NASA SPINOFF

1990

SPINOFF

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ON THE COVER:
Symbolic of NASA's reinvigorated space science program is a striking image of Neptune's cloud deck, taken by Voyager 2 on August 24, 1989 two hours before the spacecraft's closest approach to the giant gaseous planet. Voyager 2 was then 98,000 miles from Neptune and 2.8 billion miles from Earth, making the last planetary encounter of its 12-year odyssey before heading out of the solar system. Additional Voyager 2 views of Neptune lead each section of this volume.

National Aeronautics and
Space Administration
Office of Commercial Programs
Technology Utilization Division
by James J. Haggerty

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Foreword

Among the greatest benefits of America's space exploration and aeronautics research programs are the spinoffs. These are commercial products and processes created when private enterprise adapts new aerospace technology to take advantage of opportunities in the marketplace.

Over the years, NASA-derived technology has been the basis for more than 30,000 spinoffs. Thousands of spinoffs are individual items which improve the quality of life, such as heart pacemakers and laser surgery. Some spinoffs have enormous economic impact, such as hastening the development of today's international microelectronics industry.

The process of developing and marketing spinoffs based on NASA technology has had a dramatic effect on the American economy. Because of it, America won and has never relinquished the world lead in aeronautical products and services, computers, medical equipment and other areas.

NASA is developing a wide range of new, cutting edge technologies such as artificial intelligence, advanced robotics, artificial self sustaining ecological systems, virtual reality, telepresence and teleoperation, process automation, optical communication and data processing, ultra high-strength and high-temperature resistant materials, highly advanced computers, wireless power transmisssion and hypersonic flight. We are looking to the creative genius of the American people to adopt these technologies for use in bringing new products to market, maintaining America's competitive edge and enhancing the quality of life for all.

This new wave of technology development has come about because of renewed national emphasis on space exploration and aeronautical research. President Bush has provided the greatest support by offering a bold new vision of America's future in space. The President firmly believes that an expanded, well-balanced program of space exploration can give our citizens new purpose, provide the technical boost America needs to retain its position in the world economy, and inspire our children to do better in school by providing personal and national goals worth striving for. NASA is currently engaged in an aggressive program to achieve the President's ambitious goals.

The Space Shuttle has proven itself to be a workhorse for flexible, highly sophisticated operations in Earth orbit. Since return to flight on September 29, 1988, 10 highly successful missions have been completed. Our Shuttle operations schedule will continue to be demanding, and the results most rewarding.

The Magellan and Galileo spacecraft deployed by the Space Shuttle in 1989 have embarked upon missions to Venus and Jupiter, respectively. These spacecraft will conduct detailed, long-term explorations from the vantage point of planetary orbit. They are the advance guard of a family of orbiters that will study the Sun, the Moon, Mars, Saturn, and other bodies of the solar system.

Similarly, COBE and the Hubble Space Telescope are the first-in-orbit members of a new series of advanced observatories whose findings will greatly expand man's knowledge of the origin and evolution of the universe and of mankind's role in it.

We are also embarking on Mission to Planet Earth, an effort to study Earth's systems on a global scale in order to obtain the data that is essential to facilitate intelligent decisions as to how we can preserve the endangered global environment.

Space Station *Freedom* has progressed to the hardware development stage. In the latter years of this century, it will provide a permanently manned facility where we can learn to live in microgravity and conduct experiments that will allow advances in materials and medical research.

Finally, we are laying the foundation for the President's Space Exploration Initiative, with ambitious goals of placing a manned outpost on the Moon and extending human presence to Mars. This is a program of extraordinary scope that will generate vast new libraries of scientific information and technological advancements of enormous order.

Our aeronautics program, which marks its 75th anniversary this year, continues to generate advanced technology for the enhancement of U.S. international competitiveness, with such research projects as a next-generation supersonic transport and a hypersonic spaceplane capable of airplane-like horizontal takeoff and orbital capability.

As you can see, America is embarking upon a new era of aeronautics and space exploration. This exploration will produce innumerable new technologies. The people of NASA are working hard to bring a knowledge of these technologies to the American people so they can develop the next generation of beneficial spinoffs. *Spinoff 1990* is one important way NASA provides this information to the citizens of our nation. I hope you enjoy *Spinoff 1990* and are able to put its information to great use!

Richard H. Truly
Administrator
National Aeronautics and
Space Administration

Introduction

Technology is simply another word for knowledge, or technical know-how. Like other forms of knowledge, it is transferable; technology developed for one purpose can often be applied to uses different from the original intent.

Thus, the great storehouse of technology NASA has built in three decades of pursuing aeronautical and space goals is a valuable national resource, a bank of know-how available for secondary application, or "spinoff."

Thousands of companies have taken advantage of the technology bank to develop tens of thousands of spinoff products and processes. Collectively, these spinoffs represent a substantial dividend on the national investment in aerospace research.

How much of a dividend? It is impossible to quantify total benefits, but a recent NASA-sponsored study—conducted by Chapman Research Group, Littleton, Colorado—provides an impressive partial answer. The group examined 441 secondary applications described in the 1978-86 volumes of this annual *Spinoff* publication. The group interviewed officials of the companies involved, who provided estimates of sales and savings. There were 368 cases with acknowledged sales or savings, but in 109 cases the figures could not be quantified.

However, the other 259 cases generated benefits amounting to almost $22 billion in combined product sales and savings to the companies.

There were additional benefits. Based on the sales data, federal income tax revenues were estimated at almost $356 million. It was also estimated that the spinoff applications created or retained 352,000 jobs. There were 67 instances in which a product or process—and in some cases an entire company—would not have come into existence had it not been for the NASA-furnished technology; these cases alone represented sales/savings amounting to more than $5 billion.

And all these benefits derived from only 259 cases—out of a total of more than 30,000 spinoffs. That's a loose and undoubtedly conservative estimate, a tip-of-the-iceberg figure, because there are a great many cases wherein NASA technology may have been the basis for a series of product modifications over a period of years—but current company officials cannot recall the origin of the basic technology.

Clearly, the aerospace spinoff potential is of enormous order. The Congress recognized that fact and charged NASA with stimulating the widest possible use of the technology storehouse in the national interest. Through its Technology Utilization Program, NASA seeks to encourage greater use of the knowledge bank by providing a link between the technology and those who might be able to put it to advantageous secondary use. The aim is to accelerate and broaden the technology transfer process and to expand thereby the benefits to the nation.

This publication is intended to foster that aim by heightening awareness of the NASA technology available for transfer and its potential for benefit. *Spinoff 1990* is organized in three main sections:

Section 1 outlines NASA's mainline effort, the major programs that generate new technology and therefore replenish and expand the bank of knowledge available for transfer.

Section 2, the focal point of this volume, contains a representative sampling of spinoff products that resulted from secondary application of technology originally developed to meet mainline goals.

Section 3 describes the various mechanisms NASA employs to stimulate technology transfer and lists, in an appendix, contact sources for further information about the Technology Utilization Program.

In addition, this volume features a special Prologue section that describes NASA's unique contribution to the national effort to improve education in science, mathematics and technology.

James T. Rose
Assistant Administrator for
Commercial Programs
National Aeronautics and
Space Administration

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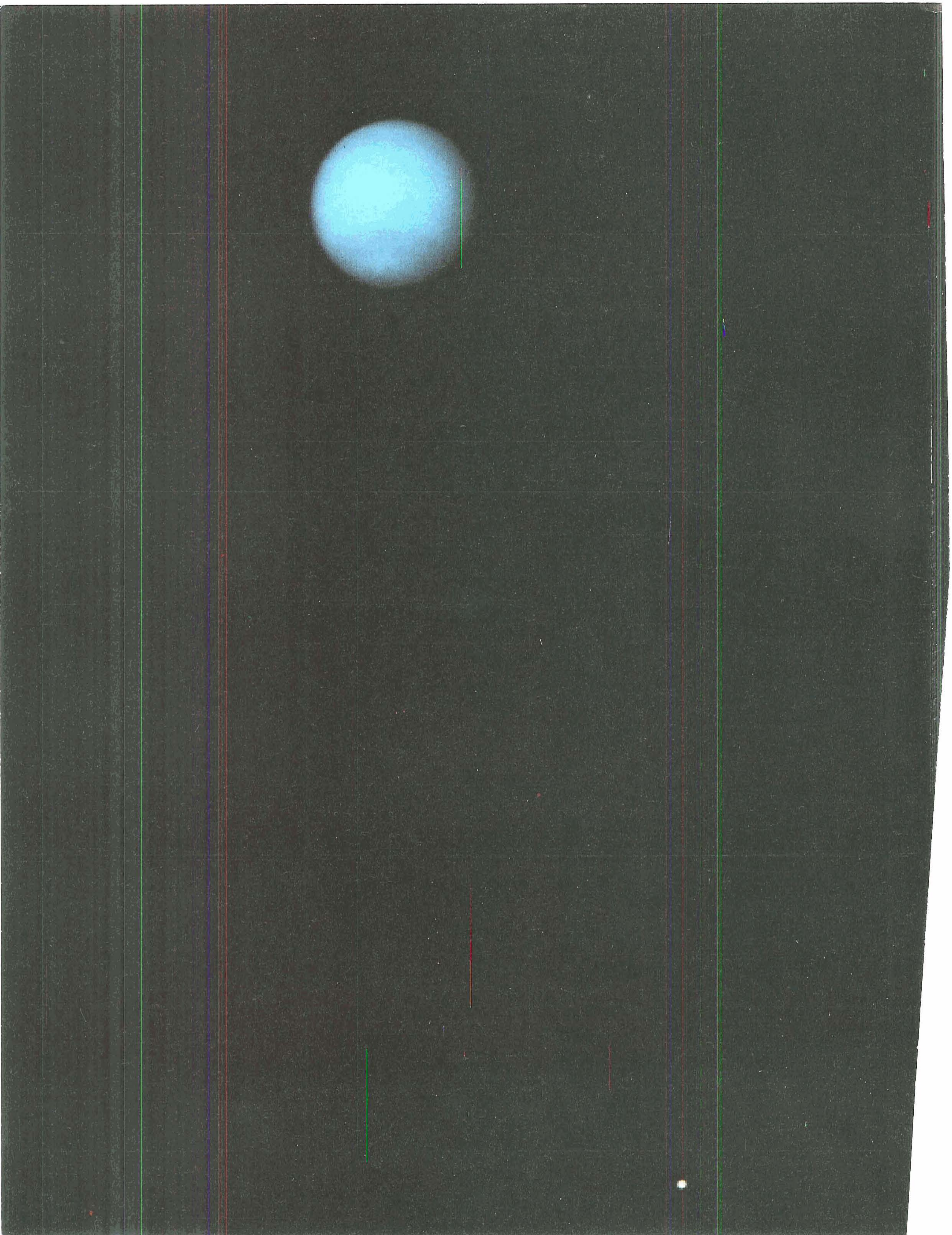
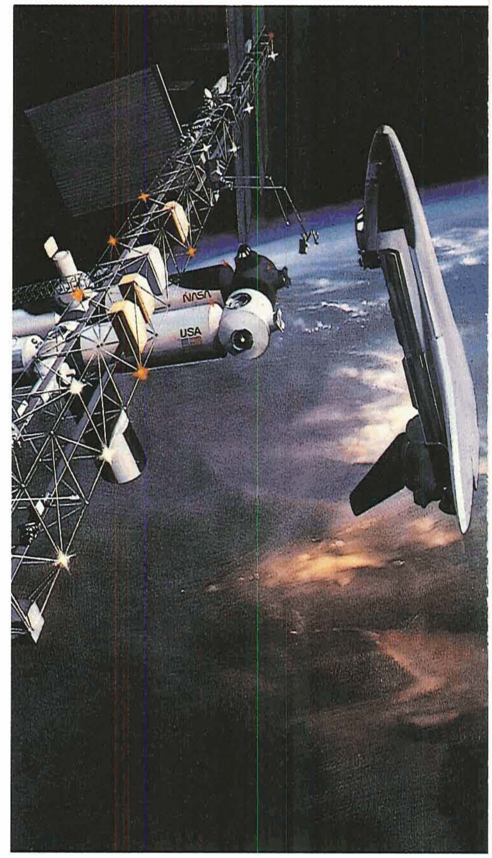


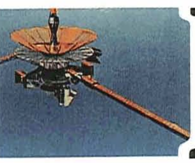
Aerospace Aims

An illustrated summary of NASA's major aeronautical and space programs, their goals and directions, their contributions to American scientific and technological growth, and their potential for practical benefit



From a distance of 47 million miles, Voyager 2's narrow angle camera captured—on July 27, 1989—this view of Neptune and the largest of its three moons, Triton (bright dot at bottom photo).

Probing the Cosmos



Man has learned in recent years that human activities can have adverse effect on Planet Earth's environment. The evidence suggests that such changes as potential global warming, ozone loss, changing sea levels and massive deforestation may have serious implications for human health, the world's food and energy supplies, and the global economy.

There is worldwide concern and demand for action. But the problem is not as clear cut as it might seem. In some instances the effects of human activities are obvious and readily measurable, but in others the processes of change are difficult to document and their consequences harder to identify. And the problem is compounded by the fact that it is often hard to tell whether an apparent effect is caused by human activity, or by change that occurs naturally, or by both. In short, there is need for a great deal more scientific information to address the matter of global change intelligently.

To reduce the scientific uncertainties, the United States has instituted a multiagency U.S. Global Research Program, the goal of which is "To establish the scientific basis for national and international policymaking relating to natural and human-induced changes in the global Earth system." In addition to NASA, the program involves the National Oceanic and Atmospheric Administration (NOAA), the Department of Energy, the Department of Defense, the Department of the Interior, the Environmental Protection Agency, the National Science Foundation and the Department of Agriculture.

NASA's role is to employ its space expertise in a comprehensive program aimed at a complete understanding of global change and a capability to make reliable predictions of future change, providing a basis for sound policy decisions about responses to global change concerns. Toward that end, NASA is undertaking a Mission to Planet Earth, a program described as one that "will dwarf any past science activity."

This program will build on and go beyond the types of environmental studies that have been carried out over the past three decades. Those studies provided a great wealth of knowledge about Earth and its environment, but the knowledge was acquired piecemeal, through separate investigations of Earth's components, such as the planet's interior, its crust, biosphere, oceans and ice cover, the atmosphere and the ionosphere. Because all these components are interlinked, it is necessary to study Earth as a single unified system to develop the requisite understanding of global change.

Mission to Planet Earth involves extensive, long term study of the Earth system with special focus on accurate observations of the critical interacting processes that contribute to global change. That will require global monitoring of the planet by space-based sensors, together with complementary surface-based measurements to validate the satellite observations and to allow study of certain processes not accessible from space. Many of the required observations must be made simultaneously from different locales and must continue over a long period of time, well into the 21st century.

The centerpiece of Mission to Planet Earth is the Earth Observing System (EOS), a new program. EOS is an internationally coordinated effort involving a number of large orbiting observational platforms that will enable interdisciplinary study of Earth, including the atmosphere, oceans, land surfaces, polar regions and the solid Earth. EOS will provide long term, systematic, continuous data about Earth's agriculture, forestry, hydrology, oceanography, snow/ice cover, geology, atmospheric chemistry and dynamics.

NASA plans call for two polar-orbiting U.S. platforms, or more properly two *series* of platforms. Each series will have three identical platforms operating successively, each with a five-year design lifetime for a total span of 15 years. Each platform will have a different area of coverage; the first, targeted for fiscal year 1998 launch, will make measurements of Earth's surface and the conditions of the lower atmosphere.

A new initiative that seeks greater understanding of changing conditions in Earth's environment highlights a resumé of NASA's broad space science and applications program

The second, to be launched $2^1/_2$ years later, will be devoted to measurements of the chemistry of the upper atmosphere, the circulation of the oceans and the behavior of the solid Earth.

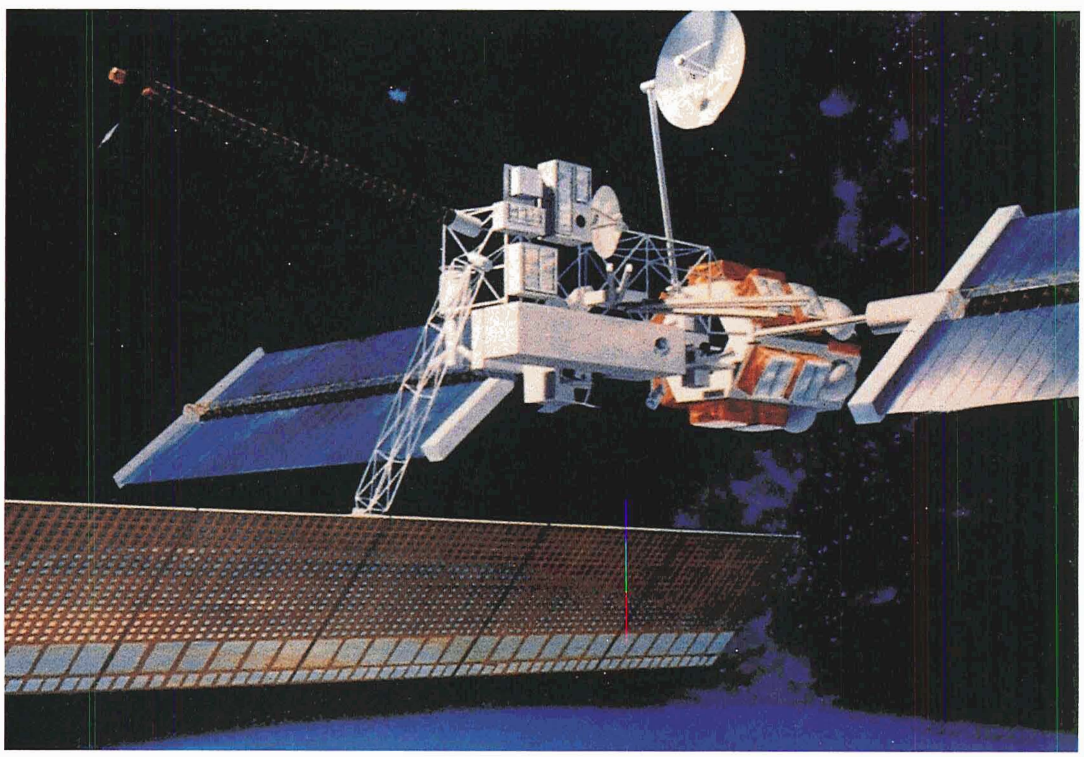
NASA's international partners, the European Space Agency, Japan and Canada, are planning to build and operate similar platforms and some U.S. instruments may be flown on those satellites. Other EOS instruments will be attached to Space Station *Freedom* to take advantage of the station's different orbit.

The EOS platforms will generate enormous volumes of data. To make optimal use of the data, NASA intends to improve computational capabilities in Earth science and to enhance the access to the data of researchers all over the globe. To handle and distribute the data, NASA is starting development of the EOS Data and Information System (EOSDIS), elements of which will begin operation in the early 1990s. EOSDIS will be used to derive maximum information from "precursor" missions, satellites already in existence or soon to be available for service, whose observations will provide the initial input to Mission to Planet Earth. Data from these missions will be used to test and perfect EOSDIS in advance of the greater data flows from the EOS platforms. EOSDIS is an interagency effort that includes participation by—in addition to NASA—the U.S. Geological Survey, the National Science Foundation, NOAA and other agencies.

Mission to Planet Earth also embraces a complementary Earth Probes program, a series of small to moderate size Explorer Class satellites for specialized studies of such subjects as ozone, rainfall, magnetic fields and other components of the Earth system.

(Continued)

An artist's concept of an Earth Observing System platform, the key element of NASA's Mission to Planet Earth program, which entails extensive observation of the planet toward understanding the global changes that are occurring and developing the ability to make reliable predictions of future changes.



Probing the Cosmos

(Continued)

Mission to Planet Earth, the central NASA contribution to the U.S. Global Change Research Program, has four major elements or phases. In a sense, the first is already under way because NASA is getting a valuable flow of Earth science data from several previously launched satellites.

In 1991, NASA will begin to employ new, advanced technology satellites. Their measurements will be complemented and expanded by observations from satellites of the NOAA meteorological/environmental system, by the Defense Meteorological Satellite Program, by remote sensing satellites of the EOSAT commercial resources survey system, and by a number of foreign satellites.

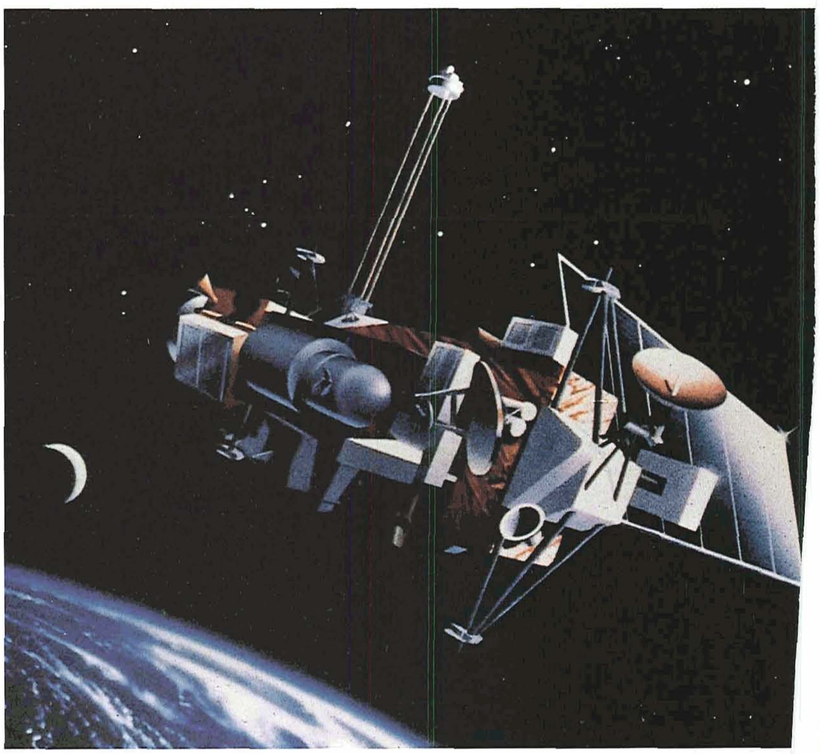
Two major NASA missions will address specific global change matters in the period preceding service introduction of the EOS platforms: the Upper Atmosphere Research Satellite (UARS) and the Ocean Topography Experiment, also known as TOPEX/POSEIDON.

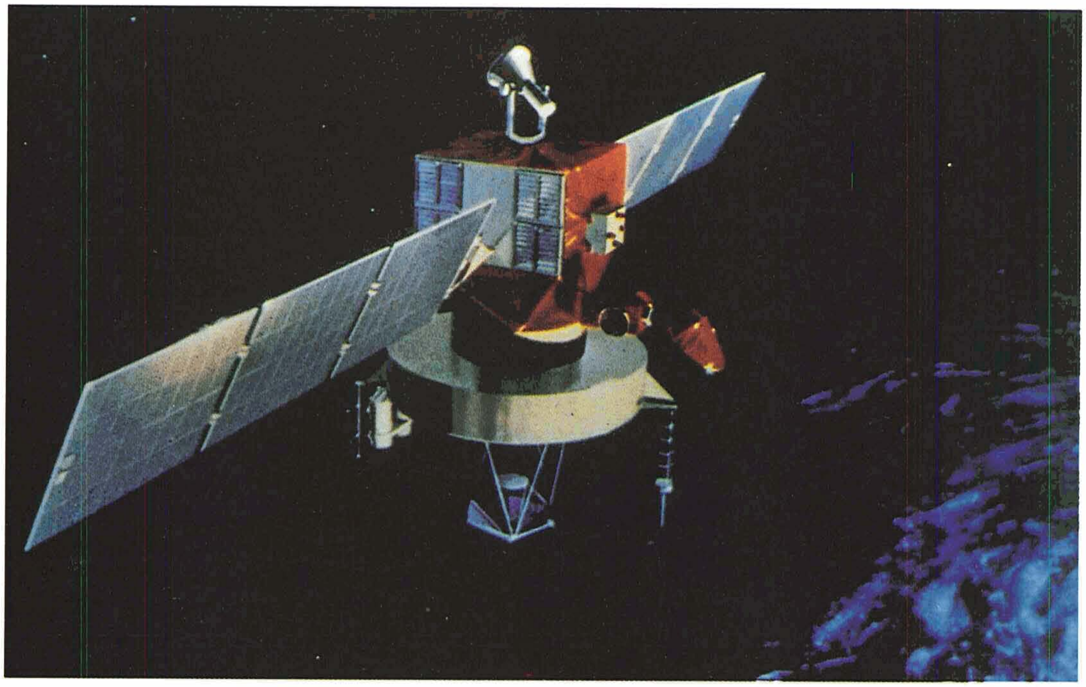
UARS (Photo A) will provide the first integrated global measurements of the chemistry, dynamics and energetics of the upper atmosphere over a span of at least three years; its launch is scheduled for August 1991. Among major objectives are understanding of the mechanisms that control the structure and variability of the upper atmosphere and the role of the upper atmosphere in climate and climatic change. Goddard Space Flight Center is manager of the UARS program; the spacecraft is being developed by General Electric Astro Space.

TOPEX/POSEIDON (Photo B) will employ radar altimetry to make highly accurate measurements of sea surface elevations over entire ocean basins for three to five years after launch in 1992, and it will also provide data for maps of currents, eddies and other features of ocean circulation. Program objectives include understanding of the oceans' general circulation and the relationship to climate change, plus knowledge of the interactions between the atmosphere and the oceans. TOPEX/POSEIDON is a joint project of NASA and the French space agency CNES. Jet Propulsion Laboratory is managing the project and Fairchild Space Company is developing the satellite.

During the pre-EOS period, data from UARS and TOPEX/POSEIDON will be augmented by short-term observations of Shuttleborne sensor systems, such as the Space Radar Laboratory for Earth remote sensing and imaging; the Shuttle Solar Backscatter Ultraviolet Sensor, designed to make accurate measurements of ozone in the upper atmosphere; and the ATLAS (Atmospheric Laboratory for Applications and Science) series of Spacelab missions for observations of solar influences on atmospheric chemistry. Each of these sensor payloads will fly multiple missions.

Scheduled for launch in August 1991, the Upper Atmosphere Research Satellite will provide the first global measurements of the chemistry, dynamics and energetics of the upper atmosphere.





TOPEX/POSEIDON is an ocean observation satellite, targeted for launch in 1992, that will study entire ocean basins for several years and seek improved understanding of ocean circulation and its relationship to climate change.

Chronologically speaking, the second element of Mission to Planet Earth is the Earth Probes program, which will be devoted to observations that cannot be made in polar orbit where EOS will operate. Earth Probes are scheduled to begin in 1991, with a launch planned every two to three years.

The first of the Earth Probes is the Total Ozone Mapping Spectrometer (TOMS), a unit similar to a TOMS instrument aboard a weather satellite that has provided a continuous global record of ozone since 1978. TOMS instruments are scheduled to fly aboard one Soviet and one Japanese spacecraft to continue these measurements; in addition, a NASA Explorer satellite designed to carry a TOMS payload has been proposed.

Examples of other Earth Probes include SeaWiFS (Sea-viewing Wide Field Sensor), an ocean color scanner intended to provide data on oceanic biological processes; TRRM (Tropical Rainfall Measuring Mission), which will measure rainfall in the tropics toward an understanding of weather, climate and hydrologic dynamic processes; and NSCAT (NASA Scatterometer), a microwave radar that enables calculation of over-ocean wind speeds and directions by measurement of reflections from waves. Designed to provide new knowledge of ocean/atmosphere interaction and its relationship to climate changes, NSCAT is scheduled for flight in the mid-1990s aboard a satellite designated ADEOS (Advanced Earth Observation Satellite) in a joint NASA/NASDA (Japanese space agency) project.

Next in the Mission to Planet Earth time line are the EOS platforms, to be introduced in 1997 and to operate for nearly two decades thereafter. The European Space Agency is planning two series of platforms and Japan one. The U.S. EOS platforms will be among the largest unmanned spececraft ever built; although the design has been finalized, they may weigh as much as 15 tons. NASA is planning a payload complement of 12-14 major observational instruments.

Not yet an approved part of the mission plan but essential to long term goals is an EOS companion spacecraft known as the Synthetic Aperture Radar (SAR). The EOS SAR is a large system that cannot be efficiently accommodated on an EOS platform, but it is necessary for surface geological studies and for understanding the global carbon cycle. So it would be a separate satellite operating in low Earth orbit; it is planned as a mid-1990s start for launch in 1999.

The final elements of Mission to Planet Earth are Geostationary Platforms, which are needed to observe certain processes that cannot be properly sampled from EOS' polar orbit, such as those that have large variations within the daily cycle of Earth's rotation, and others—such as precipitation—that occur only during short periods of time. This segment of the program is under study.

