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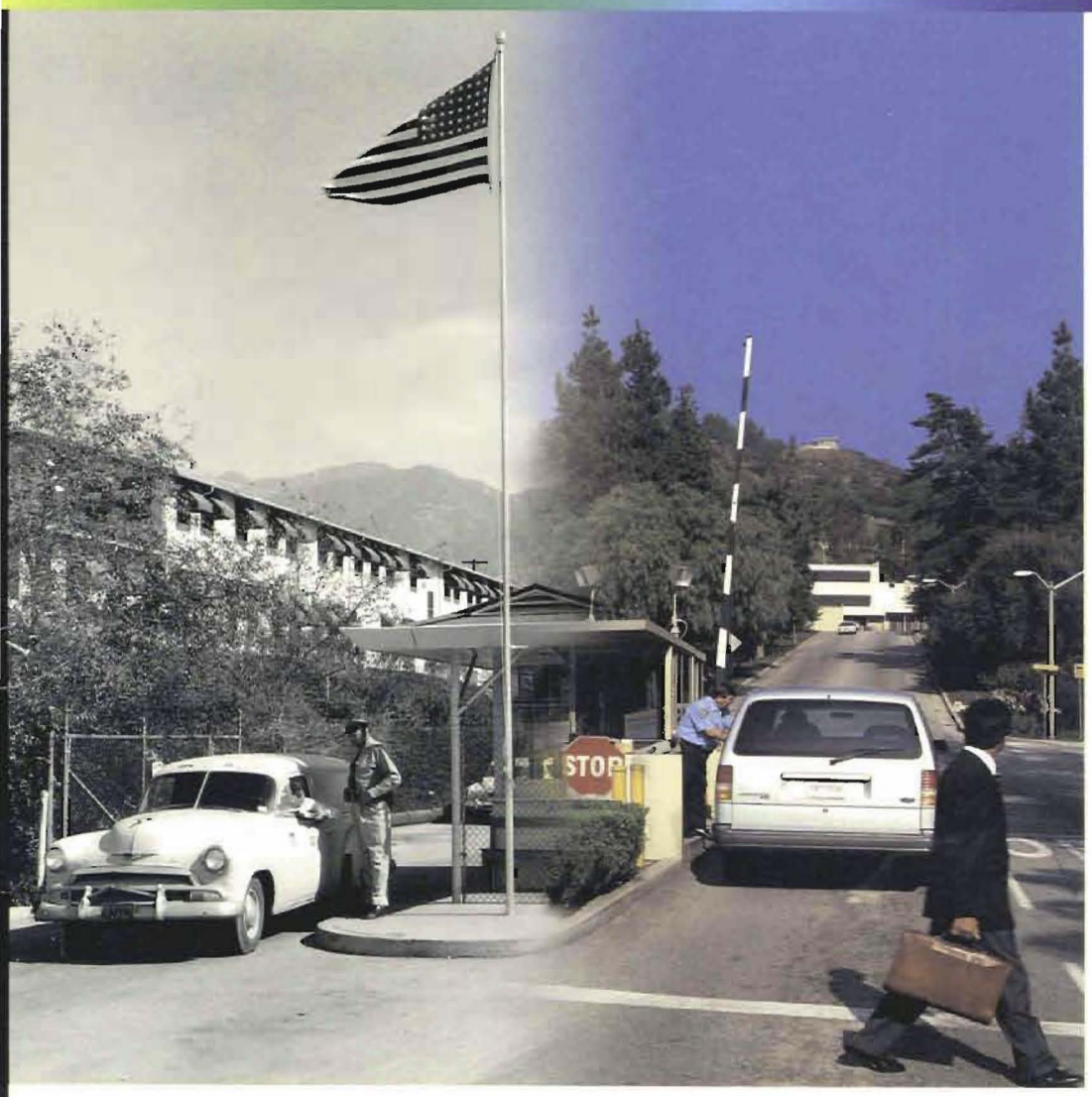
JET PROPULSION LABORATORY ANNUAL REPORT



1995

JPL — THEN AND NOW

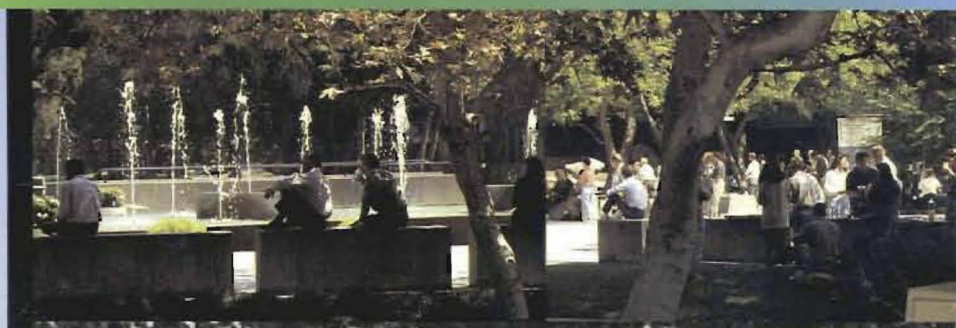
On the cover: out of the old, into the new. A composite image shows the front entrance to JPL then (1952), on the left, and now on the right. JPL (the Jet Propulsion Laboratory), a division of the California Institute of Technology, is the National Aeronautics and Space Administration lead center for robotic space exploration.

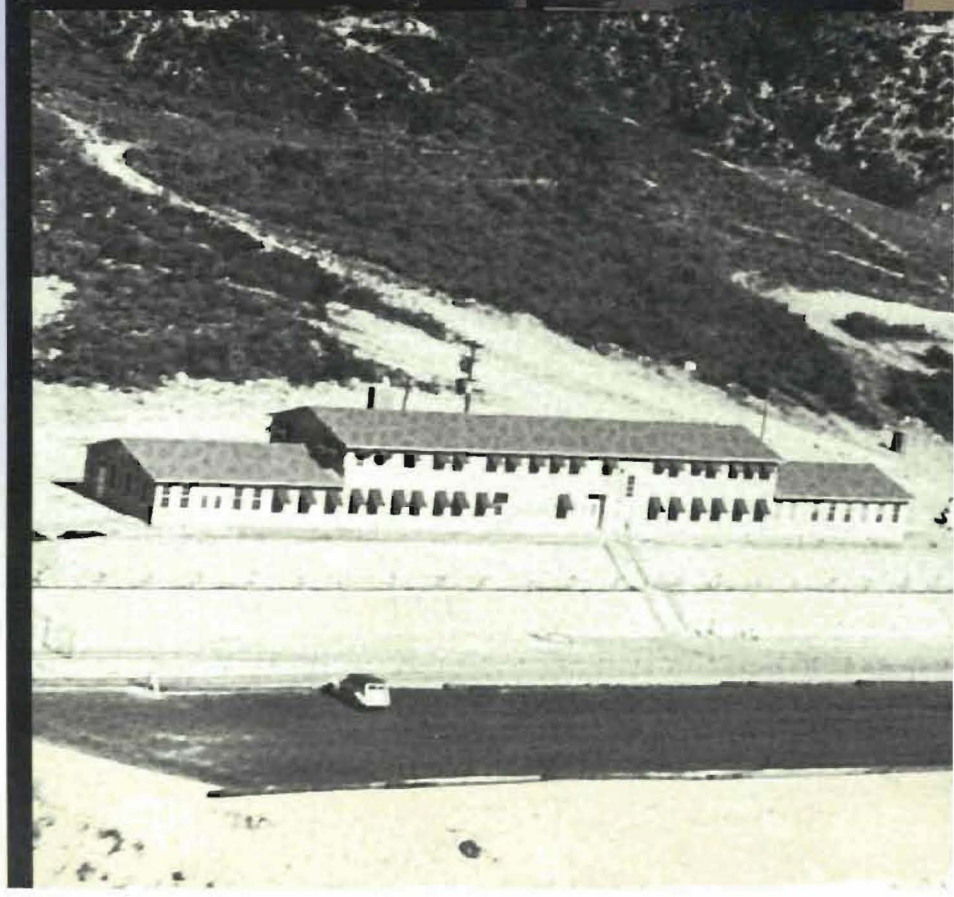
Above: Building 264, the Space Flight Support building, as it appeared in 1971. Called simply, "264," by JPLers, the building has been home to many of the Laboratory's missions.

Center: Lunch time on "The Mall" exemplifies the relaxed, campus-like atmosphere at JPL.

Right: The Material Research laboratory, Bldg. 67, one of JPL's oldest facilities, in 1941.

Opposite: Building 264 today. Like the Laboratory as a whole, 264 has grown in reflection of JPL's expanded role in the nation's research and development program.





JET PROPULSION LABORATORY ANNUAL REPORT 1995

A description of work accomplished under contract between the California Institute of Technology and the National Aeronautics and Space Administration for the period January 1 through December 31, 1995.

Funding for this publication was provided by the California Institute of Technology.

THEN

1936–

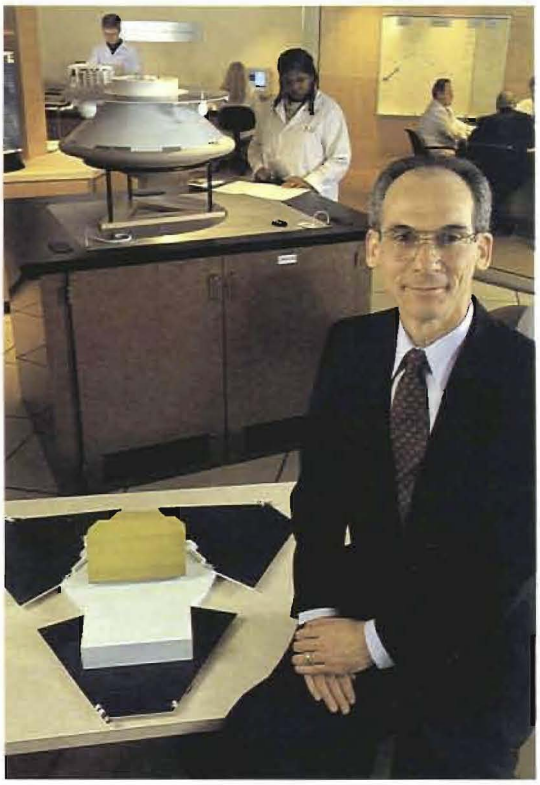
JPL Directors, clockwise from top left:

1936–1946 *Theodore von Kármán, founder, turned rocket experiments into a national resource.*
1947–1954 *Louis Dunn, acting director for last half of 1946, oversaw early military work.*
1954–1976 *William Pickering, led JPL through expansion and into outer space.*
1976–1982 *Bruce Murray, oversaw Voyager launches and Jupiter and Saturn encounters.*
1982–1990 *Lew Allen, initiated new areas of work and contacts with industry.*

Nineteen ninety-five was an exciting and productive year at the Jet Propulsion Laboratory. In pursuing our mission to conduct challenging robotic space explorations for NASA and to apply our special capabilities to technical and scientific problems of national significance, JPL-managed projects made significant contributions to increasing our understanding of the Solar System and advancing technology.

Among the many accomplishments for 1995 was the flawless delivery of the Galileo probe to Jupiter and initiation of scientific observations by Galileo's orbiter, which marked the beginning of the long-anticipated, close-up exploration of the Solar System's largest planet and its moons. The TOPEX/Poseidon mission continued to expand our understanding of Earth's ocean circulation, the key factor controlling global climate change.

Building on its surprising 1994 discoveries at the Sun's south pole, the Ulysses mission studied the north pole of the Sun, increasing not only our knowledge about the dynamics of the Sun's polar regions, but also our understanding of the effects of solar "weather" on Earth. In Shuttle-borne experiments, JPL advanced the technologies of large inflatable structures, which can significantly reduce the cost of future missions and cryogenic refrigeration, necessary for the operation of modern devices used in space instrument programs.



NOW

–1995

Preparation for future missions progressed as well. We began final integration and testing for a 1996 launch of the NASA Scatterometer, a microwave radar instrument that will give us information critical to determining regional weather patterns and global climate. We also began final integration and testing for 1996 launches of Mars Pathfinder, which will explore the Martian surface, and Mars Global Surveyor, which will create a global portrait of the Red Planet.

The Cassini mission made excellent progress toward its 1997 launch toward Saturn. The New Millennium Program — which will develop the essential technologies and capabilities required for the affordable, frequently launched deep space and Earth-observing missions of the 21st century — took shape with the definition of its first deep space flight, an asteroid and comet flyby mission to be launched in 1998.

1990–TODAY *Current JPL Director Edward Stone, Voyager project scientist and leader of the effort to "reinvent" the Laboratory as the nation approaches a new millennium.*

NOW

1995

Closer to home, the JPL team continued to emphasize sensitivity to customer needs and expectations, as well as flexibility to accommodate the rapidly changing business environment. Continuing the process of constructive change begun several years ago, we issued a Strategic Plan that positions us for success in the new era of economic constraints, redefined national goals and revised priorities for the space program. We chartered four reengineering teams to develop and implement dramatic improvements in the processes we use to make rules, deliver administrative support, develop products and nurture and assign the people who make it all happen. These steps signal our determination to lead in the way we do business just as we have in the exploration of the Solar System.

All in all, 1995 was a year of great progress for JPL. Together with our industrial, academic, government and international partners, the dedicated and talented men and women throughout the Laboratory are deservedly proud of our achievements. The JPL team is committed to our vision to expand the frontiers of space to enrich knowledge and benefit humanity. The years ahead are certain to be challenging, but I am confident that this team is equal to the task.

R C Stone

TOWARD A NEW PARADIGM

The Galileo spacecraft's "landfall" of Jupiter in December was unquestionably the most dramatic and visible public achievement of the Jet Propulsion Laboratory in 1995. As spectacular as that event was, however, it was rivaled in significance by a less visible step taken internally by the Laboratory during the year to continue the process of change and improvement — a process that will make the JPL of the 21st century capable of carrying out missions with all the scientific and engineering impact of Galileo, but with smaller, less expensive spacecraft flown on a more frequent timetable.

That equally important step, if not quite so publicly visible as Galileo's triumph, was the Laboratory's Strategic Plan. This eight-page document was issued in April after months of careful preparation. It has been variously termed a "road map" or a "blueprint" for the future, but it really is neither, for the former implies movement from one known point to another and the latter the construction of some preconceived design. Rather, JPL's Strategic Plan is more of a "compass," in that it will guide the Laboratory through the terra incognita of the political, economic, budgetary and international environment of the future. Only a flexible, responsive and customer-focused organization will be able to navigate a rapidly changing environment — and the Strategic Plan is designed to make JPL into just that kind of organization.

Change is essential if JPL is to continue its long tradition of space exploration and advanced technology development on behalf of the nation. The next few years will be transitional, as the Laboratory shifts from its previous management pattern to a new and continually evolving one. Indeed, the once and future JPL will be reflected in the range of missions operating in space between 1996 and 2000 — those from an earlier time winding down and those of the new era just beginning.

At Jupiter, for example, the 2,200-kilogram Galileo spacecraft will be concluding an extended exploration of the Solar System's largest planet, its fierce magnetosphere and its four major moons The 5,600-kilogram Cassini spacecraft will be en route to Saturn and its intriguing moon, Titan, some 700 million kilometers farther out. Both Galileo and Cassini are classic JPL spacecraft — physically large and complex, their decks crammed with scientific experiments and their computer logbooks filled with detailed directions and observations.

At Mars, two orbiters and two landers — built and launched in the mid-1990s — will near the end of their successful missions. These spacecraft are markedly smaller than anything previously flown in space, having capitalized on the advanced technologies the Laboratory and its partners developed expressly for the missions More significantly, they will be operating with more autonomy than either Galileo or Cassini ever did. Another pair of Mars craft is being readied for launch from Earth; these newer spacecraft are still smaller, less expensive and more autonomous than those they are to succeed at the Red Planet.

At the same time, the first of a revolutionary new generation of spacecraft called New Millennium is in pursuit of an asteroid in the belt just beyond Mars and will later rendezvous with a comet as it streaks into the inner reaches of the Solar System Another, called STARDUST, is chasing down a comet to gather samples of dust and bring them back to Earth for analysis

Like the Mars vehicles, the New Millennium spacecraft pack a large amount of scientific investigation into a very small volume and mass — in part because of advances made in technology by JPL and its many industrial partners — and yet are less expensive and less dependent, operationally, on ground control than any of their predecessors.

At the center of the Solar System, the Sun itself gets one last look from the Ulysses spacecraft, now in the final months of its historic 11-year mission Back at JPL in Pasadena, several new projects are in varying stages of development· a spacecraft to be the first visitor to Pluto, Earth-observing instruments (some are already functioning aboard NASA's Mission to Planet Earth orbiting platforms), and three new and extremely sensitive infrared astronomical spacecraft (Space Infrared Telescope Facility, or SIRTF, Far Infrared Space Telescope, or FIRST and Wide-Field Infrared Explorer, or WIRE)

In still another development, interferometry, JPL will be demonstrating anew its unique capability to synthesize science, engineering and technology Laboratory scientists and engineers are working on a system of four or more telescopes, 0 5 meter to 1.5 meters in diameter, spaced tens of meters apart in Earth orbit so as to have angular resolution equivalent to that of a single telescope of that diameter This interferometric system will, among other things, measure distances to distant galaxies with extreme precision and thus better define the Universe's rate of expansion, observe the dynamics of globular clusters of stars at the centers of some galaxies, detect and image planets and protoplanetary discs around other stars and peer at the turbulent nuclei of active galaxies

It is a challenging projection of the future, but it is in accord with JPL's Strategic Plan. The Plan consists of these elements·

- **VISION.** *An expression of an organization's self-image and purpose; JPL's vision is to "expand the frontiers of space to enrich knowledge and benefit humanity "*

- **MISSION.** *Activities that fulfill a vision are defined as "missions" and JPL's include challenging robotic space ventures to explore the Solar System, Universe and Earth — some of which will establish a foundation for later human exploration — as well as applying the Laboratory's special capabilities to technical and scientific problems of national importance.*

- **VALUES** *These are the characteristics that an organization's workforce brings to bear in the conduct of its missions. JPL's values are openness (of people and processes), integrity (of both the individual and the Laboratory), quality (a commitment to excellence in everything done) and innovation (employee creativity)*

- **STRATEGIES.** *The Plan identifies 10 actions that must be taken to meet customer needs·*

  - *Focusing the Laboratory's science, technology and engineering resources to do those missions that no one else has done before, or can do now*

  - *Enhancing humanity's understanding of Earth's environment and the Universe through small, frequent, low-cost missions*

  - *Combining JPL's strengths with those of other NASA field centers, industry, federal laboratories, academia and foreign nations to build the very best robotic science and Earth-observing programs.*

  - *Broadening and deepening the Laboratory's capabilities to execute successful robotic space-science and Earth-monitoring programs.*

  - *Acting as a scientific and technological bridge between NASA and other U S agencies to help the latter achieve important national goals.*

  - *Using and verifying the best business practices in carrying out JPL's processes.*

  - *Infusing new technologies into flight and ground systems and capturing the benefits for the commercial sector through technology transfer programs.*

  - *Inspiring the public with the wonder of space science and enhancing science and engineering education.*

  - *Promoting individual and organizational excellence through employee training and growth and by creating a work environment characterized by mutual trust and respect.*

  - *Contributing to the nation as a socially responsible organization*

Equally important, the Plan sets out a number of "change goals" — specific actions that JPL must achieve in the next three to five years to transform its institutional culture from the former state to the new. These include a greater emphasis on managing costs, identifying

and carrying out best business practices, focusing on customer needs, supporting, rewarding and recognizing employees and developing small and moderate space missions.

