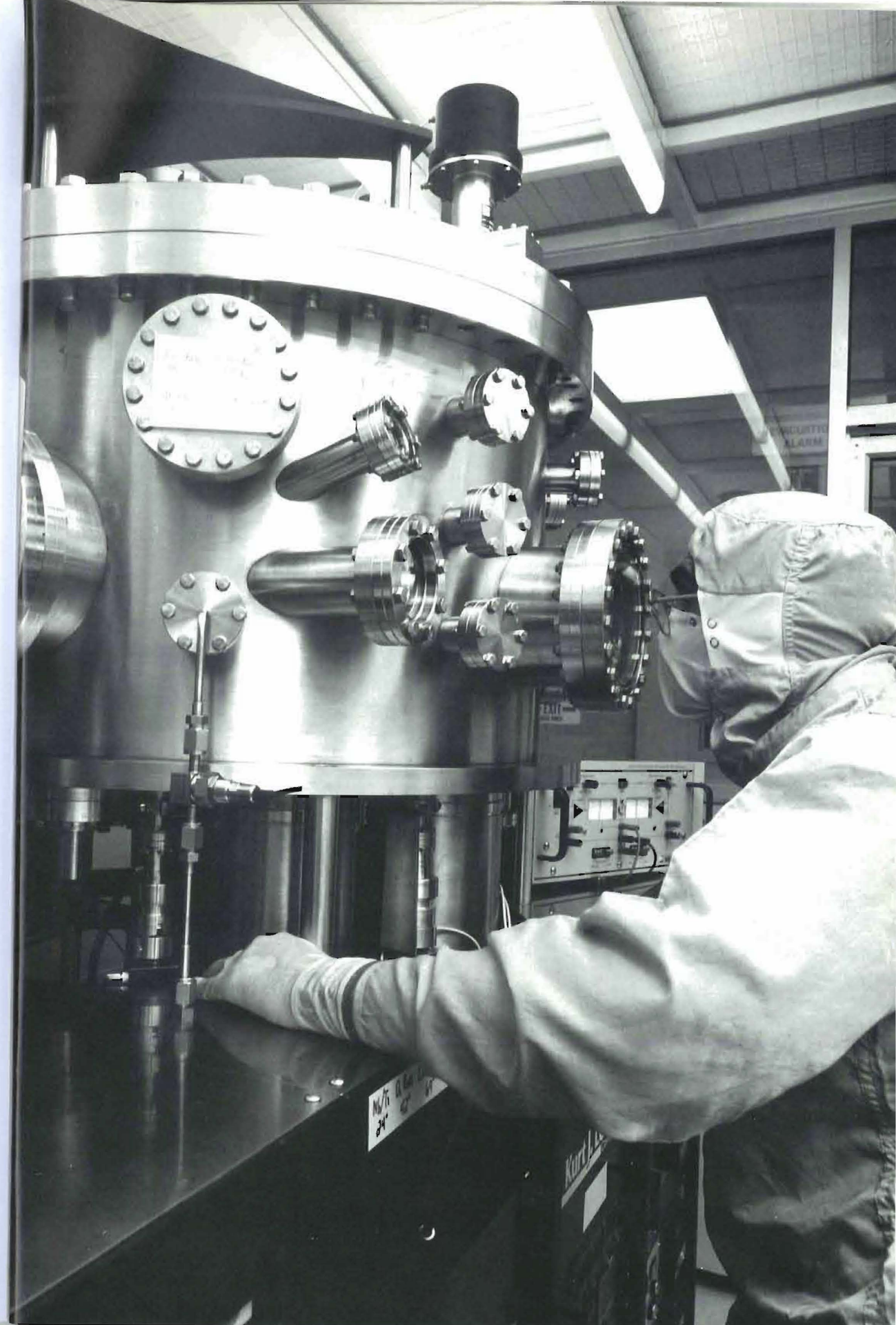
Over the last nine years, the Congressionally mandated Small Business Innovation Research Program at JPL has succeeded in promoting small business participation in Federal research and development throughout the country. Recent legislation will systematically double the size of the program over the next five years. In 1992, 33 contracts of $50,000 each were awarded for proof-of-concept or feasibility demonstrations of new ideas. Another 16 contracts of $500,000 each were placed for follow-on prototype or process development work. Such contracts have led to many products of direct interest to JPL's programs.