Great Observatories

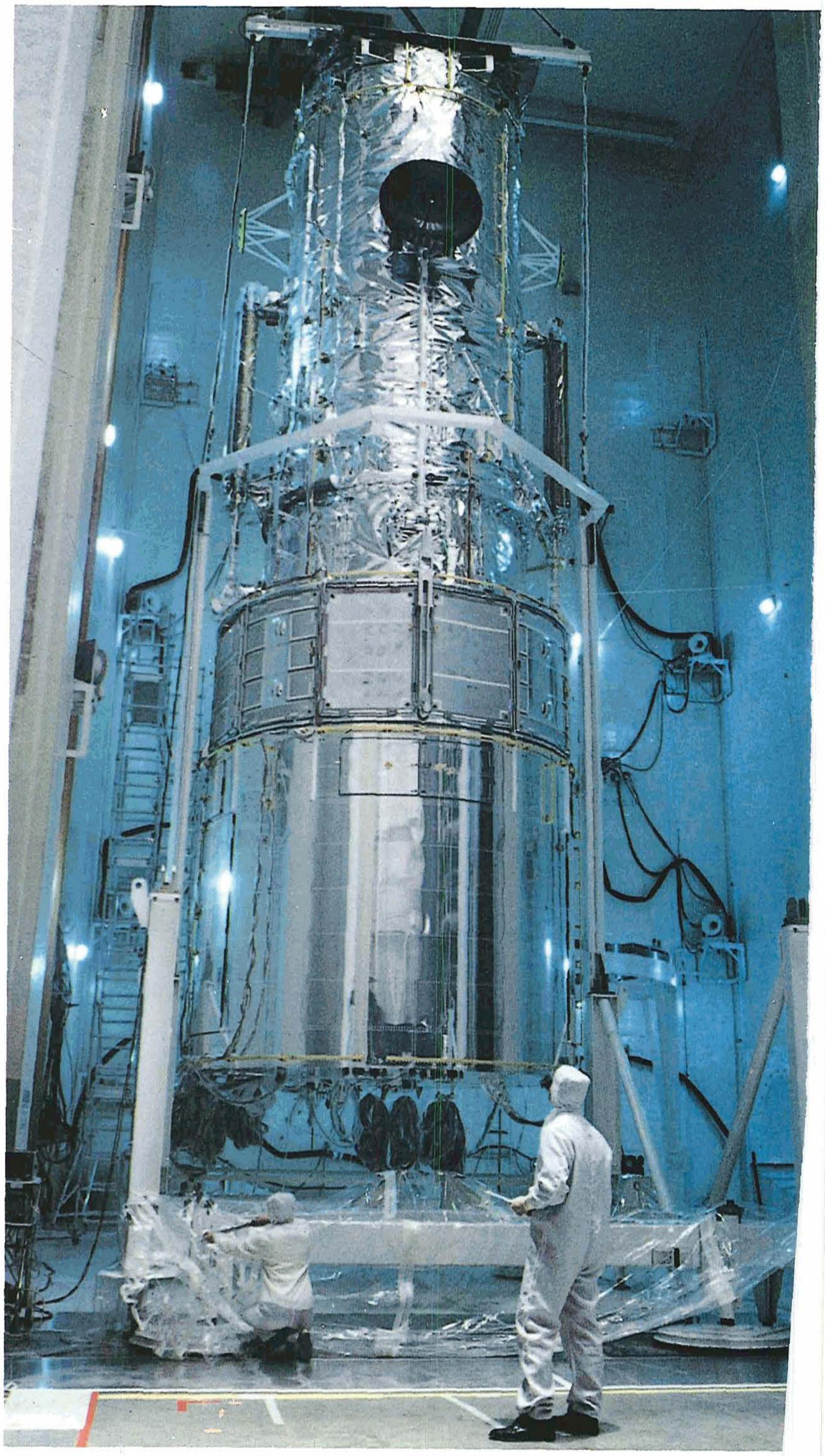
Since the invention of the telescope in 1609, the science of astronomy has advanced enormously, but for three and a half centuries it remained handicapped by the fact that it was Earthbound. Even the finest Earth-based telescopes are limited in observational capability because their instruments must peer through a murky layer of atmosphere that distorts the cosmic view. Even more importantly, the atmosphere absorbs or blocks out almost all the invisible radiation emanating from the stars so that it never reaches Earth's surface. Earth-based telescopes, therefore, can never see the total universe, only the small portion of it that radiates visible light.

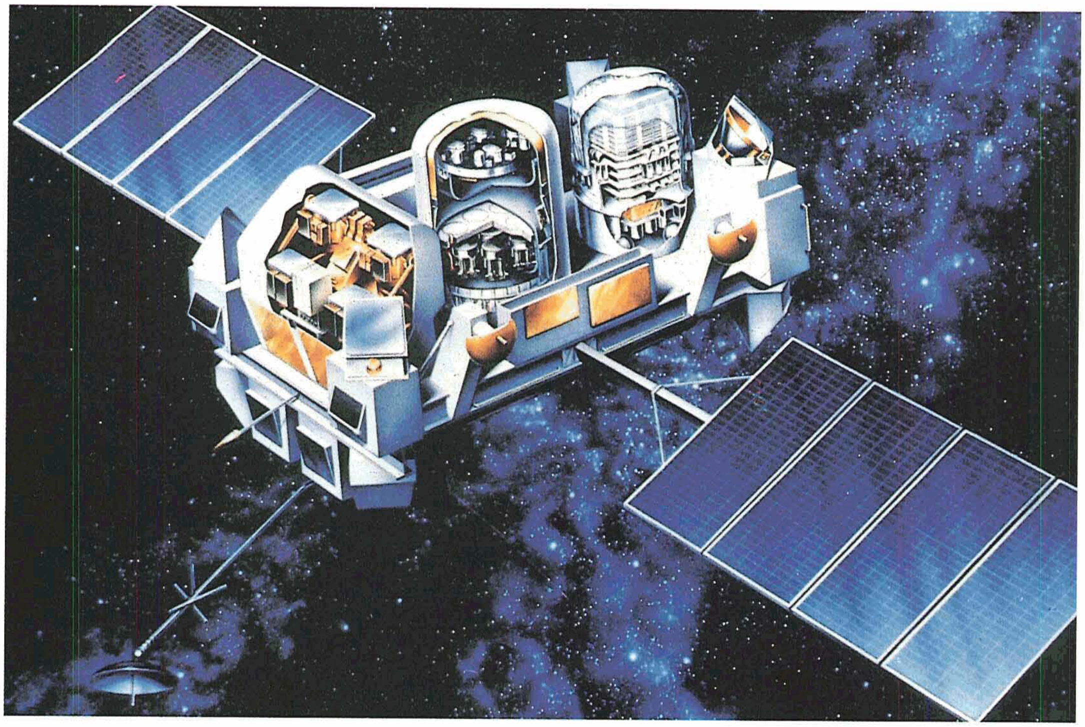
With the advent of satellite-based telescopes in the 1960s, astronomy made a giant step forward. Operating *above* the atmosphere, these instruments provide an undistorted view of the universe, and they can observe in bands of the electromagnetic spectrum other than visible light—ultraviolet, infrared, x-rays and gamma rays, for example. This latter capability is particularly important to astronomical science, because each band of the spectrum offers a different set of clues to the origin of the universe.

NASA has successfully operated a number of orbiting observatories and they have significantly expanded man's view of the cosmos—but they, too, are restricted by their relatively small size and limited spectral coverage.

The year 1990 marks a milestone in man's capability for learning about the universe one inhabits: the service debut of one of NASA's "Great Observatories." The Great Observatories program embraces four large orbital astronomical systems, each operating in a different segment of the spectrum, so that collectively they can examine the full range of phenomena in the universe. The Great Observatories will enable scientists to study the cosmic happenings of the early years of the universe and produce a comprehensive picture of the cosmos that no single observatory could provide.

The first of the Great Observatories to enter service was the Hubble Space Telescope (HST),





launched April 24, 1990 and deployed the following day to begin a series of pointing, focusing and calibration tests prior to the start of scientific investigations. These tests disclosed a defect in the HST's mirror system that cannot be corrected by Earth commands and will be corrected as part of a previously manifested Space Shuttle rendezvous/repair mission. At publication time an investigation as to cause, effect and remedy was under way. The flaw affects only a portion of the HST's instrument system and some of the scientific agenda can be accomplished prior to the repair mission. NASA officials believed that 100 percent of the highest priority science planned would eventually be performed over the HST's 15-year lifetime.

When fully operational, the HST will literally look back in time some 14 billion years to the early days of the universe. Viewing in the visible light and ultraviolet ranges, it will ultimately be capable of detecting objects 25 times fainter and viewing them in 10 times finer detail. The size of the 12½-ton spacecraft is evident in the photo at left, a preflight view of the HST encased in thermal protection covers.

The HST spacecraft was developed by Lockheed Missiles & Space Company and the Optical Telescope Assembly was designed and built by Perkin-Elmer Corporation (now Hughes Danbury Optical Systems, Inc.). Marshall Space Flight Center is manager for the development effort and orbital verification; after verification, Goddard Space Flight Center takes over responsibility for controlling the telescope and processing its data. The European Space Agency (ESA) furnished the power-generating solar arrays and one of the system's five major instruments.

In 1991, the HST will be joined in orbit by the second Great Observatory, the Gamma Ray Observatory (GRO), which will investigate gamma radiation, the most energetic of all forms of radiation, and its violent sources—pulsars, quasars and black holes. Managed by Goddard, GRO (above) is a joint development of the U.S., the Federal Republic of Germany, the Netherlands, the United Kingdom and the ESA. TRW Inc. is the U.S. prime contractor.

Planned for launch in 1997 is the third Great Observatory, the Advanced X-ray Astrophysics Facility (AXAF), which will have instruments 100 times more sensitive than those of the best prior x-ray observatory. AXAF is designed to obtain high resolution imagery from celestial x-ray sources and study such subjects as stellar black holes, the contribution of hot gas to the mass of the universe, clusters and superclusters of galaxies, and the existence of "dark matter" in the universe. AXAF is managed by Marshall Space Flight Center with TRW Inc. as major contractor. Foreign participation includes the Federal Republic of Germany, the Netherlands and the United Kingdom.

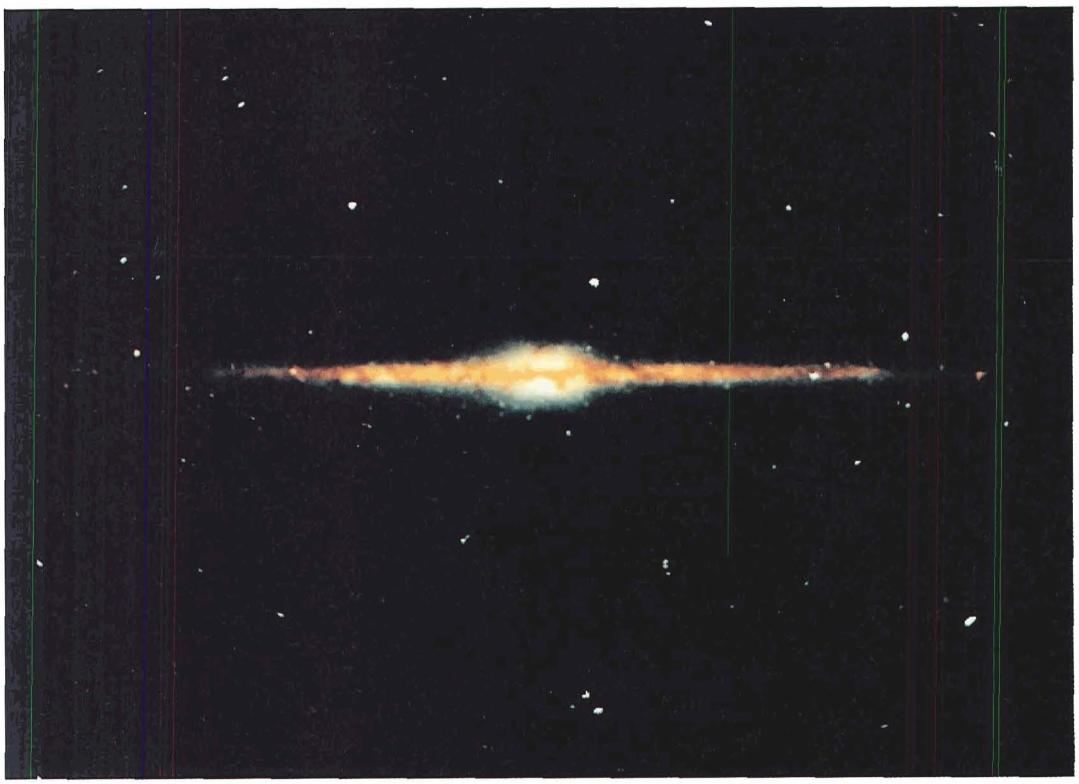
The contemplated fourth Great Observatory, planned as a new start in 1993 for launch near the end of the century, is the Space Infrared Telescope Facility (SIRTF), managed by Ames Research Center. SIRTF will study areas of prime interest identified by earlier infrared observatories, such as powerful infrared sources at the edge of the universe, cosmic births of stars and galaxies, and the "missing mass," the 90 percent of matter in the universe that cannot be seen but is thought to exist because of gravitational forces apparently exerted on stars and galaxies.

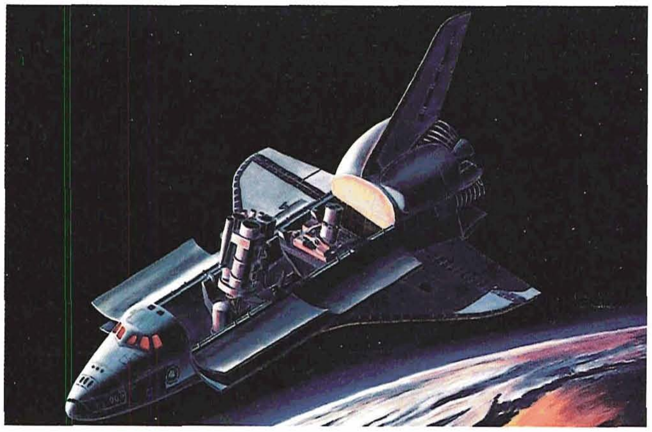
Astronomy and Astrophysics

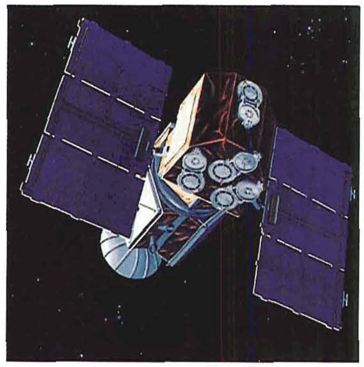
With the four Great Observatories (see previous page) NASA will be able to observe the universe, over a period of two decades, in the four major wavelength bands of the electromagnetic spectrum—infrared, ultraviolet/visible light, x-ray and gamma radiation. To bridge gaps and complement the measurements made by the Great Observatories, NASA will employ a number of other astronomy/astrophysics systems, including Shuttle-based and Space Station *Freedom*-based instruments, orbital satellites, and suborbital observations from sounding rockets, aircraft and balloons.

Fulfillment of the goal of contemporaneously observing the universe across the entire spectrum will, some astronomers feel, bring about a revolution in world thinking rivaling the one that occurred when the 16th century astronomer Copernicus showed that Earth was not the center of the universe.

A particularly important space system is the Cosmic Background Explorer (COBE), which was launched on November 18, 1989 to study the origin and dynamics of the universe and seek evidence supporting the theory that the universe began with a cataclysmic explosion—the Big Bang. Operating in a polar orbit 560 miles high, COBE is mapping the diffuse infrared radiation—called the cosmic background—that bombards Earth from every direction, determining the detailed spectrum of the background radiation, and searching for the earliest-formed galaxies. Below is an infrared image taken by COBE in April 1990, showing the plane of the Milky Way galaxy. The image strikingly shows both the thin disc and the "central bulge" populations of stars closer to the Galactic Center, which lies in the disc some 28,000 light years from the center. It is expected that the two-year mission will help clarify such matters as the nature of the primeval explosion and the processes leading to the formation of galaxies.







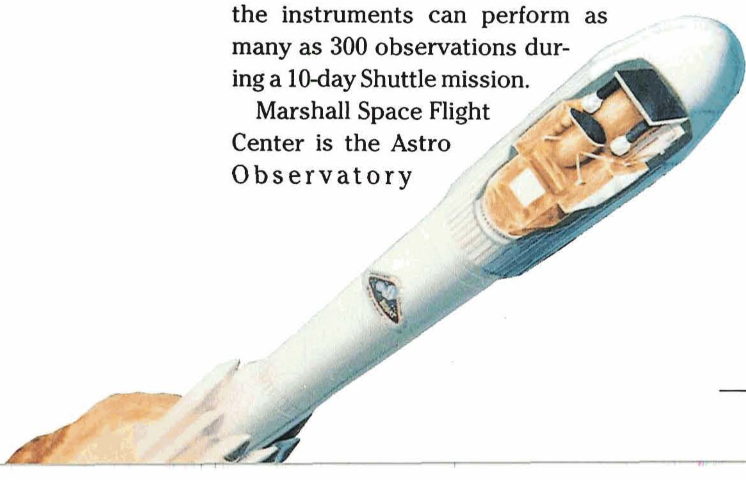
Another new observatory—ROSAT—was launched June 1, 1990 and a third—Astro-1—was being readied for launch at publication time in late summer 1990.

ROSAT (below) is a compression of Roentgen Satellite. Named for the German discoverer of x-rays, Wilhelm Conrad Roentgen, the term roentgen is, in Germany, another word for x-ray and, internationally, a unit of radiation measurement. ROSAT is a cooperative U.S./United Kingdom/ Federal Republic of Germany project in which NASA provided a high resolution x-ray imaging system, the U.K. a wide field camera and Germany the spacecraft and main telescope.

ROSAT will conduct a sweeping five-year survey of x-ray sources and make dedicated observations of specific sources, allowing astronomers to study in greater detail many of the phenomena discovered, but not thoroughly investigated, by earlier x-ray satellites.

The Astro Observatory (left above) is a Shuttle-based astronomical system, mounted in the Orbiter's payload bay on two unpressurized Spacelab pallets (Spacelab is a set of modular components developed by the European Space Agency for manned or unmanned missions aboard the Shuttle). Astro-1, a 9-11 day mission, is intended to complement findings of the Hubble Space Telescope by studying quasars, galaxies and active nuclei in the ultraviolet range. Its instruments include three ultraviolet telescopes aligned to each other on a single pointing system, which in turn is mounted on the Spacelab pallets. The mission also includes a broad band x-ray telescope. Operated by the Shuttle crew, the instruments can perform as many as 300 observations during a 10-day Shuttle mission.

Marshall Space Flight Center is the Astro Observatory program manager. The x-ray telescope and one of the ultraviolet telescopes was developed by Goddard Space Flight Center; the other ultraviolet instruments were developed by The Johns Hopkins University Center for Astrophysical Sciences and the University of Wisconsin.



Planned for launch in August 1991 is the Extreme Ultraviolet Explorer (EUVE), shown above. The designation refers to a wavelength band between the ultraviolet and x-ray ranges that has never been explored. EUVE's four sensitive telescopes will conduct a two-year all-sky survey in that band of the spectrum. The project is managed by Jet Propulsion Laboratory. Major contractors include Fairchild Space Company, General Electric Company and McDonnell Douglas Astronautics Company.

The EUVE payload is mounted on a spacecraft "bus" known as the Explorer Platform. In a novel space operation, a Shuttle crew will rendezvous with the platform when EUVE's mission is completed, remove the EUVE payload module and replace it with a new X-ray Timing Explorer payload developed by the University of California-Berkeley. NASA plans to fly other payloads on the Explorer Platform, and also plans a series of small-size Explorer satellites with specific observational assignments. The Explorer Program additionally includes a series of international collaborations in which U.S. instruments are to be flown aboard Japanese, European Space Agency and Soviet spacecraft.

Another international collaboration is the Stratospheric Observatory for Infrared Astronomy (SOFIA) project with the Federal Republic of Germany. Proposed for service in the mid-1990s, SOFIA is a unique airborne observatory designed to complement the planned Space Infrared Telescope Facility (see previous page). Expected to operate for 20 years, the SOFIA system includes a three-meter-class telescope mounted in a Boeing 747SP transport for observations at altitudes above 40,000 feet in infrared wavelengths inaccessible from the ground. Ames Research Center is NASA program manager.

Venus Mapper

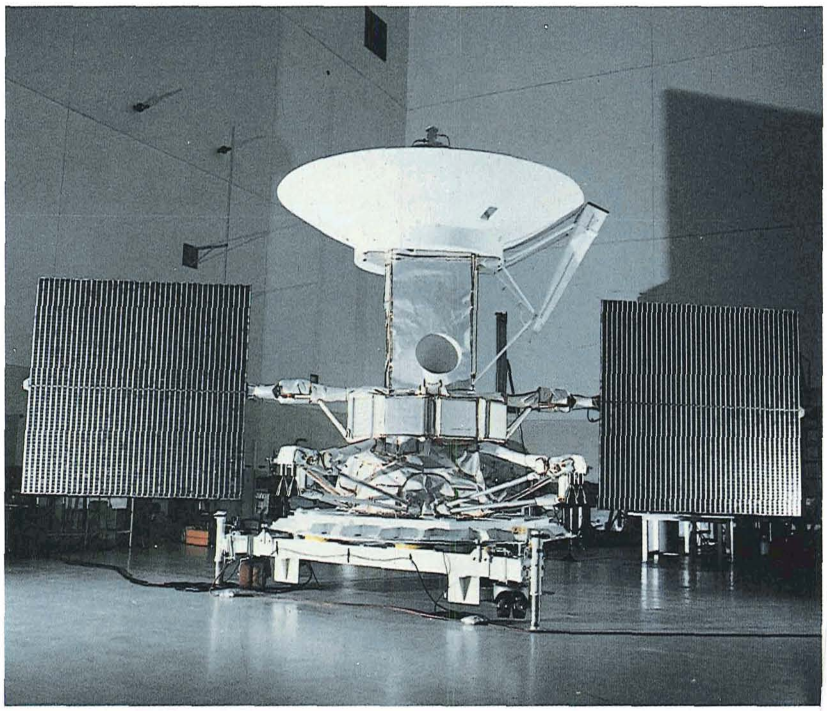
Shown below is a view of the Magellan spacecraft as it was undergoing prelaunch checkout at Kennedy Space Center. On May 4, 1989, Magellan was launched on a 15-month journey to Venus, there to go into elliptical orbit around the planet and map its surface.

Venus has been visited often, by 20 U.S. and Soviet spacecraft, and great amounts of data have been acquired on the planet's atmospheric structure and composition. But because Venus is permanently cloud-shrouded and conventional cameras cannot photograph its surface, information about the solid "face" of the planet is sketchy. Since the early 1960s, scientists have used cloud-penetrating radar systems to provide data for images derived from computer processed radar reflections. Earth-based radar imaging has proved valuable but limited since only a fraction of the planet can be covered. Previous spacecraft have answered some of the questions about Venus' large-scale surface features, but their imagery lacked sufficient resolution—a measure of the smallest objects that can be seen on radar maps—to provide precise information about small-scale features.

Magellan will map up to 90 percent of the planet's surface with 10 times the detail of the best previous spacecraft images and 100 times the resolution of its predecessor, Pioneer Venus. Magellan's maps will reveal, for the first time, such keys to Venus' geology as small-scale hills and valleys, craters and lava flows. The images will provide information on the extent to which Venus' surface has been influenced by volcanoes, plate tectonics, meteorites, water and wind erosion, processes that determine a planet's geologic history and shape its face.

The four-ton Magellan spacecraft carries only one science instrument, a radar sensor known as Synthetic Aperture Radar (SAR). The term "synthetic" refers to an ingenious method of figuratively increasing the size of the antenna—to get better resolution—by computer synthesis; SAR signals are computer-processed on Earth so that the spacecraft's 12-foot-diameter dish antenna (at top in the photo but oriented toward Venus while in orbit) serves the purpose of a much larger antenna. The SAR performs three functions: collecting data for surface imaging; measuring height variations as small as 100 feet to allow construction of a topographic profile of Venus; and measuring natural thermal emissions from the planet to show surface temperature variations.

To be completed in the spring of 1991, the primary mapping mission will take 243 days (one Venus day, or the time it takes for most of the planet's surface to pass beneath the SAR's gaze). The Magellan program is managed for NASA by Jet Propulsion Laboratory; Martin Marietta Astronautics is spacecraft prime contractor and Hughes Aircraft developed the SAR.



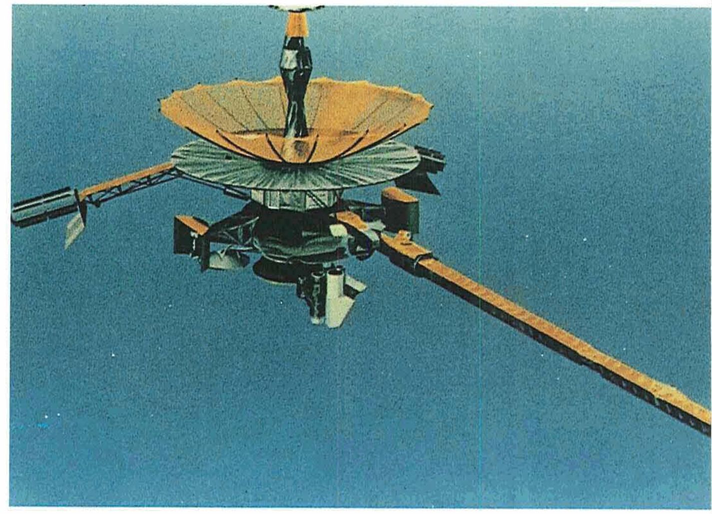
Jupiter Exploration

Scientists believe that Jupiter and its eight moons have undergone fewer changes than Earth since the solar system came into being, and therefore offer an especially promising objective for scientific investigation. Following up on two prior reconnaissance missions to Jupiter, NASA has launched an advanced observatory with a large complement of sophisticated instrumentation to conduct—beginning in 1995—a comprehensive examination of the Jupiter system that is expected to yield new knowledge of early planetary formation, perhaps broaden understanding of Earth's place in the solar system and the factors that influence Earth's environment.

The spacecraft, known as Galileo (right), was launched October 18, 1989 into a complicated trajectory that will take it more than six years to reach Jupiter. Galileo's principal assignments include investigation of the structure and physical dynamics of Jupiter's complex atmosphere; measurement of the chemical composition and physical state of the Jovian moons; and determination of the composition of Jupiter's atmosphere. The latter assignment will be accomplished by an instrumented probe that will be released from the main spacecraft in July 1995 to make an independent five-month trip to the planet. The probe will then descend into the Jovian atmosphere, sending data to the main spacecraft for up to 75 minutes.

The main spacecraft, or orbiter, will make its closest approach (620 miles) to Jupiter on December 7, 1995 and swing into orbit around the giant planet. Galileo's primary mission is planned to last 22 months, during which the spacecraft will make 10 orbits, make a close flyby of one Jovian moon on each orbit, study the Jupiter system with 18 sophisticated instruments, and acquire images of Jupiter and the moons from vantage points up to 1,000 times closer than the distances at which the Voyager spacecraft made their superb pictures.

A cooperative project with the Federal Republic of Germany, Galileo is managed for NASA by Jet Propulsion Laboratory, which also designed and built the orbiter. Ames Research Center has



responsibility for the probe, which was built by Hughes Aircraft. General Electric Company developed the nuclear generators under contract to the Department of Energy.

Substitution of a less powerful upper stage solid fuel booster for a cancelled liquid fueled booster necessitated the complicated "triple gravity assist" trajectory in which the gravity fields of Venus and Earth are employed as "slingshots" to accelerate the spacecraft. Employment of this technique provided scientific bonuses: it enabled special observations of Venus and the Earth-Moon system and created opportunities for close-up looks at asteroids. In 1992, between the second and third gravity assists (from Earth), Galileo will fly by a 10-mile-diameter main belt asteroid known as Gaspra, passing within 620 miles of the asteroid and taking hundreds of pictures. In August 1993, after the final gravity assist, the spacecraft will fly by Ida, an asteriod about twice as large as Gaspra, and repeat the imaging process. Galileo will spend a total of about 15 months in the asteriod belt on its 2.5 billion mile journey to Jupiter.

Solar System Exploration

NASA classifies solar system exploration in three distinct stages. The first is reconnaissance, involving flyby missions. Next comes exploration, more comprehensive coverage generally acquired by spacecraft that orbit the target planet and perhaps release atmospheric probes. The third stage, intensive study, involves the use of planetary soft landers, vehicles for returning planetary samples to Earth, and, eventually, human exploration.

The Voyager 2 encounter with Neptune in August 1989 virtually completed the reconnaissance phase, which began in 1962. The 1989 departures of Magellan to Venus and Galileo to Jupiter (see pages 16-17) marked the start of the exploration phase. NASA has several other exploratory craft in development and plans for others that would both continue the traditional scientific program and pave the way for human exploration of the Moon and Mars.

Not to be forgotten are the durable Voyagers 1 and 2, managed for NASA by Jet Propulsion Laboratory (JPL). Now 13 years out of home port Earth and headed out of the solar system, they are still doing important work. Their new job, known as the Voyager Interstellar Mission, is to report solar wind/solar cycle data from the distant reaches of the solar system and try to determine the location of the heliopause, the boundary line that represents the outer edge of the Sun's magnetic influence and the beginning of interstellar space. The never-charted heliopause is believed to be somewhere between five billion and 14 billion miles from the Sun. The Voyagers' power supply is expected to last—with conservation measures—25 to 30 years, perhaps long enough to reach and report on the heliopause.

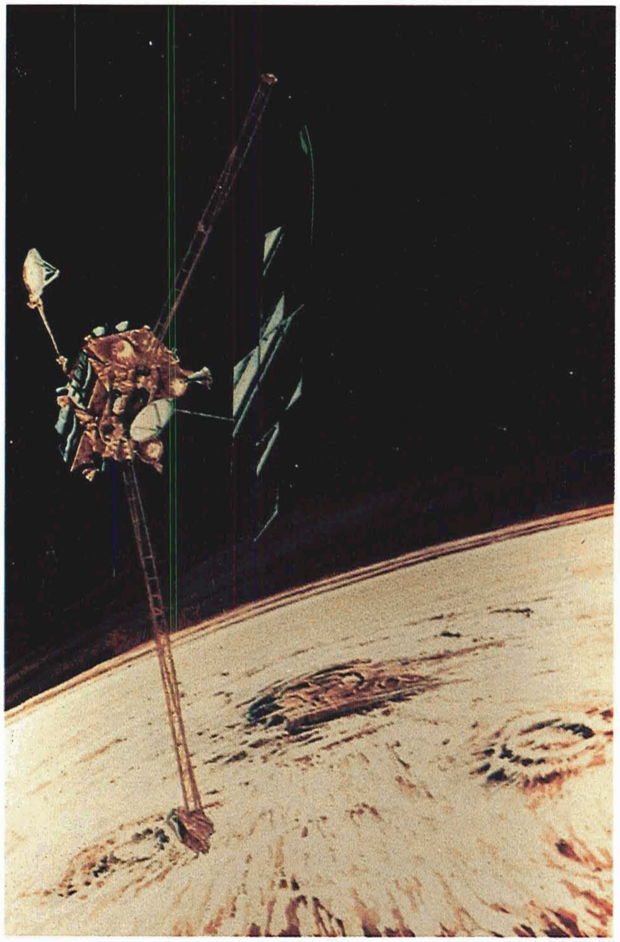
Study of the heliosphere from a different perspective is the assignment of the NASA/European Space Agency (ESA) mission Ulysses (right center), slated to embark in 1990 on a multiyear journey toward the Sun's polar regions, which have never been explored by spacecraft. Because no upper stage propulsion system has sufficient energy to send Ulysses directly from Earth over the Sun's poles, the spacecraft will be launched on an interplanetary trajectory. It will fly first to Jupiter and use Jupiter's immense gravity to sling the spacecraft out of the plane of the ecliptic, the imaginary plane through the solar system that approximates an extension of the Sun's equator.