With the release of the Plan, the Laboratory established four reengineering teams and charged them with defining breakthrough changes to four key processes — Flight Project Product Development; Growth and Assignment of People; Define and Maintain the Institutional Environment; and Administrative Processes. To underscore the importance of these efforts, some of the Laboratory's most respected managers and senior staff members were named to direct the teams as "process owners" and team leaders After six months on the job, the teams reported significant progress by year's end.

- **FLIGHT PROJECTS.** *Drawing on the experiences of such firms as the Boeing Co. and Ford Motor Co , the team focused on concurrent engineering, greater "up-front" planning and streamlined review processes as means toward significantly reducing the development time and cost of flight projects without sacrificing capability or unduly increasing risk*

To meet these challenging requirements, JPL managers are adopting new strategies. One is the use of Integrated Product Development Teams, a concept borrowed from industry, that periodically brings together experts from JPL, its aerospace partners, universities, other NASA field centers, government agencies and federal laboratories to identify and develop those technologies necessary for future mission success.

Another strategy is meant to draw upon the resources, experience, knowledge, skills and personnel from previous flights One way of achieving this is expansion of the existing Flight System Testbed — a facility where engineers and scientists can resolve design problems of spacecraft and instruments early in a project's life cycle — to include an auxiliary Mission Testbed where mission operations and Deep Space Network tracking can be simulated.

Still another is the Design Hub, which would be an extension of the Project Design Center The Center, established in 1994, is a facility where the conceptual elements, system design and cost estimates of a new mission can be explored, the Hub is a facility where the next, more detailed, steps of design, manufacture, assembly and test of an approved mission will be carried out. The first New Millennium flight, an asteroid–comet flyby to be launched in 1998, would provide a test of some of the reengineering team's ideas

- **PEOPLE.** *"JPL's employees are its most valuable asset," the Growth and Assignment of Our People Team declared in its charter. "They bring the stars within reach " The team is studying ways to sustain both a workforce that adds value to the Laboratory and, in turn, an environment that supports valuable employees The team is focusing on employee development, job assignment and reassignment.*

In the first area, the team proposed that the Laboratory increase employee education and training to at least the industry norm of 40 hours per year per person with an online catalog and registration system In the second, the team suggested steps to fill most personnel assignments in one or two weeks, compared to the current three to nine months.

- **RULES.** *To comply with federal and state laws, as well as the terms of the NASA prime contract and Caltech policies, JPL has evolved a body of workplace rules. Employees made it clear in opinion surveys and other forums that they find many of these rules difficult, unnecessary or even, at times, counterproductive to getting the job done. Coincidentally, JPL has come in for criticism from outsiders for failing to follow its own rules. The Rule Making Team concluded that both employees and critics were essentially correct· too many JPL rules are unduly complex and confusing*

In response, the team is trying to untangle the process by which rules are made, reviewed, changed and retired. The resulting system should produce fewer rules — and rules that are not just easier to follow, but that actually help employees carry out their tasks An employee wanting to know which rules apply to a given situation will be able to find and understand them easily and know why they exist and who at the Laboratory can explain or waive them

- **BUSINESS PRACTICES.** *Team Élan — "élan" is French for "vigorous spirit" or "enthusiasm" — addresses improvements in JPL's business systems, building on senior management's commitment to the industry standard of "best business practices." By improving in such areas as accounting, cost controls and procurement, the Laboratory will be able to take advantage of the breakthroughs achieved by the three other reengineering teams.*

Team Élan's charge is to develop online systems and other tools to ensure that "best business practices" pervade the Laboratory. One way is to rely on commercial, off-the-shelf software and other products in lieu of developing customized systems from scratch

The formation of the team was one element in Laboratory-wide efforts to better manage the funds entrusted to it by the federal government — in short, to function more like a business In January, all business and financial operations were realigned after a four-month study that drew on the experiences of 10 other organizations in the public and private sectors. Under the new structure, the Laboratory's Associate Director effectively serves as a chief administrative officer, with oversight of all physical and financial resources as well as computer and information systems.

A key appointment followed in August when William Harrison was named JPL's first controller. Formerly with the Allied Signal Corp , Harrison acts as the Laboratory's senior financial executive and sits on the Executive Council, JPL's senior advisory body.

INTO THE NEW MILLENNIUM

Perhaps no effort at JPL better illustrates the spirit of change than the New Millennium Program. A cornerstone of the new, reengineered JPL, this program moved from a study early in the year to a new budget start with $50 million in funding in the fall. That funding will provide a beginning for three bold, yet low-cost, missions to be flown by the year 2000; these missions will develop and demonstrate advanced technologies for space science goals.

New Millennium will lead to small, highly capable spacecraft, some carrying instruments no bigger than a postage stamp, to study Earth's atmosphere, oceans and land masses; to reach out to the farthest corners of the Solar System and to look deep into the Cosmos beyond. Instead of flying one or two space science missions each decade, this program should make it possible, after the turn of the century, to stage several exciting missions every year with the objective of proving new technologies and operations techniques through actual flight testing

Last spring, JPL teams reviewed more than 230 proposals from aerospace and other industrial firms, universities, nonprofit research organizations, and federal agencies seeking a part in New Millennium. By June, the review teams had completed their screening, with 23 organizations selected to take part in four Integrated Product Development Teams — communications, autonomy, microelectronics and modular architectures/multifunctional systems. The engineers and scientists on these teams will be involved in all aspects of the program, from technology development through processing of the data gathered during the course of the missions.

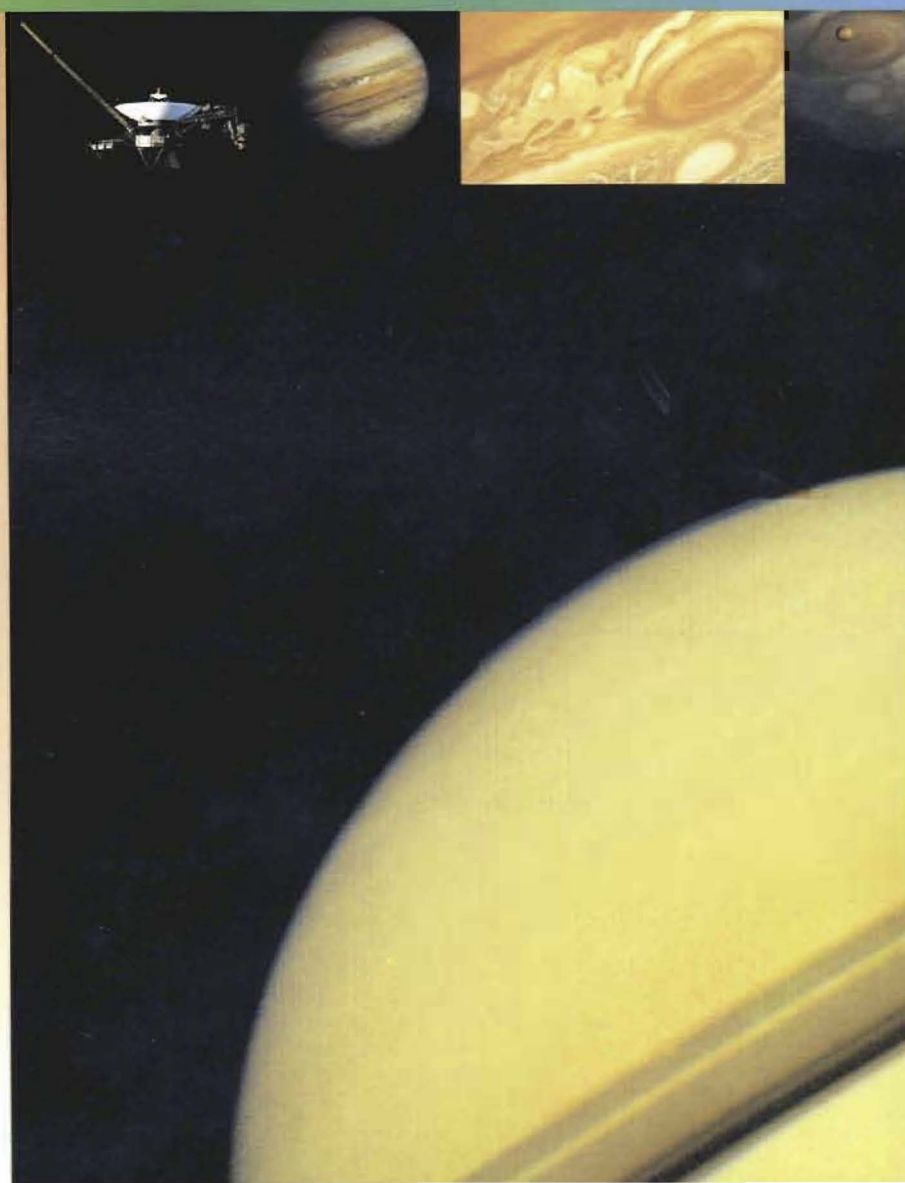
The first mission under the New Millennium banner will be a flyby of an asteroid and a comet (both yet to be selected), with a launch in 1998. Spectrum Astro Inc , of Gilbert, Arizona, was selected in September to design and build the spacecraft's structural bus; the proposed spacecraft will weigh only 100 kilograms and be the first interplanetary vehicle to employ solar electric propulsion rather than conventional solid or liquid propellants.

Solar electric propulsion, which uses solar panels to convert sunlight into electrical power and then uses that power to ionize a gas like xenon, provides a small, but very extended, period of thrust Precisely because it can run continuously for long stretches, the engine can accelerate a spacecraft to very high speeds, reducing the time it would otherwise take to reach distant objects or making more trajectory changes so as to fly by more objects.

This novel propulsion system will be one of several new technologies demonstrated on the first New Millennium flight Other possibilities — depending on how fast they can be developed — include a miniaturized deep-space antenna, advanced solar arrays, lightweight spacecraft structures and long-lived lithium ion batteries for onboard power.

SPACEFLIGHT EXPLORATION

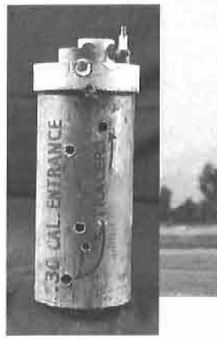
Future spaceflight missions will be radically different from those of the past. Objectives, instrumentation, operations — and spacecraft design — all will be affected by advanced technologies, computer-aided design and testing tools, enhanced design methodologies and streamlined operations concepts. Frequent, "smaller, better, cheaper" missions with highly specific objectives will become the rule. Multidisciplinary facilities such as the Project Design Center, the Flight System Testbed and the Multimission Ground Systems Office enable JPL to design, test and operate innovative missions that are both publicly engaging and scientifically exciting. JPL's intent is to bring the nation maximum scientific, technical, social and educational returns on our investment in space.



THEN

NOW

1941



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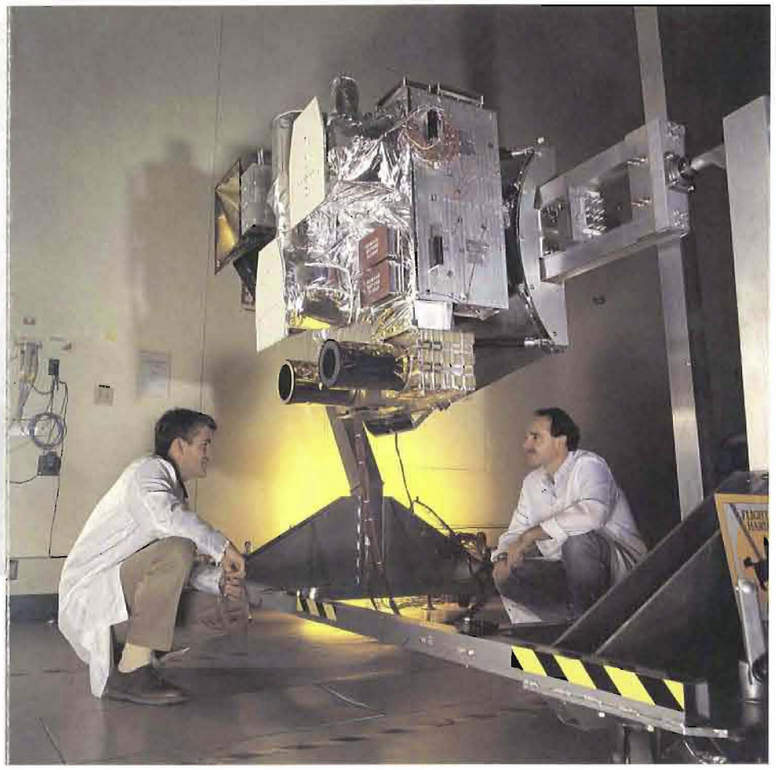


The roots of the Laboratory's work are in rocket propulsion and its military applications. One of JPL's earliest programs was Jet-Assisted Takeoff (JATO) units, which were solid-fuel rockets designed to boost military aircraft off short runways. The Laboratory's focus began to shift in 1958, when JPL engineers and scientists built, launched and operated the 31-pound Explorer 1, the first U.S. satellite. In 1959, JPL was transferred from the U.S. Army to a newly created NASA. Drawing on a heritage in rocketry — including missile guidance and control techniques and integrated test methods — JPL embarked on its new mission: the scientific exploration of the solar system.

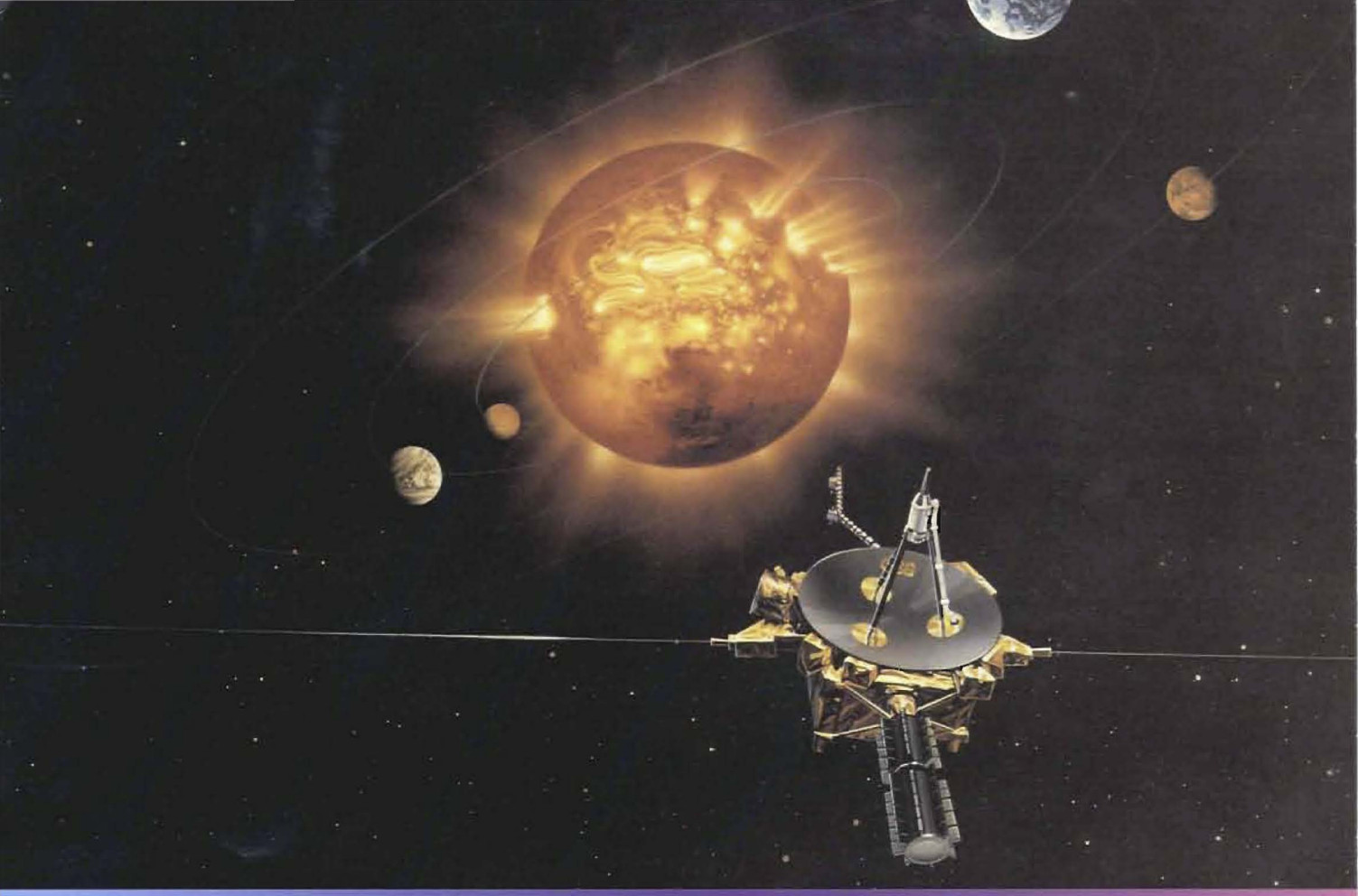
Between 1959 and 1975, the Laboratory's Ranger, Surveyor and Mariner robotic spacecraft were dispatched to study Earth's Moon, the solar environment and the planets Mercury, Venus and Mars. In the 1970s, two Voyagers were sent to tour the outer Solar System as interest shifted to Jupiter, Saturn, Uranus and Neptune. JPL also developed the Viking Orbiter spacecraft which, with the Viking Landers developed by the Langley Research Center, revisited Mars in the middle to late 1970s. This legacy of successful planetary exploration set the stage for the next generation of automated spacecraft — including Magellan, Galileo and Ulysses.