This year saw completion of the Biocatalysis project, an effort to develop enabling technology for the production of bulk chemicals through the use of biocatalysts such as microorganisms and enzymes The project achieved significant practi-

Firefly, an infrared imaging system for airborne detection and mapping of wildland fires, was delivered to the U.S. Forest Service following almost a decade of development.

cal innovations in molecular modeling; highly efficient bioreactors; genetic enhancements to bioprocessing, and nonaqueous enzymology for facilitating the use of biological systems to enhance chemical processes. By the end of 1992, the project had effectively transferred its technology to industry, resulting in the formation of three new companies. At least 10 patents, 3 licenses and several software copyrights are attributable to the project as well. In addition, a Materials Simulation Center, designed to be a national resource in computational molecular modeling, was formed at the Caltech Campus.

JPL's commercialization activity was expanded with the addition of intellectual property management and research collaboration with industry. Transferred to the Commercial Program Office, the Technology Utilization information dissemination program distributed technical support packages concerning JPL inventions and innovations in response to over 30,000 separate inquiries in 1992.



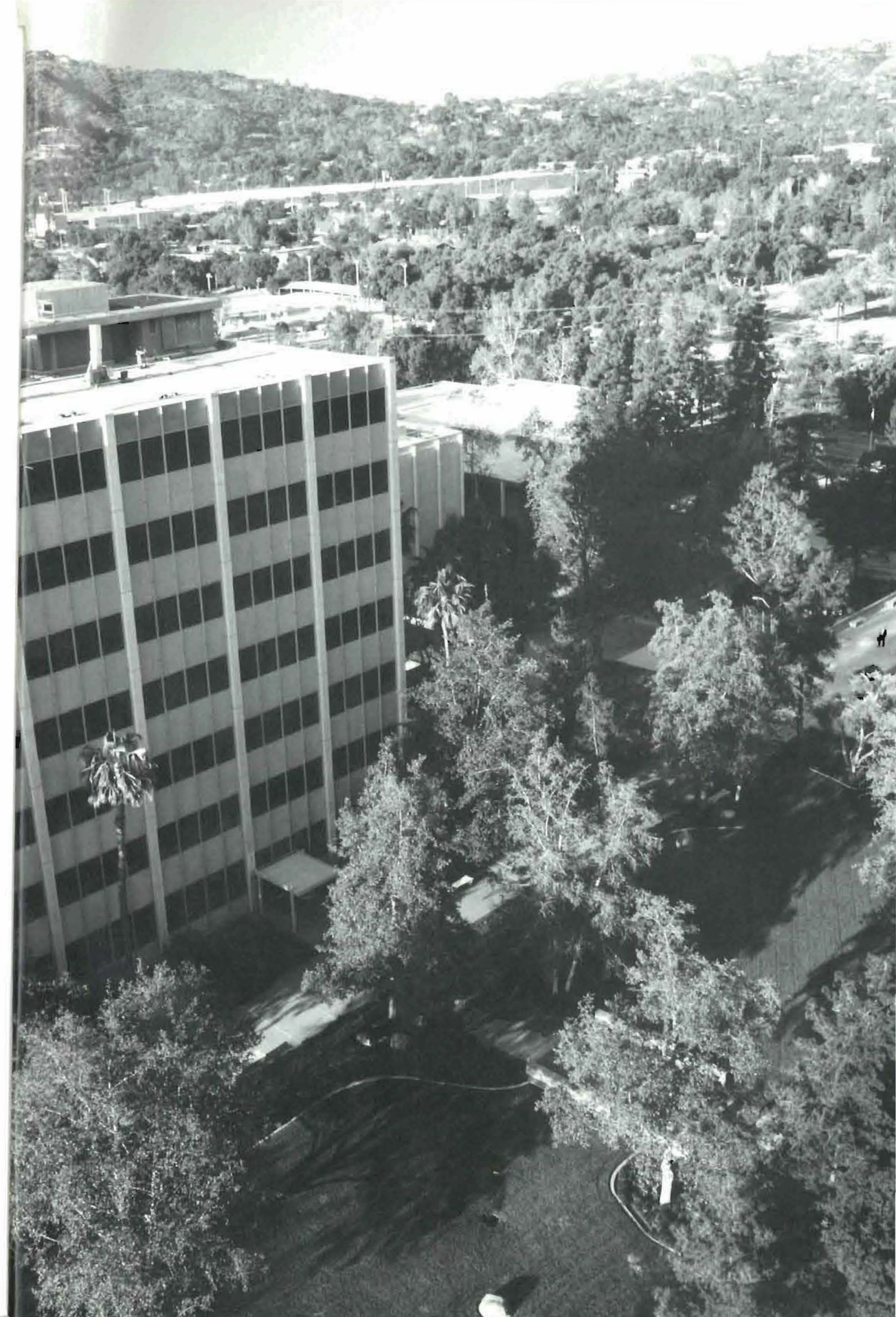
> **This superconductor deposition** *system is used in the processing of niobium-based receivers for submillimeter electromagnetic wave detection. 500-gigahertz niobium-based receivers with unparalled sensitivity have allowed astronomers studying star formation to detect molecular species in interstellar space.*