Flying a path that will take it over the Sun's south pole in 1994, Ulysses will report—from the fresh perspective of a never before penetrated out-of-the-ecliptic region of the heliosphere—on such features as the solar wind, solar and galactic radiation, cosmic dust and solar/interplanetary magnetic fields. JPL is NASA's project manager.

Planned for launch in 1992 is the Mars Observer (far right, top), which will make a two-year global survey of Mars from orbit, providing data on the planet's surface and atmosphere with the highest resolutions yet obtained and collecting new information in two general areas: Mars geoscience and climatology. To minimize cost, the Mars Observer is being built around a dependable spacecraft bus, the Tiros weather satellite in service since 1960. JPL manages the Mars Observer program; General Electric Astro Space is developing the spacecraft. The project includes participation by Australia, the Federal Republic of Germany, France, the United Kingdom and the Soviet Union.

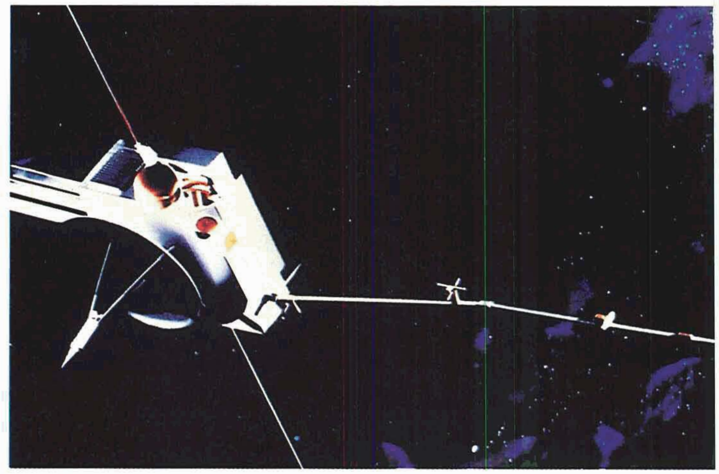
The two most recently authorized solar system exploration missions—the Comet Rendezvous Asteroid Flyby (CRAF) and Cassini—will share a common modular spacecraft known as Mariner Mark 2. CRAF's assignment is to take close looks at an asteroid (right, lower) and a comet. Because they are small and "cold" bodies, asteroids and comets did not evolve like the major bodies of the solar system; they remain largely unchanged from the solar system's formative epoch four and a half billion years ago. Thus, investigation of their chemical and elemental composition offers an opportunity to observe material as it existed when the solar system was born.

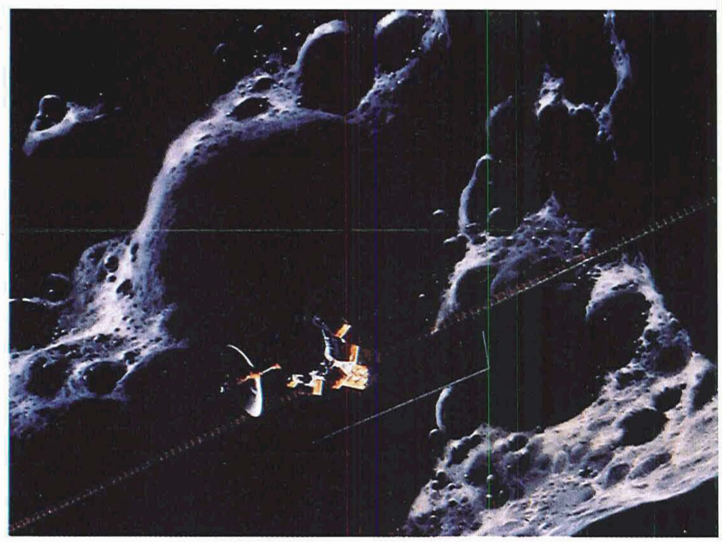
To be launched in 1995, CRAF will fly a complicated gravity-assisted trajectory to the main asteroid belt between Mars and Jupiter. There,



in 1998, it will fly past and study the 53-mile-diameter asteroid Hamburga. In August 2000, CRAF will rendezvous with the Comet Kopff. Matching the comet's speed and direction, the CRAF spacecraft will "fly formation" with Kopff for two and a half years. It will make high resolution images of the comet's nucleus; determine Kopff's chemical, isotopic and mineral composition; observe the coma, the comet's atmosphere, and its interaction with the solar wind and magnetic field; and it will collect comet dust and examine it with an on-board electron microscope. Additionally, CRAF will send a penetrator device into the comet's nucleus for on-site analysis of the material.

The Cassini spacecraft will be launched in 1996 to fly past an 18-mile-diameter asteroid named Maja in 1997, then make a flyby of Jupiter in 2000, making observations during the close approach. In 2002, Cassini will reach Saturn and go into orbit around the planet. On the initial orbit, it will release a probe into the atmosphere of Saturn's moon Titan. The spacecraft will spend four years in orbit—about 40 revolutions—studying Saturn, its rings, its moons and its magnetosphere.





JPL is project manager for both CRAF and Cassini. The Federal Republic of Germany is a participant in both missions; ESA is supplying instruments for both the Cassini orbiter and its Titan probe. The sophisticated CRAF/Cassini missions are expected to provide unprecedented information on the origin and evolution of the solar system and shed light on how the building blocks for life are formed in the universe.

Space Physics

Seemingly empty space is actually an ocean of invisible magnetic and electric fields, radiation and plasmas, streams of electrified particles. Complex interactions among these fields and particles extract energy from the solar wind and deposit much of it into Earth's atmosphere, ionosphere and magnetosphere.

NASA's space physics program seeks expanded knowledge of these phenomena and the effects of their interactions, both for scientific gain and for practical reasons; the sophisticated electronics of modern spacecraft are subject to damage from radiation. Scientists, employing satellite observations and ground-based instruments, have been studying the subject for decades. In 1990, a new satellite added the capability of visualizing interactions in the ionosphere and magnetosphere.

Launched July 25 by an Atlas/Centaur launch vehicle, the NASA/Department of Defense Combined Release and Radiation Effects Satellite (CRRES), shown at right, is equipped to release chemical vapors that will briefly "paint" the invisible magnetic field lines with luminous particles. By observing the motion of the luminous chemicals, scientists will be able to measure the electric fields that exist in space, to "see" how these fields interact with charged particles to form waves, and to gain new knowledge of how energy is extracted from the solar wind.

The chemical payload is carried in 24 canisters, which are to be released from the main spacecraft at specific times during the year-plus mission. The chemical clouds created will be observed by instruments aboard CRRES, aboard aircraft and on the ground.

In addition to the chemical payload, CRRES carries four instrument payloads for studies of ionospheric structure and chemistry, for an investigation of how radiation affects electronic devices, and for experiments in high efficiency solar cells. CRRES is managed for NASA by Marshall Space Flight Center and for the Department of Defense by the Air Force Space Test and Transportation Program. The satellite was built by the Space Systems Division of Ball Corporation.

In other areas of NASA's space physics program, the Ulysses mission will study the heliosphere out-of-the-ecliptic plane (see page 18) and the U.S./Italian Tethered Satellite System will—in 1991—investigate electrodynamic plasma effects by means of a diagnostic satellite tethered to the Space Shuttle Orbiter by a 20-kilometer conducting wire.

The next major space physics flight program is the International Solar Terrestrial Program, to begin in 1992. The program will employ several spacecraft in different orbits making simultaneous and sequential measurements to establish cause and effect relationships among Sun/Earth phenomena. A planned CRRES extended mission would be part of this effort.

Communications Systems

NASA pioneered space communications in the early 1960s and built a technology base that has allowed U.S. manufacturers to dominate the market for commercial satellites. In recent years, however, advanced communications technology developments by Japan and European nations have challenged U.S. preeminence. To assure continued U.S. leadership, NASA is conducting a communications research program that focuses on developing high-risk technology for satellite and ground systems needed to enable new services and increase the capacity and flexibility of telecommunications resources.

The centerpiece of the program is the Advanced Communications Technology Satellite (ACTS). The ACTS spacecraft incorporates several revolutionary technologies designed to allow more effective use of available frequencies, to increase the message handling capacity of the individual satellite, and to provide a capabilty to high volume communications to small Earth terminals. A major innovation is the "spot beam" approach, in which advanced satellite equipment will generate multiple message-carrying spot beams, each focused on a narrow Earth region rather than the wide beams generated by existing satellites. This technique affords significant capacity gain.

ACTS is scheduled to conduct a two-year test and demonstration mission following its Space Shuttle launch in April 1992 (right). The system will be made available to satellite users and developers, corporations, universities and government agencies for experiments to test, evaluate and determine the feasibility of ACTS technologies. ACTS is being developed by General Electric Astro Space under the management of Lewis Research Center. Harris Corporation is developing a prototype Earth station for use with ACTS.

Among other communications research projects, NASA is cooperating with U.S. industry in an effort to accelerate the introduction of satellite relayed two-way voice and data communications for trucks, cars, boats and airplanes in the Mobile Satellite (MSAT) program. In cooperation with communications organizations, Jet Propulsion Laboratory, NASA's program manager, has conducted a series of mobile communications field tests to evaluate equipment—antennas, encoders and other hardware—for use in the surface/air segment of the system. The first MSAT spacecraft is scheduled for launch in 1993; NASA will procure commercial launch services in exchange for a portion of the satellite's capacity, to be used for government experiments.

The three-satellite system will be operated by American Mobile Satellite Corporation, a U.S. consortium of eight firms. Major contractors include Teledyne Brown, Ball Aerospace and satellite builders Hughes Aircraft and TRW Inc., who are competing for the space segment contract. The Canadian Department of Commerce is an MSAT participant.

Life Sciences and Microgravity Research

In three decades of spaceflight experience, man has learned that humans can live and work productively in the weightless environment of Space. But, as NASA prepares to extend human presence beyond Earth orbit in the 21st century, there is need for a great deal more information about the mechanisms, magnitudes and time courses of certain physiological changes that occur during exposure to microgravity.

For example, how does spaceflight influence the heart and circulatory system, the metabolic processes, the muscle and bones, and the cells? How can adverse influences of spaceflight be prevented or controlled? Can a body maintain its physical and chemical equilibrium for the long periods that service aboard a space station, at a lunar outpost or on a mission to Mars entails? And what happens when astronauts return to Earth's gravity?

NASA is seeking the answers to these and many other questions related to understanding the role of gravity with respect to living systems in space. The aim is not only to ensure safe and productive human spaceflight, but to apply the results of the research to improve the quality of life on Earth. Cardiovascular research in microgravity, for example, may help scientists learn more about such disorders as hypertension and heart failure; musculoskeletal research may shed new light on bone and muscle diseases.

NASA's life sciences program combines Earth-based research in NASA and university laboratories with orbital research involving study of basic processes on human, animal and plant life. The centerpiece of the program is a series of dedicated Spacelab life sciences missions beginning in 1991 and continuing at the rate of one mission every two years until Space Station Freedom is available for such research.

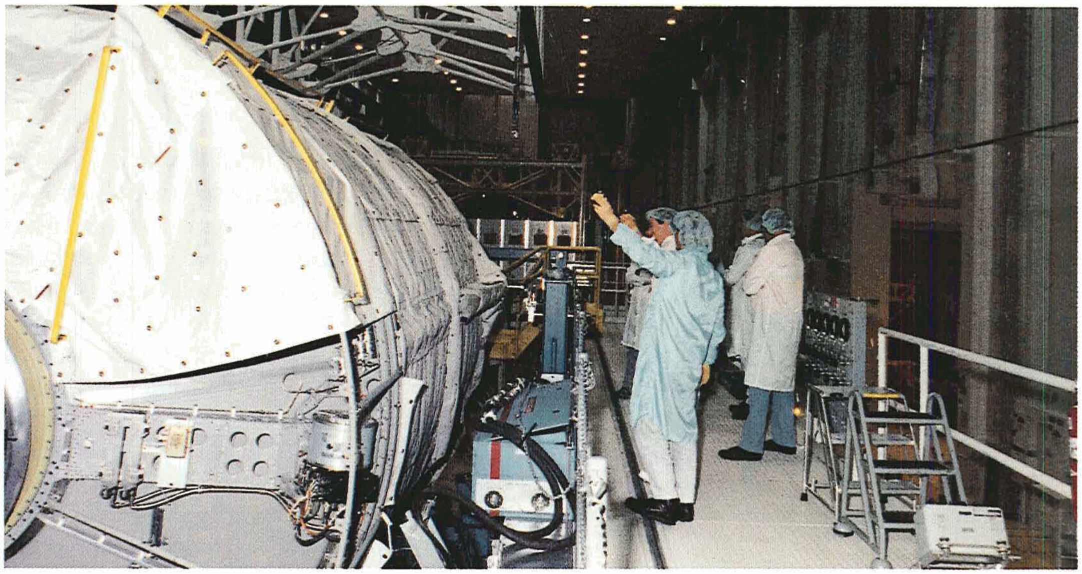
Developed by the European Space Agency for NASA, with U.S. coordination provided by Marshall Space Flight Center, Spacelab is a unique orbital laboratory carried in the payload bay of the Space Shuttle Orbiter. The flexible Spacelab system includes a pressurized module, where up to four investigators can work in shirtsleeve environment, and non-pressurized pallets mounted in the open cargo bay for experiments that require direct exposure to space. These elements can be flown in a number of different combinations, for example, a two-segment long pressurized module with one pallet, or a single-segment short pressurized module with three pallets, or as many as five pallets without the manned module. In the latter instance, experiments are controlled from the Orbiter's rear flight deck. Spacelab has been flown on a number of occasions with multiple experiments in different disciplines—astronomy, materials processing, life sciences—but the 1991 Spacelab Life Sciences-1 mission (SLS-1) marks the first time the laboratory has been used solely as a biological research center.

SLS-1 (far right) employs the two-segment long pressurized module, which provides a cylindrical laboratory about the length of a medium-size bus for the mission's science crew of two mission specialists and two payload specialists. The module contains utilities, computers, work areas and 12 racks of instruments. Additionally, some smaller equipment is contained on the Orbiter's middeck.

The equipment includes the types of instruments routinely found in Earth-based biomedical research laboratories. It is employed in 20 SLS-1 investigations devoted to study of six body systems: heart, lungs and blood vessels; kidneys and hormone secreting organs; the blood system; the immune system; muscles and bones; and the neurovestibular system, which embraces the brain, nerves, eyes and inner ear. Other investigations involve hardware and operations tests pertinent to future life sciences experimentation.

The second SLS mission is scheduled for October 1992 and the third is targeted for early 1995. NASA's program manager for the SLS series is Johnson Space Center.

SLS investigations will be augmented by a number of other Spacelab flights, including the International Microgravity Laboratory (IML) series, devoted to investigations of both life



sciences and materials science. IML is part of NASA's microgravity science program conducted in parallel with the life sciences effort. Its aim is to develop understanding of gravity dependent phenomena in both Earth and non-Earth environments; to foster growth of a microgravity research community, including international cooperation; promote industrial applications for development of new products resulting from microgravity research; and ultimately to operate a permanently manned national microgravity laboratory in Earth orbit.

IML-1, to fly aboard the Space Shuttle in April 1991, will employ the long pressurized module and use four life sciences facilities designed for multiple experiments and repeated reuse in Spacelab: equipment for investigations in biology, plant physiology and vestibular systems, and experiments in space physiology. Materials facilities include a fluid experiment system and several racks for different types of crystal growth experiments. These reusable facilities were developed by U.S., European, Canadian and Japanese organizations. In addition, IML-1 will carry two other life sciences and three other materials processing facilities.

IML missions will be flown at intervals of 17 to 25 months after IML-1 to allow time for post-mission analyses and permit scientists to build new investigations on the results of the earlier mission. The second flight is planned for early 1993. IML is managed by Marshall Space Flight Center; international participation includes ESA, France, Canada, Japan and the Federal Republic of Germany.

A similar type of microgravity mission is Spacelab J, jointly sponsored by NASA and Japan's National Space Development Agency. Spacelab J involves materials processing and life sciences investigations in the pressurized Spacelab long module. The mission is scheduled for June 1991.

Another NASA Spacelab-based program is the United States Microgravity Laboratory (USML) series, which will focus on materials science and applications experiments, together with materials processing technology development. The program is intended to provide an orbiting microgravity facility to U.S. government, academic and commercial researchers and to develop a science and technology base for Space Station *Freedom* applications.

The series will be flown in an Extended Duration Orbiter fitted with fuel and energy supplies that allow Shuttle flight durations up to 16 days. Some missions will employ the pressurized Spacelab long module, others will use Spacelab pallets that provide direct exposure of the experiments to the space environment. The latter missions are designated USMP (P for Pallet). Six missions are planned, three USMLs and three USMPs; the first, USML-1 is planned for March 1992. Marshall Space Flight Center is project manager.

AERONAUTICS

Trailblazing Future Flight

An important part of NASA's aeronautical research program involves study of atmospheric phenomena that can have serious effect on flight safety, in particular such critical hazards as wind shear, heavy rain, icing and lightning. Conducted in close cooperation with the Federal Aviation Administration (FAA), which has primary responsibility for aviation safety, the NASA effort concentrates on finding better ways to operate safely in a hostile weather environment by predicting, avoiding or reducing the effects of such hazards.

Wind shear is a sudden shift in wind velocity and direction; its most violent characteristic is the microburst, an intense downdraft that has been identified as the probable cause of many aircraft accidents. FAA regulations will require that all transport aircraft carry wind shear detection systems by 1994, but available systems can only alert the crew that the airplane *is experiencing* wind shear; NASA's aim is to provide an advance warning to avoid the encounter.

In a jointly funded NASA/FAA program, Langley Research Center is conducting research that seeks to provide aircraft with an on-board capability for detecting wind shear in flight by means of practically-sized, affordable instrumentation. Langley is pursuing three separate approaches: a Doppler radar system, a pulse Doppler LIDAR (laser radar) system, and a system based on an infrared radiometer. The latter is currently undergoing flight test aboard Langley's Boeing 737 research jetliner; the radar system is to begin flight testing in 1990 and the laser system will be flown in 1991.

Each of these systems has promising potential, but each has technical problems not yet resolved. NASA hopes that the program will lead to development of one successful wind shear detection and warning system available for installation by the FAA's 1994 deadline date.

In a related effort, Langley is conducting an investigation of the effects of heavy rain on aircraft performance. In tests at the center's Aircraft Landing Dynamics Facility, a full scale wing section mounted on a tubular steel carriage is accelerated to takeoff/landing speed and then subjected to a deluge of water simulating heavy rain. Initial tests confirmed earlier wind tunnel indications that heavy rain can reduce an airplane's maximum lift by as much as 20 percent and cause the wing to stall at angles of attack three to four degrees lower than under normal dry conditions. The results are being reviewed with industry to decide what additional testing might be needed to establish design and operational guidelines for operating in heavy rain.

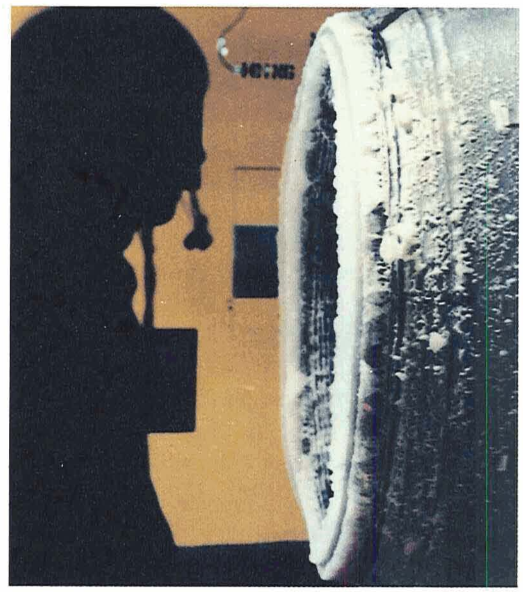
In recent years, de-icing modern jetliners has been a routine matter of drawing hot "bleed air" from the engines to deliver heat for melting ice accumulations. However, the advent of new, more efficient high bypass ratio turbofan engines has brought a renewed requirement for ice protection research, because the new turbofans do not provide much bleed air. Thus, there is new emphasis on developing highly efficient de-icing systems to make the best use of the limited bleed air available. Advancing technology is providing an answer.

"The new dimension in icing research," says Louis J. Williams of NASA's Office of Aeronautics, Exploration and Space Technology, "is the tremendous advancement in computerized analysis. We can now determine analytically the water droplet trajectories, where the drops will hit the aircraft and freeze, how and in what shape the ice will build, and how the ice will affect aircraft performance. And we can verify the analysis by icing tunnel tests where necessary. With these prediction capabilities, we can identify where and how much ice protection is necessary."

He adds that computer analysis also helps develop some of the newer de-icing techniques, such as electromagnetic impulse de-icing, in which ice is allowed to form, then is dislodged from the surface of the airfoil by sharp impact pulses. "A lot remains to be done," says Williams, "but the problem of in-flight icing is fairly well in hand."

Lightning has not been a serious safety issue in recent years but here again advancing tech-

Investigation of severe weather conditions highlights selected examples of NASA aeronautical research, which is providing new technology for coming generations of better performing, more efficient aircraft



Obscured by the water deluge at left is an aircraft wing section undergoing a simulation test at Langley Research Center to determine how an airplane's takeoff/landing performance is affected by heavy rain. Above, a technician outlined in shadow monitors ice buildup on a jet engine inlet in Lewis Research Center's Icing Research Tunnel. Heavy rain and icing research are part of a broader NASA effort to find ways of predicting, avoiding or neutralizing severe weather hazards to flight safety.

nology has revived a problem. Composite materials, increasingly used in aircraft structures, are less conductive—hence less protective—than conventional aluminum skins. In addition, new electronic control systems are more sensitive to lightning damage than mechanical controls.

To learn more about lightning strikes and the conditions under which they are likely to occur, Langley conducted a seven-year research program in which a specially instrumented NASA F-106 made 1,500 thunderstorm penetrations and recorded 714 lightning strikes. The data from this program provided new insights on flight operation under severe storm conditions, led to new design guidelines and a revised procedure for qualification testing of airborne electronic systems.

Severe storm research exemplifies one facet of NASA's broad aeronautical research and technology program: solution of current and predictable aviation problems. Other examples include curbing aircraft fuel consumption, reducing airplane and helicopter noise levels, finding ways to alleviate air traffic congestion and a variety of safety-related investigations.

The main thrust of NASA'S program is anticipating the longer range needs of future flight and developing applicable technology. Part of this effort involves research of a general nature aimed at advancing aerodynamics, propulsion, materials and structures, aviation electronics and knowledge of the human factors in flight operations. The other part embraces technology development for improving the performance, efficiency and environmental acceptability of specific types of flight vehicles, such as tomorrow's general aviation planes, rotary wing aircraft, advanced jetliners and high performance military aircraft.

AERONAUTICS

Hypersonic Technology

Shown below is an artist's concept of the X-30, a flight research vehicle intended to demonstrate the successful integration of aeronautical and space technologies across the speed range from takeoff to orbital velocities. The X-30 is the focal point of the National Aero-Space Plane (NASP) program, a joint NASA/Department of Defense (DoD) effort for development of the technologies essential to a revolutionary class of vehicles capable of taking off and landing horizontally like an airplane, operating in the upper atmosphere at hypersonic speed (above 3,000 miles per hour), or flying directly into Earth orbit.

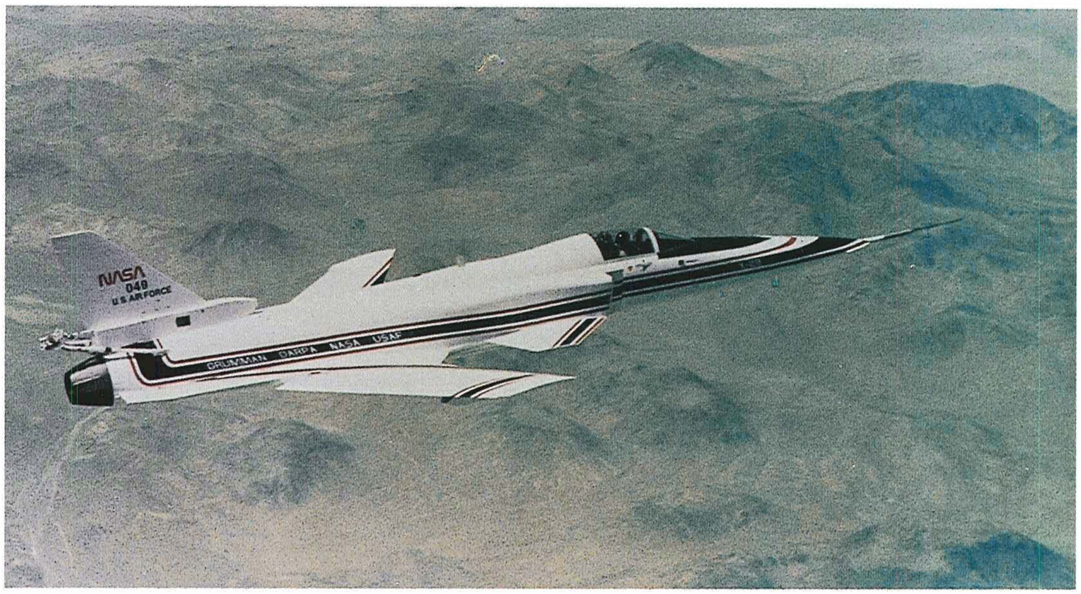
A successful NASP program could lead to civil or military single-stage-to-orbit spaceplanes providing on-demand access to space with airplane-like flexibility. Because they would not need the extensive facilities and lengthy countdown operations needed for vertical space launches, such craft promise dramatically greater cost efficiencies and responsiveness.

The current phase of the program involves development of key technologies in propulsion, aerodynamics, high temperature materials and structures, and computational fluid dynamics (computer simulation). This phase will continue until early 1993, when a decision will be made whether to proceed with construction of the X-30. A positive decision could lead to flight tests in 1997 and open the door to operational use of NASP-derived vehicles after the turn of the century.

The NASP program is a nationwide effort in which a contractor team of five major industry firms shares development costs with NASA and DoD. The program is managed by the NASP Joint Program Office, located at Wright-Patterson Air Force Base, Ohio and staffed by Air Force, Navy and NASA personnel. Government research facilities participating include NASA's Ames, Langley and Lewis Research Centers; the USAF's Aeronautical Systems Division, Air Force Weapons Laboratory and Arnold Engineering and Development Center; the Naval Surface Weapons Center; and the Department of Energy's Los Alamos Laboratory.

In May 1990, NASA and DoD approved a proposal whereby the five major contractors join forces and operate as a National Contractor Team to develop the X-30. The team approach will allow pooling of the separately-developed technology bases of the individual contractors; this could permit definition of a single X-30 airframe/propulsion concept before the end of 1990. The contractor team includes three airframe companies—General Dynamics Corporation, McDonnell Douglas Corporation, Rockwell International—and two engine companies—Pratt & Whitney division of United Technologies and Rocketdyne Division of Rockwell International.

Forward Swept Wing Research



Pictured above is the second of two X-29A research aircraft, built in a joint NASA/Air Force/ Defense Advanced Research Projects Agency program intended to demonstrate a variety of advanced technologies that collectively offer promise of constructing smaller, lighter and more efficient military aircraft without sacrificing performance. Among the technologies are a unique forward-swept wing (FSW) made of composite materials; rotating canards that replace conventional horizontal tail surfaces to control pitch; and an advanced digital flight control system that stabilizes the aircraft by adjusting the wing trailing edges, canards and other control surfaces more than 40 times a second.

The Number Two X-29A is completing an advanced phase of a test program that began in 1984 with Number One X-29A under the management of the USAF's Aeronautical Systems Division. NASA's Ames-Dryden Flight Research Facility is responsible for flight test activity. The two research craft were built by Grumman Aerospace Corporation.

The Number One X-29A completed a 242-flight concept demonstration program in December 1988. During four years of testing, more than 20 pilots provided their assessments of the aircraft's performance and handling capabilities. That phase of the program demonstrated that FSW aircraft offer drag reductions of 10 to 20 percent, weight savings of five to 25 percent, and that it is feasible to operate inherently unstable FSW aircraft in stable condition through application of closed-loop control of the close-coupled wing and canards. The program established the design techniques for successful aeroelastic tailoring of composite wings and the integration of digital control systems with three-surface pitch control.

The Number Two aircraft, identical in configuration to its predecessor but equipped with special instrumentation and a spin recovery parachute, is being flown to demonstrate the performance benefits resulting from the X-29A's combination of technologies with regard to aircraft maneuverability at high angles of attack (the angle of attack is the angle between the wing of an airplane and the air through which it is moving). This area of research was not covered in the earlier program; the Number One X-29A was never flown at angles of attack above 22 degrees. The Number Two aircraft is being tested at angles of attack up to 70 degrees.