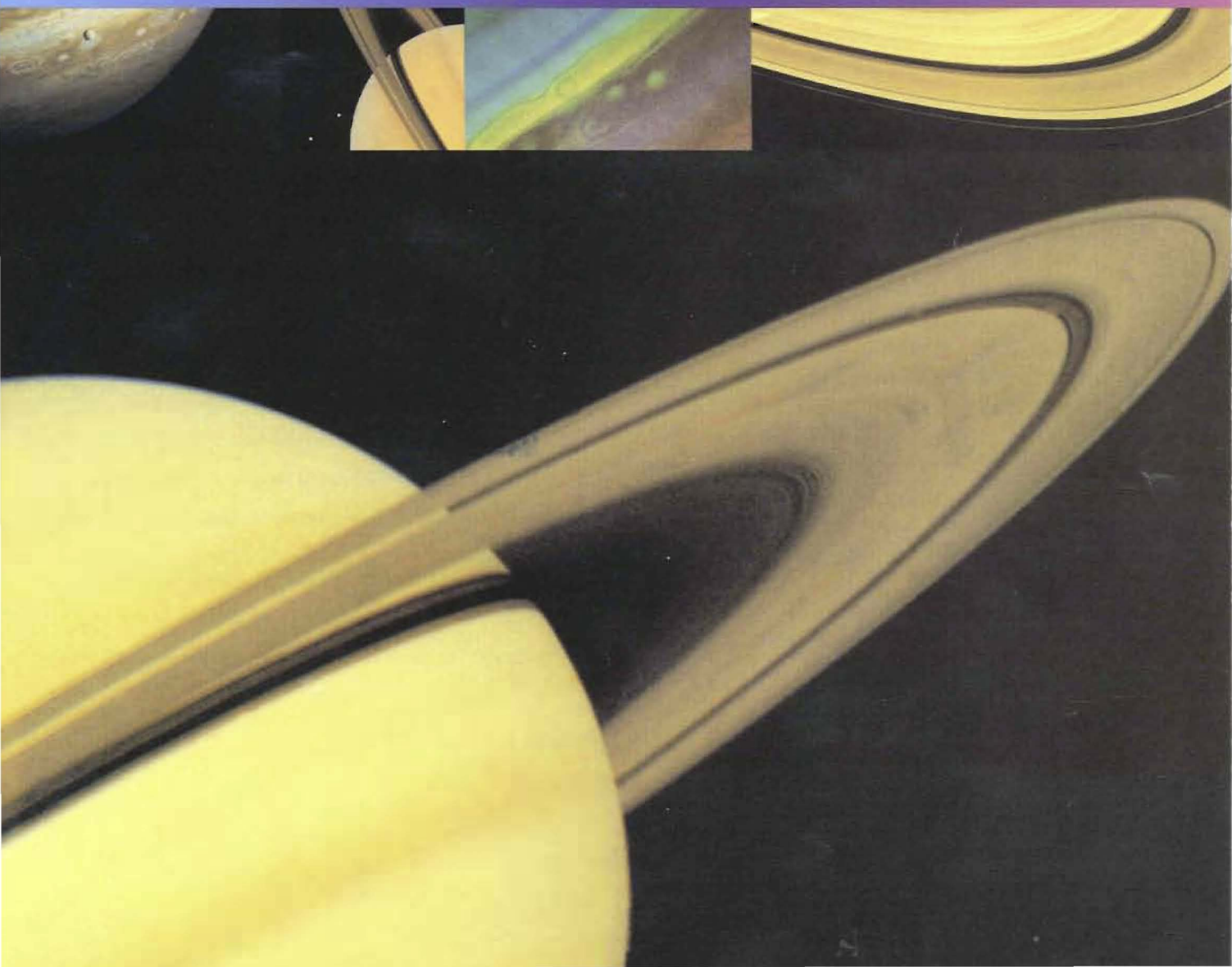
Top to bottom:

1941 EARLY *test flight for the Jet-Assisted Takeoff of Aircraft (JATO).*
1942 BULLET *holes riddle a JATO unit to show that it would not explode under enemy gunfire.*
1961 ENGINEERS *in conference, modifying an existing spacecraft design.*
1949 HAND-WELDING *on the manifold of a Corporal missile axial flow motor.*
1961 SCIENTIST *at work with the then-current tools.*

Top to bottom:

FLIGHT HARDWARE
Technicians checking spacecraft assembly.
COMPUTER SYSTEMS
Engineers designing the Cassini spacecraft.
MODERN METHODS
Scientist at work today.
LAUNCH READY
Preparing the Cassini spacecraft for launch.
RETURN JOURNEY
(Left) Mars Global Surveyor's road to Mars.





The first New Millennium spacecraft's science package will carry miniaturized sensors much smaller than those flown on any previous spacecraft. The Planetary Integrated Camera–Spectrometer, or PICAS, for example, consists of an ultraviolet imaging spectrometer, an infrared imaging spectrometer and two visible-light cameras that can characterize the chemical makeup, thermal properties, weather, atmospheric physics and geophysics of a planet or planetary moon. Using 1995 technology, this PICAS system weighs only 5 kilograms — compared to the 85-kilograms/1970-era technology of the Voyager spacecraft's scan platform.

For the Laboratory to successfully fly more spacecraft more frequently, a more efficient way of mission operations will be necessary. Rather than monitoring a deep space vehicle through round-the-clock shifts of human spacecraft controllers, JPL engineers are devising techniques that would effectively place operational control in the spacecraft themselves Future spacecraft could be largely self-navigating, their computer memories preprogrammed with maps of celestial objects to be used as reference points enabling them to chart their own courses through space. Such techniques should greatly reduce, if not eliminate, the need for costly constant human supervision and control

The changes under discussion could be summed up by the phrase "faster, better, cheaper," but that would be an oversimplification of what is really taking place at JPL The projects that the Laboratory will deliver in the course of the next two to seven years, such as New Millennium, will be characterized by short development cycles, by "design-to-cost" and by the application of enabling technologies such as solar electric propulsion and microelectronics The resulting advances in spacecraft autonomy and capability, coupled with critical savings in weight and thus development and launch costs, should revolutionize deep space exploration by making frequent missions more affordable and feasible

With the Strategic Plan in place, the reengineering teams working toward late-1996 deadlines to complete their studies and the industry-tested concepts of Total Quality Management having been infused into every corner of the Laboratory since their introduction in 1993, JPL ended the year on a clear path to its goal of cultural transformation Yet even as change is starting to become an everyday occurrence at the Laboratory, there is one unchanging, overarching principle· JPL's primary mission of exploring the Solar System and the Universe through robotic spacecraft and instruments.

Because of this principle, JPL continues to pursue the most creative spacecraft missions, missions that begin at home with Earth and the other planets of the Solar System and extend outward to the search for extrasolar planetary systems Earth and its dynamic atmospheric, hydrospheric and lithospheric systems constitute fully a fourth of the Laboratory's scientific inquiries Mars, with its tantalizing suggestions of an earlier, wetter environment, is the object of a 10-year-long investigation involving four missions, some to

be carried out in conjunction with international partners. Jupiter and its clutch of variegated moons, and Saturn and its intriguing moon, Titan, are expected to yield revealing information not only about the outer planets, but also about the earliest stages of the Solar System's formation Pluto, at present the only unexplored planet, could be visited relatively soon And then there is the Milky Way Galaxy, within which there might be other extrasolar planetary systems and, beyond that, galaxies where the never-ending story of star birth, star death and other extraordinary processes is waiting to be read — by spacecraft and instruments properly equipped JPL has plans for all these goals

ACROSS THE SOLAR SYSTEM

Galileo at Jupiter — On December 7, a small craft from Earth took perhaps the bumpiest 560-kilometer ride in history Hitting Jupiter's cloud tops at more than 170,000 kilometers per hour, the Galileo probe plunged deeply into the planet and endured temperatures twice those on the surface of the Sun and deceleration pressures 230 times the force of gravity on Earth.

After a six-year, 3.6-billion-kilometer trek, it was indeed those last few hundred kilometers of the journey that would prove most critical The 339-kilogram probe and its seven instruments plunged down through the turbulent Jovian atmosphere, transmitting a trove of previously unobtainable data to its mother ship, the 2,000-kilogram Galileo orbiter, 215,000 kilometers overhead, before succumbing to great heat and pressures. The orbiter, after getting a gravity assist during a close flyby of the volcanic moon Io four hours earlier, received and recorded the probe data and then fired its main engine to enter a long, looping orbit around the planet and begin its planned two-year tour through the Jovian system The crucial 49-minute burn, or orbit insertion maneuver, was essentially perfect Processing of probe data was under way at year's end, with early analysis verifying the functioning of all instruments and safe receipt of the probe's transmissions by the orbiter.

Project engineers calculated that the orbiter flew within 900 kilometers of Io, about 100 kilometers closer than originally planned As a result, the moon's gravity exerted a stronger influence in slowing the spacecraft before orbit insertion, thus bringing a saving in propellant and a rescheduling of the orbiter's first satellite encounter, with Ganymede, for June 27, 1996, instead of the originally planned July 4.

Galileo's 11 scientific instruments represent the most capable payload of experiments ever sent to another planet. The spacecraft is the first to visit an outer planet since Voyager 2 flew past Neptune in 1989, the first to orbit one of the outer planets and the first to send an instrument probe directly into one of their atmospheres.

The probe's penetration of the Jovian atmosphere and the orbiter's precise entry into orbit around the planet were a triumph for all involved — JPL, NASA's Ames Research Center

(who managed the probe), the Hughes Aircraft Corp (who built the probe) and the German consortium of Deutsche Agentur fur Raumfahrtangelegenheiten (DARA), Deutsche Forschungsanstalt für Luft-und-Raumfahrt (DLR) and Daimler Benz Aerospace (who manufactured the orbiter's 400-newton rocket engine).

In the coming year, the orbiter will encounter Ganymede twice and Callisto and Europa once each during the first four of 11 planned orbits. These flybys of the Jovian moons will be at distances as close as 200 kilometers and typically 100 to 300 times closer than the Voyager flybys, enabling Galileo's instruments to determine the surface chemical composition, geological features and geophysical history of the targeted bodies.

The orbiter will regularly gather data on the Jovian magnetospheric and dust environment throughout its two-year-long tour. Despite the partial deployment of its primary, high-gain antenna, which has left this antenna useless, Galileo is expected to send back more than 1,500 images and science data over its low-gain antenna and should ultimately achieve 70 percent of the mission's original objectives

The past year was focused on preparing Galileo for its arrival at Jupiter Because the high-gain antenna is not available to send back the high volume of data originally planned, upgrades to onboard computer software and ground-based communications hardware and software were developed and tested by JPL to return as much of the crucial information as possible. The spacecraft was successfully reprogrammed by year's end.

Meanwhile, NASA's Deep Space Network (DSN) continued efforts on the ground to enhance its support of the mission. S-band telecommunication was once the standard for space missions and several performance-enhancing capabilities for this set of frequencies were implemented at network tracking stations in the 1980s. With Galileo now communicating solely through its S-band low-gain antenna, these capabilities are being restored at the 70-meter antenna near Canberra, Australia, with the active help of the Commonwealth of Scientific and Industrial Research Organizations (CSIRO), the Australian entity that manages much of that nation's science programs Because Jupiter will be in the southern sky throughout Galileo's tour, the Canberra complex with its Block-V receiver will capture most of the spacecraft's data.

Preparations were also continuing at year's end to enhance data recovery by arraying the Deep Space Network 70-meter Canberra antenna, two neighboring 34-meter antennas and the Australian 64-meter Parks antenna, several hundred kilometers north of the DSN station at Tidbinbilla, to receive Galileo's signals concurrently and combine them electronically The arraying technique, to begin early in the orbital tour, will allow more of the spacecraft's weak signal to be captured

JPL engineers faced another telecommunications challenge when the orbiter's onboard tape recorder malfunctioned in October, just weeks before arrival at Jupiter. By that time, the recorder had become a critical link in techniques developed to compensate for the loss of the high-gain antenna, as the device is to be used to store all data until they can be compressed and edited by spacecraft computers and radioed to Earth by the low-gain antenna. Indeed, all indications were that the recorder had performed perfectly during the probe portion of the mission

In the summer, Galileo flew through the most intense interplanetary dust storm ever measured, just the latest of several such storms that the spacecraft had encountered since December 1994, when it was still almost 175 million kilometers from Jupiter. The spacecraft counted up to 20,000 particles a day, compared to the normal interplanetary rate of about one particle every three days

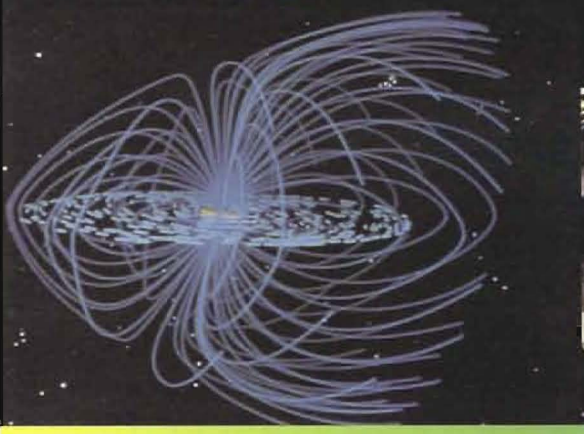
Scientists believe that the particles emanate from somewhere in the Jovian system — perhaps the volcanoes on Io, Jupiter's faint ring system or even material left over from comet Shoemaker-Levy 9's spectacular collision with the planet in July 1994 The particles are thought to be electrically charged and then accelerated by Jupiter's powerful magnetic field to speeds of 145,000 to 720,000 kilometers per hour. Even at such high speeds, however, these particles pose no danger to the spacecraft because they are so small. Early measurements during the orbital tour should shed light on their source.

ULYSSES AND THE SUN

More than 3 billion kilometers and five years into its journey, Ulysses, managed by JPL and the European Space Agency (ESA), completed its first circumnavigation of the Sun in September. The completion of this initial solar orbit gave the spacecraft the distinction of becoming the first to survey solar phenomena at all latitudes. Data collected by the joint NASA/ESA mission are enabling scientists to construct their first three-dimensional picture of the heliosphere, the extended region of space dominated by the solar wind

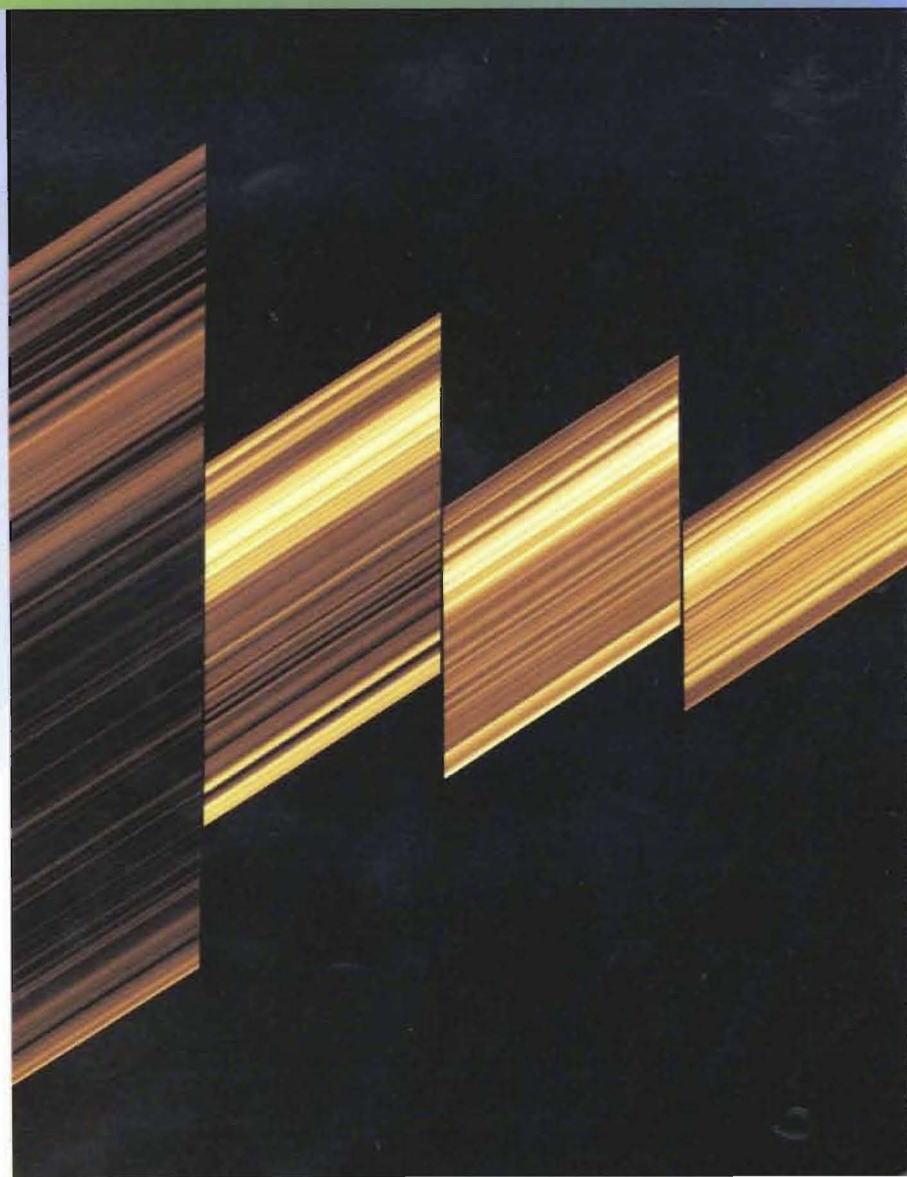
The solar wind — a stream of ionized gas particles that escapes from the Sun's corona and extends in all directions into interplanetary space — was the subject of scientific results announced in the spring by Ulysses project scientists. The findings confirm that the solar wind varies in speed at different magnetic latitudes. about 1.5 million kilometers per hour in the Sun's equatorial zone, about 3 million kilometers per hour at the poles.

As the Sun rotates, the magnetic equator appears to wobble up and down, and the solar wind in Earth's vicinity alternates between the fast and slow types. Before the slower, low-latitude solar wind has time to reach Earth, it is overtaken by the faster, higher-latitude wind, a phenomenon that forms a high-pressure "front" caused by coronal mass ejections These fronts are responsible for much of the interplanetary "weather" that causes aurora



ELECTRONICS DEVELOPMENT

Microelectronics are rapidly transforming space research. With advanced technology, spacecraft, instruments and sensors can be made smaller and more compact than before, leading to lighter-weight structures, lower power requirements and smaller, less expensive launch vehicles. JPL is developing efficient microinstruments, microsensors and micro-technologies for the smaller, lower-cost and higher-return space missions of the future. Planetary exploration in the 21st century most likely will be carried out by sets of small spacecraft or sensors rather than single, large vehicles. Microelectronics also hold out similar promise for Earth-monitoring satellites and instruments. Finally, JPL's work in microelectronics is brought "down to Earth" via commercial spinoffs that contribute to the economy by bolstering American competitiveness.