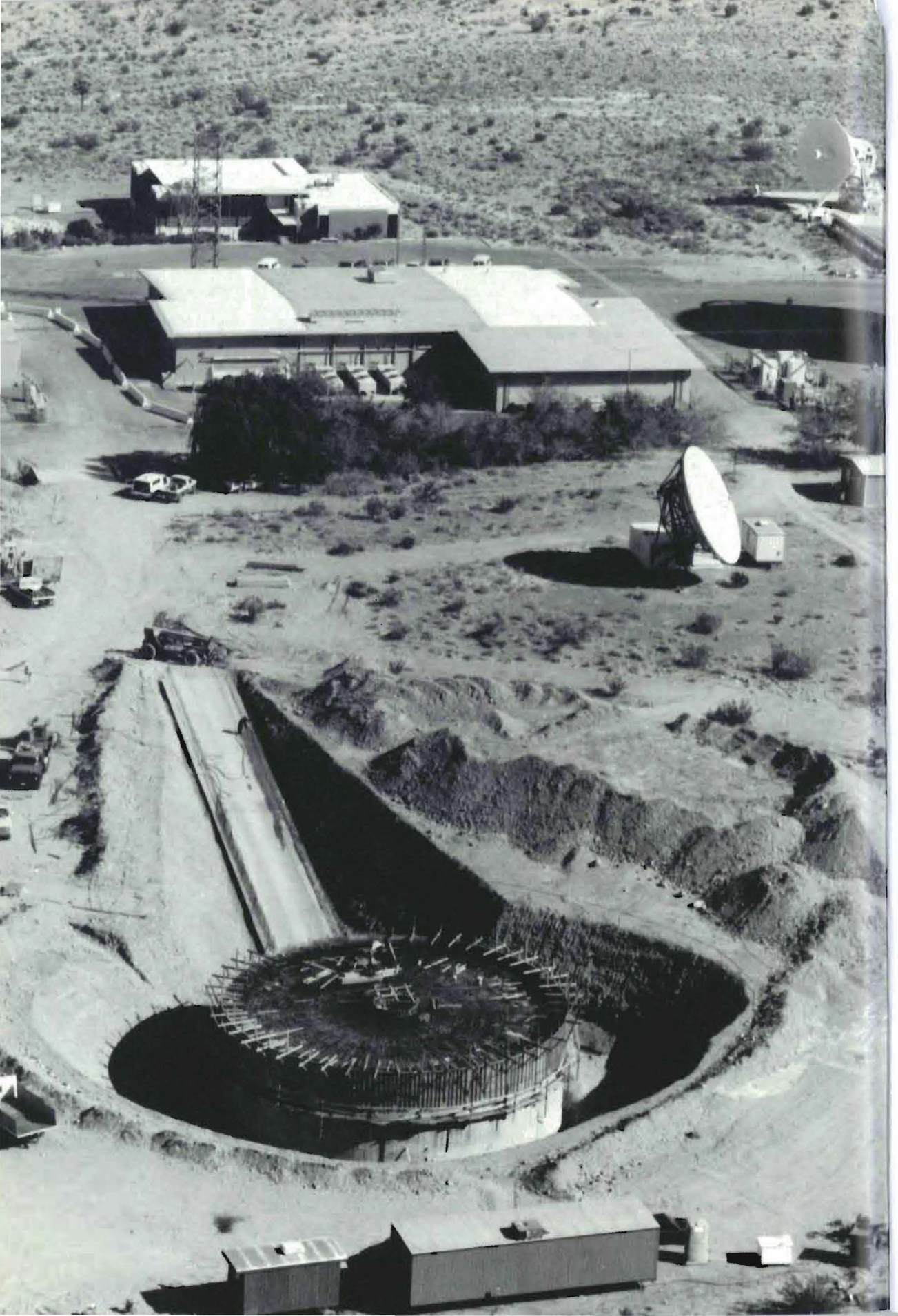
Institutional Activities

JPL's institutional character reflects the Laboratory's heritage as a premier space science, engineering and applications laboratory. As employees of Caltech, JPL personnel strive to maintain the highest standards of scientific and engineering achievement. Recognizing their duty to serve the national interest, staff members are committed to carrying out technically challenging projects of national significance. To encourage innovation, JPL sponsors "seed efforts" in space science and engineering and has launched a program to implement Total Quality Management principles throughout the Laboratory. Research and development costs for the fiscal year ending in September were $1.104 billion, a 1.1-percent increase from the previous year. Costs for NASA-funded activities rose 2.6 percent to $861.6 million. Costs for other activities dropped 3.8 percent to $242.5 million. The work force increased slightly during 1992 to 6,430 employees, compared with 6,359 in 1991 and 6,114 in 1990. Procurement obligations during the fiscal year totaled $683 million, 3.3 percent more than in 1991. These outlays included $635 million to business firms — including $213 million to small businesses, $74 million to women-owned businesses, $19 million to small disadvantaged businesses and $1.5 million to Historically Black Colleges and Universities and other minority educational institutions.

> **Meeting all customer needs** is the focus of strategies being devised at JPL to deliver low-cost, rapidly developed flight missions. Innovation is the hallmark of this effort.

Below: Dedicated to microelectronics research, the modern Microdevices Laboratory houses clean rooms, laboratories and utility and equipment bays.





Honors and Awards

A number of special honors (listed below in alphabetical order) and NASA Honor Awards were presented to JPL employees in recognition of their exceptional achievements and service.

Special honors were awarded to both individuals and groups by a variety of organizations, professional societies and public associations. The annual NASA Honor Awards were presented to JPL employees by NASA in recognition of outstanding individual achievements.

SPECIAL HONORS

Brazilian National Space Medal, Brazilian Ministry of Science

Bruce T. Tsurutani, for contributions to space science and research collaboration at the Brazilian National Institute of Space Research.