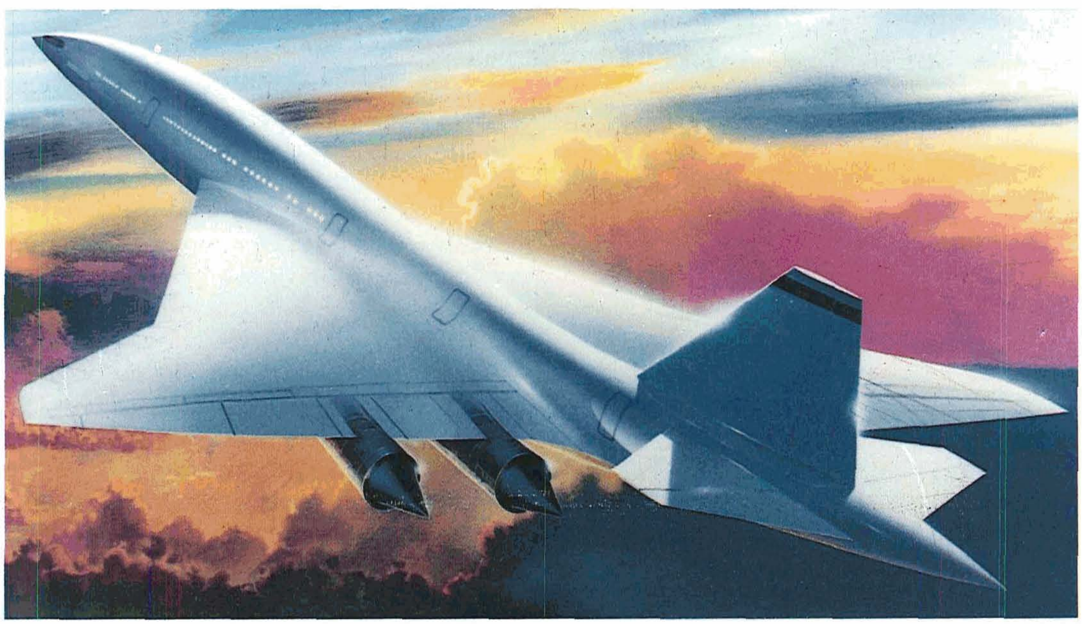
Supersonic Transport Research

Do the world's airlines want a second generation supersonic transport? Yes, was the consensus report from a late 1989 symposium at Strasbourg, France where a summary of airline views was presented. But the new airplane will have to be economically viable, environmentally acceptable and highly productive.

Tomorrow's supersonic transport, according to the consensus view, will have to have considerably greater range than the Concorde in order to serve the long overwater routes from the U.S. to Pacific Rim nations and between the Pacific Rim and Europe; transpacific travel is expected to increase fourfold by the turn of the century. The airplane will have to be more productive and its operating costs must be competitive with future subsonic airliners, so that tomorrow's supersonic airliner need not be a premium fare vehicle but may become *the* standard long-haul airliner. As for when, the airlines, now engaged in large-scale procurement of new subsonic transports, believed that the proposed time frame for development of the necessary technology will coincide with their own projections for a next-generation long-haul transport: early in the 21st century.

The airlines' requirements did not surprise U.S. transport manufacturers Boeing Commercial Airplanes and McDonnell Douglas Corporation's Douglas Aircraft Company; their own NASA-commissioned studies had indicated similar requirements. NASA and the two companies completed two years of High Speed Civil Transport studies in late 1989 and embarked on a second-phase High Speed Research Program. NASA is not engaged in supersonic transport development; in the U.S., commercial transport development is conducted by private industry. NASA's role is to provide, in the interest of U.S. competitiveness, a technological assist to help make advanced jetliner development feasible.

In the High Speed Civil Transport studies, each company focused on a different class of aircraft. Boeing studied a Mach 2.4 (about 1,600 miles per hour) concept (below) that could carry 250 passengers over a distance of 5,800 statute miles. Douglas studied a larger, faster airplane that would take longer to put into service: a Mach 3.2 (2,150 miles per hour) design (below) sized to carry 300 passengers 7,500 statute miles. Both companies concluded, on the basis of projections of substantially increased transoceanic



travel, that there will be a market for Mach 2-3 supersonic transports between the years 2000-2015. Of particular interest was the economic estimate that the next generation supersonic transport could operate at less than one-seventh the Concorde's cost per passenger mile.

The High Speed Research Program will focus on environmental considerations, because the earlier round of studies determined that substantial demand for an advanced supersonic transport will materialize only if the aircraft meets allowable standards of airport noise, has no harmful effects on the atmosphere, can meet acceptable overland sonic boom levels or fly efficiently at subsonic speed over land areas. It must, the studies agreed, also be economically competitive with future long-haul subsonic airliners. If the High Speed Research Program, which will continue through the mid-1990s, shows promise that these requirements can be satisfied, the next step might be a cooperative NASA/industry focused vehicle technology development effort.

Tiltrotor Research

Pictured below is the XV-15 tiltrotor research aircraft, being flown by Ames Research Center to test advanced technology rotor blades that promise increased performance and significantly quieter operation. These tests are part of a broader NASA/research effort that addresses civil and military tiltrotor technology in cooperation with the Federal Aviation Administration and the Department of Defense.

Built by Bell Helicopter Textron, the two models of the XV-15 were flown—beginning in 1977—in a lengthy evaluation of tiltrotor potential. The highly successful flight test program led to a DoD decision to develop a larger, more advanced tiltrotor, the Bell/Boeing V-22 Osprey. The V-22 has been undergoing flight test since 1988; a decision as to whether to proceed with production of operational V-22s for use by the military services was pending at publication time.

Meanwhile, the V-22 has become the design focal point for NASA/FAA/DoD studies of the impact on the nation of further military/civil tiltrotor development. A 1987 study showed that a large potential market exists for economically viable civil tiltrotors in high density, short haul city-to-city markets. A more recent study suggests that such aircraft could significantly relieve the nation's airport congestion problem. However, both studies identified some high risk areas related to development and operation, and the need for technological improvements to make the tiltrotor a viable commercial transport.

NASA's current and planned tiltrotor research focuses on these "barrier technologies," including those intended to improve the vehicle itself and those that would help integrate the tiltrotor into the U.S. civil aviation infrastructure. For example, testing of the all-composite Advanced Technology Blade is designed to improve the tiltrotor's cruise efficiency and reduce noise.

Other barrier areas in need of investigation include ways of reducing weight, lowering manufacturing costs, noise and vibration reduction, performance and payload improvements, cockpit automation and control integration, and the best flight profiles for noise abatement and safety. A Phase II study has been initiated that will further prioritize the technology opportunities for highest payoff; it is being conducted by Boeing Commercial Airplane Group, which is sharing the study cost with NASA and FAA.

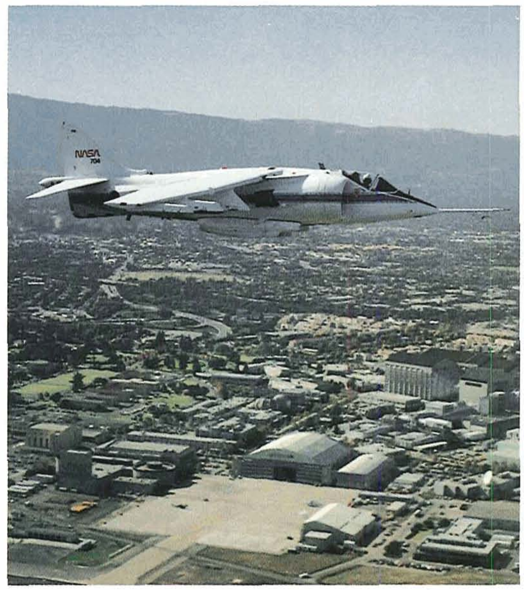
STOVL Research

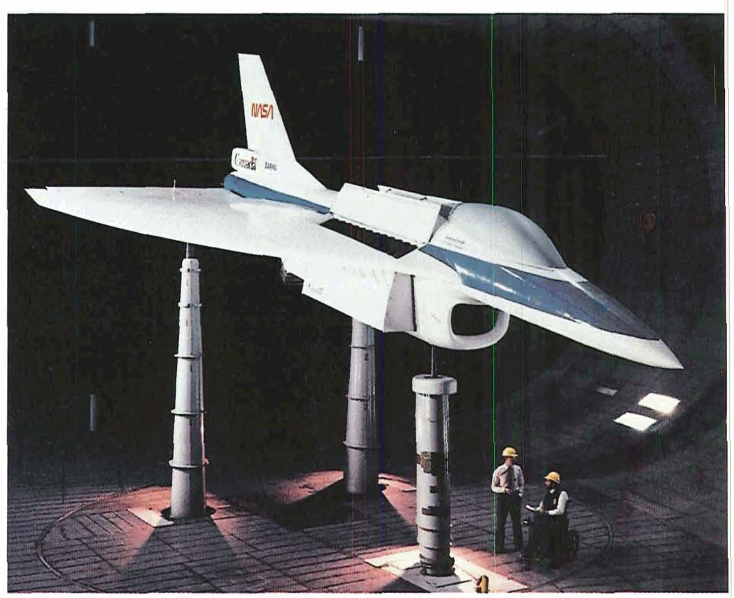
A STOVL is a Short TakeOff and Vertical Landing aircraft, typically a military tactical aircraft employing deflected engine exhaust for propulsive lift, exemplified by the U.S. Navy/Marine Corps AV-8B Harrier, the British Royal Navy Sea Harrier and the Soviet YAK-38 Forger. Operational STOVLs thus far have been subsonic designs, but there is interest in the United States and the United Kingdom in an Advanced STOVL (ASTOVL) capable of supersonic speed. NASA is cooperating on ASTOVL research with the U.S. Defense Advanced Research Projects Agency (DARPA) and investigators in the United Kingdom and Canada.

NASA is conducting wind tunnel, computational simulation and flight tests, the latter with a modified Marine Corps YAV-8B Harrier (top left) operated by Ames Research Center as the NASA VSRA (Vertical/Short TakeOff and Landing Research Aircraft). Flight tests are aimed primarily at developing criteria for integrated flight/propulsion control and cockpit display.

Ames is also conducting wind tunnel tests of a full-scale model of General Dynamics Corporation's E-7A supersonic fighter design (bottom right) that employs an ejector system for augmented vertical lift. In this design, engine air is routed to four different exhaust nozzles: a conventional tail nozzle whose thrust is exhausted rearward for forward flight, a swiveling ventral nozzle whose thrust line can be changed through four positions from vertical to near-horizontal, and two downward-directed ejector nozzles at the wing root that provide vertical lift. The E-7A test program is being conducted cooperatively by NASA, DARPA and the Canadian Department of Industry, Science and Technology.

Other NASA work involves wind tunnel investigations of various STOVL propulsion systems and components by Lewis Research Center, and outdoor tests at Ames of propulsion rigs.





High Performance Aircraft

Shown below is the NASA F-16XL research aircraft undergoing test at Ames-Dryden Flight Facility in a program to evaluate concepts for improving the airflow over highly sweptback wings in supersonic flight.

The F-16XL's initial assignment involves study of the boundary layer transition. The boundary layer is the layer of air immediately adjacent to the aircraft's skin; the transition is the point at which the airflow over the wing becomes turbulent as speed increases. Friction between the turbulent air and the aircraft skin causes aerodynamic drag that reduces aircraft fuel efficiency.

NASA has employed wind tunnel model testing and computational analysis to learn more about the mechanisms involved in the transition-to-turbulence process and to develop a capability for predicting the occurrence of transition. F-16XL flight tests are intended to amplify the wind tunnel/computational results and to provide a technology base for development of drag reduction techniques applicable to high performance military aircraft and future high speed civil transports.

Over a long period, NASA has investigated a number of ways of keeping the airflow "laminar" (smooth or non-turbulent) throughout a flight, in order to realize exceptional gains in fuel efficiency. One promising approach to laminar flow control is the suction mode, wherein an air pump draws boundary air into the wing through millions of tiny, laser-cut holes, thereby smoothing the turbulent air. This approach has been flight tested, but only at subsonic speeds. In a second phase of the F-16XL program, beginning in 1991, the suction mode will be investigated at speeds up to Mach 2.

At near right is NASA's F-18 HARV (High Alpha Research Vehicle). High Alpha refers to high angle of attack, the angle between an airplane's wing and the air through which it is moving. At high angles of attack, the airflow becomes extremely complex and aircraft designers need much more information about such airflows.

The aim of NASA's High Alpha research is to develop a design capability that will enable high performance aircraft to achieve "supermaneuverability" and maintain stability and controlla-

bility at extreme angles of attack. The F-18 HARV, which has been flying at Ames-Dryden since 1987, is supplying flight test data. Phase I testing, in which the research craft was flown at angles of attack up to 50 degrees, has been completed and the results have been correlated with computational analyses and ground test data acquired by Ames, Langley and Lewis Research Centers.

The next step is to explore maneuverability of the F-18 HARV at angles of attack up to 70 degrees and beyond. To allow controllability at such high angles, the research craft will employ a thrust vectoring system in which the aircraft is controlled by deflecting engine exhaust. McDonnell Douglas Corporation, original builder of the F-18, has developed a thrust vectoring system for installation in the HARV.

At right above is a modified F-15 military fighter being used as a NASA research craft in a cooperative program known a HIDEC (for Highly Integrated Digital Electronic Controls), whose aim is to advance technology for integration of airframe and propulsion control systems in high performance aircraft. Participants in the program include NASA, the Air Force, F-15 builder McDonnell Douglas Corporation, and engine builder Pratt & Whitney division of United Technologies.

In the HIDEC program, NASA has demonstrated that it is possible to realize significant gains in engine thrust and fuel efficiency through employment of an advanced engine control system together with engine/flight control integration technology. This technology could make it possible to extend the service life of existing military aircraft and engines and defer costly development of new types.

A major milestone of the program was a 1990 series of successful tests of a computerized flight control system that detects in-flight failures and automatically reconfigures an aircraft's control surfaces to compensate for the failure. On the first demonstration flight of the self-repairing system, NASA research pilot James Smolka purposely locked the F-15's right horizontal stabilator to simulate a failure of hydraulic or electronic equipment. The self-repairing system instantly selected the best pre-computed solution from its memory bank and reconfigured the remaining stabilator, ailerons and rudder to establish pitch and roll control—although the right stabilator remained in "failed" condition. The self-repairing flight control program was a U.S. Air Force program that evolved from earlier NASA/Langley Research Center research on restructable controls for civil transport aircraft. NASA officials termed the self-repairing system—developed by McDonnell Douglas and General Electric Company's Aircraft Control Division—a "far reaching development" that can greatly increase the combat survivability and peacetime safety of tactical aircraft. It also has potential for safety enhancement in civil aircraft.

Space Operations: To the Moon and Mars

"We stand at the halfway point in our exploration of the immediate solar system—the planet Earth, its Moon, and the terrestrial neighborhood. Thirty years ago, NASA was founded and the space race began. And 30 years from now, I believe that man will stand on another planet. So I am pleased . . . to announce a new Age of Exploration with not only a goal but a timetable: I believe that before Apollo celebrates the 50th anniversary of its landing on the Moon, the American flag should be planted on Mars."

President George Bush
May 11, 1990
Texas A&I University

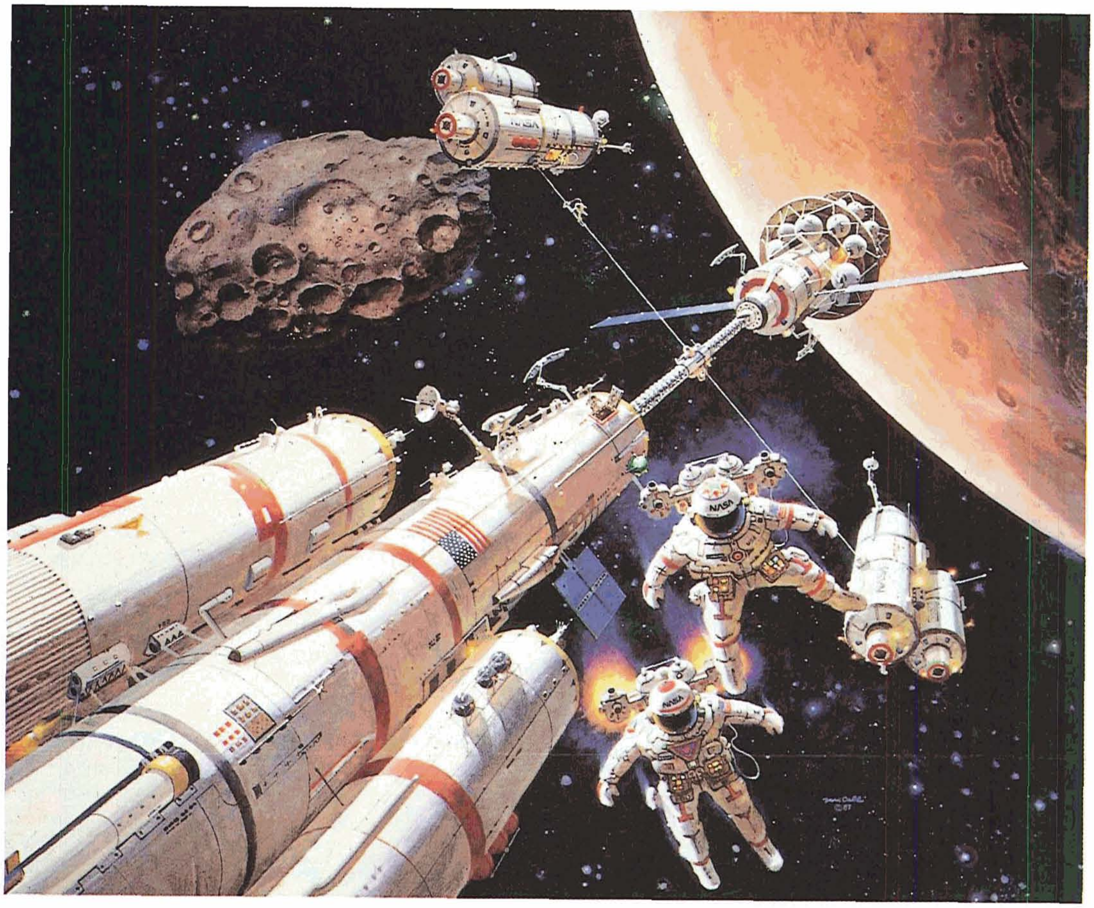
One of the goals stated in the National Space Policy is "to expand human presence and activity beyond Earth orbit into the solar system." On July 20, 1989, President Bush proposed the Space Exploration Initiative (SEI), a long-term, continuing commitment to fulfill this goal: Space Station Freedom in the 1990s, followed by a return to the Moon to establish a permanent outpost, and, later, a manned mission to Mars. In his speech at Texas A&I University, the President provided a target date for this last goal: humans on Mars no later than July 20, 2019.

Why should the United States undertake this bold endeavor? The reasons are as varied as the people of this nation. At a very basic level, SEI responds to a fundamental human need to explore. From Columbus' discovery of America to the trek of Lewis and Clark to the first astronauts on the Moon, America has been a nation of explorers. SEI provides the opportunity to renew our pioneering spirit. Another reason we undertake SEI is to expand our storehouse of knowledge about the universe, our solar system, our own Earth, and the nature of life. SEI gives us the chance to answer one of the most profound questions humans have considered: whether life ever existed on Mars.

Exploration typically brings many more benefits than first anticipated. Based on our past experiences in space, we can predict a number of tangible and intangible benefits for the U.S. and the world from SEI, and we can anticipate that there will also be many unpredicted benefits. The report to the National Space Council by the Aerospace Industries Association SEI Task Force said "SEI can be the springboard that reinstates the United States as acknowledged world leader in science and technology. The initiative offers enormous return on the investment in technology development: improvements in industrial productivity and competitiveness, education, and national/international economics."

The economic benefits of SEI will begin flowing long before men and women step foot on Mars, for that step will be the fruit of a lot of hard work on Earth. Establishing a permanent outpost on the Moon and safely sending humans to explore Mars are challenges that will stimulate the development of a broad range of new tech-

The Space Exploration Initiative and Space Station Freedom highlight NASA's thrust toward expanding human activities in space



At left, astronauts break ground for a uniquely advantageous astronomical observatory on the far side of the Moon, one of many scenarios being studied in the Space Exploration Initiative. Another scenario, illustrated above, envisions a transportation depot in Mars orbit.

nologies, improving American competitiveness in the high-tech global marketplace.

Likewise, SEI will have an early impact on education. What better incentive for children to study math and science than the thought that they could be the ones to fulfill the President's goal—landing on Mars within 30 years? Teachers, parents and other adults will also benefit from SEI, learning more about the contributions made by science and technology to the quality of life and becoming better role models for children.

As the Apollo program and other space programs have enhanced the quality of life on Earth, so too will the Space Exploration Initiative. New technologies developed to sustain permanent human presence on another planetary body will undoubtedly have terrestrial applications which will help man preserve his planet, such as waste recycling systems, advanced life support, clean energy production, advanced public transportation systems, and pollution reduction systems. In the longer run, it may be possible to develop new, efficient and non-polluting power sources that can meet needs on Earth. There are also likely to be a wide variety of medical/health benefits from SEI, such as nutritional advancements, advanced medical technologies and procedures, and advancements in psychological care.

(Continued)

Space Operations: To the Moon and Mars

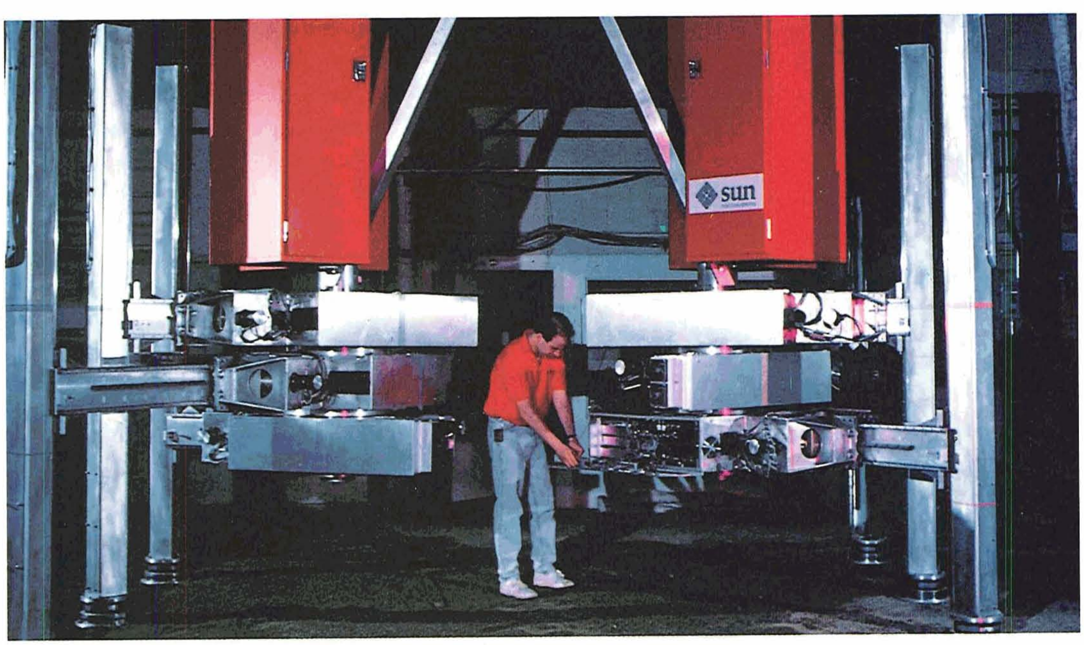
(Continued)

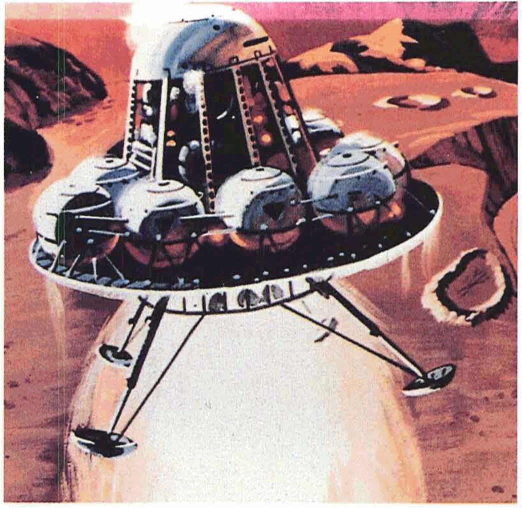
There are a variety of opportunities for international cooperation on SEI which could have significant foreign policy benefits. On March 30, 1990, President Bush announced that the U.S. will seek an exploratory dialogue on SEI with Europe, Canada, Japan, the U.S.S.R., and other nations as appropriate. The dialogue will focus solely on conceptual possibilities for cooperation. Guidelines for conducting the exploratory dialogue have been developed by the National Space Council with interagency participation, taking account of U.S. national security, foreign policy, scientific and economic interests.

Beyond the goals and general timetable established by President Bush, no specific plan for accomplishing SEI has been set. There is much work to do before it can be determined how best to fulfill this vision for America's future in space. On February 21, 1990, President Bush approved a policy that provides some basic guidelines for proceeding with SEI. The Initiative will include both lunar and Mars elements, and both human and robotic missions. Initially, the program will focus on technology development, including a search for new and innovative approaches and technologies and investment in high-leverage technologies that offer major benefits in terms of cost, schedule and/or performance. A specific program architecture will be selected after several years of study. NASA will be the principal implementing agency for SEI, and the Departments of Defense and Energy will play major roles in technology development and concept definition. The National Space Council will coordinate the development of an implementation strategy by the three agencies.

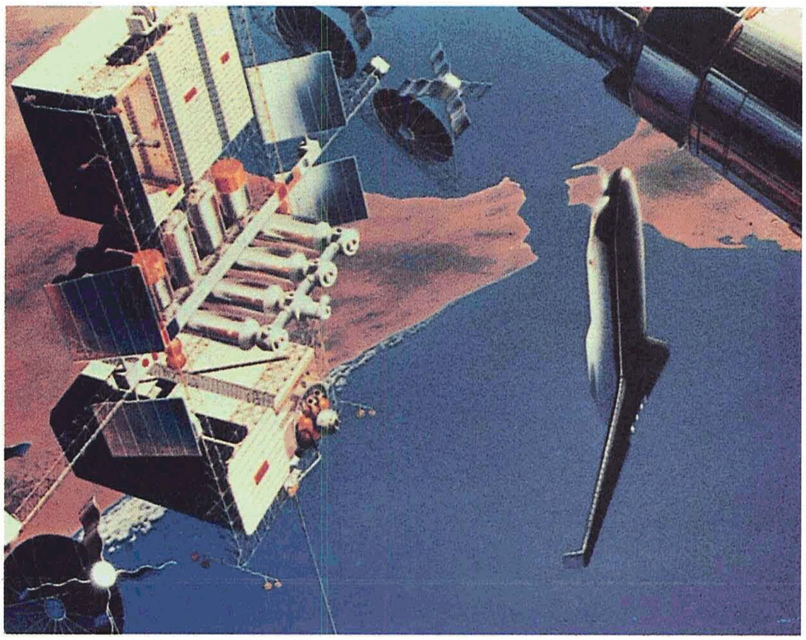
Before selecting a specific strategy for implementing SEI, it is important to ensure that all reasonable alternatives have been evaluated. In December 1989 Vice President Quayle requested that NASA take the lead in seeking new and innovative concepts and technologies for SEI from across the nation. In cooperation with the National Space Council, NASA developed and started an outreach and synthesis process toward that end. Outreach includes three basic elements: a direct nationwide solicitation from

Under development at Carnegie Mellon University is the "Ambler," a six-legged, 12-feet-tall prototype mobile robot that can step over crevices and large boulders, reaching Moon/Mars areas inaccessible to wheeled vehicles or too dangerous for human exploration.





An artist's concept of an autonomous Mars lander, meaning one capable of avoiding surface hazards and landing at a precise spot without the help of Earth-based control or advisories.



One area of exploration technology under study is in-space assembly and construction, exemplified by this concept of an orbiting transportation depot for Moon/ Mars vehicles.

the NASA Administrator, results of which will be evaluated by the RAND Corporation; a review of federally-sponsored research; and a study by the American Institute of Aeronautics and Astronautics. A Synthesis Group, chaired by Lieutenant General Thomas P. Stafford, USAF (Retired), will synthesize inputs from the three sources into several significantly different architectures, identify promising technologies to be pursued, and identify near-term milestones. The group includes individuals from NASA, other government agencies, industry and academia. The Synthesis Group is expected to present its final report to the NASA Administrator early in 1991.

Because of the enormous challenges presented by SEI, accomplishment of the goals requires a broader science and technology base than currently exists. NASA is building that base in a number of ways: through the ongoing Research and Technology Base program, which addresses generic, fundamental research; through the Civil Space Technology Initiative, which focuses on near-term transportation, technologies to support science investigations, and technologies to enhance operations in Earth orbit; and through a new Exploration Technology Program (ETP), which is devoted to development of critical capabilities that will make possible a wide range of manned and robotic missions beyond Earth orbit.

The broad ETP effort embraces these subdivisions:

- *Space Transportation:* development of technologies for transfer vehicles, space-based engines, autonomous vehicles and aerobraking, a technique that utilizes planetary atmospheres to decelerate a spacecraft.
- *Surface Operations:* planetary roving vehicles, construction of habitats and other surface structures, utilization of extraterrestrial resources, solar power and space nuclear power systems.
- *Human Support:* regenerative life support systems (wherein water, air and other resources are reused); protection from radiation, extravehicular activity systems, and exploration human factors (understanding of human performance and behavior in long duration space missions).
- *Lunar and Mars Science:* planetary probes and penetrators, systems for acquiring, analyzing and preserving Moon/Mars samples.
- *Information Systems and Automation:* high-rate communications, planetary photonics (optical rather than electronic processing systems), exploration automation and robotics.
- *Nuclear Propulsion:* nuclear thermal and nuclear electric systems.
- *Innovative Technologies and Systems Analysis:* continuing pursuit of new approaches to SEI challenges and integrated analyses of technology readiness and plans.

Long Duration Exposure Facility

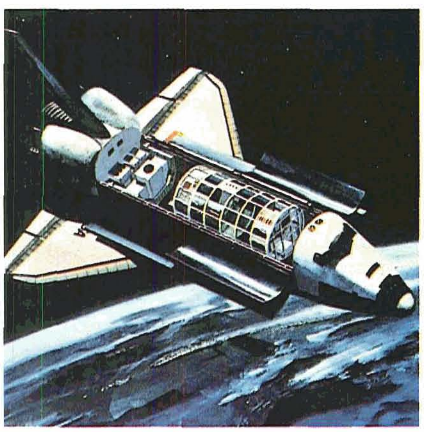
On April 7, 1984, the Space Shuttle *Challenger* delivered to orbit the Long Duration Space Facility (LDEF), a school bus-size spacecraft containing 57 science and technology experiments covering a broad spectrum of investigations (below left). LDEF's general assignment was to measure the effects of atomic oxygen, radiation, micrometeoroids, man-made debris and other space phenomena on more than 10,000 specimens—materials, coatings, solar cells, electronic parts and living organisms.