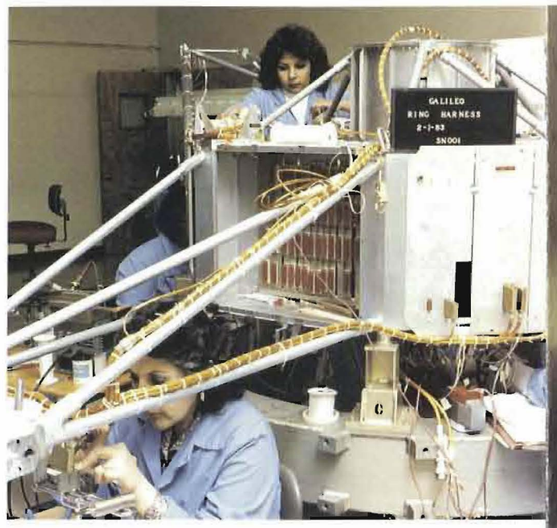


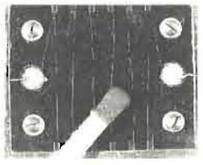
THEN

NOW

1983

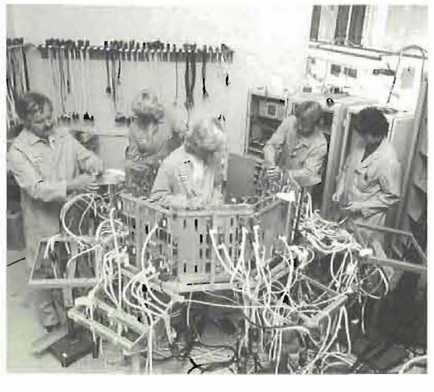
1995





Top to bottom:

1983 RING *harness being prepared for the Galileo spacecraft.*
1954 COMMON *match shows size comparison for a Corporal missile skin-temperature sensor.*
1965 ASSEMBLY *operations for a Mariner mission to Mars.*
1983 TECHNICIANS *wiring the Galileo spacecraft's electronics.*



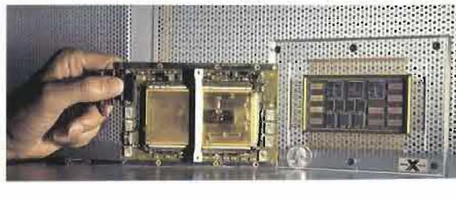
In the 1940s, JPL used vacuum tubes, resistors, capacitors and large dry-cell batteries hand-wired in metal chassis. They performed relatively simple electronic tasks of detection, amplification, rectification and transmission/reception. The need to make these parts smaller, lighter and more resistant to launch-related forces led to the development of solid-state devices, such as transistors, in the late 1940s. Used in ballistic missiles by the early 1950s, transistors required less power than vacuum tubes and also fitted more easily into a new wiring device called the printed circuit board.

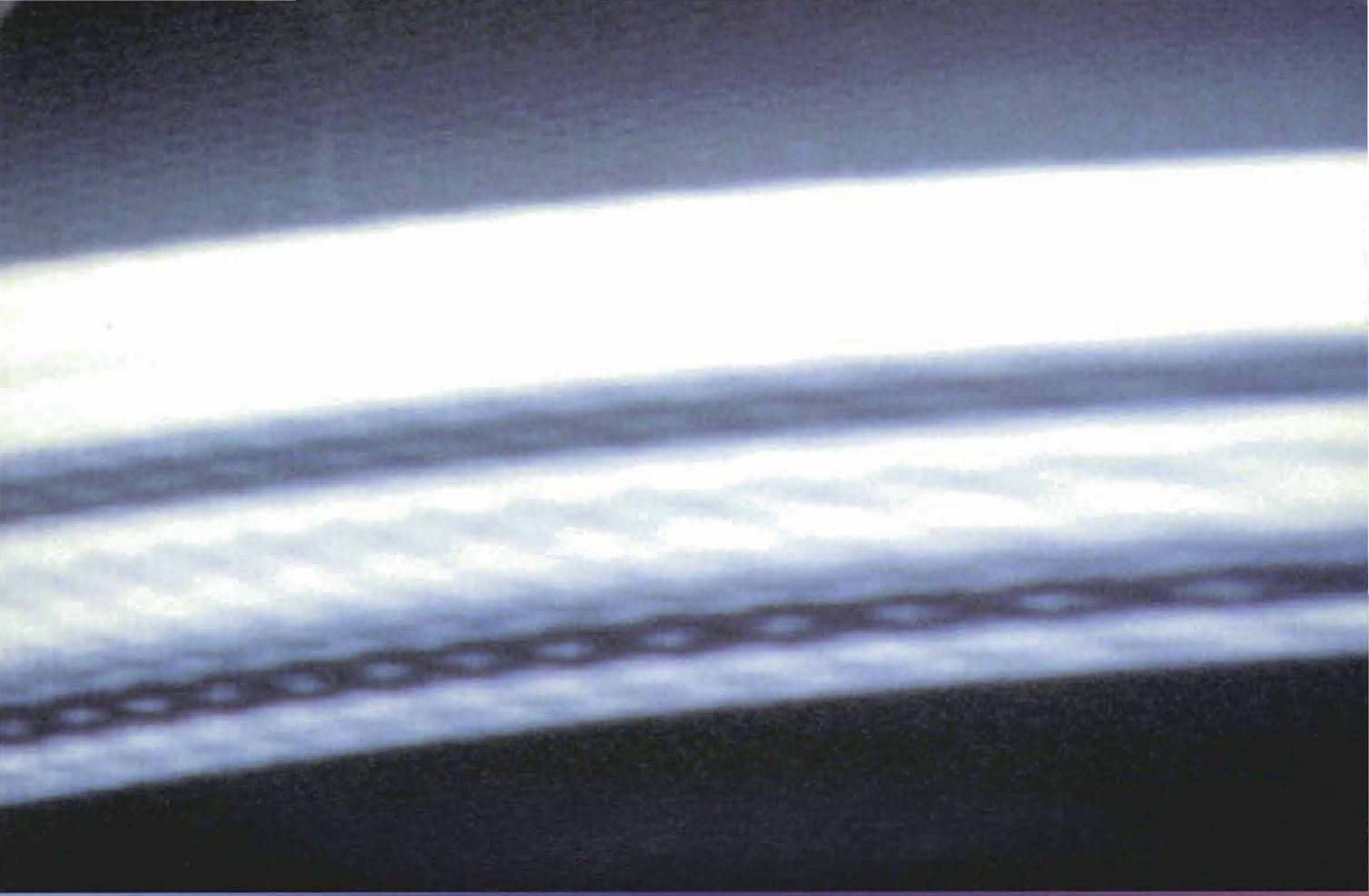
The next advance came in the late 1950s with the invention of the integrated circuit — electronic pathways laid down in miniature, multilayer silicon "sandwiches." This device became the new basis of missile and spacecraft electronics. Several integrated circuits could be combined on one printed circuit board, meeting the evolving demands of spacecraft performance: extreme reliability, lower weight and size, greater power efficiency and the ability to survive the extreme conditions of launch and the space environment.

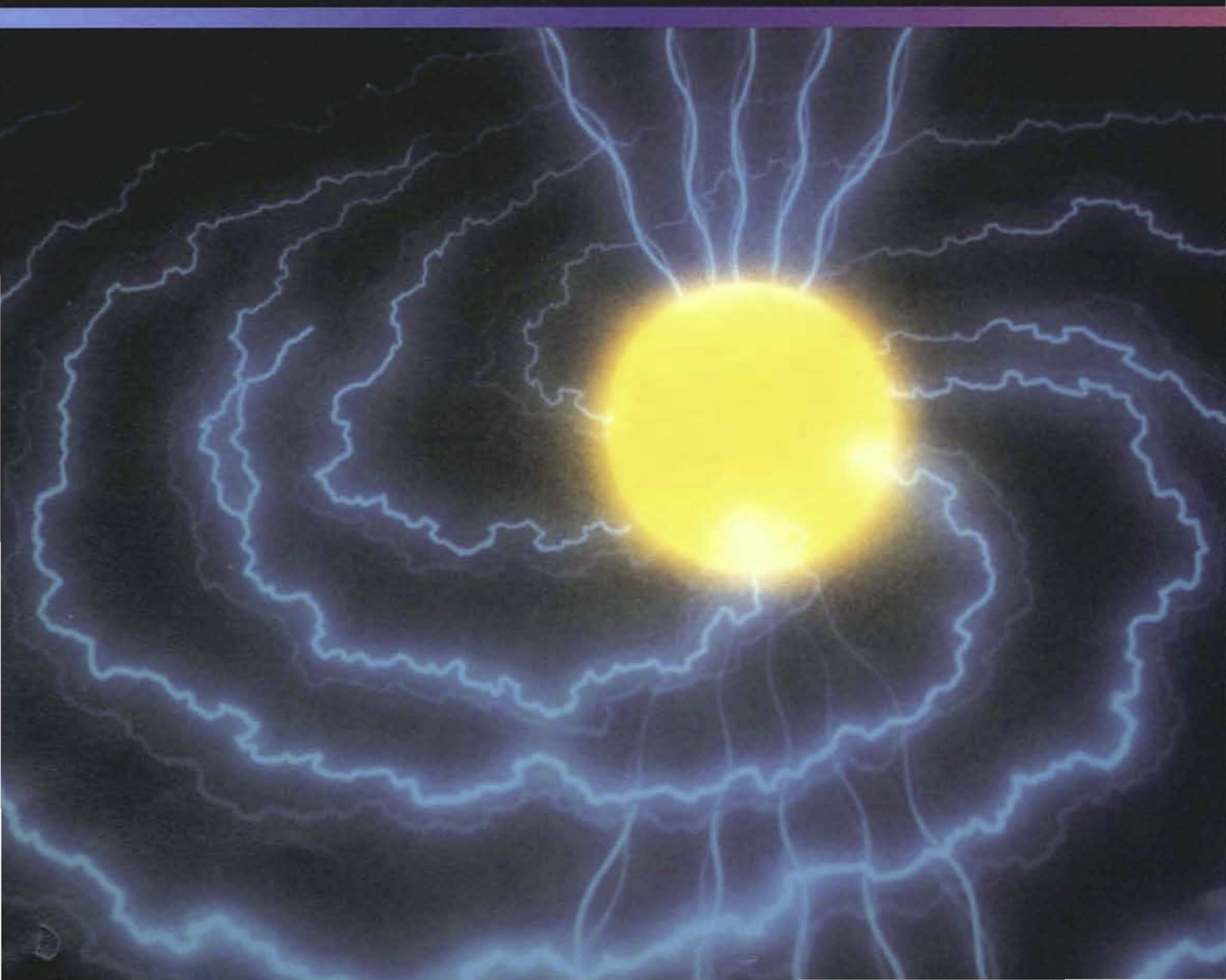
Today and into the future, microelectronics — smaller and better — will continue to meet the increasing challenges of deep space exploration.

Top to bottom

ION ENGINE
Powering Cassini on its forthcoming journey to Saturn.
MOLECULAR BEAM EPITAXY
Tailoring the properties of semiconductor devices.
COMMUNICATIONS SYSTEMS
Development of solid-state components development.
FLIGHT COMPUTER
Cassini exemplifies the "smaller is better" ideal in electronics.







(the so-called northern and southern lights) in Earth's atmosphere as well as the magnetic storms that occasionally interrupt radio and satellite communications.

The mission has been nearly flawless since launch in October 1990, and all operations and science experiments continued to function normally at year's end. Ulysses, currently traveling away from the Sun toward the orbit of Jupiter, will loop back toward the vicinity of the Sun in September 2000 during the Sun's most active sunspot phase and its magnetic environment reversed By the end of its second solar orbit in December 2001, the spacecraft will have collected data at all solar latitudes during both the quietest and most active phases of the 11-year solar cycle

CASSINI TO SATURN

As Galileo and Ulysses continued in flight, JPL technicians and engineers were preparing another spacecraft to take wing — the Saturn-bound Cassini This big spacecraft was successfully powered-on for the first time in early December, the first time that all its major elements were electrically linked. No problems were detected as power flowed through the 11 kilometers of cabling that link the spacecraft's computers, scientific instruments and mechanical and propulsion systems.

That success capped an eventful year as the project remained within budget and on schedule for an October, 1997, launch and a July, 2004, arrival at Saturn. The mission, a joint effort of NASA, ESA and Italy's Agenzia Spaziale Italiana (ASI), is similar in concept to Galileo But it is, in its scope and approach, the most advanced of the large-scale flagship projects and a long stride beyond any previous mission in terms of sophisticated instruments.

Cassini will send a parachute-equipped probe, called Huygens, through the atmosphere and to the surface of Saturn's largest moon, Titan, which appears to harbor organic chemistry that may hold clues to how life formed on primitive Earth The Cassini orbiter will explore the Saturnian system for four years, obtaining close-up data on Saturn's moons, its rings, the planet itself and its magnetic environment A key piece of the science payload is an imaging radar that will peer through Titan's atmospheric haze to produce photograph-like images of the surface.

Major Cassini milestones during the year included the arrival of the developmental test models of the Huygens probe from ESA and the orbiter's high-gain antenna from ASI Assembly and testing of the spacecraft will continue at JPL through mid-1997, when the spacecraft will be shipped to Cape Canaveral, Florida, for launch preparations

The Cassini mission has achieved a number of management innovations. Throughout the mission, costs are contained and efficiency enhanced by streamlined operations, and the

project uses simplified organizational groups to make decisions. An electronically based system developed by Cassini planners to manage conflicting electrical power and data rate needs has already been adapted by several municipal and state governmental organizations to applications involving allocation of environmental resources and waste products.

Early in the year, NASA directed JPL to assume programmatic responsibility for Cassini. The move is designed to centralize and strengthen the Laboratory's accountability for all elements of the mission (including the Titan IV/Centaur launch vehicle) as well as relations with other federal agencies and NASA's European partners. Reviews of the Cassini program throughout the year by outside experts brought praise for the program's technical performance and the actions it has taken to assure the mission's success.

RETURN TO MARS

Nearly two decades after the historic Viking landings on Mars, JPL's Mars Pathfinder and Mars Global Surveyor project teams took giant steps in 1995 toward a return to the Red Planet. Pathfinder, the second mission in NASA's Discovery program, will launch in December, 1996, with the goal of placing a lander on the Martian surface the following July 4. Mars Global Surveyor will launch in November, 1996, on a 10-month cruise to the planet, where it will conduct global mapping from a polar orbit for two years and remain for another three years to serve as a relay station for future craft.

Mars Global Surveyor is the first mission in a decade-long Mars Surveyor exploration effort designed to launch two spacecraft to the planet when it moves into a favorable position relative to Earth — about every 26 months. The Surveyor program is designed to be affordable, costing about $100 million a year, engage the public by providing new global and close-up images of Mars and return information of high scientific value through the inclusion of leading-edge space technologies. Landers in future years — 1998, 2001, 2003, 2005 and beyond — will capitalize on the experience of both the Pathfinder lander and Mars Global Surveyor orbiter.

As part of the Discovery program, Mars Pathfinder is being restricted to a three-year development cycle and a development cost cap of $150 million (as measured in fiscal 1992 dollars). Total development costs for Mars Global Surveyor will be even less because of its use of spares from the Mars Observer project; in keeping with tight management of all Mars program costs, a single operations project will operate Mars Global Surveyor and all future Mars Surveyor missions.

The Pathfinder mission will land and deploy a 11.5-kilogram solar-powered rover, dubbed Sojourner, onto an ancient flood basin called Ares Vallis. The mission will study the Martian atmosphere, the geology of the surface and the composition of rocks and soil at the outflow of a Martian canyon. In addition to gathering important data from the surface, Pathfinder

will be an in-flight engineering demonstration of key technologies and concepts that will be used in other, future missions to Mars or other planets — in particular, the entry, descent and landing approach.

This approach calls for the spacecraft to fly directly into the atmosphere, braking with a combination of an aeroshell, a parachute and small retrorockets before landing with the aid of huge shock-absorbing air bags Validated by engineering tests completed at several test sites throughout the year, this is considered by JPL engineers to be a robust technique that will lend itself to a variety of landing conditions

By the end of 1995, Pathfinder teams had completed all entry, descent and landing development tests, air bag inflation tests, rocket stand tests and rocket-assisted deceleration tests. JPL and its partners began looking forward to launching the spacecraft in late 1996.

The Mars Global Surveyor spacecraft came alive for the first time in October with a successful powering-on at the Lockheed Martin Astronautics Corp plant in Denver, Colorado, where it is being assembled The spacecraft is a much smaller version of Mars Observer, and, in fact, uses spare or rebuilt hardware from that earlier project

The new mission is to create a global portrait of Mars by surveying the planet's topography, magnetic field, mineral composition and weather In a polar orbit 360 kilometers above the planet, the spacecraft will circle Mars once every two hours, covering the entire planet every seven days. The six instruments in Surveyor's payload include the Mars Orbital Camera (built by Malin Space Science Systems of San Diego, California, and delivered to Lockheed Martin in November), which will produce a daily wide-angle image of the entire planet and narrow-angle images of objects as small as three meters across, representing a hundred-fold improvement in resolution over most of the Viking pictures of Mars. Other instruments will measure the planet's atmospheric density, topography and surface composition over the course of a full Martian year

Like Pathfinder, Mars Global Surveyor is more than a scientific mission; it will also serve as a further test of the fuel-saving aerobraking approach pioneered by the Magellan spacecraft at Venus in 1994 Using this technique, Surveyor will dip into the top of the Martian atmosphere each time it orbits closest to the planet. Gradually, atmospheric drag will slow the spacecraft, altering its orbit from an elliptical trajectory to the desired near-circular path over the poles. Aerobraking reduces the amount of fuel that the spacecraft must use for trajectory correction, thus providing a critical weight reduction when it is launched from Earth.

By year's end, Lockheed Martin had built and delivered the flight structure, adapted all spare Mars Observer hardware and completed 95 percent of spacecraft component fabrication. All avionics were integrated and assembly of the propulsion system was completed.

As work progressed toward the two 1996 launches, JPL had already begun looking ahead to the following Mars opportunity in December, 1998, and two missions that will search for water in the Martian soil and seek information on climatic conditions early in the planet's history. This data could bear significantly on whether or not some form of life might have existed at some point on the planet.

In March, Lockheed Martin was selected to build the Mars '98 orbiter and lander after a fast-paced, industry-wide competition that lasted only two months. The contract, valued at $96 million, should result in significant cost saving, as both spacecraft will be developed under the same roof, drawing on the company's experience in building the Mars Global Surveyor spacecraft.