Computer and Communications Prize, Foundation for Computer and Communications Promotion, Japan

Eberhardt Rechtin, Andrew J. Viterbi and Walter K. Victor (former JPL employees), for the development of digital deep space communication systems as embodied in the Deep Space Network.

Distinguished Engineering Alumnus Award, University of California, Berkeley

Peter T. Lyman, for exceptional achievements in engineering research, industry, education and public service.

Elected Fellow, American Association for the Advancement of Science

Moustafa T. Chahine, for outstanding contributions to Earth and planetary atmospheric sciences and global remote sensing.

Elected Fellow, American Geophysical Union

Edward J. Smith, for outstanding contributions to instrument development and data interpretation in magnetospheric and heliospheric exploration.

Elected Fellow, International Society for Optical Engineering

Marjorie P. Meinel, for contributions to astronomical optics and solar energy.

Frederic Ives Medal, Optical Society of America

Robert W. Terhune, for distinction in optics development.

Goddard Memorial Trophy, National Space Club

Magellan project leaders, for achievements in the exploration of Venus.

Group Diploma for Astronautics, Federation Aeronautique Internationale

The Magellan project

Honorary Doctor of Science Degree, Occidental College

Eleanor F. Helin, for pioneering studies of near-Earth asteroids and comets.

Honorary Doctor of Science Degree, University of Pennsylvania

John R. Casani

Lew Allen Awards for Excellence

- L. Douglas Bell II
- Edward T. Chow
- James L. Fanson
- Eric R. Fossum

Losey Atmospheric Sciences Award, American Institute of Aeronautics and Astronautics

Moustafa T. Chahine, for outstanding contributions to the atmospheric sciences.

Medal for Engineering Excellence, Institute of Electrical and Electronics Engineers

Charles Elachi, for the development, demonstration and application of synthetic aperture radar for remote mapping of planets.

National Air and Space Museum Trophy for Current Achievement, Smithsonian Institution

The Magellan project, for extraordinary service in air and space science and technology.

Retiree Public Service Excellence Award, Public Employees Roundtable

Volunteer Professionals for Medical Advancement of the Associated Retirees of Caltech and JPL, for research and development support to local hospitals.