The intent was to leave LDEF in orbit for 10 months and then retrieve it by Shuttle Orbiter and return it to Earth for examination. Scientists wanted to find out what happens to such samples over a long period of space exposure, information important to design of future spacecraft and on-board equipment.

Subsequent changes in the Space Shuttle schedule moved the retrieval mission back a year and a half, then it was further delayed by the 1986-88 Shuttle flight suspension in the wake of the *Challenger* accident. On January 12, 1990, the crew of the Shuttle Orbiter *Columbia* retrieved LDEF and returned it to Kennedy Space Center (KSC) after more than 68 months in space (at right below, the Shuttle Orbiter's remote manipulator system prepares to grasp LDEF). The duration extension is regarded as a bonus; scientists expect more and better science and technology data due to an orbital duration almost seven times that originally planned.

In February 1990, NASA officials and LDEF principal scientific investigators made their first post retrieval inspection of the spacecraft at KSC. LDEF's exterior showed obvious effects of long term bombardment by micrometeoroids and orbital debris, atomic oxygen impingement and solar ultraviolet radiation. Later, NASA removed the experiment trays for return to the principal investigators and extensive analysis.

The analyses are expected to provide unprecedented data on the changes caused by environmental phenomena of low Earth Orbit. Accurate simulations of the complex space environment and reproduction of synergistic effects are difficult to perform on Earth. LDEF experiments involve more than 200 investigators, 33 private companies, 21 universities, seven NASA centers, nine Department of Defense laboratories and organizations in eight foreign countries.



Advanced Launch Vehicles

"A flexible, robust, reliable and responsive launch system capable of significantly lower costs of getting payloads to space." Those are the goals for the Advanced Launch System (ALS), a joint development effort of NASA and the Department of Defense for a next-generation family of heavy lift boosters intended for service before 2000.

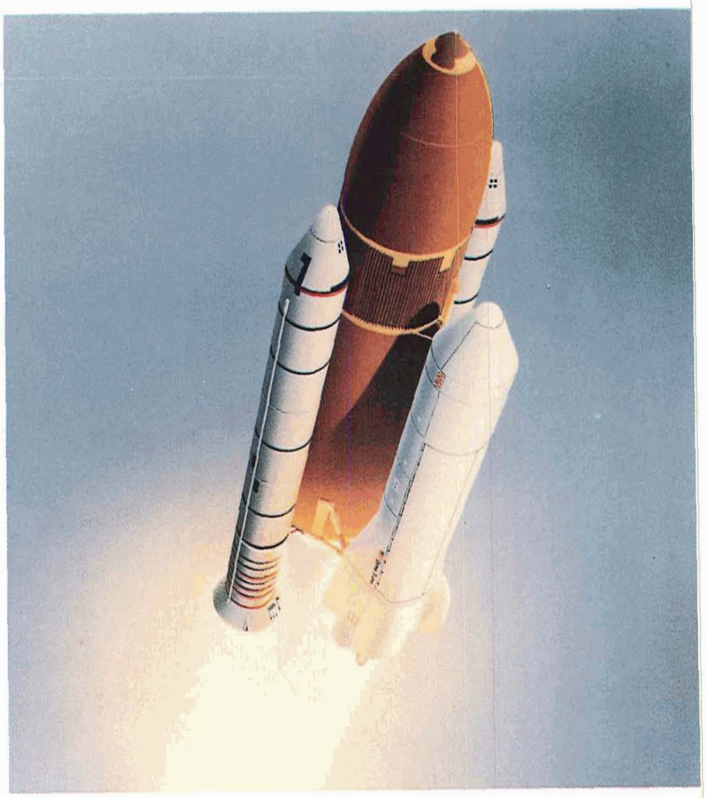
Significantly lower costs mean about one-tenth the current cost of delivering a pound of payload to low Earth Orbit; the target is $300 a pound. Other ALS objectives include the ability to deliver effectively a wide range of payloads up to more than 100 tons (compared with the Space Shuttle capability of 20 tons), streamlined operations procedures for reduced time between flights, high reliability and reduced system complexity.

The Department of Defense is managing systems engineering and integration, the basic vehicle, the payload module and logistics. Contractors for defining vehicle designs and technology demonstrations are Martin Marietta Corporation and McDonnell Douglas Corporation, working as a team, and Boeing Aerospace and General Dynamics Corporation, each working independently.

NASA is responsible for developing advanced liquid engine technologies and vehicle technologies in the agency's areas of expertise: aerodynamics, materials, structures and operations. Marshall Space Flight Center is the lead center for NASA's ALS activities. NASA's contractors for propulsion technology are Aerojet Corporation, Pratt & Whitney Division of United Technologies, and Rocketdyne division of Rockwell International. In May, the three contractors signed an agreement—at NASA's request—to work as a single team in the interests of improved cost effectiveness and more efficient technology development through technology sharing.

As currently envisioned, the ALS would consist of a core stage powered by liquid hydrogen/liquid oxygen fueled engines, with either a solid or liquid-fueled rocket booster stage, plus a payload canister. Both core and booster may be expendable or partially recoverable; another option is a fully reusable glideback/flyback booster.

NASA is also studying an expendable cargo delivery evolution of the Space Shuttle, a Shuttle–C system (below) capable of lifting 50 to 75 tons to low Earth orbit. Shuttle-C could be developed economically and in a relatively short time (four years) because its design takes advantage of existing components and facilities. The vehicle employs without change the Space Shuttle's two solid rocket boosters and the External Tank, and it would use the same ground facilities as the Space Shuttle. The winged Orbiter, not required because the system is unmanned and does not return to Earth, is replaced by an 82-foot-long Shuttle-C Cargo Element and an aft fuselage housing two or three Space Shuttle main engines, depending on payload requirements. Study contractors are Martin Marietta Aerospace, Rockwell International and United Technologies Space Systems Division.



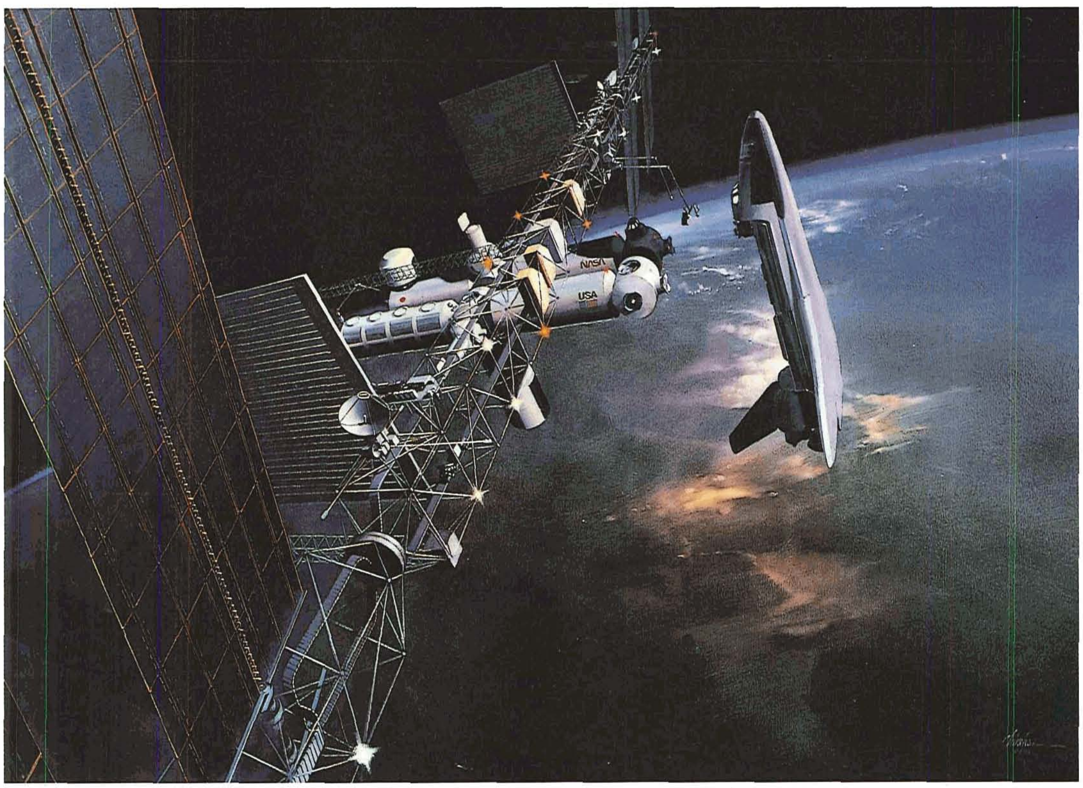
Space Station Freedom

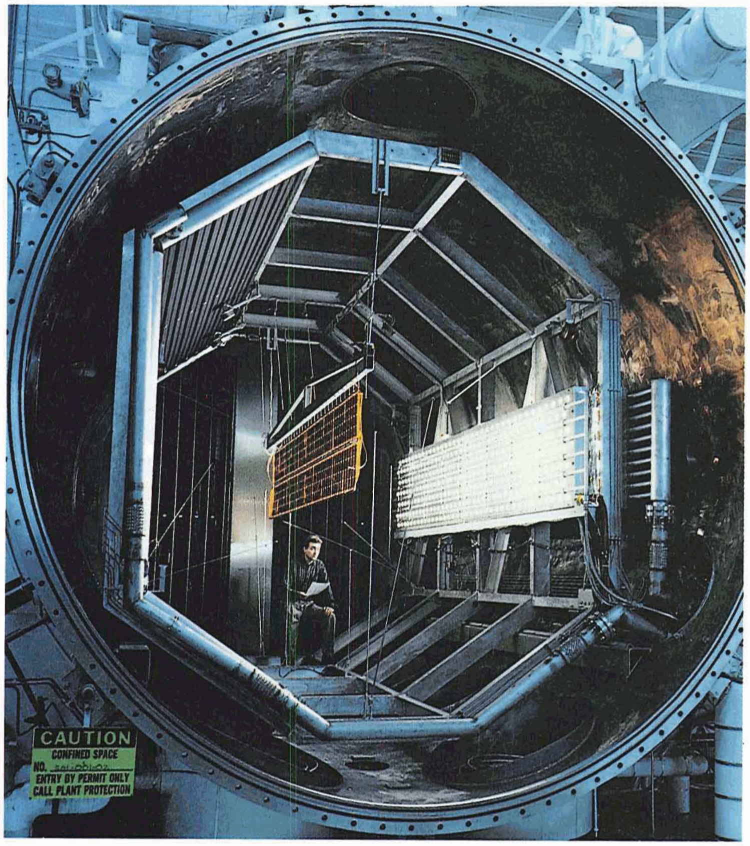
Shown below is an artist's concept of the baseline configuration of Space Station *Freedom*, being developed by NASA in partnership with the European Space Agency (ESA), Canada and Japan.

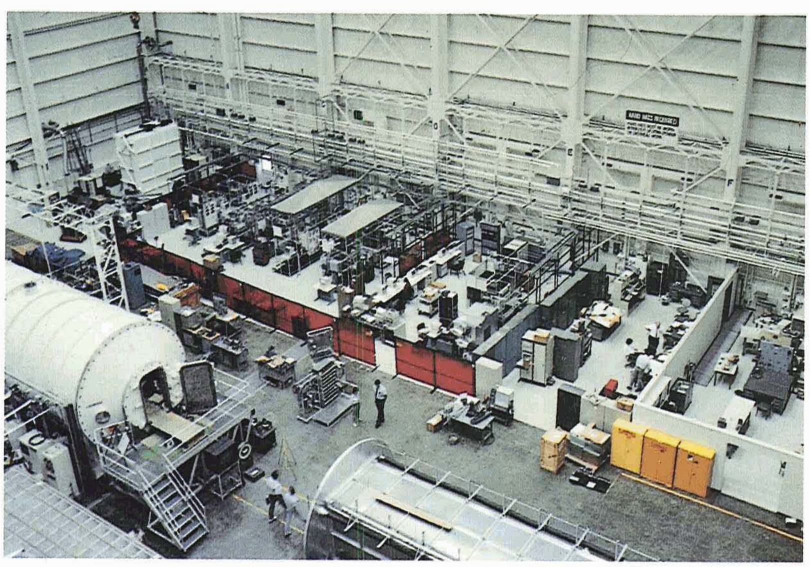
The space station will be a permanently manned outpost in low Earth orbit. In its initial configuration, it will provide a laboratory for research in many scientific disciplines and a platform for observing instruments that "look out" at the universe and "look back" toward Earth. Additionally, it will be a unique facility for development of technologies applicable to future space systems, and for materials processing research in the microgravity environment. Later, it can serve as an assembly and staging base for the advanced missions contemplated for the 21st century.

Space Station *Freedom* is built around an integrated truss assembly that provides the structure for four pressurized modules and supporting element and systems. The main transverse boom, more than 500 feet long, suspends eight solar array panels that supply power to the station. The photo at right shows a 1990 vacuum chamber test of one of the panels, one of a series of tests in which Lewis Research Center evaluated panel performance under conditions that simulate the plasma environment of low Earth orbit; research has shown that there can be electrical interactions between the space plasma and a solar cell power source that can cause short-circuiting and arcing problems. In the lower right photo is a new facility at Marshall Space Flight Center for another type of testing getting under way, comprehensive evaluation of the space station's Environmental Control and Life Support System.

In 1989/90, there was considerable progress as the *Freedom* program moved into the hardware development phase, including hundreds of "breadboard" systems, proof-of-concept devel-







opment items, test beds, test articles, mockups for human factors analyses and technology demonstration hardware.

NASA made a number of changes to the baseline configuration to reduce technical, schedule and cost risks, but maintained the basic design and the first quarter 1995 target for the initial milestone in the station assembly sequence: the First Element Launch, which involves Space Shuttle delivery to orbit of a "cornerstone" set of components for the manned base, including a power module, communications equipment, a mobile transporter, an assembly work platform and parts of the truss.

Reduced funding and other considerations forced changes in the schedule for "outyear" assembly milestones and the addition of planned capabilities. The second major milestone—the achievement of man-tended capability—will now occur on the seventh Shuttle flight in the second quarter of 1996. Targeted for the third quarter of 1997 is the third major milestone, permanent manned capability. The final milestone—assembly completed, with all modules and components in place and an eight person crew on board—is planned for the third quarter of 1999. The complete assembly, including logistics missions, will require 28 Space Shuttle delivery flights.

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Space Station Freedom

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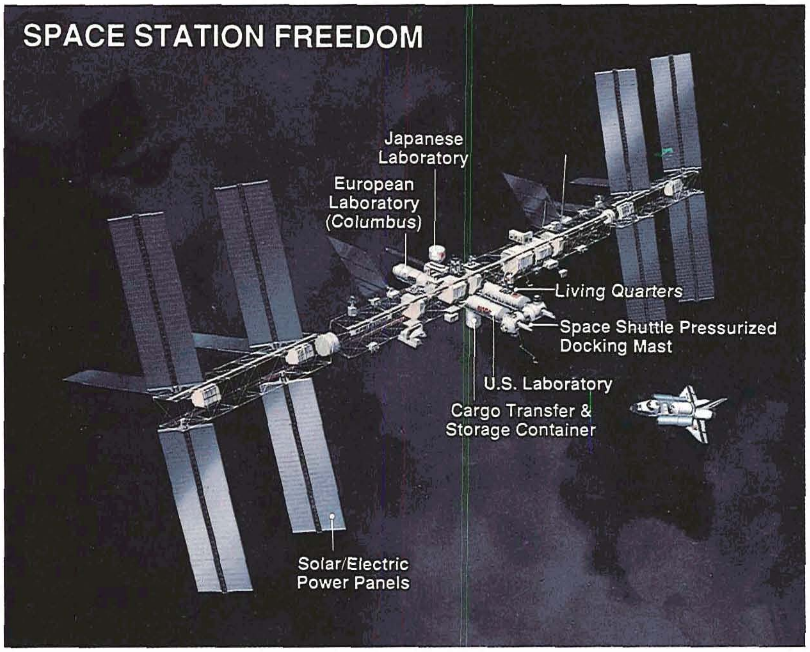
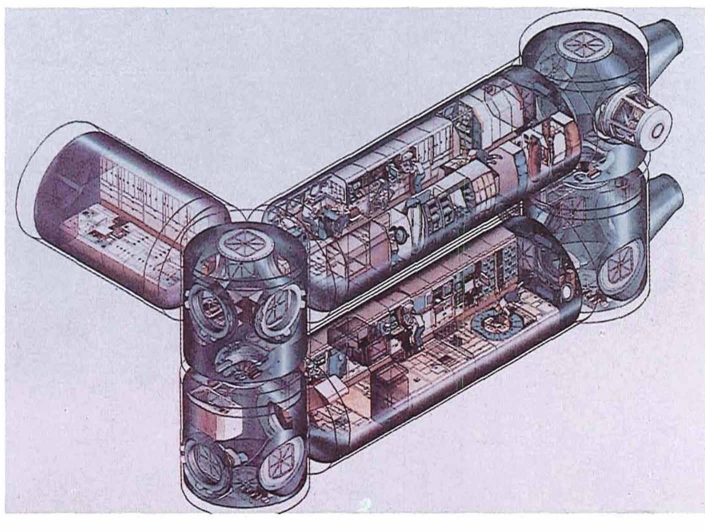




Space Station *Freedom's* pressurized living and working areas, located in the center of the transverse boom, are labeled at right. They include a U.S.-built habitation module ("living quarters" in the illustration), a docking facility for the Space Shuttle Orbiter, and three laboratories, one each to be provided by the U.S., ESA and Japan. Linking the modules are four pressurized "resource nodes" that serve as command and control centers and as passageways to and from the various modules.

Below is a concept of the two U.S. pressurized modules, the habitat module on top, the laboratory module below it, and resource nodes at either end. The cylinder at left photo is a logistics module for transport and storage of supplies and experiments. Two of the resource nodes have "cupolas," one an Earth-viewing observation port, the other facing outward to space.

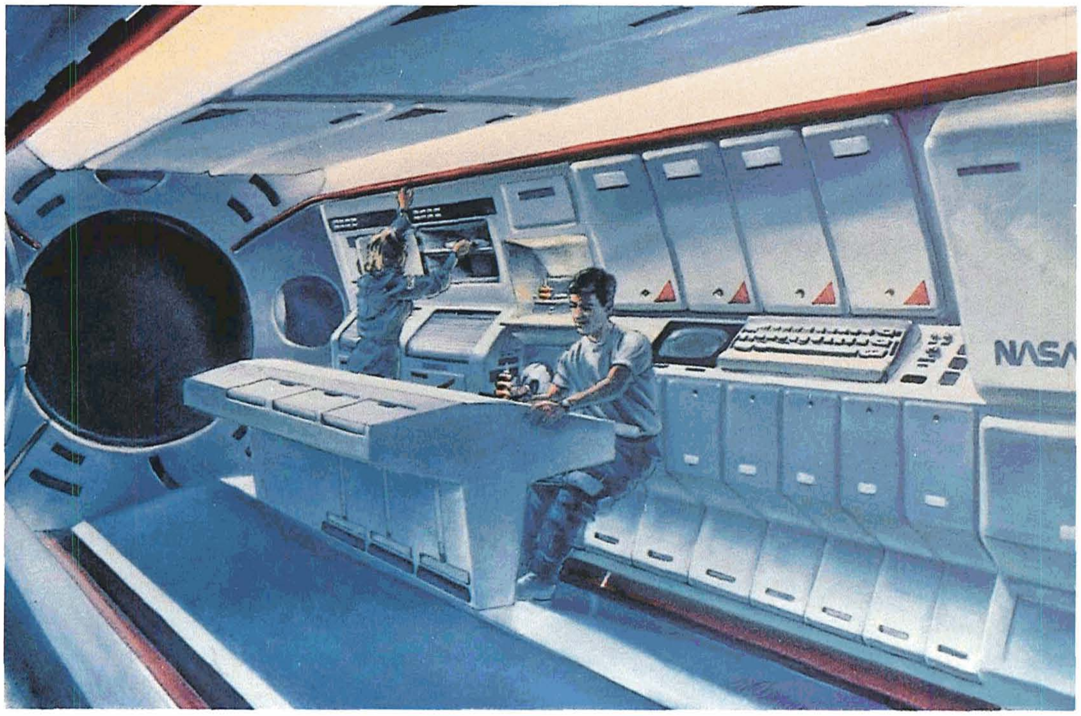
One concept of the habitation module's interior is shown in on the opposite page, top. The crew member in center photo sits at a workstation while another, in the background, prepares a meal at the module's galley; not visible is a wardroom opposite the galley for dining, conferences and audio/video entertainment.

Responsibility for developing the space station is divided among NASA centers, their contractors and the international partners:

Work Package One, managed by Marshall Space Flight Center with Boeing Aerospace Company as prime contractor: the U.S. laboratory and habitation modules, associated systems, logistics elements and payload operations.

Work Package Two, Johnson Space Center with McDonnell Douglas Astronautics Company as prime contractor: central truss structure, resource node outfitting, various flight systems, crew training and flight operations.

Work Package Three, Goddard Space Flight Center with General Electric Astro Space as prime contractor: accommodations for attached payloads. This work package also includes the U.S. unmanned polar orbiting platform, once a part of the space station complex but since transferred to NASA's Earth Observing System (EOS) program.

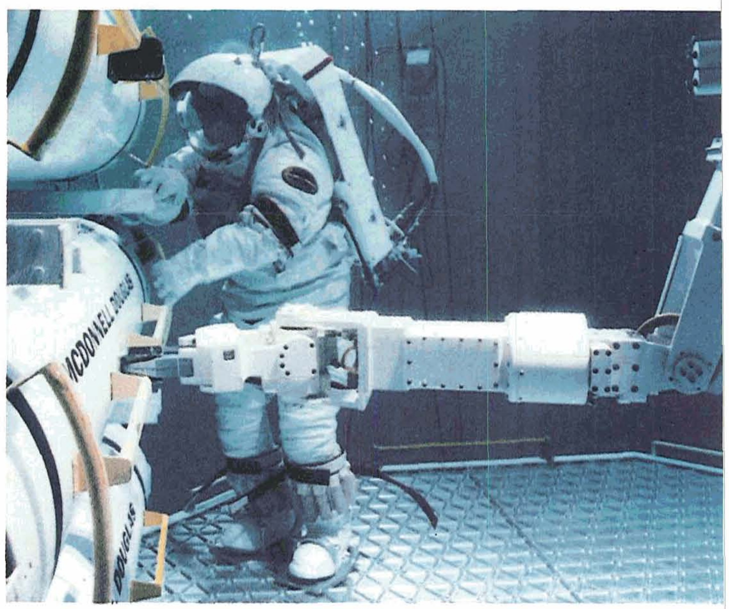


The Flight Telerobotic Servicer, (FTS), Goddard Space Flight Center with Martin Marietta Space Systems as prime contractor. The FTS is a robot that can operate autonomously or under human remote control; equipped with two highly dextrous arms, it will play a role in the assembly of Space Station *Freedom* and later will become a station adjunct handling servicing and repair tasks. At lower right, an astronaut in a neutral buoyancy tank is conducting a simulated berthing of a propellant tank with the help of an FTS robotic arm. First development test flight of the FTS is scheduled for 1991.

Work Package Four, Lewis Research Center with Rocketdyne Division of Rockwell International: the station's complete power system with associated software.

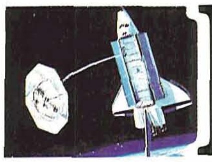
The ESA is providing the *Columbus* pressurized laboratory, a Man-tended Free Flyer and the European Polar Platform, with which ESA will conduct Earth environmental observations in concert with NASA's EOS systems.

Japan is providing the third laboratory, known as the Japanese Experiment Module, which includes a pressurized segment to which a dome-shaped experiment logistics module can be attached, plus an "outdoors" facility for experiments wherein unpressurized space conditions are preferred or essential.



Canada's contribution is the Mobile Servicing System (MSS), including a Mobile Servicing Center and a powerful manipulator arm. The MSS will play the main role in assembling *Freedom*, moving equipment and supplies around the station, servicing attached payloads, supporting astronaut extravehicular activity, and loading/unloading materials from docked Shuttle Orbiters.

Commercial Use of Space



In 1984, recognizing the broad economic potential of commercial space activities, the Congress amended the National Aeronautics and Space Act to direct that NASA "seek and encourage to the maximum extent the commercial use of space."

Despite a 30-month standdown of the Space Shuttle that severely limited U.S. access to orbit, hence dulled industry interest in commercial space for lack of flight opportunitites, NASA has achieved remarkable progress in responding to the Congressional mandate. The agency has set up a comprehensive program to foster the creation of new space-related products and services that will generate new markets and spawn new businesses—and that, in turn, will support the growth of other commercial space industries, such as transportation and infrastructure, meaning the provision of vehicles, facilities and equipment for conducting in-flight or Earth-based investigation and development.

Since the resumption of Shuttle flights in late 1988, private sector interest has rebounded. The number of private firms participating in the NASA program has increased sharply, as has the number of payload flight tests planned.

The two principal elements of the NASA program are the Centers for the Commercial Development of Space (CCDS) and partnerships with industry through cooperative agreements.

The CCDS are competitively selected consortia of industrial firms, universities and government organizations, established to expedite development of a technology base on which to build new commercial space industries and to help move emerging technologies from the laboratory to the marketplace with speed and efficiency.

There are 16 CCDS, each working in a particular field of space endeavor: five are specializing in materials processing, two in remote sensing, two in space power, three in biotechnology, two in robotics, and one each in space propulsion and materials for space structures.

The CCDS involve the active participation of 58 universities and 175 industrial firms. Industry has demonstrated its strong commitment by investing substantial sums. For example, the average ratio of industry funds to government funds is 2.2 to one for all 16 CCDS. For the five older centers, the original group established in 1985, the ratio is even higher: 3.4 to one.

The centers collectively have identified 61 technologies of sufficient promise to warrant flight testing in the space environment. Each technology will require a number of flights to mature it to the point where a decision can be made as to the practicability of commercial application.

Given adequate flight opportunities, the technologies are expected to reach maturity by 1995, most of them in the 1993-95 time frame. As of midyear 1990, the number of payload flight tests necessary to mature the technologies was 277 through 1995; most will be flown on the Space Shuttle, some on suborbital sounding rockets and some aboard expendable launch vehicles.

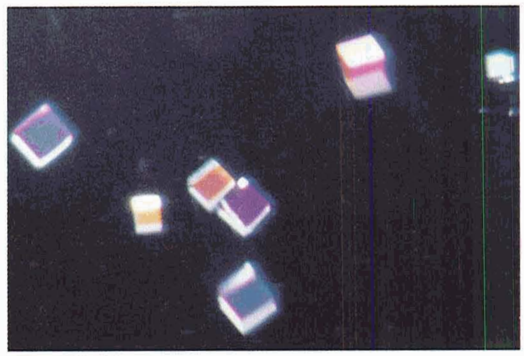
The other major element of the commercial development of space program involves research partnerships with industry through cooperative agreements. NASA employs innovative working arrangements to attract industry participation by reducing the technical and financial risks associated with space projects. The principal type of arrangement is the Joint Endeavor Agreement, wherein U.S. companies provide private funding to build and conduct space experiments and NASA provides space transportation, access to government facilities, equipment and supporting services. There are several other types of agreements, each tailored to the varying requirements of different space commercial ventures.

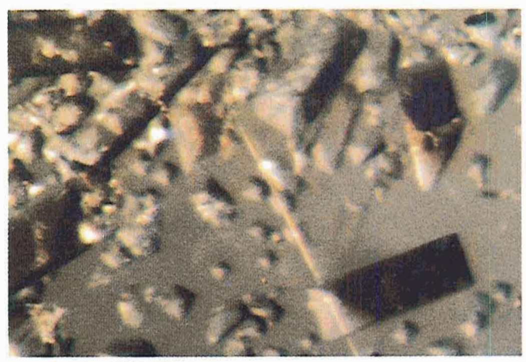
Another aspect of NASA's work involves fostering industry involvement, advice and support in developing programs, since commercial development of space will ultimately be accomplished by the private sector. In 1988, the Commercial Programs Advisory Committee (CPAC), composed of top level industry executives and university presidents, was established as a standing committee of the NASA Advisory Council to provide NASA with continuing advice on

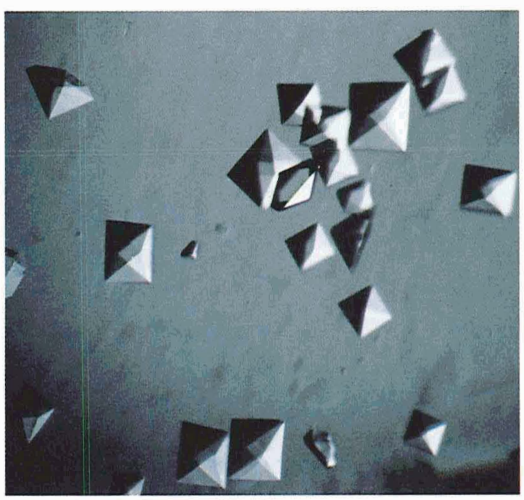
NASA seeks to stimulate private sector interest and investment in space ventures to assure U.S. competitiveness in commercial space activity

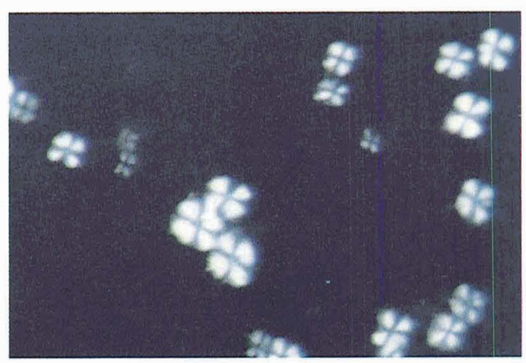
the proper roles of government and industry in the commercial development of space. In 1989, CPAC published a report summarizing its first year of effort and advancing key recommendations that the Administration and the Congress can implement to advance U.S. space enterprise and space industrial development. NASA is reviewing the recommendations.