The missions will bring unprecedented improvements in mass and capability, even when measured against the new standards being set by the 1996 Mars missions. For example, the Mars Surveyor '98 orbiter will weigh about only half as much as Mars Global Surveyor; the Mars Surveyor '98 lander will similarly be just over half the mass of Mars Pathfinder, which to date is the smallest planetary lander ever constructed. The '98 lander will be the first mission sent to a polar region of Mars, the southern cap, whose ice-laden terrain has long intrigued scientists.

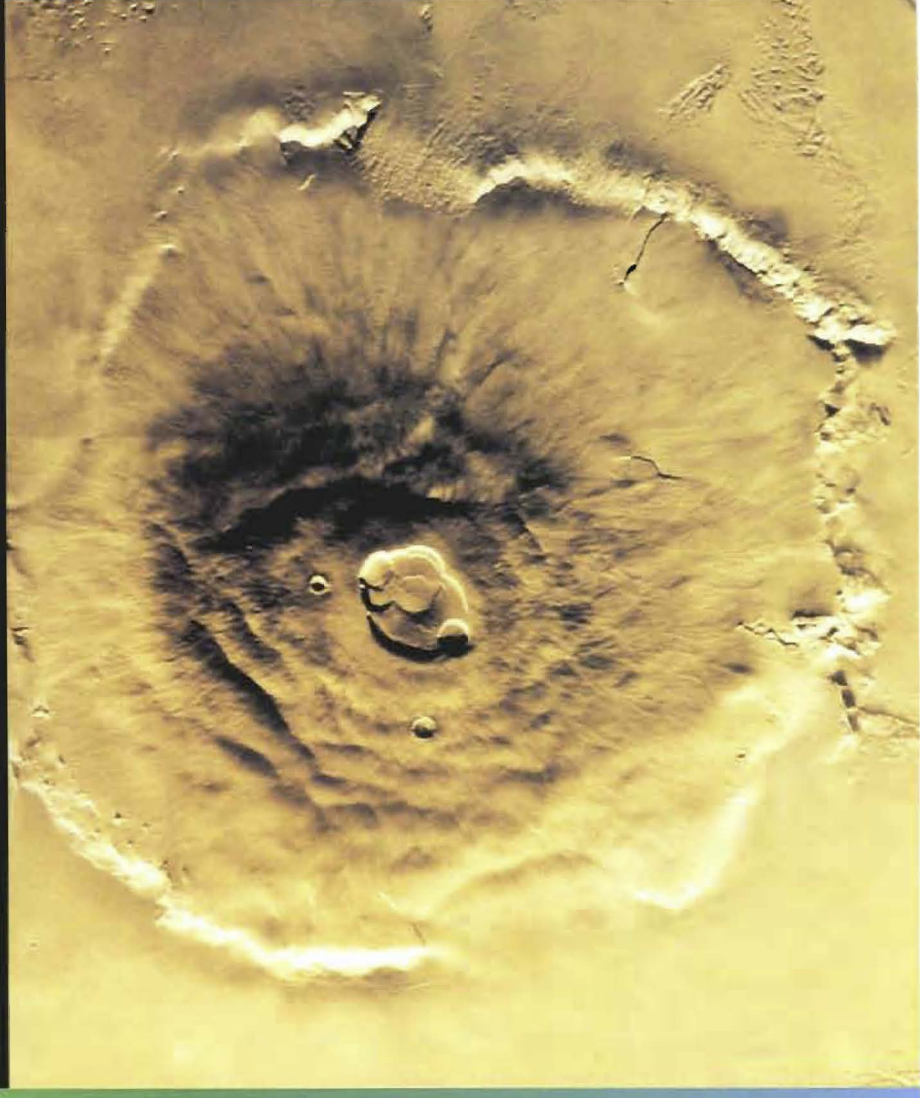
In addition to an infrared radiometer, which will measure atmospheric properties there, the lander will be equipped with an extendable, 2-meter-long robotic arm that will dig trenches in the dust and ice at the site and scoop up soil samples for an onboard chemical analysis experiment.

The orbiter will carry an advanced-technology imaging system called the Mars Color Imager, which has a mass of just 1 kilogram, less than one-tenth the mass of the Mars Global Surveyor camera. The lander will carry another low-mass camera, the Mars Descent Imager, that will operate only as it parachutes to the surface, as well as an integrated volatile and climate science package weighing just 20 kilograms.

The mass reductions in both '98 spacecraft make it possible to use a relatively inexpensive new launch vehicle, the Delta 7425, that has a little more than half the capability of the Delta 7925 rockets scheduled to launch the '96 missions.

FUTURE EXPLORATIONS

In November, NASA approved a joint University of Washington, Lockheed Martin and JPL mission that will snatch a bit of a comet in deep space and return it to Earth. The Discovery-class STARDUST mission will fly through the extended coma, or tail, of comet Wild-2 and capture a dust sample on an aerogel (a special form of silicon dioxide) plate for scientific

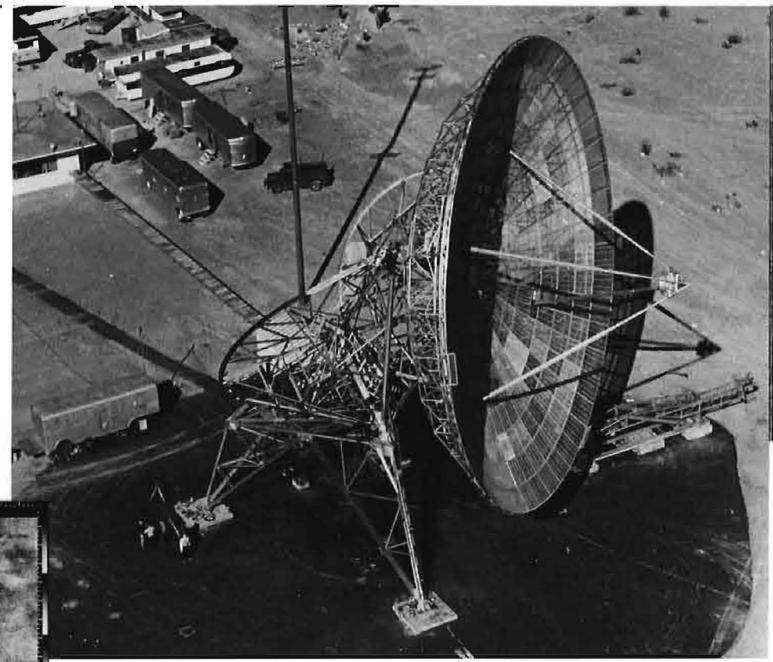


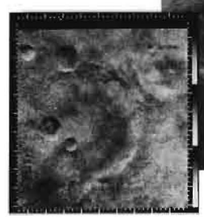
TELECOMMUNICATIONS RESEARCH

***A** vital element in every endeavor is the ability to communicate effectively: JPL projects must communicate with spacecraft in orbit around Earth or in transit across the Solar System. The Deep Space Network enables us to transmit instructions to, and receive data from, our numerous spacecraft, satellites and space-based instruments. This ongoing dialog with our robotic ambassadors expands our knowledge — helping us achieve a better understanding of our place in the Universe. And while discoveries from a spacecraft reconnoitering a distant planet might command more public attention, JPL technology has also found many useful commercial applications here on Earth — enabling us to become better informed about ourselves and the world on which we live.*

THEN

1958





NOW

1995

Top to bottom:

1958 PIONEER, *the first Deep Space Network antenna station, is now a National Historic Landmark.*
1965 MARINER *image of the Martian surface.*
1966 LOOKING *up from the subreflector of the 64-meter antenna at Goldstone, California.*
1966 CONTROL *room at the Space Flight Operations Facility at JPL in Pasadena, California.*

Accurate, reliable communications are essential to every space mission. Through the antennas of the Deep Space Network (DSN) at three sites around the world (California, Spain and Australia), JPL continually transmits instructions to, and receives data from, satellites orbiting Earth and spacecraft transiting the Solar System.

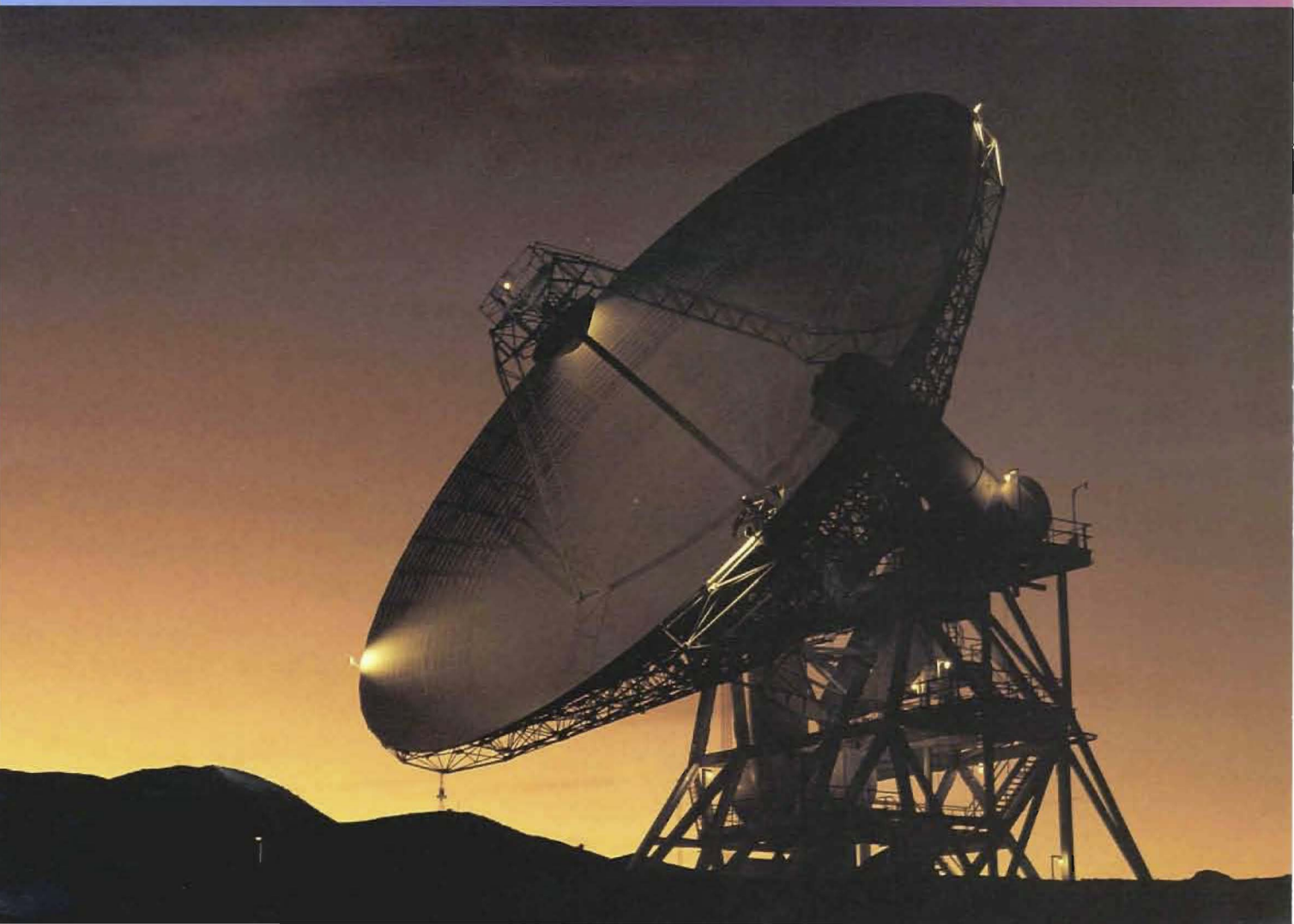
The Laboratory began development of deep space tracking stations in 1958 with the 26-meter Pioneer dish antenna at Goldstone in California's Mojave Desert. Since that time, the DSN has grown into a worldwide system of antenna stations. The DSN can provide 24-hour, simultaneous coverage of several spacecraft.

Besides supporting deep space and near-Earth missions, the DSN is an important resource for flight radio-science experiments and radio and radar astronomy observations. DSN stations receive telemetry signals from spacecraft, transmit commands that control spacecraft operations and generate radio navigation data that locate the spacecraft and guide them to their destinations. From 1958 through 1988, the DSN provided principal tracking, telemetry and command support for 27 flight projects, involving a total of 68 automated Earth-orbiting, lunar and planetary spacecraft.

With 30 spacecraft presently scattered high and low across the sky, scheduling and coordination — pointing the appropriate antenna at the right coordinates for a particular spacecraft — are difficult and complex tasks, but accomplished round-the-clock every day of the year.

Top to bottom:

DATA SYSTEMS OPERATIONS
Processing information from space missions.
ANECHOIC CHAMBER
Characterizing elements for the 34-meter antenna.
34-METER BEAM
Waveguide antenna's massive support structure at the Goldstone, California, complex.
MISSION FLIGHT TEAM
Coordinating and monitoring mission status.



analysis Scientists have long been fascinated by comets, because they believe these so-called "dirty snowballs" could have been the primary building blocks for the outer planets as well as a significant source of water and organic materials for the early atmosphere and oceans of Earth.

STARDUST, the fourth announced Discovery mission, will be budgeted at slightly under $200 million in current dollars Like other missions in the Discovery program, Stardust will go from start-up to launch in 36 months or less and will be a joint venture with industry and academia. The current timetable calls for launch in 1999, rendezvous with Wild-2 in January, 2004, and arrival at Earth, via return capsule, of the cometary samples in January, 2006. Lockheed Martin, builder of Pathfinder and the Mars '98 spacecraft, will also manufacture STARDUST; Dr Don Brownlee of the University of Washington is the principal investigator and JPL will provide project management

In October, NASA and the French space agency, Centre National d'Études Spatiales (CNES), announced the provisional selection of instruments for a JPL-built comet lander called Champollion. The lander, named for Jean-François Champollion, the French scholar who solved the mystery of Egyptian hieroglyphics by decoding the Rosetta Stone, is one of two small (45 kilograms each) craft to be deployed by ESA's Rosetta spacecraft onto the nucleus of comet Wirtanen in 2012

Rosetta, the first spacecraft to orbit a comet, will image and, with other instruments, examine the comet's structure and composition. The landers will provide measurements of the strength, temperature and composition (elemental, chemical and mineralogical) of the comet's surface and subsurface structure, as well as very high-resolution images of its crust and underlying material

Champollion's observations will not only be the first in situ examination of a body thought to contain some of the primordial matter from which the Solar System formed, but will also provide "ground truth" for the Rosetta orbiter's instruments. Confirmation of the scientific payload is expected in early 1997 as development proceeds toward a planned January, 2003, launch

A mission to explore the only uncharted planet in our Solar System moved closer to realization in 1995 The Pluto Express preproject, in keeping with the new thinking affecting other projects at the Laboratory, has moved from a fast-flyby direct trajectory requiring a large launch vehicle to an approach employing multiple gravity assists like those used for Galileo and Cassini. The mission, which would entail a flight of more than 10 years, will focus in the coming year on such areas as design of scientific investigations and studies of the mission operations challenges posed by a flight of such unprecedented duration and distance.

BACK TO PLANET EARTH

Even as teams of JPL planners, scientists and engineers continue to reach out into the Solar System, others were focusing their efforts closer to home in 1995. The Laboratory, working closely with the NASA Goddard Space Flight Center, continued its key role in NASA's Mission to Planet Earth — a program inaugurated in 1991 to enhance knowledge of the changing global environment.

From the uniquely revealing vantage point of space, a variety of current and upcoming missions will observe, monitor and assess large-scale environmental processes, in particular, changes in Earth's climate. Spaceborne studies should yield detailed information that will help distinguish natural changes in the environment from those caused by human activity, while broadening our perspective on Earth's history and the planet's place in the Solar System.

SPACEBORNE IMAGING RADAR

The Spaceborne Imaging Radar–C/X-band Synthetic Aperture Radar (SIR–C/X-SAR) space radar system, developed collaboratively with the German and Italian space agencies, the Ball Aerospace & Technologies Corp. and JPL, was singularly productive during two flights in 1994 aboard the Space Shuttle Endeavour. The reams of data collected during those missions continued to deliver exciting new scientific insights throughout 1995 and probably will continue to do so for years to come.

The radar measurements — from hundreds of sites around the globe — created an important new data set for studying changes in Earth's environment. Because radar provides its own "illumination," in the form of microwaves, it can do what ordinary camera systems cannot: peer through clouds, take images at night, look through forest canopies and even "see" through one or two meters of desert sands. Among the findings announced in 1995:

- **SCIENTISTS** *discovered a suture from the ancient supercontinent, Greater Gondwana. The suture marks the collision zone where East Gondwana (present-day Australia, Antarctica and India) and West Gondwana (Africa, North America and South America) came together to form one huge land mass 650 million years ago. SIR–C found a short segment of this thousands-of-kilometers-long zone in what is now northern Sudan. This revealing look at a key stage in the supercontinent cycle — the periodic separation and recombination of continental fragments — may offer important insight into Earth's past, as harsher climates are believed to prevail when the continents coalesce and more humid climates when the continents are separated.*

- **SIR-C/X-SAR** *data also shed light on the perplexing meanderings of the Nile River, as a geologic fault discovered in the ancient suture zone may determine the river's bends and twists in that part of Sudan. Data collected over southeast Libya revealed a system of once-active stream valleys now obscured by desert sands In earlier, wetter times, these so-called paleo-drainage systems are believed to have carried running water northward across the Sahara, supporting Paleolithic and Neolithic peoples The SIR-C/X-SAR images may provide a map that archaeologists can use to locate artifacts and more accurately interpret the region's history of habitation and climate change.*

- **ICE FIELD IMAGES** *of the Patagonian region of Chile and Argentina revealed previously unobtainable details on glacier movements and the effects of changes in weather on snow and ice. The remoteness of the region and its generally inhospitable climate had allowed exploration by only a few scientific mountaineering expeditions before the SIR-C/X-SAR missions; in addition, the region imaged is nearly always covered by clouds, so other forms of remote sensing had proved less useful.*

Looking to the future, JPL last year discussed a third, joint flight of SIR-C/X-SAR with the Defense Mapping Agency that would produce a digital global elevation map of unprecedented accuracy. Under the proposal, the Defense agency would provide funds to add a 60-meter-long boom and two outboard antennas (one for C-band and another for X-band) to the instrument, as well as create the map products resulting from the mission.

TOPEX/POSEIDON

The joint U S -French ocean-observing satellite completed a highly successful three-year primary mission in 1995, a year that also brought important new findings on the continuing phenomenon of El Niño in the equatorial Pacific Ocean.