< **A 34-meter beam waveguide antenna** *is under construction at Goldstone. By removing all electronics from the exposed antenna dish, this design allows increased efficiency and reduces operating costs. The concrete pedestal, visible in the photograph, will house the antenna electronics safely underground.*

Distinguished Service Medal

- Peter T. Lyman

Outstanding Leadership Medal

- Marshall E Alper
- Willis G Meeks
- Joseph L Savino
- Anthony J. Spear
- Malvin L Yeater

Exceptional Achievement Medal

- Frank T Barath
- Harry E. Cotrill
- James A Evans
- Charles N. Jennings
- Edward E. Kellum
- Carl A. Kukkonen
- Gary L. Parker
- James F Scott
- David Swenson

Exceptional Scientific Achievement Medal

- Michael A. Janssen
- I. Stuart McDermid
- Joseph W. Perry
- R Stephen Saunders
- Christopher R Webster

Exceptional Engineering Achievement Medal

- William G Breckenridge
- Kevin J Hussey
- James R Janesick
- William T. K. Johnson
- Timothy N Krabach
- Nicholas A Renzetti
- Homayoun Seraji
- Jerry E Solomon

Exceptional Service Medal

- Olen Adams
- James W. Alexander
- Harry I Ashkenas
- Robert M. Bamford
- Andrew J. Beck
- Jewel C Beckert
- Allen L. Berman
- Thomas C. Bickler
- Jay E Bandi
- Richard P. Brace
- Glenn L. Bummer
- Nathan A. Burow
- Frank D. Carsey
- James S. Carter
- Jerry Clark
- Maurice C. Clary
- Terry Cole
- Bradley I. Compton
- John Curlander
- Frances de Freitas Bart
- Eric M De Jong
- Edwin W. Dennison
- Stephen P. Dombrowski
- Judith A. Falstreaux
- Elmer L Floyd
- Thomas N. Goutier
- Robert B. Gounley
- Douglas G. Griffith
- Johanna M Gunn
- Arthur G. Gussner
- William M Harris
- George Helou
- Michael Y. Jin
- Pearline Johnson
- Michael K Jones
- Sanford G. Jones
- I J Justice
- Donald H Kindt
- John R. Kolden
- Charles E. Lifer
- Robert Lockhart
- Earl H Maize
- Ed B Massey
- James R McClure
- Brian C. McGlinchey
- John B. McNamee
- Donald D. Meyer
- Fred W. Miller
- Warren K. Moore
- Ray B. Morris
- David D. Norris
- Young Park
- Harry E. Peacock, Jr.
- Raymond G Piereson
- Leslie Pieri
- Joseph A Plamondon
- David F. Quinn
- Ronald T. Reeve
- David H Rodgers
- Kenneth E. Savary
- Charles G Schutz
- Donald R Sevilla
- Thomas W Shain
- R Wayne Sible
- John J. Simmonds
- John P Slonski, Jr
- David B. Smith
- Fernando L Sola
- James R Staats
- Joseph Statman
- James M. Stewart
- Theodore N Tate
- Anna M. Tavormina
- Thomas W. Thompson
- Tommy A Tomey
- William H. Tyler
- Stephen D. Wall
- William J. Weber III
- Elizabeth A. Wilson
- Gene H. Winn
- Vincent A. Wirth, Jr
- David F. Woerner
- Larry W. Wright
- Max E Wyatt
- Chen-Wan Liu Yen

Certificate of Appreciation

- Andrea K Alazard
- Richard E Babel
- Julian O Blosiu
- Stephanie A. Clements
- Letricia Eckerle
- Ben Honda
- Lanny Lafferty
- K Gordon Maughan
- Gary G McCutcheon
- Richard A. McKay
- Jeffrey A Mellstrom
- Sylvia Miller
- Edward E Morassini
- Marcia Morocco
- Marie Petrie
- W. Richard Scott
- Marjorie A. Sims
- Clara Sneed
- Winifred B Staniford
- Joan M. Swan
- Betty Van Meel
- Yolanda C Walton
- Justine D. Weiher
- Inez L. Wickland

Equal Employment Opportunity Medal

- Brooks H. Vinson

Patents and Technology Utilization

During the fiscal year, the Office of Patents and Technology Utilization prepared, evaluated and forwarded to NASA reports on 256 inventions and technical innovations resulting from JPL work. The office answered 57, 757 requests from industry and the public for technical information on JPL inventions and innovations published in the NASA-sponsored *Tech Briefs*. During the year, 277 briefs on JPL inventions and innovations were published in *Tech Briefs*, representing 36 percent of the NASA-wide total. The U.S. Patent and Trademark Office issued 57 patents to Caltech and NASA on inventions developed at JPL. NASA approved and JPL conferred the following awards, totaling $100,750, for JPL inventions·

Exceptional Awards

Jack A Jones received $5,000 for *Near Azeotropic Mixture Substitute for Dichlorodifluoromethane*.