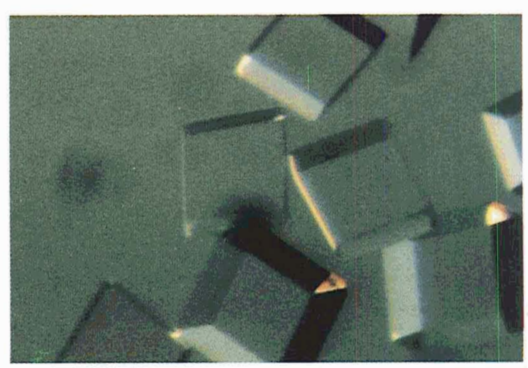
Additionally, NASA contracted with the American Institute of Aeronautics and Astronautics for study of issues and potential objectives associated with commercial development of space. The resulting study report, representing inputs from more than 90 space-experienced industry experts, is being used by NASA to support its development of a strategic plan.











Several of NASA's Centers for the Commercial Development of Space are engaged in orbital protein crystal growth experiments toward development of powerful new drugs for combating disease. Here are five different types of protein crystals grown in Space Shuttle experiments conducted by the Center for Macromolecular Crystallography at the University of Alabama–Birmingham.

Shuttleborne Research

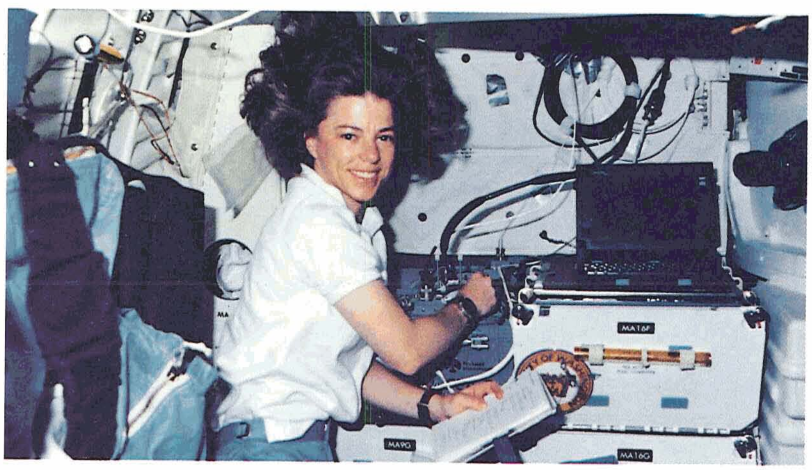
Commercial space flight research in the microgravity environment is conducted largely aboard the Space Shuttle, although NASA has initiated suborbital flights with sounding rockets (see page 48) and plans to fly some payloads on expendable launch vehicles. The experimental payloads are developed for the most part by NASA's 16 Centers for the Commercial Development of Space (CCDS); others are generated by industrial firms or teams operating under cooperative agreements with NASA. In 1990, flight research included investigations in protein crystal growth, polymer membranes, float zone processes and biomedicine.

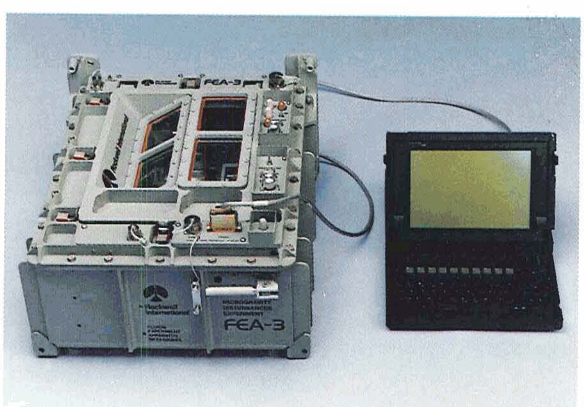
In crystallography, the science that deals with the form, structure and properties of crystals, investigators can determine the three dimensional molecular structure of a protein by bombarding a protein crystal with x-rays, then computer-analyzing the resulting diffraction patterns. Knowledge of the three-dimensional structure enables a more systematic approach to learning how protein molecules function and how they can be altered to create new compounds that have broad potential in agricultural and medical research. In the latter area, space grown proteins may become vitally important research tools for scientists working to develop powerful new drugs for combating cancer, high blood pressure, organ transplant rejection, rheumatoid arthritis and many other disorders.

The key is growing large, high quality crystals to obtain high resolution x-ray diffraction data. Crystals grown in Earth's gravity are often small and flawed, but early research indicates that crystals grown under microgravity conditions are far superior and offer a much improved capability for determining a protein's molecular structure. Seeking confirmation, the Center for Macromolecular Crystallography (CMC) at the University of Alabama-Birmingham, one of NASA's 16 CCDS, is conducting extensive research in protein crystal growth.

Through mid-1990, CMC and its industrial affiliates had put four experimental payloads into orbit aboard Shuttle flights. On all flights high quality crystals were obtained, some of exceptional size and quality. The fourth CMC experiment, carried on the April 1990 STS-31 flight that delivered the Hubble Space Telescope to orbit, produced some of the highest quality crystals ever grown (below, astronauts Bruce McCandless and Kathryn Sullivan conduct a protein growth experiment on the Orbiter *Discovery*'s middeck). Although more confirming data is needed, available information suggests that in-space production of tiny protein crystals could become one of the first commercial applications of orbital materials processing research.

Also aboard STS-31 was another CCDS payload, this one sponsored by the Advanced Materials Center (AMC) at Battelle Columbus (Ohio) Laboratories. Being flown for the first time, the payload was called IPMP, for Investigations into Polymer Membrane Processing (shown undergoing preflight checkout at top right).





Polymer membranes have long been used in separating materials for such applications as filtration, atmospheric purification, electrolysis and dialysis. Polymer membranes are prepared by forming a thin layer from a mixed solution of polymer and solvent. The solution is then evaporated, leaving a dry porous membrane.

In the IPMP experiment, a flash evaporation technique is employed to study the importance of the evaporation step in the formation of thin film membranes. AMC and an industrial affiliate, Amoco Chemical Company, are using the microgravity environment to study convection-free polymer membrane casting, with the aim of gaining knowledge that will permit improvement of Earth-based thin film membrane processing techniques and optimize membrane properties.

On Shuttle mission STS-32, January 9-19, 1990, Orbiter *Columbia* carried—along with a protein crystal growth experiment—the Rockwell International Fluids Experiment Apparatus (FEA), a small microgravity laboratory about the size of a 19-inch TV. Being flown for the second time under a NASA/Rockwell Joint Endeavor Agreement, the FEA supported an investigation known as the Microgravity Disturbances Experiment (MDE). This investigation was prompted by concerns that disturbances induced by spacecraft or crew actions—for example, astronaut treadmill exercising on Space Station *Freedom*—might have adverse effect on certain sensitive orbital processing applications. The MDE was conducted by mission specialist Dr. Bonnie Dunbar, shown working with the FEA at left above; the FEA is pictured in the bottom photo.

The FEA carried eight samples of the metal indium, which were processed by a "float zone" technique. The MDE experiment was designed to quantify how Orbiter and crew activities affect the stability of molten zones used in float zone crystal growth. MDE results were being analyzed at publication time.

Sounding Rocket Research

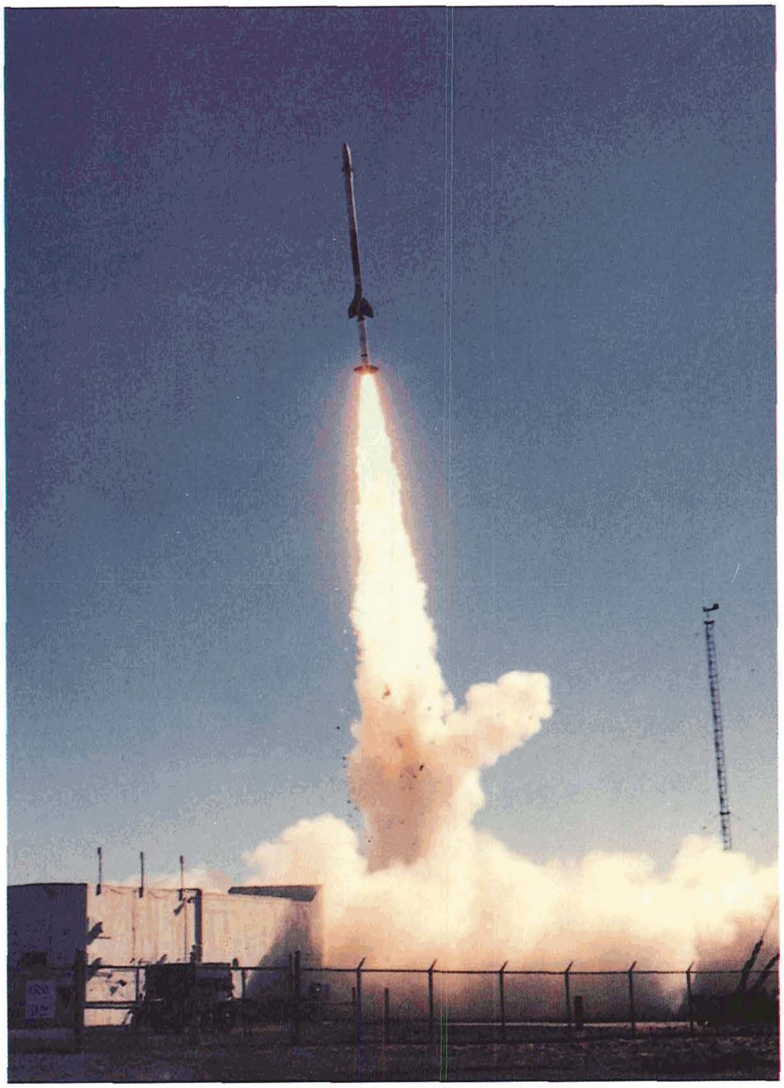
In addition to making available orbital research facilities aboard the Space Shuttle, NASA provides opportunities for commercial space investigators to fly experiment packages at relatively low cost on sounding rockets. Such vehicles do not go into orbit but fly suborbital parabolic flight paths that expose experiments to microgravity conditions for periods in the range of five to fifteen minutes.

On May 16, 1990, a commercial launch services provider—Space Services, Inc., Houston, Texas—launched its Starfire rocket (right) from the White Sands (New Mexico) Missile Range on a mission designated Consort 3 by its sponsor, the Consortium for Materials Development in Space (CMDS) at the University of Alabama-Huntsville. Launch services and payload recovery were funded by a NASA grant; commercial participants provided most of the funding for the payload.

In addition to CMDS, participants included three other NASA Centers for the Commercial Development of Space. CMDS and the Center for Advanced Materials, Battelle Columbus Laboratories, conducted materials science research. The Center for Cell Research/Penn State University and the Center for Bioserve Space Technologies/University of Colorado-Boulder, conducted biotechnology experiments. Consort 3 carried 12 experiments that were exposed to microgravity for eight minutes.

Consort 3 was the second successful sounding rocket flight under NASA's Centers for the Commercial Development of Space program. Consort 1—which marked the first flight of a U.S.-licensed commercial sounding rocket—was launched by a Starfire vehicle on March 29, 1989. Consort 2, launched November 16, 1989, experienced a second stage guidance failure seconds after liftoff and the vehicle was destroyed, but the payload was parachuted to safety. Essentially the same payload package was used on Consort 3.

A new series of suborbital flights will commence late in 1990 with the first flight of a Joust-1 vehicle, whose configuration differs from that of the Starfire rocket and will provide 12-16 minutes of microgravity, depending on payload mass.



Launch Services

On July 25, 1990, A General Dynamics Atlas/Centaur launch vehicle sent the NASA/Department of Defense Combined Release and Radiation Effects Satellite into orbit, marking the third major U.S. launch vehicle type to enter commercial service. General Dynamics Corporation is building an initial group of 18 commercial launch vehicles, a mix of 12 Atlas Is and six of the improved performance Atlas IIs, both using Centaur upper stages.

McDonnell Douglas Corporation's Delta vehicle (near right below) inaugurated U.S. commercial launch service on August 27, 1989 with the delivery to orbit of a British communications satellite. McDonnell Douglas launched three additional commercial Deltas in 1990. The fourth launch, a June delivery of the government of India's Insat D multipurpose satellite, was the last of the Delta I series. The company's schedule called for three more commercial launches in 1990 with the improved Delta II.

On December 31, 1989, Martin Marietta Commercial Titan, Inc. became the second commercial launch service operator to deliver a satellite to orbit when the company's Commercial Titan (far right) successfully orbited two communications satellites, one Japanese and one British. On June 23, Martin Marietta scored a second success with launch of an Intelsat VI communications satellite. In between, on the second Commercial Titan launch, March 14, 1990, a second stage malfunction left the Intersat VI payload in low Earth orbit instead of its intended geostationary orbit. At publication time, NASA and the international Intelsat communications consortium were negotiating an agreement whereby NASA would retrieve the satellite on a Space Shuttle mission and boost it to its proper altitude.

NASA has agreements with these three principal producers of commercial launch vehicles whereby the companies are granted access to NASA-managed facilities at Kennedy Space Center and are provided technical assistance in support of commercial launches.

NASA has another agreement with LTV Missiles and Electronics Group granting the company exclusive rights to produce and launch the NASA-developed Scout vehicle on a commercial basis. The agreement gives LTV use of NASA-controlled production tooling and special test equipment for Scout manufacture; additionally, it allows use of Scout launch support facilities at NASA Wallops Flight Facility.

In addition to these agreements for commercial satellite launch vehicles, NASA is supporting commercial suborbital research as part of its Centers for the Commercial Development of Space program. NASA has an agreement with Space Services, Inc. (see opposite page) under which the agency finances the purchase of launch services and payload integration for sounding rocket flights that provide opportunities for investigation of commercial industrial space applications.

Commercial Space Developments

Studies by NASA, Penn State University and other investigators in the U.S. and abroad have found that microgravity accelerates reductions in bone calcium, body mass and immune cell function. Space and medical researchers want to expand those findings.

Toward that end, Ames Research Center, Penn State's Center for Cell Research (CCR) and Genentech, Inc., a biotechnology firm located in South San Francisco, California, have concluded an agreement for long term collaboration on a major commercial space research project in life sciences. The objective is to expand existing knowledge, define the fundamental mechanisms of mammal cell function on Earth and in space, and commercialize the knowledge. Researchers feel that a successful program could lead to new capabilities for treating human bone disease, organ regeneration and transplantation, and immune and skeletal muscle cell deficiency. The program is also expected to provide more specific information on space flight's effect on the human body. For Genentech and other private firms, early identification of medically important compounds could provide a competitive advantage in the international marketplace.

The project involves a series of ground-based and Space Shuttle experiments beginning in 1990. The program is coordinated by Penn State's CCR, one of NASA's 16 Centers for the Commercial Development of Space (CCDS).

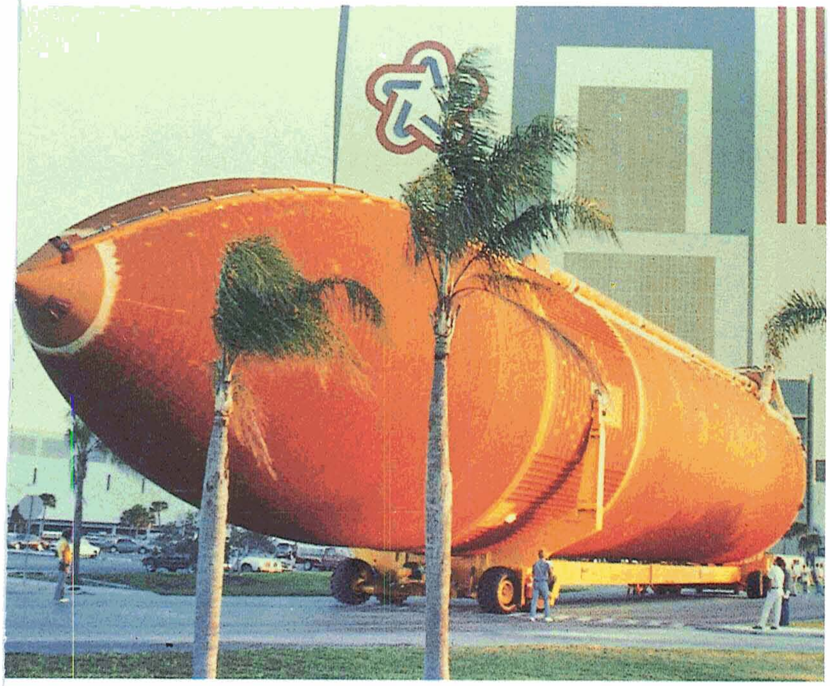
In another commercial space development, NASA signed an agreement in January 1990 with Global Outpost, Inc., Alexandria, Virginia, for orbital use of expended Space Shuttle External Tanks (top right). This followed an earlier—1989—agreement with the University Corporation for Atmospheric Research (UCAR), a consortium of 58 universities headquartered in Boulder, Colorado. External Tanks Corporation (ETCO), also located in Boulder, is UCAR's program manager. ETCO will provide private financing for the development, marketing and operation of the tanks.

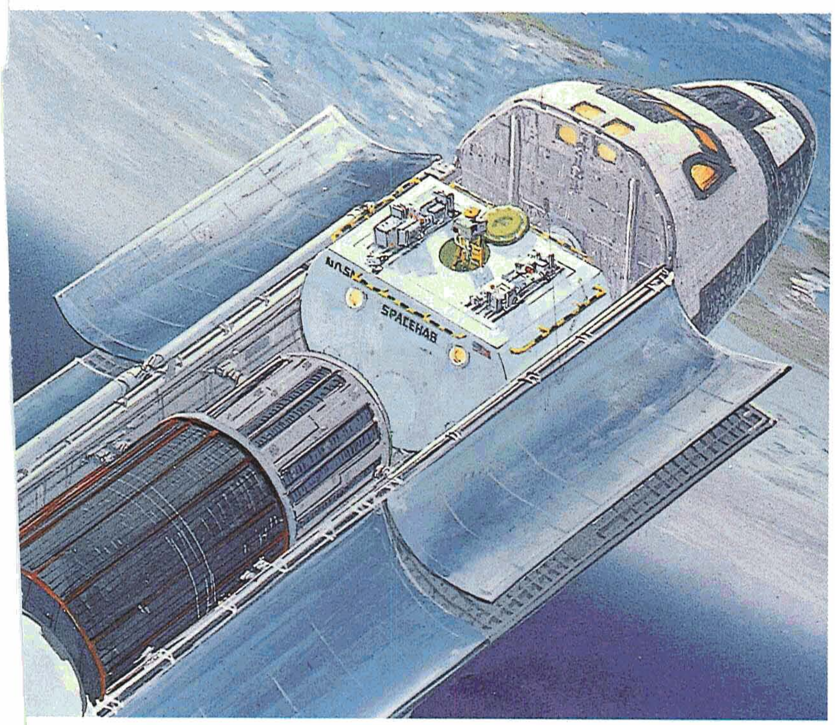
The tanks, normally discarded after use on a Shuttle launch, have 72,000 cubic feet of volume. On a Shuttle flight, they reach 99 percent of orbital velocity so they can be sent into orbit with a small additional expenditure of energy. Under the agreements, Global Outpost and UCAR will each be provided five tanks after they complete studies and engineering designs and meet other conditions of the agreement. NASA will support their efforts on a direct cost reimbursable basis.

Global Outpost plans to use the tanks to create commercial microgravity platforms. UCAR intends to employ them as unpressurized platforms for tethering, as elements of large space structures, and as recycling stations for discarded waste. Later, UCAR may develop advanced versions to be used as pressurized facilities.

In March 1990, NASA called for proposals from industry for provision of a pressurized manned module to expand the Space Shuttle Orbiter's middeck locker experiment facilities, because NASA's CCDS program is generating requirements for experiment space far in excess of the accommodations available in the Orbiter middeck, particularly in the period 1992-95. Spacehab, Inc. submitted the only proposal and at publication time NASA was negotiating a contract with the company. Spacehab (far right) is a commercially developed and company owned facility that will ride in the Orbiter's payload bay when it is carried on Shuttle missions; it will be accessible through the airlock and it will add the volume equivalent of about 50 middeck lockers. In addition to leasing accommodations to NASA, Spacehab, Inc. will lease locker space and experiment-related services to other research organizations on a commercial basis.

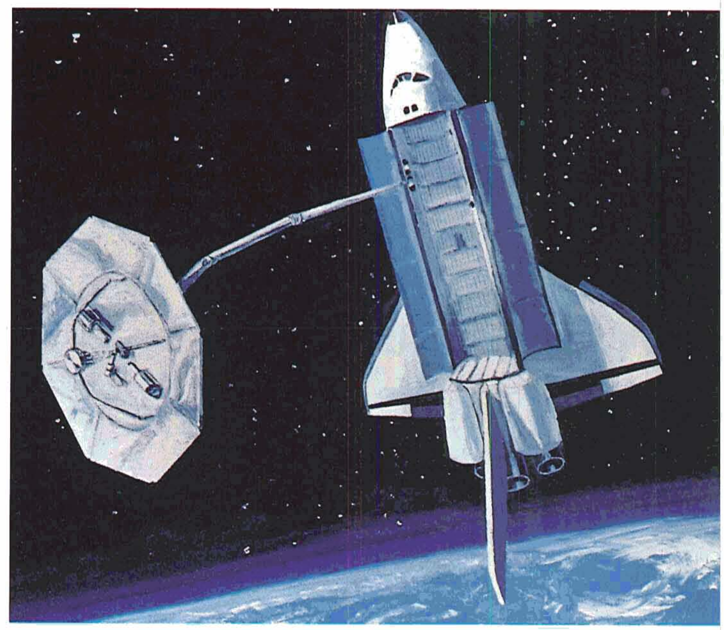
Under another commercial space agreement, Space Services, Inc., Houston, Texas is developing a Wake Shield Facility (WSF) for the Space Vacuum Epitaxy Center at the University of Houston, another of NASA's CCDS. Epitaxy is a term for the growth of crystals in a special atom by atom, layer by layer manner to produce varying crystalline structures. Epitaxial growth under high vacuum conditions can produce crystalline thin films of higher quality and purity

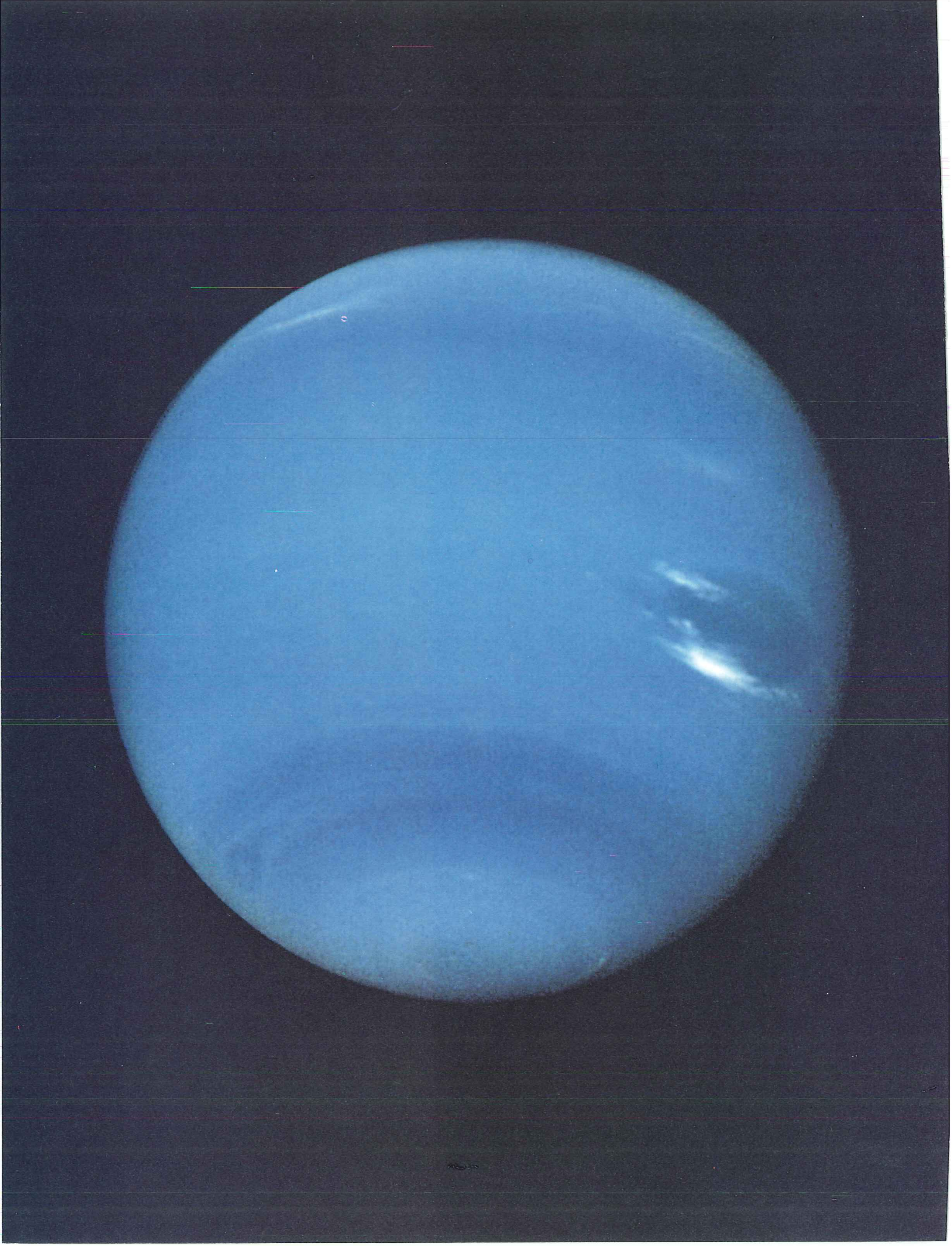




than can be grown on Earth. Such films offer promise of important technological advances in superspeed computers, lasers, communications and infrared devices, and many other high technology microelectronic applications.

The WSF will make possible orbital epitaxial research. A 10-foot-diameter disc to be carried in the Shuttle Orbiter's payload bay, the WSF will be extracted by the Shuttle's remote manipulator arm and held aloft (at left below) to sweep an orbital "wake," creating an ultravacuum region behind the disc for growth of epitaxial thin films. Four WSF flights are planned, beginning in 1990.





Technology Twice Used

A representative selection of new products and processes adapted from technology originally developed for NASA mainline programs, underlining the broad diversity of spinoff applications and the social/economic benefits they provide

Spinoff developments highlighted in this section are based on information provided by secondary users of aerospace technology, individuals and manufacturers who acknowledge that aerospace technology contributed wholly or in part to development of the product or process described. Publication herein does not constitute NASA endorsement of the product or process, nor confirmation of manufacturers' performance claims related to the particular spinoff development.

A remarkable view of great interest to scientists is this Voyager 2 image of Neptune, taken on August 14, 1989 when the planet was 9.2 million miles distant. Bright, wispy cirrus type clouds are seen overlying the mysterious Great Dark Spot and global bands frame the south polar region.

PROLOGUE

NASA and Education

In February 1990, President Bush met with the governors of the 50 states to address one of the nation's most urgent problems: the quality of education in the United States, particularly technical education. The President endorsed a package of six goals developed by the governors, among them making the United States first in the world in mathematics and science achievement.

> *Today, our focus on education in NASA is very broad and it's growing. We have 162 programs starting with the elementary and secondary schools through the university levels. Our outreach to minorities is assisting employment throughout the country, and it's lifting up the general public awareness in science, the environment and technology across America today. We directly touch over six million students and educators. Last year we visited over 2,000 schools, 3,000 classrooms, sponsored 250 science fairs, and assisted 27,000 teachers in school workshops focusing both on math and science.*
>
> James R. Thompson
> Deputy Administrator, NASA

That's a big order. Recent comparisons of science students in industrialized nations show the U.S. at or near the bottom of the list.

The problem facing the nation is succinctly summed in a study conducted by the Aerospace Education Foundation:

"The crux of the technical manpower problem is that too few people in the workforce today have the skills required to function in a technologically advanced society...In the end, this gap, or deficit, dulls the nation's competitive edge. In the long run, if the technical manpower gap widens and the adverse trends persist, our very economic survival is in jeopardy."

The problem is twofold. First, there already exists a shortage in numbers and it is getting worse; the National Science Foundation estimates that, at current graduation rates, the U.S. will be short more than 700,000 scientists and engineers by 2010. Second, there is a "skill gap" along with the numbers gap; many of the people emerging from the education pipeline are not sufficiently qualified to meet the demands of the high technology workplace today or tomorrow.

All over the U.S., government, industry and academic organizations, individually and in concert, at the national, state and local levels, are accelerating efforts to find remedies for the educational and training maladies that threaten America's scientific and technological future.

NASA is among the leading education promoting organizations and the agency is expanding its effort. In May 1990, NASA and the Department of Energy concluded an agreement for a cooperative program directed at encouraging more U.S. students to pursue careers in science, engineering and mathematics, and at improving the instructional process in those areas at the precollege and university levels.

NASA's Educational Affairs Division, long engaged in a general program of aerospace education, is broadening its effort. The agency's Technology Utilization Division, which operates a nationwide network of technology transfer facilities, is employing those facilities to foster public awareness of the economic benefits of technology development, to help teachers improve their skills, and to stimulate interest in science careers among America's youth.

With the cooperation of NASA's nine field centers and 10 Industrial Applications Centers, these units conduct a wide array of educational activities, among them "open house" presentations for students, sponsorship of State Educators Conferences and support of state departments of education, developing fixed and traveling science/technology exhibits, sponsoring student internships, developing science curricula for schools, providing direct support for graduate research, providing educational resources to teachers, and participating in a broad range of seminars, workshops and special presentations. The following pages highlight a sampling of NASA educational activities.