The primary goal of the JPL-managed mission is a better understanding of oceanic circulation by measuring ocean topography, or sea level relative to Earth's center As the satellite orbits the planet, its dual-frequency altimeter bounces radar signals off the ocean's surface. The device records the time it takes a signal to leave the transmitter, strike the surface and return, thus providing a precise measurement of the distance between the satellite and the sea surface. From these and other data gathered by a total of six instruments, scientists are able to construct a global map of ocean topography accurate to within 5 centimeters.

During the winter of 1994-1995, oceanographers using TOPEX/Poseidon data confirmed the existence of a new El Niño condition in the central equatorial Pacific. The event — an overlay of warm water over normally cold, upwelling waters off the west coast of South

America with disruptive shifts in currents, precipitation and winds — contributed to unusually wet weather in California and an unseasonably warm winter in the northeastern United States. This El Niño showed up in TOPEX/Poseidon data as a wedge of water, some 10 to 20 centimeters higher than normal, across the equatorial region of the Pacific.

The finding followed the detection during the mission's first two years of an average yearly rise in global sea level of 3 millimeters, an increase researchers attributed to recent prolonged El Niño events. Indeed, data from TOPEX/Poseidon have indicated that the effects of El Niños last much longer than was previously thought, as residual signs of the 1982–1983, 1986–1987 and 1991–1993 events were detected.

As TOPEX/Poseidon moved into an extended mission phase, the data set continued to exceed all prelaunch expectations. By year's end, the satellite had completed more than 15,000 orbits of Earth. Project officials, looking carefully at the satellite's general health and its life-limiting components, happily projected a total mission life span of seven years. Studies are already under way for a follow-up program that would again involve NASA and its French partner, CNES.

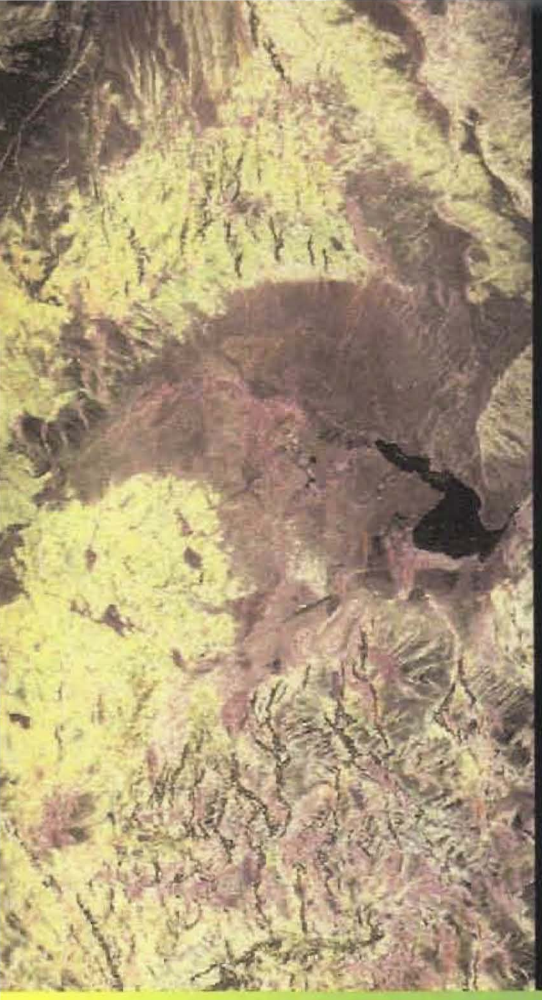
NASA SCATTEROMETER

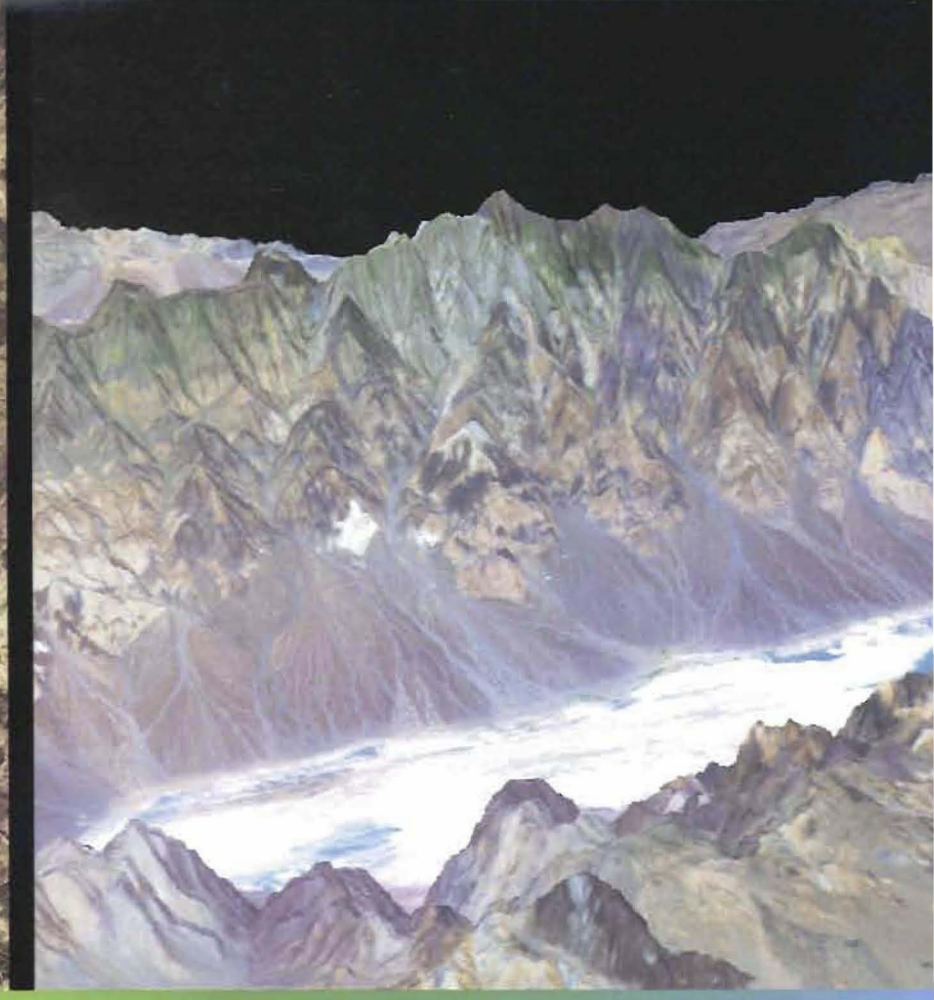
In much the same way that TOPEX/Poseidon has revolutionized the study of ocean circulation, the JPL-developed NASA Scatterometer, or NSCAT, is expected to open a new chapter in research on ocean winds.

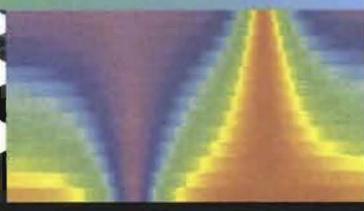
From low Earth orbit aboard Japan's Advanced Earth Observing Satellite (ADEOS), the instrument will take 190,000 wind measurements daily, mapping more than 90 percent of the world's ice-free oceans every two days. NSCAT will generate more than 100 times the amount of ocean wind information currently derived from ship reports. Such data will enhance scientific understanding of the complex interplay between ocean winds and currents and the role of air–sea interactions in the global ecosystem. In turn, this new understanding may one day improve predictions of climate change and weather.

The instrument will use an array of microwave-radiating antennas to examine the small waves on the ocean surface that are caused by winds, and from such measurements will be able to infer the direction and magnitude of near-surface winds with great accuracy, day or night and under all weather conditions.

NSCAT was integrated into the host Japanese spacecraft in spring 1995, in anticipation of a 1996 launch on a three-year mission.

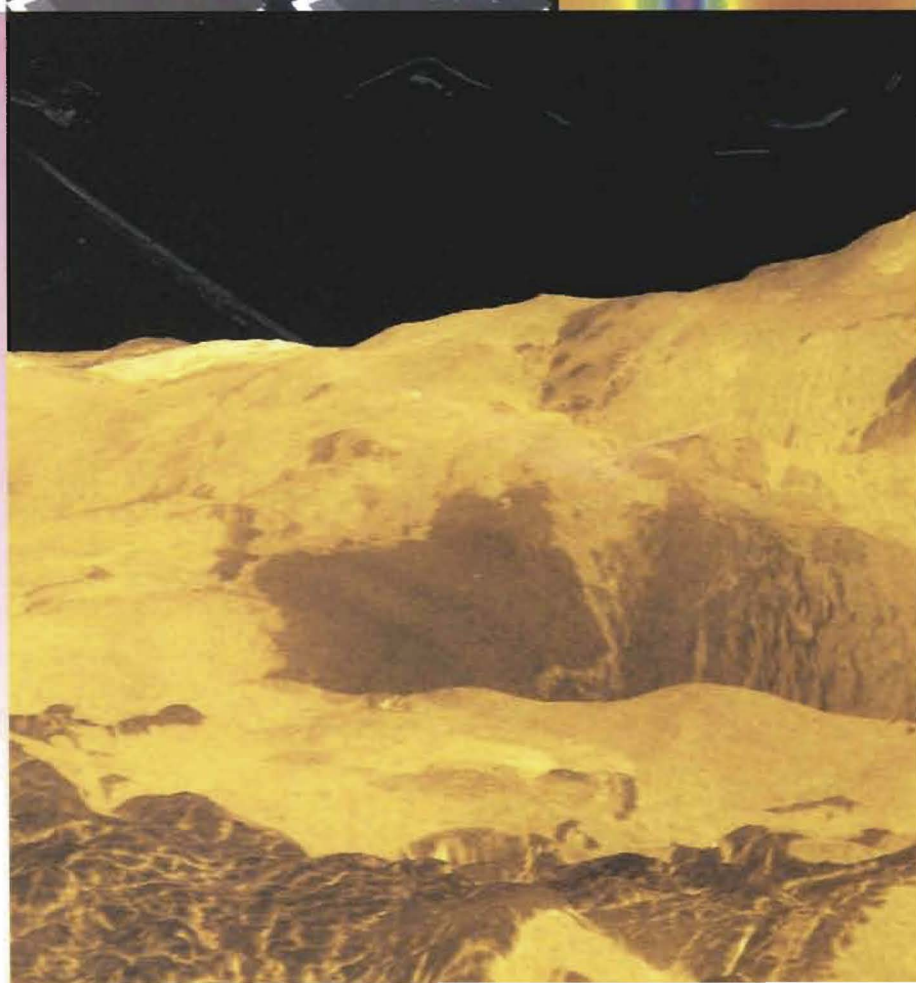






COMPUTER TECHNOLOGY

Modern computers enable JPL's complex space missions: software programs monitor spacecraft and ground systems, computer-driven vehicles explore planetary surfaces and robots perform maintenance of satellites in Earth orbit. Labor-intensive tasks — mission design, trajectory calculation, data analysis — are faster, better and cheaper. This growing sophistication is a result of JPL innovations in computing and information processing; some of the fastest supercomputers in the world are operated by JPL and the Caltech Campus to address science and engineering applications. In the near future, computing for spacecraft power, propulsion, communications and data systems could increase science return from space missions by a factor of as much as 10,000.

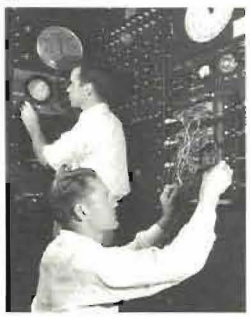


THEN

In the early 1950s, digital computers filled whole rooms. They consisted of separate machines connected by cables: input/output devices such as punch-card typewriters, sorters, compilers and readers; a vacuum-tube-based central processing unit (CPU); and control devices for running magnetic tape drives, which constituted the computer's transient memory.

Data and input commands to the computer required punch cards; these were machine-read to transfer their information to magnetic tape drives for input to the CPU. After computation, the process was reversed, with output punch cards fed to printers that produced paper copies.

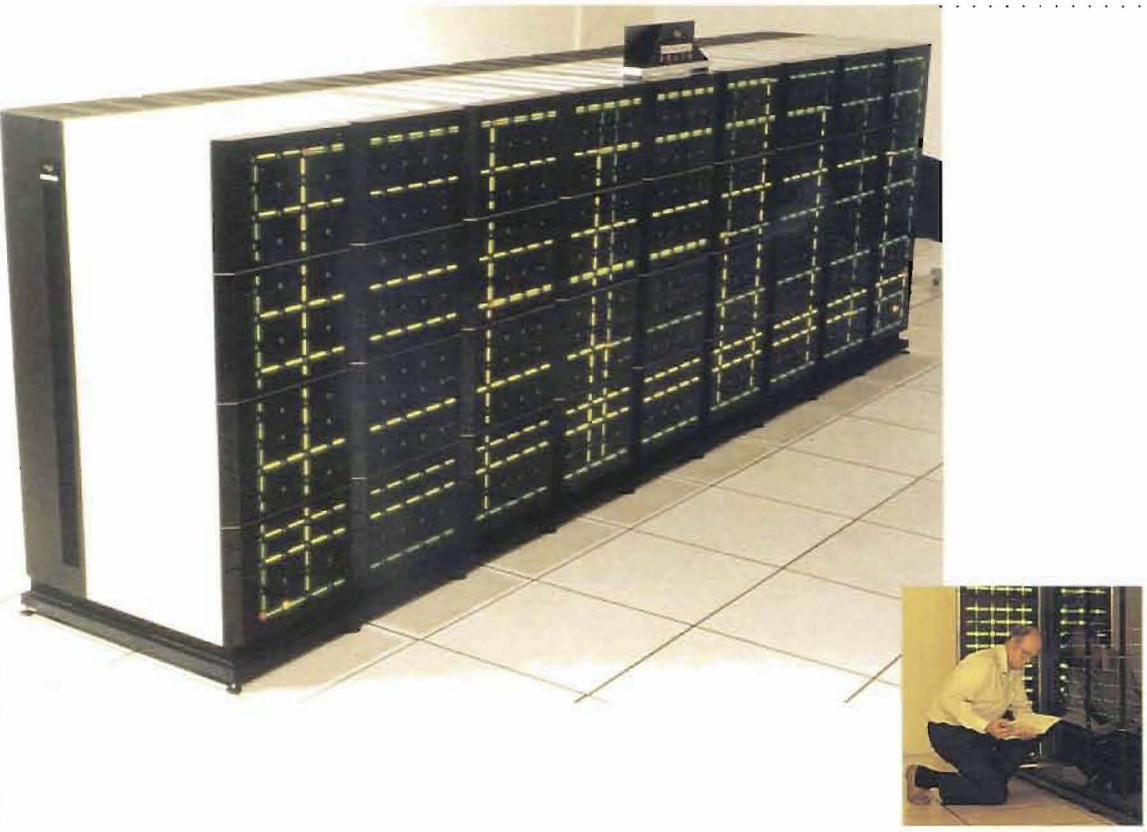
When digital computers became commercially available in the early 1950s, JPL began using them to calculate trajectories and predict aerodynamic variables for missiles and to handle performance data from rocket-motor tests. They were much



Top to bottom:

1953 MEMBERS *of JPL's computing section figuring trajectories using mechanical calculators.*
1955 COMPUTER *tasks depended on a modified typewriter for data input and output.*
1955 DATA-RECORDING *devices for controlling magnetic-tape banks.*
1952 REAC, *Reeves Analog Computer, achieved 6,000 "solutions" over a three-year period.*
1953 "COMPUTERS," *the all-woman section that performed theoretical calculation and experimental data reduction.*

NOW



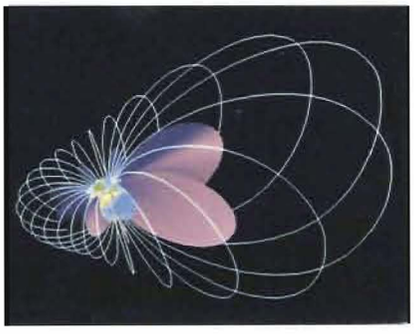
faster at these jobs than Laboratory personnel operating mechanical desktop calculators — but hardly a match for today's personal computers.

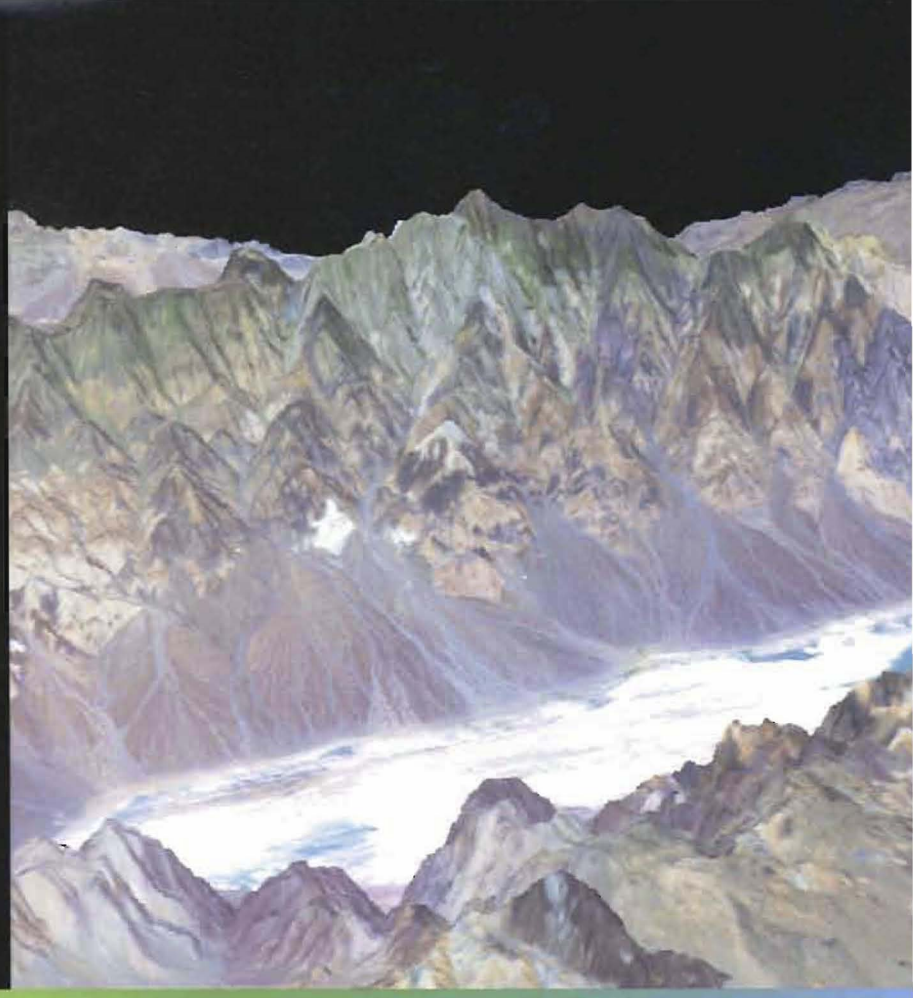
From the 1950s through the 1960s, computers became increasingly sophisticated and complex in terms of software capabilities, languages, operating systems and user interfaces. With the advent of solid-state devices, the machines got smaller and considerably faster; they were also linked by networks to allow shared and dispersed processing. Video terminals replaced the original paper- and magnetic-tape-based input/output devices.