Jack A Jones, and Alfred Johnson of The Aerospace Corporation, shared $5,000 equally for *Quick Cool-down Ten Degree Kelvin Refrigerator*

Major Awards

Gary L Friedman received $2,000 for *Computer Keyboard*.

Andrew Gabriel, Richard M. Goldstein and Howard A. Zebker shared $3,000 equally for *Method for Mapping Small Surface Deformations Over Large Areas With Synthetic Aperture Radar*.

Jack A. Jones received $2,000 for *Regenerative Adsorbent Heat Pump*.

Farzin Manshadi received $1,000 for *Crossed Slot Antenna*.

William R. McGrath received $1,000 for *Non-contacting Backshot*.

John C. Peterson, Edward T. Chow, Michael S Waterman and Timothy J. Hunkapiller shared $4,000 equally for *Sequence Information Signal Processor*.

J. Brooks Thomas, Jr., received $4,000 for *Improved Digital Phase Lock Loop*.

Richard Yu-Hwan Lin and Boris J. Lurie shared $2,000 equally for *Non-linear Dynamic Compensation System*.

Other Awards

Smaller monetary awards totaling $71,750 were made to 310 JPL inventors and innovators.

Director's Discretionary Fund

The Director's Discretionary Fund (DDF) is the major resource for innovative and seed efforts that do not receive conventional task-order funding. For 1992, the DDF level of funding was $3.5 million.

The fund initiated 30 new research tasks, extended the objectives of 9 ongoing tasks — awarding more funds to them — and provided modest assistance to several other support efforts. Proposals eligible for DDF monies cover a broad range of sciences and technologies. Areas of recent emphasis have included advanced microelectronics, automation and robotics, advanced observational techniques and advanced optical systems.

The DDF recognizes important mutual benefits from collaboration with faculty and students at the Caltech Campus and at other academic institutions, so cooperation is specifically encouraged. Twelve new and extended principal tasks funded this year involve 17 university faculty collaborators.

Caltech President's Fund

The Caltech President's Fund provides a second, although smaller, source of discretionary funding Currently at a level of $1 million a year, the fund is sponsored by Caltech and NASA on a dollar-for-dollar matching basis and is administered by Caltech. An explicit objective of the President's Fund is to encourage the interest and participation of university faculty and students in JPL research activities, affording JPL staff members an opportu-

nity for close association with research workers from the university community. The President's Fund provided resources for 14 new collaborative tasks this year.

Additional Activities

Total Quality Management

The Laboratory embarked on an aggressive Total Quality Management (TQM) program to streamline operations and develop new, more efficient ways of working with customers. Inspired by TQM, JPL is searching for ways of designing low-cost spaceflight missions that can be accomplished in a short time span and delivered on schedule. A rigorous TQM training effort was initiated to educate the JPL work force by the end of fiscal year 1993.

As one of the program cornerstones, 10 Process Action Teams were created to expedite Laboratory-wide implementation of TQM principles. The teams were charged with identifying areas in which performance could be improved, costs contained and staff better utilized. The teams were asked to identify, analyze and recommend ways of improving performance in specific divisions, and to find ways of executing those strategies. The Process Action Teams are expected to proliferate as successful strategies take hold and are applied to several organizations.

International Space Year Expo

JPL celebrated International Space Year with its second annual weekend Expo, attended by about 12,000 people. Twenty-three sites around the Laboratory — with video productions, exhibits and information on current and future spaceflight missions — were open to the public.

Commemorative Stamp

The U.S. Postal Service paid tribute to JPL's founder, Dr. Theodore von Kármán, by issuing a 29-cent stamp bearing a portrait of the aerospace scientist. The stamp was released in August at the World Space Congress in Washington, D.C., and a second-day-of-issue ceremony was held at the Laboratory. The von Kármán stamp was issued to post offices nationwide in September.