Satellite Videoconferences

By means of live, educational satellite videoconferences, NASA is helping thousands of teachers to learn more about aerospace matters, improve their classroom skills, and expand significantly the content of their aerospace education curricula.

The $1^1/_2$ hour "Update for Teachers" programs originate at Oklahoma State University (OSU) Telecommunications Center. The television signals are transmitted to the WESTAR IV geostationary communications satellite, which retransmits them to hundreds of schools across the U.S. and in parts of Mexico and Canada. Participating schools are equipped with small, home-style satellite reception dishes.

Relatively inexpensive satellite reception dishes, like this one at a Stillwater (Oklahoma) elementary school, allow videoconference participation by hundreds of schools in the U.S., Canada and Mexico.

Education Satellite Videoconference programs are conducted four times yearly. Examples of subject matter include astronauts describing training activities, engineers and systems planners demonstrating spacesuits and space foods, tours of the Space Station *Freedom* mockup, the various processing steps required to prepare the Space Shuttle for launch, aerodynamic design computation by supercomputer, and educational technology aids. The first program of 1990 was devoted to a tomato seed growth in space project; the second highlighted advances in space robotics and the planned use of robots to do jobs that are impractical, too dangerous or too difficult for humans.

NASA's Education Satellite Videoconference series updates thousands of teachers on NASA activities and broadens the content of the nation's aerospace education programs. In photo, series host Bill Nixon of the NASA Educational Affairs Division interviews education specialist Norman Poff.

After the speakers' presentations, teachers are invited to telephone toll-free and ask questions. Participants are told about available NASA educational resources and how to obtain them, then aerospace education specialists conclude the conferences with practical, hands-on sessions that illustrate methods for teaching aerospace concepts in the classroom. The combination of live presentations and interactive telephone participation make the videoconferences useful and dynamic tools for the development of professional educators.

The series is produced for NASA's Educational Affairs Division by the NASA Educational Technology Branch and the Aerospace Education Services Project, OSU, with the assistance of the OSU Educational Television Service.

PROLOGUE

Project LASER

In March 1990, at a public ceremony in Washington, D.C., NASA formally launched Project LASER (Learning About Science, Engineering and Research), a program intended to help teachers improve science and mathematics education and to provide "hands-on" experiences designed to attract children to science and math studies.

The event featured the first LASER Mobile Teacher Resource Center (MTRC), a facility patterned after the highly successful Teacher Resource Rooms located at NASA field centers. The MTRC is designed to reach educators all over the nation, especially those who might be too distant from NASA centers. NASA hopes to operate several MTRCs, with funds provided by private industry.

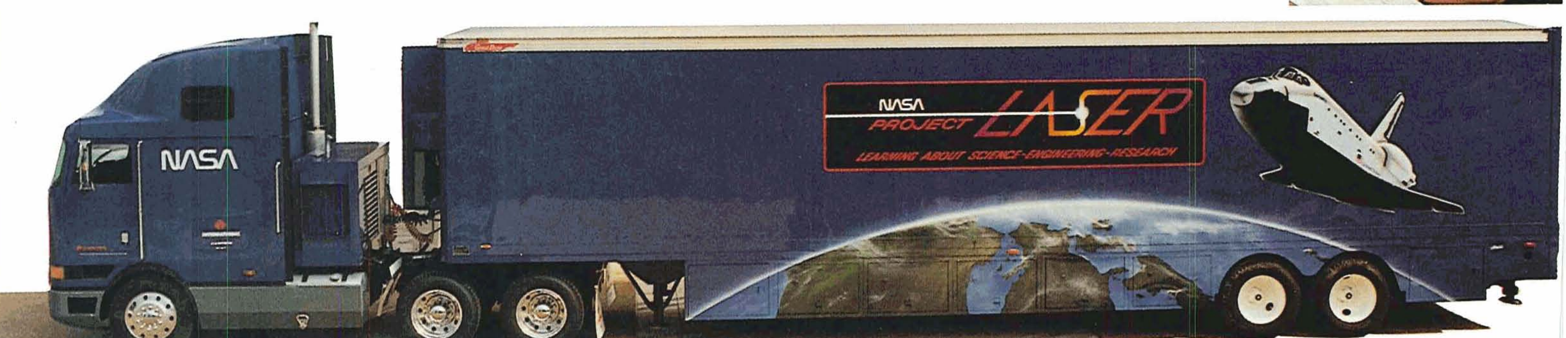
The mobile unit is a 22-ton tractor-trailer stocked with NASA educational publications and outfitted with six work stations, each capable of servicing two teachers. Each work station has a computer providing access to NASA Spacelink, an electronic database containing a wealth of educational information. Workstations also have video recorders, allowing teachers to copy from a large library of educational videotapes, and photocopy/photographic equipment that permits teachers to copy and take home for classroom use a broad selection of lesson plans, suggested activities and slides.

The MTRC is one of five major elements within Project LASER. The others are:

- A Space Technology Course, developed by a team of teachers and NASA scientists/engineers, to promote integration of space science studies with traditional courses.
- The Volunteer Databank, in which current and retired NASA employees are encouraged to volunteer as tutors, instructors, field trip guides, teacher consultants, science fair judges and other educational jobs.
- Mobile Discovery Laboratories that will carry simple laboratory equipment and computers to provide hands-on activities for students and demonstrations of classroom activities for teachers.
- The Public Library Science Program, which will present library-based science and math programs as an adjunct to classroom studies; the libraries may also host weekend, evening and summer programs with NASA-provided materials.

The prototype LASER program is being developed by Marshall Space Flight Center. The plan calls for "spinning off" the elements, as they mature, to other NASA centers, federal agencies, school systems, businesses or other sponsoring organizations. The Marshall-operated NASA Spacelink is sponsored by the NASA Educational Affairs Division; system software was developed and donated by Data General Corporation.

Below is NASA's Mobile Teacher Resource Center. The interior view at right shows a teacher accessing the NASA Spacelink databank, which offers a broad collection of aerospace information and educational materials.



IAC Activities

An important part of NASA's educational effort is the work of the agency's 10 Industrial Application Centers (IACs). In addition to their principal job of providing technical assistance to U.S. industry, the IACs are engaged in a variety of educational programs, such as sponsoring seminars, workshops, open houses and executive briefings, conducting tours of NASA facilities for school science classes, holding educator conferences, and providing courses in space technology for college undergraduate and graduate level students.

One of the IACs is the Southern Technology Applications Center (STAC), Alachua, Florida; one of STAC's six regional offices is located at the University of South Florida (USF). A couple of STAC sample activities offer examples of the type of contribution the IACs are making.

STAC sponsored a one-day seminar titled "Technology, NASA and You—Imagine the Possibilities," aimed at generating technology awareness among several levels of the community—educators, manufacturers, small business operators, students, etc. Former astronaut Lodewijk van den Berg talked on living and working in space. Leslie Neihouse, director of the U.S. Space Camp, Titusville, Florida, spoke on "Education, the Next High Tech Generation." Experts from NASA and the National Institute of Standards and Technology discussed technologies available for transfer and told businessmen how to take advantage of technology transfer opportunities.

The program also featured a demonstration of an artificial intelligence software shell, success stories about commercialization of NASA technology, a display of commercial spinoffs, and videos of Space Shuttle operations and the Factory of the Future.

A highlight of the day was an exercise taken from the Space Camp curriculum: students of two area schools, East Bay High and Eisenhower Junior High, accepted the challenge of designing and building a space station model in one hour.

Another STAC activity, conducted for the USF Center for Creativity, Innovation and Leadership, which coordinates the Florida Governor's Summer Program, was the "From Ideas to Dollars Workshop." This program sought to point up the economic benefits of aerospace technology transfer by challenging 10 groups of 12-14 year old students to develop a strategy for commercializing a new space-derived product—including applications, identification of target markets, cost/pricing analysis, selection of distribution channels, etc. The "Ideas to Dollars" challenge was subsequently repeated at the Lee Academy for Academically Gifted Students, Tampa, Florida.

STAC and other IACs continue to develop new mechanisms like these to stimulate general interest in aerospace technology transfer and student interest in science and mathematics.

At a Florida seminar, students use Ramegon materials to build a space station model of their own design.

Photo by Gordon Myrhe

Students of Florida's Lee Academy discuss a challenging assignment: develop a complete plan for commercializing a new NASA technology.

Space Science Curricula

The International Education Magnet Program is designed to help students get a global perspective, develop skills needed to function in the international marketplace, and learn to communicate with people of other cultures. The high school curricula generally include studies of international business (world trade, producers and consumers, the roles of governments, the problems and benefits of foreign investment) and social science (world food and health problems, world conflicts, cultures, religions, political systems). Additionally, language courses are offered in Japanese and Russian along with the traditional high school courses in French, German, Spanish and Latin.

Johnson High School, Huntsville, Alabama started an international magnet program in 1987. Among the courses in the curriculum was one in space science. But school principal Evalyn Humphrey and science teacher Jayne Russell couldn't find a suitable textbook, nor could they locate other classes in space science to provide a guideline. They appealed to Marshall Space Flight Center (MSFC), also located in Huntsville.

MSFC agreed to help and placed Johnson High under an official "Adopt-A-School" program. MSFC's chief scientist and others at the space center helped prepare a very comprehensive space science program that includes such subjects as problems of space travel, materials processing in space, technology utilization, zero gravity experimentation, aerospace dynamics, propulsion and rocket systems, weather prediction, astronaut selection and training, the solar system, lasers, optics, robotics, space colonization, aviation and space history and a study of major NASA projects, current and historical.

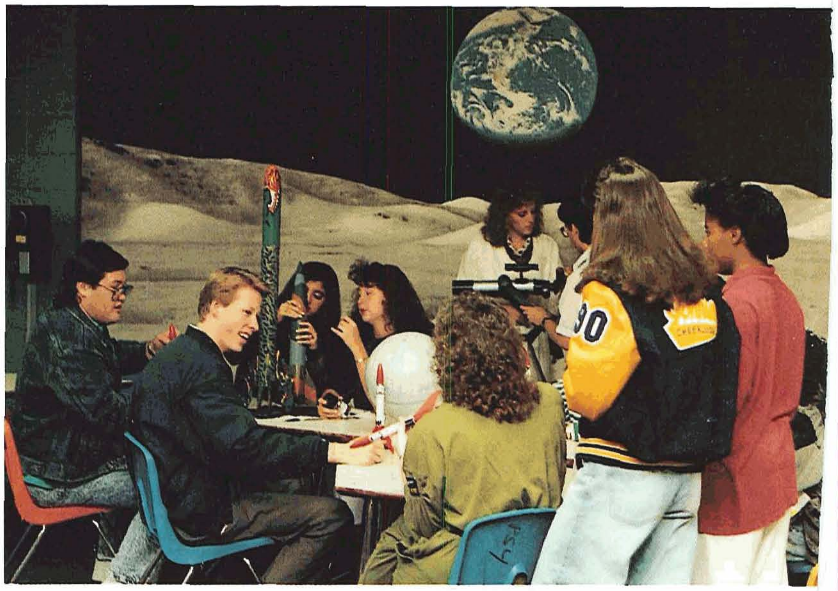
MSFC followed up by working with Johnson High to determine if the curriculum is generally usable and workable; if so, MSFC may make it available to other schools interested in starting space science courses.

MSFC's support of Johnson High School goes well beyond the classroom outline. Students are able to take annual field trips to see a Space Shuttle launch and they are also provided opportunities to witness Shuttle engine test firings at MSFC, visit laboratories and tour other MSFC facilities.

Under a Senior Work Study Program, senior astronomy students are able to experience the environment and day-to-day activities of a person involved in the space program by "shadowing" a Marshall scientist or engineer for periods up to three days.

In addition, MSFC employees volunteer their time and expertise to the space science classes. For example, they offer technological assistance to students in building sounding rocket experiments. They also serve as technology advisors and chaperones on field trips. Upper level students themselves become instructors under Project STAR (Student Training in Aeronautics and Rocketry); they go to elementary schools and help younger students build and launch rocket models.

Photo by Brian Triolo, Johnson High School



Against the backdrop of a Moon-view of Earth, a space science class at Johnson High School, Huntsville, Alabama prepares rockets for demonstration launches. In center background is space science teacher Jayne Russell. Marshall Space Flight Center developed the space science curriculum and supports the program by sponsoring hands-on activities and tours of space research facilities.

NASA/State Education Cooperation

NASA is cooperating with state departments of education in a number of special education programs. An example:

The Maryland State Department of Education sponsors the Maryland Summer Centers for Gifted and Talented Students, a program that offers intensive, advanced-level learning opportunities for students who have demonstrated outstanding academic or artistic abilities. Some 2,600 students participated in the 1990 program.

One of the 12 centers is the Center for Space Science and Technology at Goddard Space Flight Center, which provides instruction to students of the 9-12 grade level. This center is operated by a three organization partnership that includes the Maryland State Department of Education, the University of Maryland and Goddard Space Flight Center, which hosts the instructional program and provides volunteer scientists and engineers as instructors. A typical two-week space intern program includes panel discussions, lectures, tours, field trips and hands-on activity focusing on such space science topics as astronomy, geology, planetology, relativity and cosmology, and on such areas of technology as laser applications, robotics and structural design and analysis. In addition, senior high students benefit from a one-to-one mentor relationship with a volunteer scientist or engineer.

Another example of NASA/state department of education cooperation was the Paducah (Kentucky) NASA Community Involvement Project, a joint educational effort of Langley and Lewis Research Centers, Marshall Space Flight Center, the Kentucky Department of Education, the City of Paducah and Paducah Independent Schools. This was a 16-day exposition/symposium featuring seminars on space subjects, appearances by astronauts and other NASA personnel, and a wide range of exhibits. The event drew 107,000 people and NASA aerospace education specialists visited and interacted with students and teachers of 145 schools in 19 school districts.

NASA also provides assistance to the Kentucky Department of Education on 120 ongoing space education programs, helping teachers develop curricula and materials for space science courses.

A Goddard Space Flight Center engineer explains to a group of students how a computer conducts a structural analysis of a space component. The session was part of the Goddard-hosted Center for Space Science and Technology, a summer instructional course held in cooperation with the Maryland State Department of Education.

Shown above is the grand opening of NASA's space exhibit, part of the Paducah (Kentucky) NASA Community Involvement Project that included participation of students from 145 schools.

PROLOGUE

Intelligent Tutor

In addition to the wide ranging exhibit and instructional activities of its field centers, NASA seeks to advance American education in another way: by employing the technology utilization process to develop a computerized, artificial intelligence-based Intelligent Tutoring System (ITS) to help high school and college physics students improve their problem-solving skills and overcome the anxieties of learning a difficult subject.

The tutoring system is designed for use with the lecture and laboratory portions of a typical physics instructional program. Its importance lies in its ability to observe continually as a student develops problem solutions and to intervene when appropriate with assistance specifically directed at the student's difficulty and tailored to his skill level and learning style.

Equipped with Apple Macintosh II computers, teacher Beverly Lee and Physics I class of Clear Creek High School, League City, Texas are providing the classroom environment for test and evaluation of the tutoring system, which is expected to lead to further refinements and expansion of its capabilities.

The ITS originated as a project of the Johnson Space Center (JSC) Office of Technology Utilization. It is being developed by JSC's Software Technology Branch in cooperation with Dr. R. Bowen Loftin, professor of physics at the University of Houston-Downtown (Texas). The program is jointly sponsored by NASA and ACOT (Apple Classrooms of Tomorrow), a research project of Apple Computer, Inc., Cupertino, California aimed at more focused and more effective uses of technology in education. Other organizations providing support for the project include the Texas Higher Education Coordinating Board, the National Research Council, Pennzoil Products Company and the George R. Brown Foundation.

The ITS is a spinoff product. It draws on technology earlier developed by the same project team—JSC's Software Technology Branch and Dr. Loftin—to integrate artificial intelligence into training/tutoring systems for NASA astronauts, flight controllers and engineers. Success of the ITS will enable—after test, evaluation and refinement—mass production of the system for economical delivery to high schools and colleges throughout the nation In addition, the spinoff may engender further spinoffs: the methodologies employed and much of the software developed can be used to produce other intelligent tutors for academic subjects that similarly demand application of problem-solving skills, such as mathematics, chemistry and engineering.

Teacher Beverly Lee (right) and her Clear Creek High School physics class are participating in a classroom-environment test and evaluation of the Intelligent Tutoring System.

Principal investigator Dr. R. Bowen Loftin (center) discusses refinements to the tutoring system with members of the Johnson Space Center project team, who observe the classroom activities of Clear Creek High School students to determine what system improvements are needed to allow better student/tutor interface.

NASA/University Technology Cooperation

Along with the broad educational activities exemplified on the previous pages, NASA is extensively engaged in cooperative technology development efforts with the nation's research universities. Such programs broaden the university's research capability, enhance education in space science and technology, and expand the nation's technology innovation base.

An example of NASA/university cooperation is the work of the Space Technology Center at the University of Kansas (KU) and the KU Center for Research, Inc. (CRINC). Directed by Professor Bill G. Barr, the Space Technology Center is one of 27 interdisciplinary centers established as part of a NASA plan to set up a network of advanced facilities across the nation. Since 1981, CRINC has been involved in a technology transfer program supported by the NASA Technology Utilization Division and by industry.

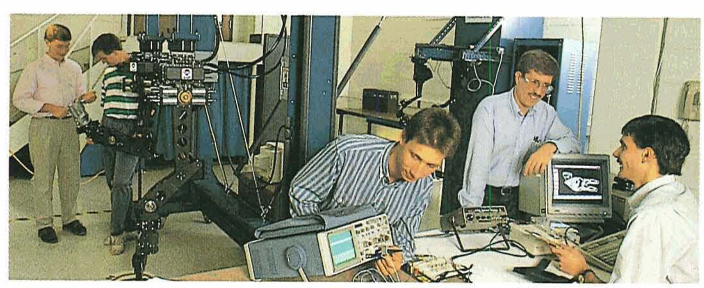
The objective of the technology transfer program is to encourage industrial innovation through utilization of NASA technology and through improved industry/university cooperation. At KU, such research is conducted by the Industrial Innovation Laboratory and the Computer Integrated Manufacturing Laboratory, which utilize graduate students in engineering and computer science as research assistants.

A new project of the Space Technology Center is one designed to advance NASA objectives in "augmented telerobotics." Unlike the robot, which is programmed to perform tasks autonomously, a telerobot is programmed to respond to commands from a human operator, or to mimic the movements of its human operator, for example, the operator moves arm-like controls and the telerobot's gripper-equipped arms move in the the same way. Remotely controlled telerobotic systems offer an alternative to exposing humans to such hazardous work as maintenance of nuclear power plants or high voltage transmission lines, or performing undersea maintenance on oil platforms.

The KU Space Technology Center will focus on "shared control" of telerobots such as those that will be employed in space station assembly and operation. Shared control involves development of sensors, software and speech recognition techniques that can supply some of the control input, and thereby increase the system's capability by enabling the telerobot to do more jobs autonomously.

The project is being conducted under the guidance of Langley Research Center's Automation Technology Branch and is jointly funded by NASA, the Kansas Technology Enterprise Corporation and Kraft Telerobotics, Inc., Overland Park, Kansas. Kraft Telerobotics supplied a dual arm telerobot that has been installed in the Space Technology Center to test new sensor technology and computer software.

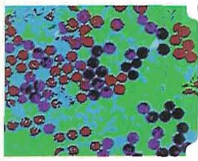
Professors Bill G. Barr (right) and Terry Faddis, co-directors of the University of Kansas Space Technology Center's telerobot advancement project, study their telerobot's performance.



University of Kansas graduate students work as research assistants in the telerobotics technology development effort.

ENVIRONMENT/RESOURCES MANAGEMENT

Space Data for Crop Management



Potatoes are a high value specialty crop that can be more profitable to the farmer if he has advance knowledge of market conditions. If a grower has a good idea of the size and condition of his own and his competitors' crops, he can better make such important decisions as when to harvest and when to take his product to market; at the least, he knows his bargaining position.

Frank G. Lamb saw an opportunity for improving the financial yield of potato farming by providing accurate information on crop acreage and conditions on a more timely basis than the routine estimates of the U.S. Department of Agriculture (USDA)—namely, by processing and distributing data collected by the NASA-developed Landsat Earth Resources survey satellites.

Frank Lamb is a unique combination of crop grower and remote sensing technologist. He is president of the Eastern Oregon Farming Company (EOFC), Irrigon, Oregon, which has 10,000 acres of agricultural land in the Columbia River Basin planted in potatoes, alfalfa and wheat. His experience in remote sensing dates back to 1974, when he first employed aerial infrared photography for managing EOFC's irrigation system.

That experience led to an invitation to participate in the Large Area Crop Inventory Experiment, a 1977-79 joint NASA/USDA/National Oceanic and Atmospheric Administration program to measure crop yields worldwide by means of Landsat data. Later, Lamb served on a National Academy of Sciences committee studying application of remote sensing to agriculture.

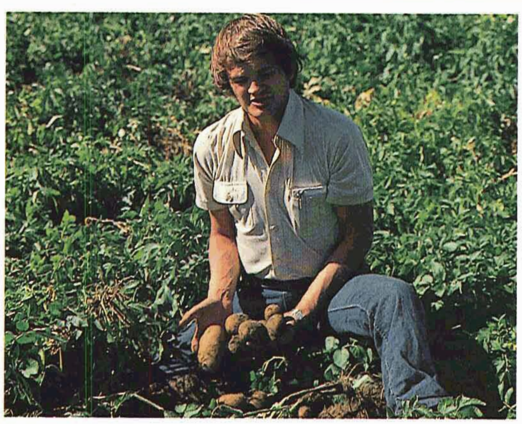
His work on those projects sold Lamb on the idea that significant financial gains could be realized by interpreting Landsat data to get a close approximation of potato acreage and conditions. The drawback, in the 1970s, was that Landsat data processing required expensive mainframe computers and complex software whose cost would negate the advantages. But by 1983 advancing technology had made it possible to process Landsat data with a personal computer and less expensive related equipment, making the technology affordable to small businesses.

That year offered a graphic example of how timely knowledge of market conditions can pay off. At early harvest time of 1983, potatoes were selling at \$80 a ton. Ninety days later the price was up to \$130 a ton because of low potato yields and low quality. A farmer armed with advance knowledge of this underproduction could have delayed selling and realized an extra \$50 a ton—and Frank Lamb had some 2,800 acres of potatoes on EOFC.

In 1984, Lamb decided to capitalize on this opportunity. With backing from other growers and a food processing company, he formed CROPIX, Inc., Hermiston, Oregon to monitor primarily potato crops in a 20,000 square mile area of northern Oregon and central Washington that produces more than a fourth of the U.S. potato crop. The company's initial management was Frank Lamb and his wife Birgitta; later they were joined by digital image analyst George Waddington, Jr. CROPIX' initial equipment, which involved an investment of \$30,000, included an IBM personal computer, a color monitor, a tape drive and a color printer.

The primary data CROPIX uses originates in Landsats 4 and 5, now operated on a commercial basis by EOSAT, Lanham, Maryland. The Landsats' utility stems from the ability of sensitive on-board detectors to pick up reflectances emanating from Earth objects. Since each object has its own unique reflectance "signature," it is possible to distinguish among surface features; for example, Landsat data can be interpreted to tell the difference between one type of crop and another, or between diseased and healthy crops.

Landsat employs two types of Earth scanning systems, a multispectral scanner (MSS), which detects reflectance information in four bands of the spectrum, and a thematic mapper (TM), which collects data in seven bands. Relayed to Earth, the Landsat data can be computer processed to generate imagery identifying specific features of importance to resources managers, *Heading spinoffs in environment and resources management is a pioneering agribusiness that employs satellite remote sensing data to monitor crops*



The upper photo shows a potato harvest at the Eastern Oregon Farming Company in the Columbia River Basin. A tractor pulls the harvester, which digs the potatoes, separates vines and rocks, and runs the potatoes up a conveyer belt into a truck. Above, company president Frank G. Lamb is hand-digging some of his potatoes to check their quality. Lamb is founder and operator of CROPIX, Inc., which employs satellite data to provide farmers and food processors timely information on potato acreage and crop health.

for instance, a large-area inventory of agricultural growths.

CROPIX buys computer tapes of Landsat data covering the irrigated 100-mile-wide Columbia River Basin and processes them to make acreage estimates of crops, particularly potatoes. In the early stages of a growing season, CROPIX is able to accurately map about 80 percent of the regional potato acreage by combining Landsat data with "ground truth," double-checking physical observation of selected crop fields. As the season progresses and Landsat supplies new data, the maps are updated and corrected. CROPIX also calculates a field-by-field vegetative index number, a numerical method for tracking and noting the vegetative health of a particular crop throughout the season.

(Continued)

Space Data for Crop Management

(Continued)

The end product CROPIX distributes to its customers is a booklet containing color-coded maps in various scales, essentially an inventory of the crops being grown in the Columbia River Basin, plus data and graphs on crop conditions and other information of value to the potato grower. CROPIX focuses on potato production because it is the Number One cash crop of the Basin area and involves the highest risk, thus the information is more valuable to farmers and potato food processors.

"If we can distill a couple of hundred megabytes of data into a few words," says Frank Lamb, "such as 'There are too many potatoes, the price is going down,' then CROPIX is performing a worthwhile service." CROPIX information, he says, enables potato growers to know better their bargaining positions when contracting with food processors.

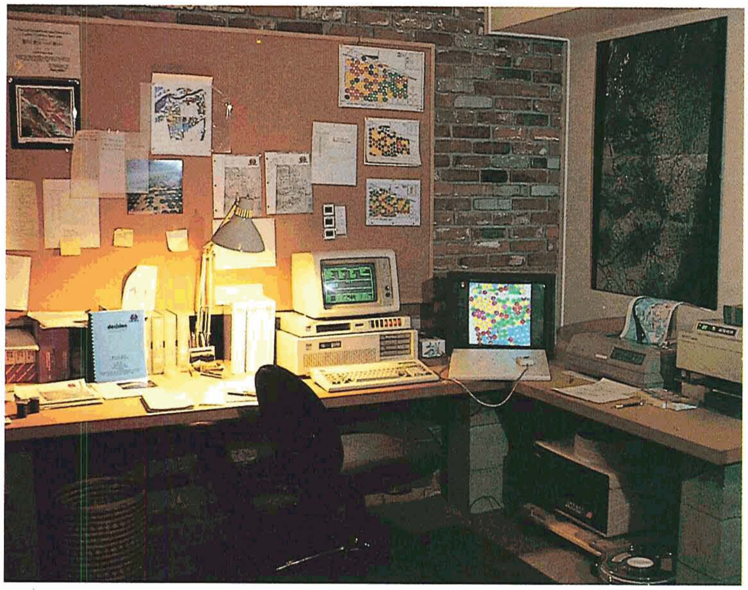
Dissemination of space-acquired data to agribusinesses, through regional service organizations like CROPIX or directly to a farmer's or processor's receiving dish, offers great potential for the future. But improvements in the system are needed to take full advantage of the potential.

For example, image resolution, or the degree of detail the system can provide. Landsat has a resolution of 30 meters (about 100 feet), which means it can provide information on features of an area about one-fourth acre. Better resolution could enhance the efficiency of the system, but that will require relaxation of Department of Defense-imposed restrictions on space imagery resolution. The French SPOT system, which CROPIX has used to complement Landsat data, can provide detail of objects as small as 10 meters, but SPOT images cover overall areas only one-third as large as Landsat offers.

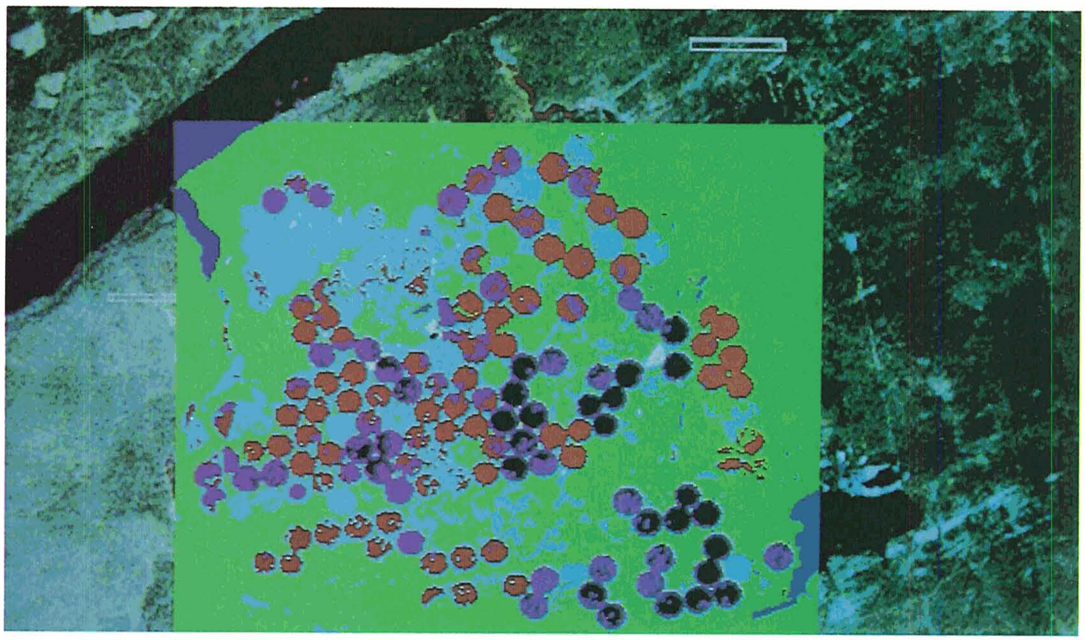
Perhaps the most significant improvement needed is time compression. Landsats 4 and 5 pass over a given point on Earth once every 16 days; once the data is relayed to Earth, it takes 10-14 days for delivery of the computer tapes. That, says Frank Lamb, is all right for the kind of regional surveys CROPIX is doing now, but it is not good enough to take advantage of one of

An Eastern Oregon Farming Company potato field.

This magnified view of a crop image shows (above) a dark wedge in one of the potato fields (red circles). The wedge represents an area of diseased or "stressed" crops. A major aim of ongoing research is to speed up data delivery to farmers so they can detect stress early and correct it before it causes significant crop losses.