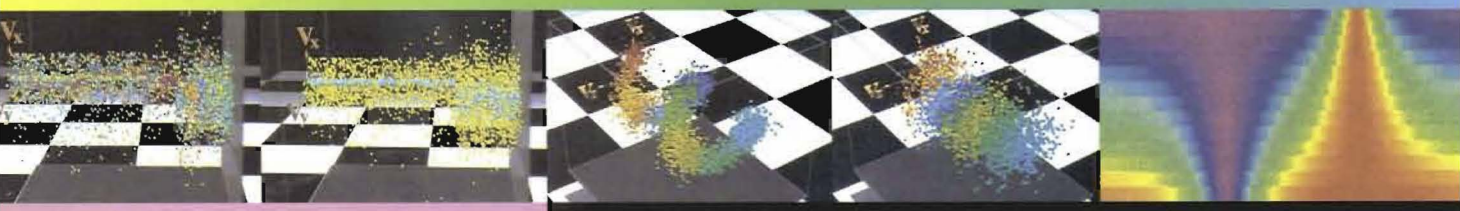
Today, the capabilities of even the simplest desktop computer surpass those of the massive early mainframes — and the possibilities for the future of computing are staggering.

Top to bottom:

TOUCHSTONE DELTA
The 32-gigaflop peak speed supercomputer at Caltech Campus.
RESEARCH APPLICATIONS
The Delta performs design, modeling, simulation and visualization.
TRAJECTORY CALCULATION
Cassini's path to Saturn is now computer-aided and precise.
SUPERCOMPUTER
Three-dimensional representation of Earth's magnetic field.







COMPUTER TECHNOLOGY

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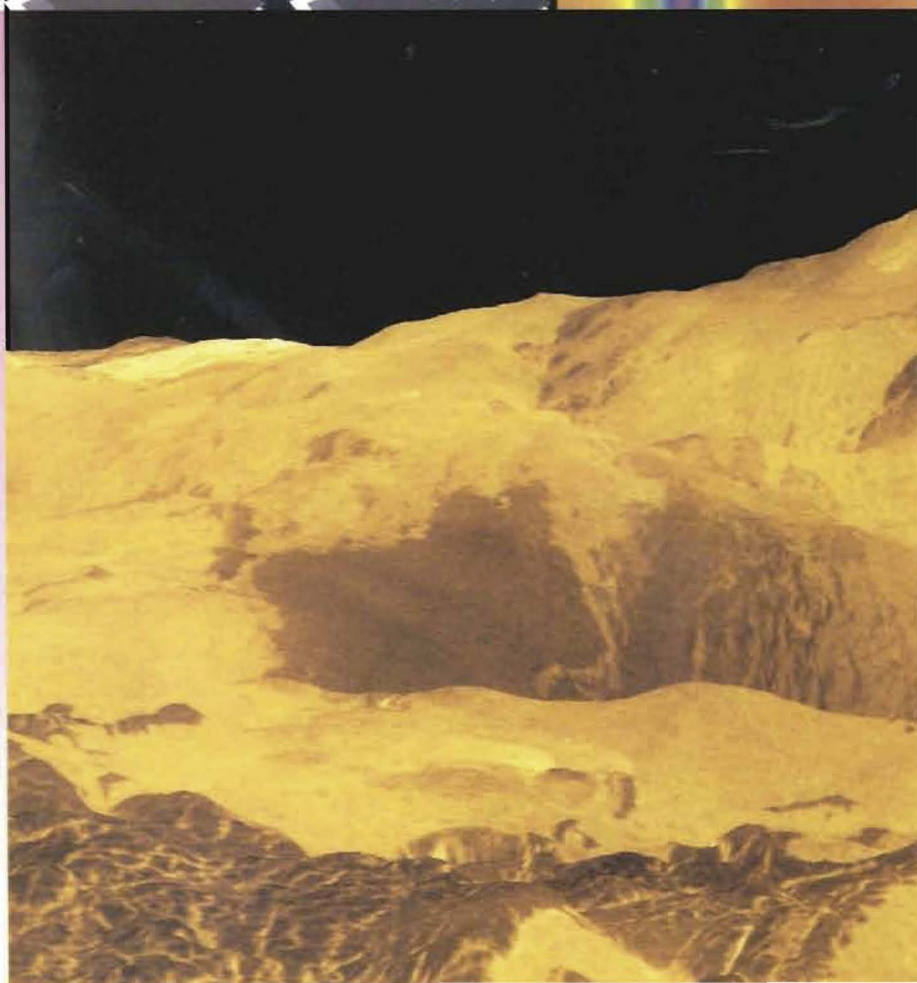


EARTH OBSERVING SYSTEM

JPL will be a major supplier of instruments for the Earth Observing System (EOS), a major element of the Mission to Planet Earth that will launch a fleet of orbiting spacecraft starting late in the decade.

The first craft, EOS-AM1 (for ante meridiem, because it will cross over the equator at about 10:30 a.m. every day) will carry JPL's Multi-Angle Imaging Spectro-Radiometer to measure the amount of sunlight absorbed by Earth's surface and by particles in the atmosphere, along with the Advanced Spaceborne Thermal Emission and Reflection Radiometer — a Japanese Ministry of International Trade and Industry instrument for which JPL is providing science support. The latter will create maps of surface temperature and digital elevation maps of surface features. The two instruments are scheduled to be launched aboard the EOS-AM1 satellite in 1998.

Later in the series, EOS-PM2 (for post meridiem, because it will cross the equator at about 4:00 p.m. every day) will carry the Loral Corp.–developed Atmospheric Infrared Sounder and other instruments into orbit in 2000. The EOS Chemistry platform will carry an advanced Microwave Limb Sounder and the Troposphere Emission Spectrometer, each of which will study the upper atmosphere after launch in 2002.

BEYOND THE SOLAR SYSTEM

Last October, two researchers at the Geneva Observatory in Switzerland announced the discovery of a large planet around a Sun-like star some 45 light years from our Solar System. Their landmark finding of a Jupiter-class planet orbiting the star 51 Pegasi has enabled scientists to move from the theoretical realm to their first conclusive scientific data on the existence of planetary systems around average stars like our own.

The philosophical implications of this discovery, of course, are perhaps even greater than the scientific ones. The discovery, and those expected to follow in this burgeoning area of research, may once and for all lay to rest the idea that our Solar System is unique. And although the planet orbiting 51 Pegasi appears to be particularly inhospitable, with a surface temperature of 1,300 degrees Celsius, its discovery raises new interest in the search for habitable, Earthlike worlds.

SPACE INTERFEROMETRY

The search for Earthlike planets will combine the well-established observational technique known as interferometry with a new class of space telescopes; JPL is already at work on concepts and preliminary designs. Interferometry, which combines the signals received by several widely dispersed mirrors so that they perform as if they were parts of one, much

larger, collecting surface, has been used with great effectiveness by radio astronomers for more than 30 years. In effect, two collecting surfaces, each 5 meters in diameter and spaced 50 meters apart, can combine their signals in such a way as to mimic a single telescope 50 meters in diameter.

JPL is operating a testbed interferometer at Palomar Observatory in which the baseline, the separation between the mirrors, is 100 meters. It is a prototype whose operation will provide useful instruction for the interferometer to be built for the two powerful Keck Telescopes in Hawaii. In future phases of this research, JPL intends to advance the science of interferometry with the Keck Telescopes and ultimately apply the technique to a set of widely spaced telescopes orbiting the Sun. A future New Millennium mission would be devoted to an in-flight test of the key technologies involved.

NEIGHBORING PLANETARY SYSTEMS

JPL is serving as the lead center for NASA's Exploration of Neighboring Planetary Systems program, or ExNPS, a proposed long-term effort to detect Earthlike planets around nearby stars. ExNPS is part of a broader NASA theme, called Origins, that will seek new knowledge on the origins of stars and planets, of life and of the Universe itself.

Some 135 scientists and engineers from 53 academic and other research organizations worked for more than six months in the past year to develop a detailed plan for the characterization of nearby planetary systems. The resulting ExNPS Road Map combines many individual ground- and space-based projects, with the goal of ensuring a continuous stream of important discoveries:

- **NEAR-TERM** *observations with ground-based telescopes will continue to identify stars with planets by indirect means. Scientists expect the possible detection of additional Jupiter-size planets during this phase.*
- **EXISTING** *or planned space missions such as the Hubble Space Telescope, which will be fitted with a new infrared camera in 1997, and the JPL-managed Space Infrared Telescope Facility (SIRTF), will make important precursor observations and test new technologies.*
- **EXNPS** *would culminate in a mission consisting of four or five infrared telescopes linked together as an interferometer and orbiting the Sun beyond Jupiter. The mission could be launched around 2005 to search for Earthlike planets around nearby stars, and examine the brightest ones for the spectral signatures of water, carbon dioxide, methane, oxygen and ozone and other signs of habitability.*

By the time frame of 2006–2012, the program will aim to acquire "family portraits" of 150 to 200 possible planetary systems and search the solar neighborhood of roughly 1,000 stars out to distances of 50 light years. After characterizing the spectra of the brightest 50 to 100 detected planetary systems, researchers will set out to identify Earthlike planets.

SPACE INFRARED TELESCOPE

In the nearer term, JPL teams continued their work in 1995 on SIRTF, the Space Infrared Telescope Facility, the last of the orbiting telescopes in NASA's program of Great Observatories. SIRTF, ranked by the National Academy of Sciences as the highest-priority major new American astronomy mission, will be submitted as a candidate for a new start in NASA's fiscal 1998 budget.

SIRTF will build on the success of the 1983 Infrared Astronomical Satellite, also managed by JPL. The new observatory, set for launch in 2002, will measure the faint heat radiated by celestial objects, using cryogenically cooled instruments to keep its own heat from distorting the radiation of those objects. It will collect infrared images and spectra of the birth of stars and galaxies, study nearby comets and asteroids as well as distant quasars and search for planetary systems around other stars.

This project is a dramatic example of how the Laboratory's new approaches can substantially reduce costs — in this case, from more than $2 billion to $450 million. And by moving the spacecraft from a comparatively "warm" station in Earth orbit (as first proposed), to a "cooler" orbit trailing Earth, mass and cost savings have been achieved without sacrificing key scientific capabilities.

The project last year also developed a test facility where telescope mirrors up to 1 meter in diameter can be subjected to temperatures as low as –270 degrees Celsius — the thermal range for some intriguing astrophysical processes and the spectral region for SIRTF's longest-wavelength observations.

TO SERVE THE NATION

As a federally funded research and development center, JPL recognizes its obligation to constantly advance those technologies within its charter and to apply the fruits of those efforts on behalf of national interests. To promote a steady stream of innovations, the Laboratory uses such programs as the Director's Discretionary Fund to support selected staff proposals, covering a broad spectrum of scientific disciplines and technologies. Last year, the Fund — operating with $3.5 million from NASA and $177,000 from other sponsors — started 26 new research tasks and provided continuing funds for four ongoing tasks.

JPL's Technology and Applications Programs (TAP) Directorate has long been a fount of advanced technology and, in 1989, formed the Technology Transfer and Commercialization Office to make its varied technologies more available and useful to American industry in the increasingly competitive world marketplace. Last year, for example, JPL and its industrial partner, DTI Technologies Inc. of Los Angeles, California, made significant progress in the development of a 1-kilowatt fuel cell for electric automotive applications, as well as other zero-emission uses. With a mixture of water, 3-percent methanol and air brought together on opposite sides of a solid polymer membrane, the fuel cell is capable of providing a continuous 50-ampere current on an approximately 10- by 15-centimeter electrode.

DTI is funding the development through JPL's Technology Affiliates Program and plans to produce the fuel cells in quantity through a sublicensee, Detroit Center Tool, Inc. The firm foresees a market of more than $8 billion annually for such a nonpolluting power source by the year 2002.

Since its establishment in 1987 by NASA and several Department of Defense agencies, JPL's Center for Space Microelectronics Technology has produced a steady stream of innovative devices. Last year, the Center began development of an "active pixel" sensor (so-called because it incorporates a transistor that amplifies the small current induced by a photon falling on the sensor's surface) for imaging systems. This solid-state sensor, which operates in the visible, ultraviolet and near-infrared parts of the spectrum, has been incorporated in a low-cost "camera on a chip" that holds great potential for a wide range of applications, from space telescope arrays and miniaturized star trackers to toys and surveillance cameras to medical endoscopes and video phones.

Another major development in 1995 for the Center was the Quantum Well Infrared Photodetector (QWIP), an extremely sensitive long-wavelength infrared sensor. JPL, working with Amber, a Raytheon company, arrayed 65,536 of these tiny sensors in the focal plane of a cooled, hand-held television camera and demonstrated the system's ability to image objects clearly, even under very low-light-level conditions. The Laboratory believes there is great commercial potential for this sensor in medicine, environmental monitoring, aviation/navigation, search-and-rescue, industrial process control and law enforcement.

A software program called Real-Time Gipsy was another TAP success in 1995. This program, an outgrowth of an earlier software package called Gipsy-Oasis (the name stands for GPS-Inferred and Orbit Analysis/Simulation System), enables users of the Defense Department's Global Positioning System (GPS) to calculate very accurately the orbital parameters of the system's navigational satellites and, from that, determine with very high precision the position of their GPS receivers — whether at fixed ground sites or on moving automotive vehicles, aircraft or space satellites.

The earlier version was, and still is, the most accurate in the world but it did not provide instantaneous position information and, moreover, required a workstation computer. The new version not only provides real-time answers (in a fraction of a second), but also can be run on the smallest personal computers or processors. Because of its reliable performance and speed, Real-Time Gipsy is attractive to commercial airlines, who need prompt, ultra-precise navigational data. Hughes Information Technology Systems has licensed Real-Time Gipsy from Caltech for use in the Federal Aviation Administration's Wide-Area Augmentation System. Starting in late 1998, this system will provide aircraft flying over the United States with instantaneous, highly accurate information on their positions.

EDUCATIONAL OUTREACH

JPL has long been dedicated to fostering science and engineering education, especially among younger children. Last year, as part of NASA's implementation of the Stevenson–Wydler Surplus Equipment Act, a Congressionally approved program, the Laboratory distributed 12,201 pieces of surplus equipment (9,512 were computers or computer-related equipment) to 96 grammar, middle and high schools, community colleges, universities and Native American institutions in California and several southwestern states. The equipment was valued at approximately $18 million when initially purchased.

JPL's Educational Affairs Office also partnered with the California Museum of Science and Industry to establish Project Los Angeles Endeavour, a program designed to attract more women, members of underrepresented minorities and disabled people to science careers. Key to this effort is a new California Science Center, to be located at the Museum near downtown Los Angeles, California, which will include a science center, elementary science school and a science education resource center.

Another partnership involved JPL, California State University at Los Angeles, North Carolina A&T State University and the University of Texas at El Paso in the development of an implementation plan for a future Earth resources–monitoring satellite. Students at those universities will be able to work on the satellite with JPL engineers at the Laboratory's Project Design Center through computer-linked pods at their campuses and, in the process, learn to optimize the design of a product while holding down costs.

TECHNOLOGY COMMERCIALIZATION

The Laboratory is committed to sharing with American industry the technology developed for NASA and federally sponsored projects through information dissemination, software distribution, affiliation, small business innovation research, patent licenses and cooperative ventures.

Information on JPL-developed technology available for commercialization is made available through NASA Tech Briefs; in 1995, the Laboratory produced 220 of the 712 (30 percent) of all Tech Briefs published at NASA field centers. Readers and other interested parties can request Technical Support Packages about any of these items and, last year, JPL sent out 29,097 such packages.

The Laboratory's Technology Affiliates Program provides American firms access to this technology resource. Any U.S. company with a technical problem can contact the Laboratory, describe the difficulty and ask for an evaluation. If JPL determines that there is technology available and appropriate to the problem, it will enter into an agreement with the firm (there are currently more than 90 participating firms). The company funds the research and its employees work closely with JPL engineers in applying the technology to the firm's needs.

The Caltech Office of Patents and New Technology submitted 309 new reports on inventions or technical innovations to NASA and concluded dozens of licenses for both the Laboratory and the Campus last year. Moreover, the U.S. Patent and Trademark Office issued numerous patents on inventions developed at JPL.

Through its Small Business Innovation Research (SBIR) Program, the Laboratory encourages others — specifically, small companies — to develop promising "dual use" technologies for both NASA and commercial needs; last year it awarded 60 such contracts with a total value of $14.5 million.

Technology Cooperation Agreements are still another vehicle for furthering technology for both NASA's and American industry's benefit. These collaborative ventures, in which no funds are exchanged, allow private companies to participate in research and development projects early on so that the emerging technology is useful both to government agencies and to commercial interests. Last year, JPL signed 10 new agreements; 18 others were in negotiation as the year ended.

CONCLUSION

All in all, 1995 was a year characterized by fulfillment and promise — fulfillment provided by ongoing missions like Galileo, Ulysses and TOPEX/Poseidon, and promise offered by flight projects like Cassini, the Mars ventures and New Millennium. Change was also a hallmark of the year, as JPL took steps to improve business practices and enhance technology transfer and commercialization. Taken together, these activities reflect a Laboratory entering a new and different era, with a new and different approach to achieving success.

HONORS AND AWARDS

During 1995, a number of special honors, NASA Honor Awards and Laboratory honors were presented to JPL personnel in recognition of their exceptional achievements and service. Special honors were awarded to both individuals and groups by a variety of organizations and professional societies. The annual NASA Honor Awards are presented to JPL personnel by NASA in recognition of outstanding individual or group achievements. And through a variety of special appointments, Caltech Campus and the Laboratory recognize the accomplishments of individuals and promote the exchange of information in areas of research.