Superfund Cleanup

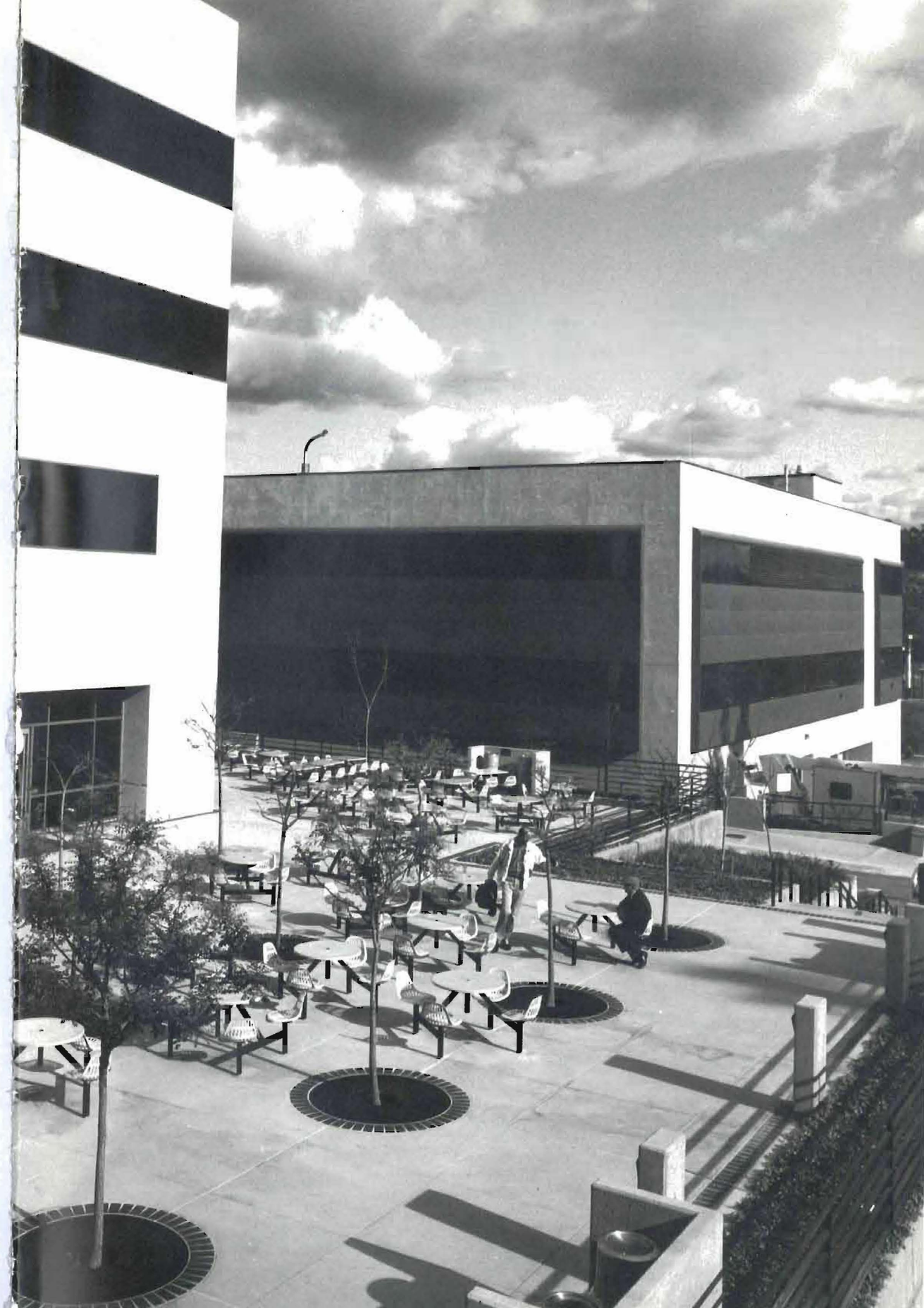
JPL was added to the Environmental Protection Agency's (EPA's) Superfund list and asked to work closely with the agency in an effort to identify and clean up soil and groundwater contamination. Over the years, JPL has actively supported state and Federal guidelines for waste disposal and recently joined with the City of Pasadena to fund a Pasadena water treatment plant. Under EPA guidelines, the Laboratory's new cleanup effort will be funded by NASA.

Business Ethics

The Laboratory adopted a formal business ethics program to maintain its commitment to high ethical standards in light of increased Government regulation in recent years. Handbooks and related materials covering a wide range of topics — including fraud, kickbacks, gratuities, conflict of interest and use of Government property — were distributed to employees and contractors. A business ethics advisor was appointed to administer the program.

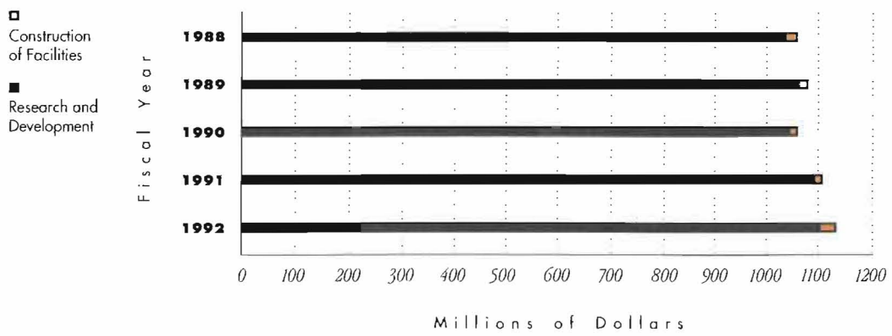
Industry Day

JPL and the National Space Club cohosted the first Briefing for Industry conference in May for 200 attendees. The one-day briefing provided insight into business opportunities at JPL over the next five years and served as a forum for an exchange of information. Major future technological thrusts in the areas of hardware, software and commercialization were presented by the Director and JPL management, who also provided information on NASA and JPL organizational structures and relationships.

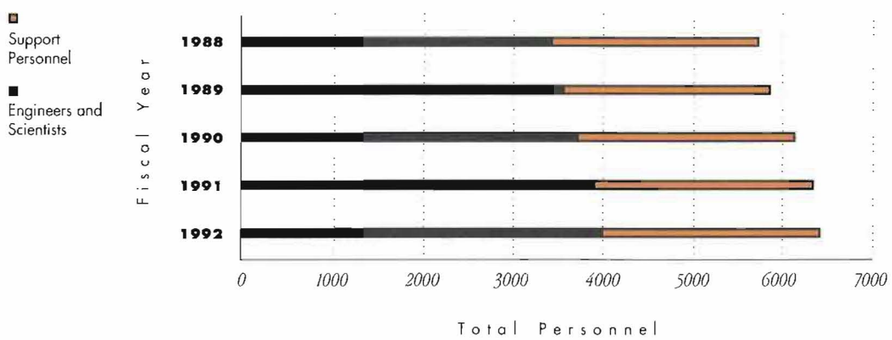


> **The Laboratory's role has grown** *significantly since JPL's beginnings with a small band of students who conducted rocket experiments near Pasadena's Arroyo Seco. Today, JPL is internationally known for its achievements in space exploration as well as in astrophysics, Earth sciences and space physics.*

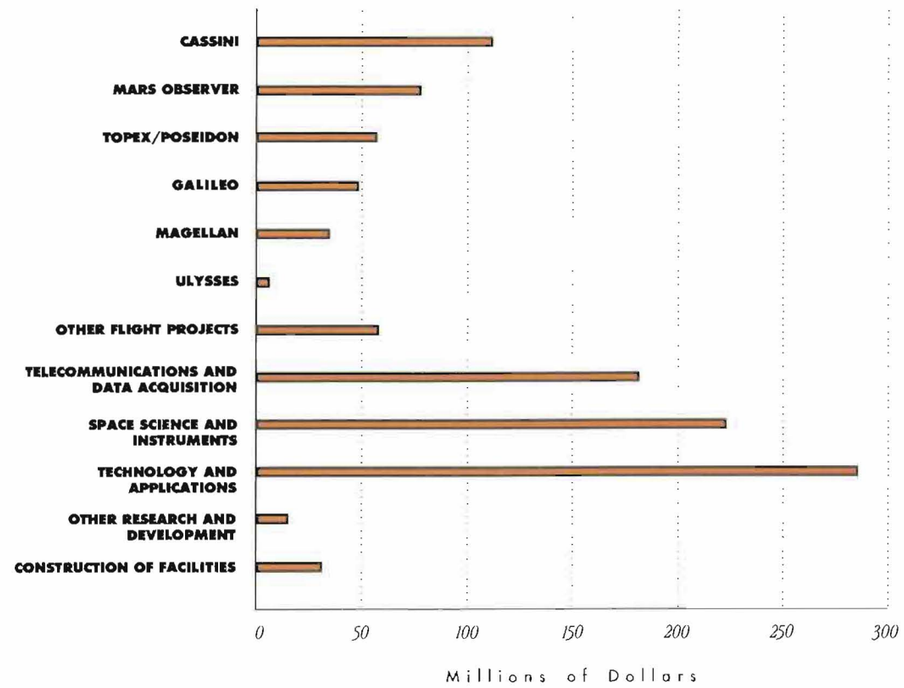
Total Costs



Personnel



Fiscal 1992 Costs



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