SPECIAL HONORS

American Institute of Aeronautics and Astronautics Award

Lew Allen (Retired)

Elected Fellow, American Geophysical Union

Dennis L. Matson

Lew Allen Award for Excellence

George A. Hajj

NASA HONOR AWARDS

Outstanding Leadership Medal

Edward R. Caro
Diane L. Evans
Michael J. Sander
Frank L. Schutz
Edward C. Stone

Exceptional Achievement Medal

Terrence P. Adamski
Kirk D Barrow
James W. Brown
Douglas G. Griffith
Michael R. Gunson
Dennis N. Horgan, Jr.
Robert A. Laskin
Daniel T. Lyons
Gloria L. Manney
Brian K. Muirhead
Steven C. Ogle
David J. Rochblatt
Merle Ruiz
David B. Smith
Ellen R. Stofan
Frederick V. Stuhr
Stephen D. Wall

Exceptional Scientific Achievement Medal

Edward J. Smith

Exceptional Engineering Achievement Medal

Henry B. Garrett
Paula J. Grunthaner
William E. Layman
Marvin K. Simon

Exceptional Service Medal

George A. Alabuzos
Teresa L. Alfery
Russell O. Allen
John D. Baker
Jack B. Barengoltz
David S. Bayard
Carl W. Buck
C. Y. Chang
Faramaz Davarian
William B. DeMore
Richard J. Doyle
Stephen J. Edberg
Jordan Ellis
Pasquale B. Esposito
Anthony Freeman
Mark D. Fujishin
Janet G. Fung
Donald Gallop
Monica M. Garcia
John M. Garren
Stephen J. Giacoma
Paul V. Hardy
Adrian J. Hooke
Stuart T. Imai
Rolando L. Jordan
Yunjin Kim
Mike Kobrick
James L. Lamb
Sharon L. Langenbeck
Catherine A. Lemaster
Robert E. Lock
Glenn A. Macala
Michael J. Mangano
Carlos V. Matus
David C. Miller
Don Noon
Kathy O'Hara
Mimi Paller
Duane Petersen
Su K. Potts
Macgregor S. Reid
Linda L. Rodgers
Dennis S. Ross
Lucille C. Seeley
L. Tom Shaw, Jr.
Yuhsyen Shen
Leonard M. Snyder
John F. South
Guy C. Spitale
Daniel M. Taylor
Fred A. Tomey
Sharon K. Valentine
Louise A. Veilleux
Ray J. Wall
Gary F. Weber
Julie L. Webster
Paul Wiener

Public Service Medal

Allen W. Bucher
Allan R. Cheuvront
Philippe Escudier
Richard W. Kasuda
Gary Salisbury
Tomas Soderstrom
Stuart R. Spath
Klaus-Peter Wenzel
Dee Yeaman

Equal Employment Opportunity Medal

Alfred R. Paiz

Public Service Group Achievement Award

- *Multimission Operations Systems Office Data Systems Operations Team*
- *Optical Research Associates*
- *Spaceborne Imaging Radar–C Antenna Development Team*

Group Achievement Award

- *Atmospheric Lidar Team*
- *DSS 13 Core Equipment Development Team*
- *Facilities/Procurement Small Business and Small Disadvantaged Business Outreach Team*
- *Galileo Ida Encounter/Dactyl Discovery Team*
- *Ground Communications Facility Upgrade Phase II Implementation Team*
- *Hazbot Development Team*
- *Just-In-Time Acquisition System Team*
- *Low-Earth Orbiter Terminal Demonstration (LEO-D) Development Team*
- *Magellan Lean Mean Gravity Team*
- *Minority Science and Engineering Initiatives Team*
- *Multimission VICAR Planner Development Team*
- *Operations System Training Group*
- *Planetary Data System Education CD-ROM Team*
- *Rechargeable Lithium Battery Team*
- *Remote Manipulator System Force Torque Sensor Flight Instrument Development Team*
- *RTOP Process Improvement Team*
- *Safety Inspection Team*
- *Selective Monitoring Development Team*
- *70-meter Elevation Bearing Replacement Team*
- *Spaceborne Imaging Radar–C Instrument and Antenna Mechanical System Development Team*
- *Spaceborne Imaging Radar–C Mission Operations and Product Generation System Team*
- *Trapped Ion Frequency Standard Development Team*
- *Ulysses Ground Operations Team*
- *Venus Balloon Mobility Demonstration Team*

SPECIAL APPOINTMENTS

Distinguished Visiting Scientist

- *Mark Johnson Micromagnetic Devices and Materials — Naval Research Laboratory, Washington, DC*
- *James McWilliams Oceanography–Ocean Circulation Modeling — University of California Los Angeles, California*
- *David R. Nygren Neutrino Astrophysics Experiment — Lawrence Berkeley Laboratory, Berkeley, California*
- *John B. Rundle Radar Interferometry — University of Colorado, Boulder, Colorado*
- *Benjamin C. Shen Neutrino Astrophysics Experiment — University of California, Riverside, California*
- *Graeme L. Stephens Cloud Radiation Studies — Colorado State University, Fort Collins, Colorado*

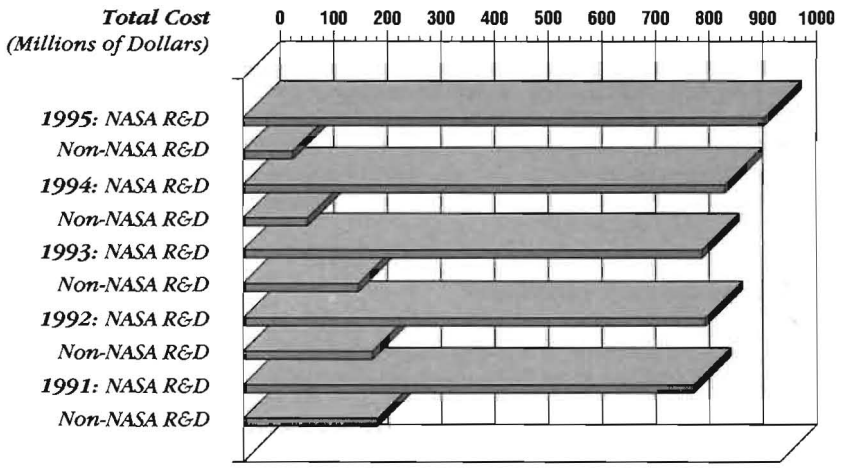
Senior Research Scientist

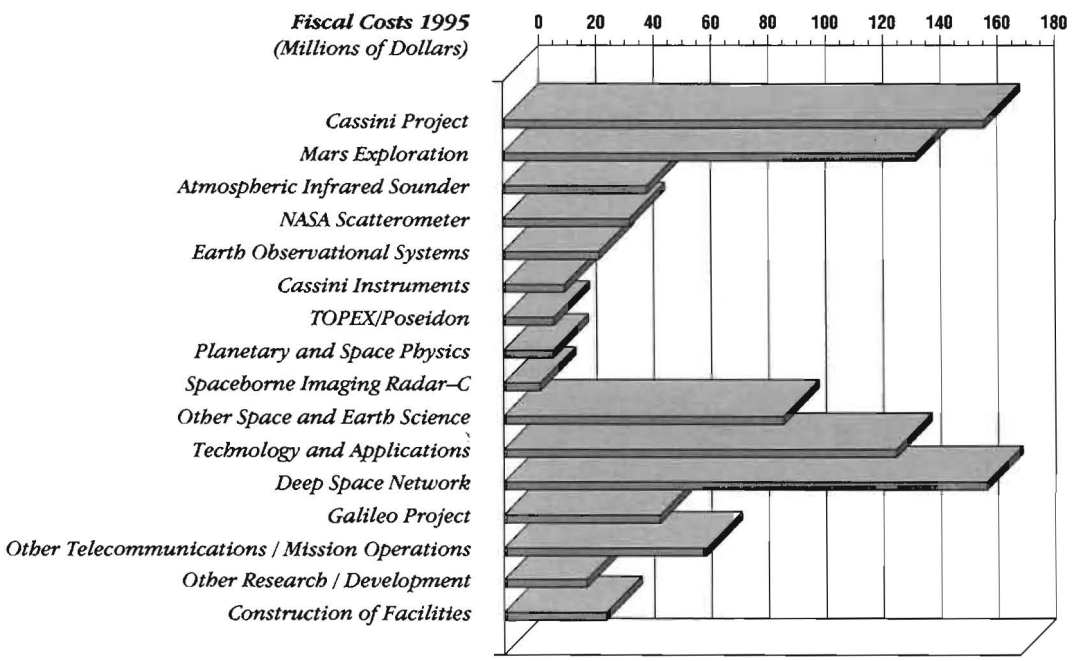
- *Robert H. Brown Origin and Evolution of Planetary Systems*
- *Glenn S. Orton Atmospheres of the Outer Planets*
- *Joseph W. Perry Physical Chemistry/Organic Photoactive Materials*
- *Paul R. Weissman Cometary Physics and Dynamics*

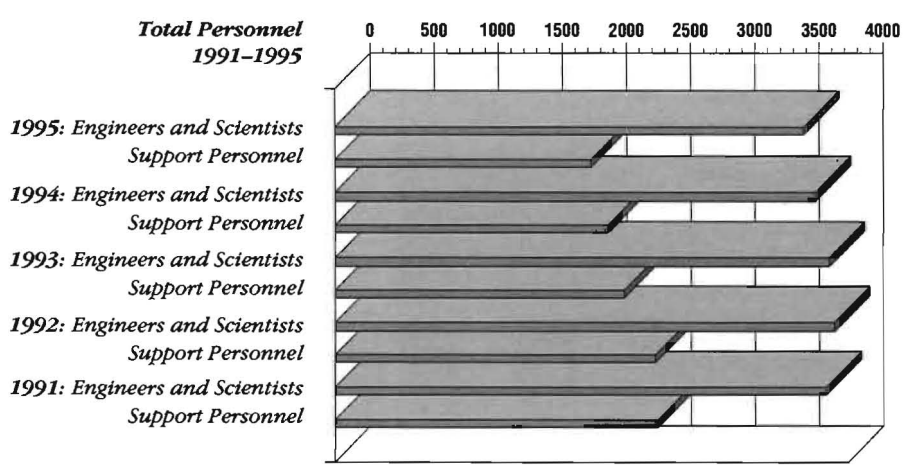
FINANCES AND PERSONNEL

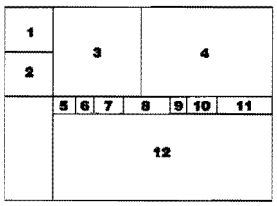
JPL's annual budget for the fiscal year ending in September 1995 was $1.1 billion. Research and development costs amounted to $1.07 billion; facilities construction costs accounted for the remainder. Costs for NASA-funded activities increased 8.1 percent from fiscal year 1994, to $972 million; costs for non-NASA activities decreased 22.5 percent, to $93 million.

The Laboratory's workforce decreased again during 1995, to 5,652 employees. The workforce had been 5,875 in 1994 and 6,108 in 1993. The following charts show financial and personnel statistics for the 1991–1995 period.


Total Cost
(Millions of Dollars)
0 100 200 300 400 500 600 700 800 900 1000
1995: NASA R&D
Non-NASA R&D
1994: NASA R&D
Non-NASA R&D
1993: NASA R&D
Non-NASA R&D
1992: NASA R&D
Non-NASA R&D
1991: NASA R&D
Non-NASA R&D

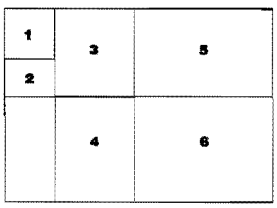

Fiscal Costs 1995
(Millions of Dollars)
0 20 40 60 80 100 120 140 160 180
Cassini Project
Mars Exploration
Atmospheric Infrared Sounder
NASA Scatterometer
Earth Observational Systems
Cassini Instruments
TOPEX/Poseidon
Planetary and Space Physics
Spaceborne Imaging Radar–C
Other Space and Earth Science
Technology and Applications
Deep Space Network
Galileo Project
Other Telecommunications / Mission Operations
Other Research / Development
Construction of Facilities


Total Personnel
1991–1995
0 500 1000 1500 2000 2500 3000 3500 4000
1995: Engineers and Scientists
Support Personnel
1994: Engineers and Scientists
Support Personnel
1993: Engineers and Scientists
Support Personnel
1992: Engineers and Scientists
Support Personnel
1991: Engineers and Scientists
Support Personnel



SPACEFLIGHT EXPLORATION

Facing page 6 — *Unforgettable images from JPL's Mariners, Voyagers and other deep space wanderers have captured our imagination for decades* **1.** *Mars, with its northern polar cap [P-43560]* **2.** *Eruptions on the Sun* **3.** *Jupiter's Great Red Spot* **4.** *Artist's rendering of the Ulysses spacecraft orbiting the Sun [P-45908]* **5.** *The Voyager spacecraft [P-24653]* **6.** *Jupiter and its moons Io and Europa [P-21083]* **7.** *Jupiter's turbulent atmosphere [P-21742]* **8.** *Io and Europa passing before the Great Red Spot [P-21082]* **9.** *Saturn and its moons Tethys and Dione [P-23058]* **10.** *False-color image of storms on Saturn [P-23922]* **11.** *Voyager's look back at Saturn [P-23346]* **12.** *Saturn and its magnificent rings [P-23077]*



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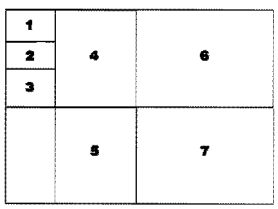

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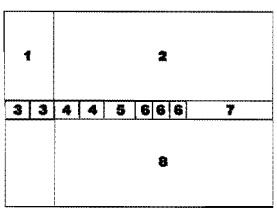

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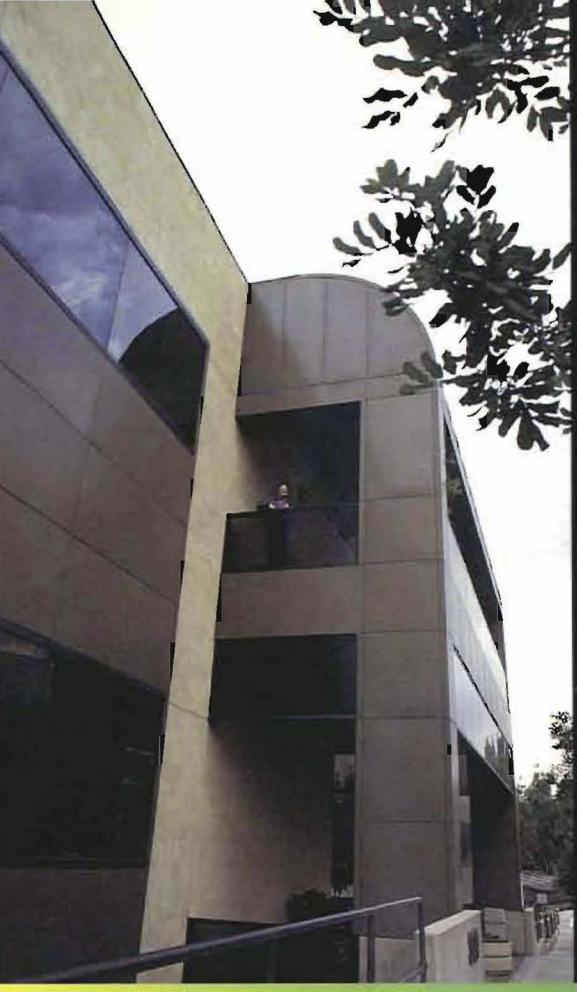

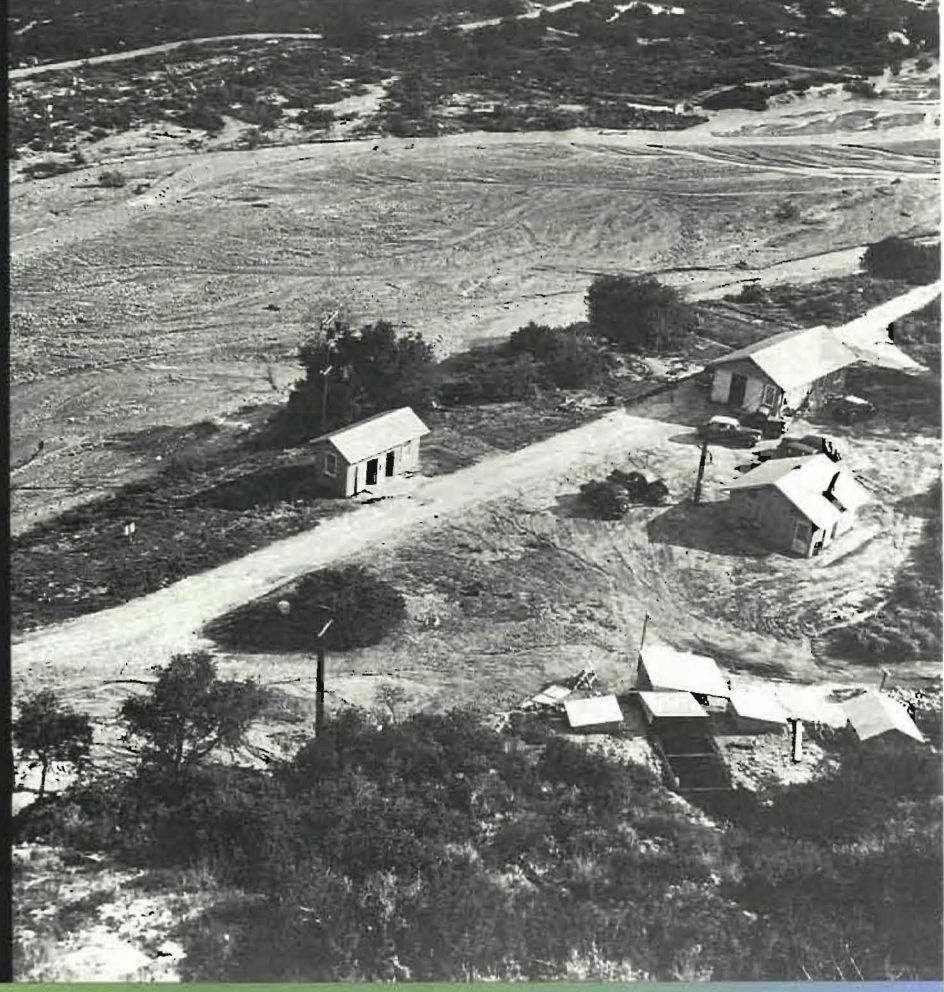

JPL — IMAGES IN TIME

Above left: The modern Earth and Space Science laboratory houses many of JPL's Earth-observing missions and imaging radar projects.

Above right: In 1936, JPL had its beginnings in some lonely research huts in the Arroyo Seco of Pasadena, California.

Center: A grand old oak tree was the perfect setting for this photograph of the Laboratory's employees in 1943.

Right: JPL's state-of-the-art Microdevices Laboratory is an internationally recognized site for research and development on advanced electronic materials and devices.

Opposite: The Jet Propulsion Laboratory today. Home to some 5,700 people, the Laboratory's main Oak Grove site is nestled on 175 acres in the foothills of the San Gabriel Mountains, just north of Los Angeles, California.

JPL

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