The compact office of CROPIX, Inc. has all the equipment necessary to process computer tapes of satellite data and prepare regional crop inventory maps, such as the one shown below. This is a classification map based on Landsat satellite data. The red and pink fields are different varieties of potatoes; blue represents water, green is range land and the other colors indicate corn and wheat fields.



the prime potential benefits of remote sensing: detection of diseased crops early enough for the farmer to do something about it.

Says Lamb:

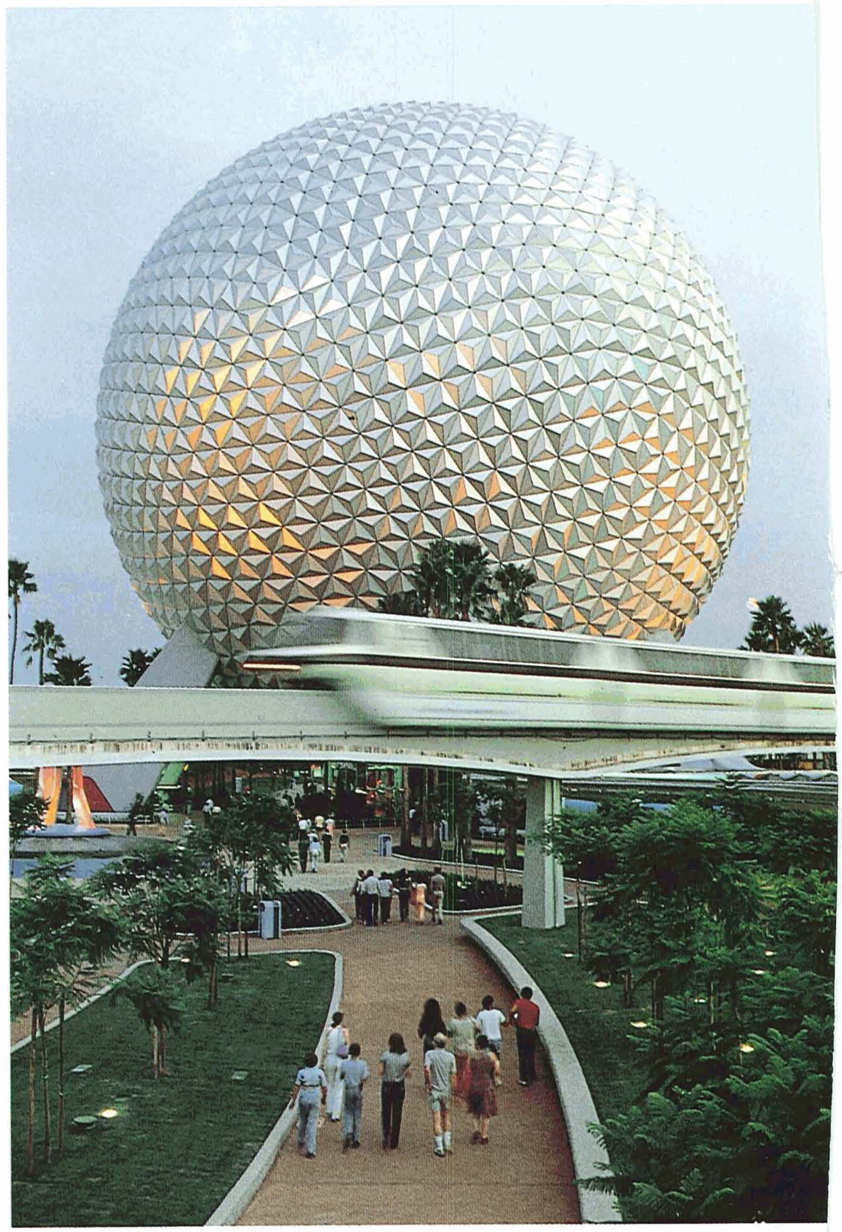
"If we could get remote sensing coverage once a week and data delivery in two to four days, we could detect stress in our fields. This frequency would be sufficient to allow us to go into our fields and correct the problem before it causes a reduction of yield."

CROPIX is playing a part in a NASA Earth Observations Commercial Application Program (EOCAP) designed to identify technological advances needed to expand the commercial benefits of remote sensing. CROPIX is teamed with Ames Research Center and Oregon State University, Corvallis, Oregon on a NASA-funded project to expand and refine the regional potato crop monitoring system, one of a number of EOCAP projects.

Ames' focus is on improvement of digital image processing techniques and field measurement support. OSU's Department of Agricultural Engineering is conducting field measurements and developing a regional potato yield model for use by CROPIX. Project scientists have made more than 20,000 ground truth measurements since 1988 to correlate actual crop acreage and conditions with the information acquired by satellite. This approach has allowed modification of forecasting techniques to the point where they are now 90-95 percent accurate. The Ames/OSU/CROPIX effort will be continued into 1991.

Plant Research

In future bases on the Moon, Mars, or elsewhere in the solar system, naturally occuring ready-to-use life support resources—such as food, air, and water—will not be available. NASA is conducting research toward the development of modules that will recycle wastes produced by human and industrial processes and provide the essential ingredients for growing plants. The plants, in turn, will provide food, oxygen, and water and obviate the need to supply such resources from outside the bases.



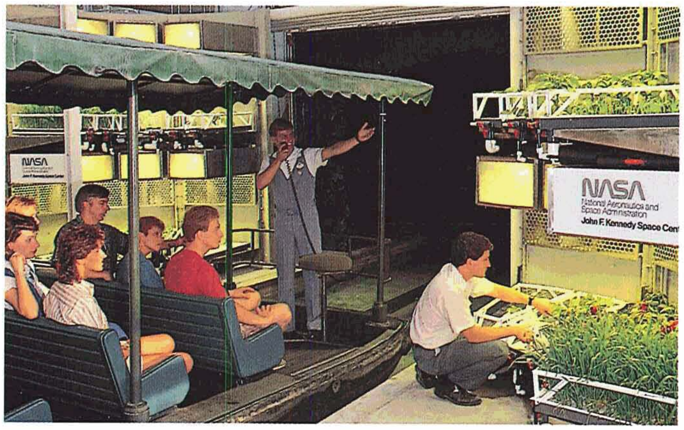
At Kennedy Space Center (KSC), NASA is developing a Controlled Ecological Life Support System (CELSS). And in a novel government/commercial industry research partnership, The Land's agricultural research team at EPCOT Center is similarly testing new ways to sustain life in space as a research participant in the CELSS effort.

The Land, sponsored by Kraft General Foods, is an entertainment, research, and education facility at EPCOT Center, part of the Walt Disney World Resort, Lake Buena Vista, Fla. (right).

The cooperative KSC/Walt Disney World effort is simultaneously a research and development program, a technology demonstration that provides the public an unsual opportunity to see high technology at work, and an area of potential spinoff; the CELSS work may generate Earth use technology beneficial to the hydroponic (soilless growing) vegetable production industries of the world.

The project involves plant-growing racks and associated KSC-supplied bioregenerative equipment installed in a greenhouse near the end of The Land's boat ride (top right), on which visitors travel through five greenhouses displaying more than 30 crops from around the world. In the experimental greenhouse, plants are grown on A-frame structures (far right center) that make it possible to spray the roots from the inside with a hydroponic nutrient solution.

At KSC, the current focus of CELSS research involves growing plants in special trays in an atmospherically sealed, environmentally controlled chamber (far right). Wheat and soybeans



have been grown hydroponically in the CELSS module; scientists monitor a number of environmental parameters, including gases produced in the process. Additional plant species will be integrated into future research, as will waste management and food processing modules.

At EPCOT Center, The Land researchers "have the latitude to try their ideas and conduct various studies on their own to maximize the scientific data return," according to Dr. William Knott, KSC CELSS project scientist. The Land researchers are in an early stage. In their environmentally controlled greenhouse, they are growing plants hydroponically in six plant-growing racks, about one-third as many as in KSC's facility. Initial research involved the testing of software and hardware subsystems controlling the plant growing racks, which were developed under the joint research partnership between NASA and Walt Disney World. Additional research will study how microbial contaminants, such as fungi and bacteria, affect plant growth; such information is critical to developing a reliable CELSS.

"Eventually we will take the research a step further," said Andrew Schuerger, research plant pathologist at The Land, "by testing biological control agents to determine how they will be able to prevent root disease and enhance plant growth." Researchers are testing more than two dozen plant species, although 95 percent of commercial hydroponic vegetables grown are lettuce and cucumbers, The Land group will also investigate wheat, mung bean, winged bean, peppers, spinach, oats, barley, strawberries, herbs and other crops. Attention will focus on finding plants that can be grown together in a hydroponic environment without interfering with each other's growth patterns.

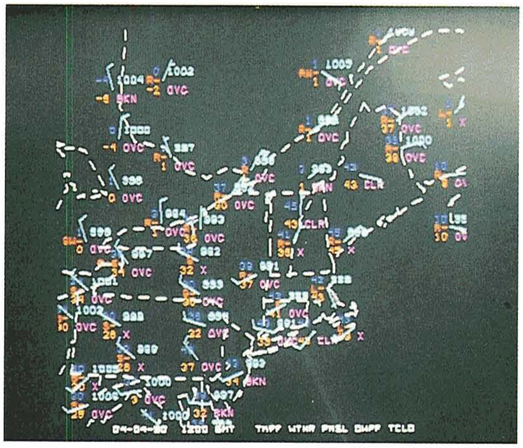
Meteorological Instruction Software

FSU Photo Lab

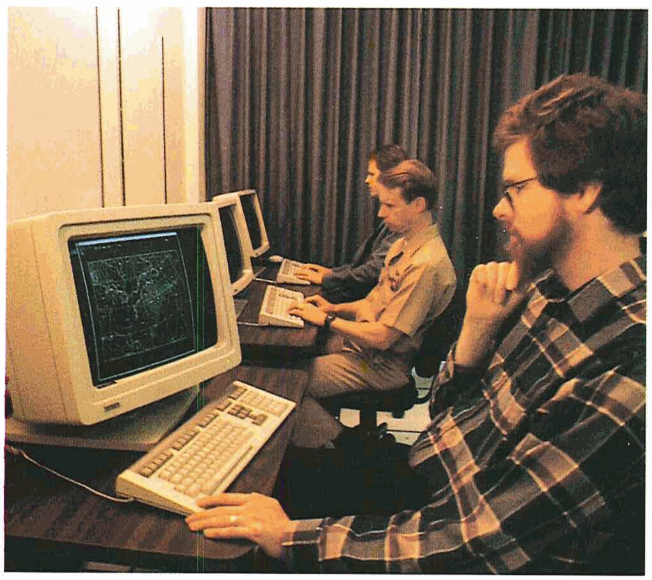
A major challenge to university professors is conveying the relevance of classroom studies to real world matters. At Florida State University, Tallahassee, Florida and the Naval Postgraduate School, Monterey, California meteorology students have an unusual opportunity to apply theoretical studies to current weather phenomena, even prepare forecasts and see how their predictions stand up. The tool that makes this innovative instructional program possible is GEMPAK, an interactive, user-friendly computer program that provides meteorology students such current weather information as temperature, humidity, winds and atmospheric pressure, and also offers a powerful analysis and graphics capability. GEMPAK was developed as a general purpose meteorological display package by Goddard Space Flight Center.

"GEMPAK is an exciting tool for all academic levels—from general education students to upper level meteorology classes," says Florida State Assistant Professor of Meteorology Dr. Paul Ruscher, who uses GEMPAK displays as visual aids to supplement his lectures (above). GEMPAK can display data quickly in both conventional and non-traditional ways (right center), allowing students to view multiple perspectives of the complex three-dimensional atmospheric structure. This helps them understand some of the data limitations that constrain professional weather forecasters.

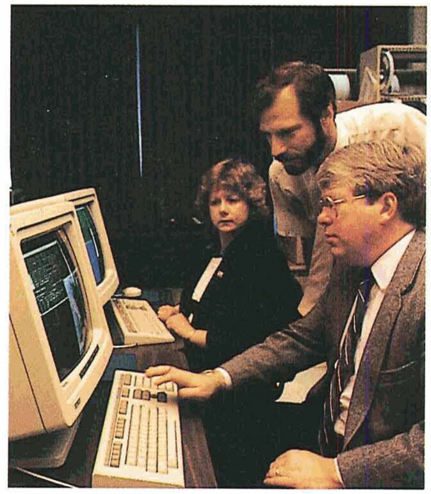
With GEMPAK, mathematical equations come alive as students do homework and laboratory assignments on the weather events happening around them. Since GEMPAK provides data on a "today" basis, each homework assignment is new, not something given the previous year's students. In addition, data from interesting past weather events can be accessed for instruction about different meteorological situations. With GEMPAK, the challenging task of managing and manipulating different data sets and displaying



FSU Photo Lab



USN Photo by Mitch Nichols



USN Photo by Mitch Nichols

the results in a readily understandable manner is a lot less formidable.

GEMPAK was supplied to Florida State by the Computer Software Management and Information Center (COSMIC)®. Located at the University of Georgia, COSMIC is NASA's mechanism for making available to private sector and government customers computer programs originally developed for government use that can be adapted to secondary applications at a fraction of the cost of a new program.

At the Naval Postgraduate School, students are now using electronically-managed environmental data in the classroom. The School's Departments of Meteorology and Oceanography have developed the Interactive Digital Environment Analysis (IDEA) Laboratory, which employs micro- and mini-computers to combine and display real-time satellite and other data that students employ in laboratory assignments and thesis research. At left, Professor Wendell Nuss (foreground) is using an IDEA Lab workstation for meteorological study.

"The IDEA Lab has been called the classroom of the future," says Dr. Carlyle H. Wash, Professor of Meteorology, "because five to 10 years from now this capability will be a basic requirement of any oceanography or meteorology department." Above, Dr. Wash is preparing an instructional program with the help of Mary Jordan and Craig Motell.

Until recently done with hard copy maps, satellite photos, light tables and grease pencils, the difficult task of combining meteorological and oceanographic data from many sources, processing it and presenting the results in convenient form has been made "considerably more tractable," according to Dr. Wash, by use of minicomputer workstations to process the information and electronic displays to present it in graphic image formats.

GEMPAK is the IDEA Lab's general purpose display package; the IDEA image processing package is a modified version of NASA's Device Management System. Bringing the graphic and image processing packages together is still another NASA product, the Transportable Application Executive (TAE), which acts as a general purpose user interface and gives a single entry point to all of the display applications available in the IDEA Lab.

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Biofeedback for Better Vision

It is estimated that about 150 million people in the United States are myopes or hyperopes. Myopes are people with myopia, or nearsightedness; they tend to overfocus when they look at distant objects and that causes blurry distant vision although near vision is clear. The opposite is true of people with hyperopia, or farsightedness; their near vision blurs when they look at close objects because they tend to underfocus.

Because those afflicted constitute some 60 percent of the national population, there is naturally great interest in new devices or systems intended to correct focusing problems, especially ways of correcting them without lenses or surgery. Such a system is the Accommotrac® Vision Trainer, a spinoff aid to natural rather than artificial vision improvement.

The Accommotrac system was invented by Dr. Joseph N. Trachtman, Doctor of Optometry, Ph.D. and a Fellow of the American Academy of Optometry. It is based on vision research performed by Ames Research Center and a special optometer developed for the Ames program by Stanford Research Institute.

Dr. Trachtman's Vision Trainer is intended to improve certain vision defects by teaching the patient to control the ciliary body, the focusing muscle of the eye. The key is biofeedback, defined as a technique wherein a patient learns to control a bodily process or function of which he is not normally aware. Blood pressure and heart rate, for example, can be controlled voluntarily; so can the ciliary body.

The Accommotrac Vision Trainer is an optical/electronic system used by a doctor as an aid in teaching a patient how to contract and relax the focusing muscle. In a darkened room, the patient—wearing a headset—looks into the optical part of the system. Harmless infrared light is directed into the eye and focusing status of the eye is measured 40 times a second. In the

Heading spinoffs in health and medicine is a training aid for lensless correction of eye focusing disorders

At left, Dr. Sanford Cohen, a Silver Spring, Maryland optometrist, is using the Accommotrac Vision Trainer to teach a patient how to improve his vision by controlling and relaxing the focusing muscle of the eye. Above, Dr. Cohen is moving a joystick to change the view the patient sees and maintain alignment of the patient's eye with the instrument; through the headset, the patient hears a signal that tells him how successfully he is controlling focus. Shown in closeup below are the two elements of the Accommotrac system, the optical subsystem that measures the eye's focusing status, and the electronic subsystem (box) that converts the measurements to sound signals and provides a digital display of information.

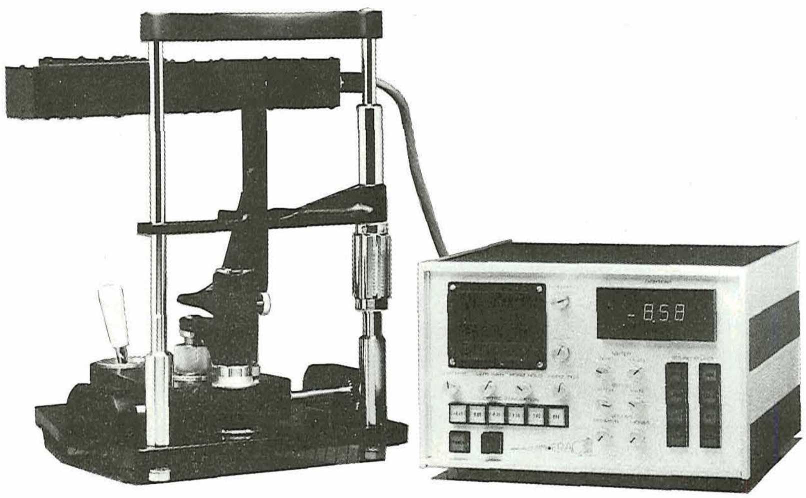
electronic segment of the system, the measurements are converted to sound signals audible to the patient through the headset.

As the patient opens and closes the eye, the auditory tone tells him how successfully he is controlling the focusing muscle. A nearsighted person, for example, would want the tone to go higher, because that means he is relaxing the muscle and therefore bringing about vision improvement, since it is the inability of the eye muscle to relax that causes the blurry vision of many nearsighted persons. A farsighted person would want to hear the tone drop to a deeper pitch, signifying that the muscle is contracting, causing the lens to change shape and focus on near objects.

Through repeated one-hour sessions, the patient gradually learns to control relaxation or contraction of the eye muscle—hence the eye's focus—by auditory feedback. "It is," says Dr. Trachtman, "a retraining program for learning to see clearly without lenses."

(Continued)

®Accommotrac is a registered trademark of BiofeedTrac, Inc.



Biofeedback for Better Vision

(Continued)

It takes a lot of practice and a great deal of motivation to learn to control the focusing muscle of the eye, but many doctors are now using the Accommotrac Vision Trainer with consistent success. Not all patients can throw away their corrective lenses, says the system's inventor, Dr. Joseph N. Trachtman, but most achieve improvement of some sort, such as halting or reversing their needs for increased lens prescription. Trachtman claims a 90 percent success rate for correcting, improving or stopping focusing problems.

The Accommotrac Vision Trainer has also proved effective in treating eye movement problems, such as nystagmus (eye oscillation), strabismus (cross eyes or wall eyes) and amblyopia (lazy eye). Recently, Trachtman has been introducing his Accommotrac/biofeedback technique to professional sports teams, because it has demonstrated ability to help increase peripheral visual awareness and therefore improve athletic performance.

There is still another important application, Trachtman believes: the Accommotrac Vision Trainer can help children develop stronger focusing muscles and foster greater attention spans in the classroom, possibly decreasing juvenile delinquency that often occurs when children are frustrated in school.

Dr. Trachtman's exciting invention had its origin more than 20 years ago, when Ames Research Center contracted with Stanford Research Institute (SRI) for studies of pilots' visual accommodation, the ability of the eye to adapt to distinct vision at different distances. Ames scientist and human factors engineer Robert J. Randle, Jr. was assigned as NASA's technical monitor of the contract; the principal investigators were Drs. Hewitt D. Crane and Thomas N. Cornsweet of SRI.

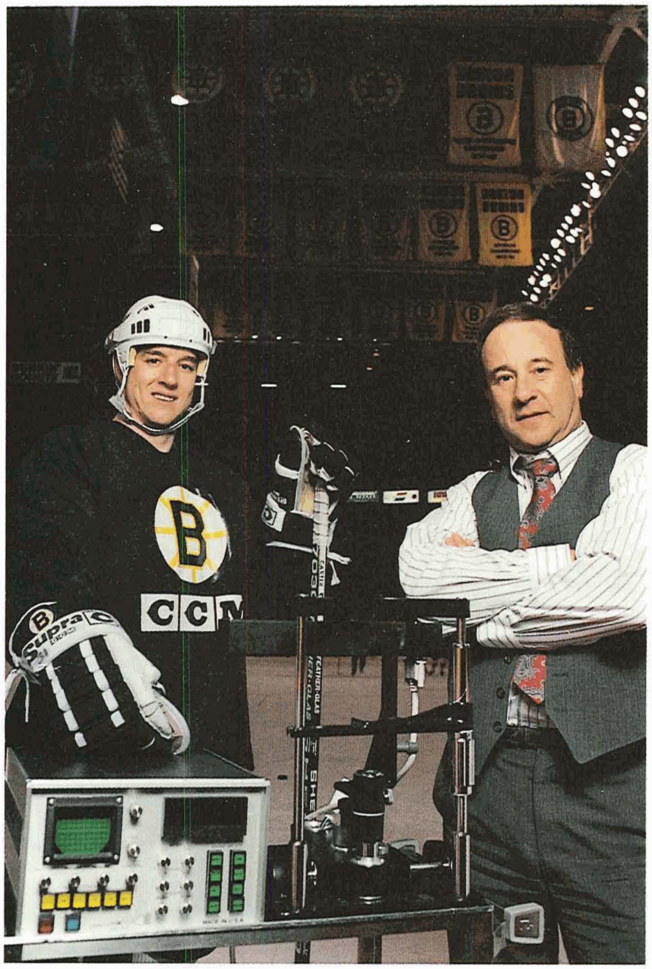
Crane and Cornsweet were assigned the job of developing an optometer, a means of objectively measuring visual accommodation, and a high accuracy eye position tracker. In 1968, they delivered what Randle describes as "the first usable, automatic, objective research optometer."

While running experiments with the optometer on pilot subjects, Randle discovered that humans could learn to control eye focus. He employed the auditory biofeedback technique as a learning enhancement measure and conducted accommodation experiments with college students and airline pilots.

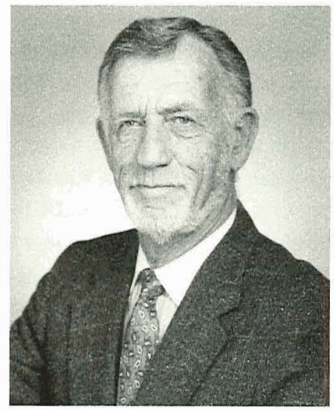
Their success in controlling focus was a finding of some significance, since optometer/biofeedback training offered a potential means of overcoming an aviation phenomenon known as "empty field myopia," the tendency of a pilot's focus at high altitude in empty, featureless skies, to stop about a yard in front of the eye and wander there; in other words, the pilot absently focuses on the windscreen when he should be focused at distance, scanning the sky for hazards.

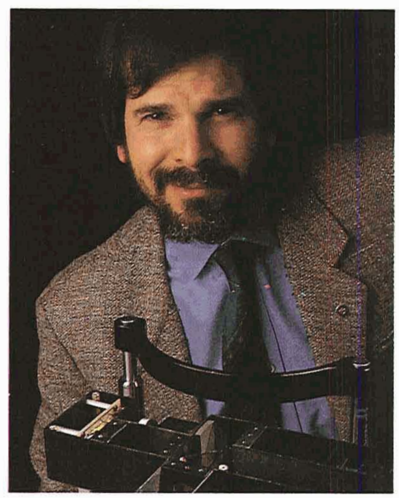
In 1970, Randle presented papers on the NASA research, the first literature on biofeedback control of accommodation, at meetings of the aerospace medical community in the U.S., Germany and France. Crane and Cornsweet subsequently published a training study confirming the NASA results using a different biofeedback technique.

At an early age, Joseph Trachtman developed a fascination for the human eye and the possibility of controlling the human nervous system by concentration and training. After earning degrees at the Pennsyslvania College of Optometry, The Johns Hopkins University and the State College of Optometry, State University of New York, Dr. Trachtman learned of the Randle/SRI research while taking postgraduate study at Yeshiva University. Armed with Randle's papers and the Crane/Cornsweet reports of the instrumentation they had developed for NASA, Trachtman chose the application of biofeedback of accommodation to reduce myopia as the subject of his doctoral dissertation. He then proceeded to develop a prototype version of the Accommotrac Vision Trainer.



The Vision Trainer is used by a number of professional sports organizations to improve athletes' peripheral vision and reaction time. Above, sports vision specialist Dr. Harvey Schneider is shown with his Vision Trainer and John Carter, one of several Vision Trainer users on the squad of professional hockey's Boston Bruins. There may be no connection, but the Bruins went all the way to the Stanley Cup finals in 1990. The Vision Trainer's inventor, Dr. Joseph N. Trachtman, has worked with the Pittsburgh Pirates of baseball's National League and sports vision specialists have conducted Accommotrac training for several other major baseball teams.

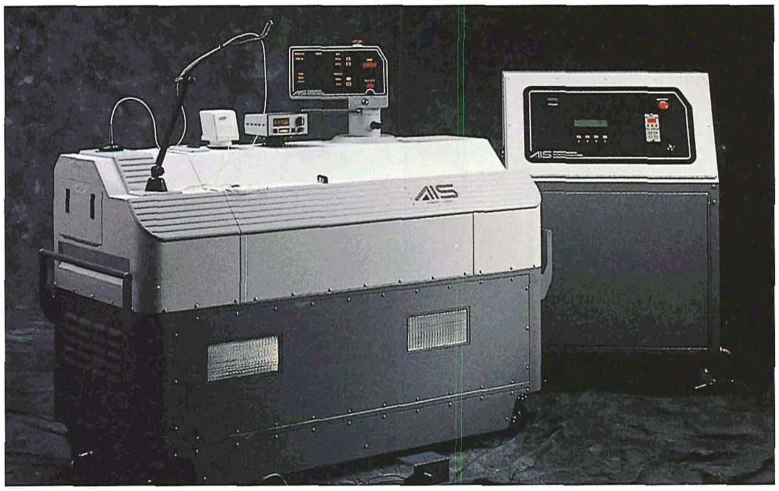




The inventors: Ames Research Center scientist Robert J. Randle, Jr. (top), who conducted the original NASA experiments in controlling human eye focus, and optometrist Dr. Joseph N. Trachtman, who developed the spinoff Accommotrac Vision Trainer as a means of correcting eye focus problems.

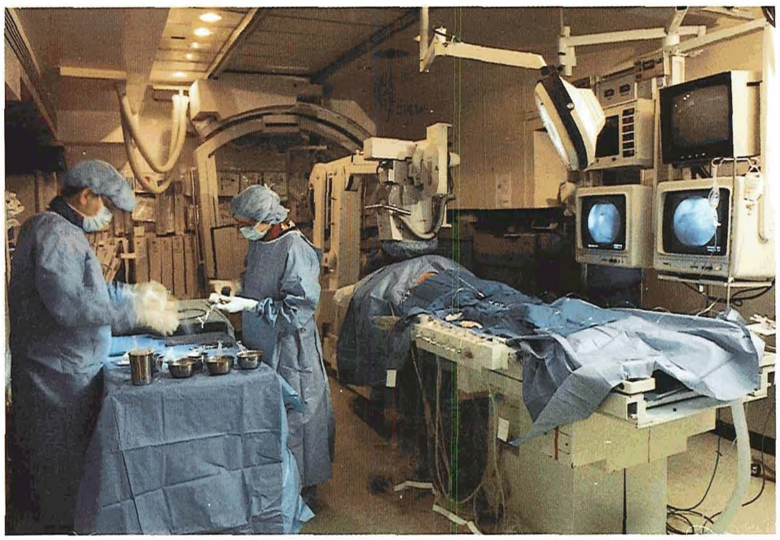
Using himself as the initial subject for Accommotrac experiments, Trachtman was able to effect a significant improvement in his own myopia. Continuing research and development over a span of seven years refined and greatly improved the Accommotrac. In 1984, Trachtman began marketing the Vision Trainer and the system is now in use in more than 200 practices in the United States and abroad.

Laser Angioplasty



Atherosclerosis is the buildup of fatty deposits—called plaque—in human arteries. In time the plaque partially or totally obstructs the flow of blood through the clogged artery and threatens life. For example, extreme blockage of a coronary artery, which carries blood to and from the heart, can result in a heart attack and death.

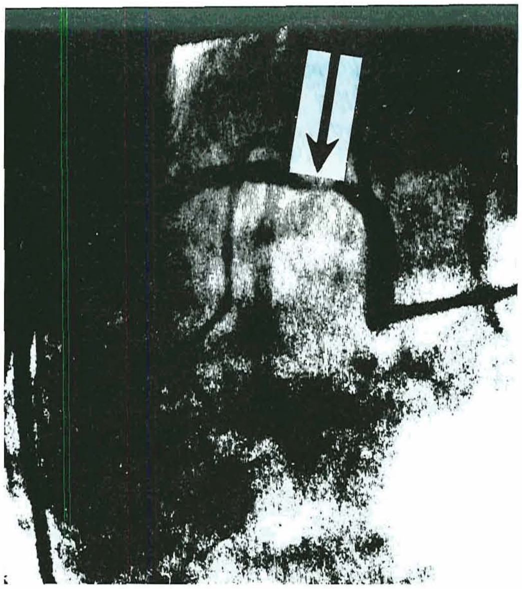
The principal method of dealing with coronary artery blockage is bypass surgery, in which clogged blood vessels are replaced—a high cost procedure with some risk. A non-surgical alternative available to some patients is balloon angioplasty, in which a flexible catheter with a tiny balloon at its tip is worked into the blocked artery; inflation of the balloon pushes aside the plaque and widens the artery for improved blood flow.

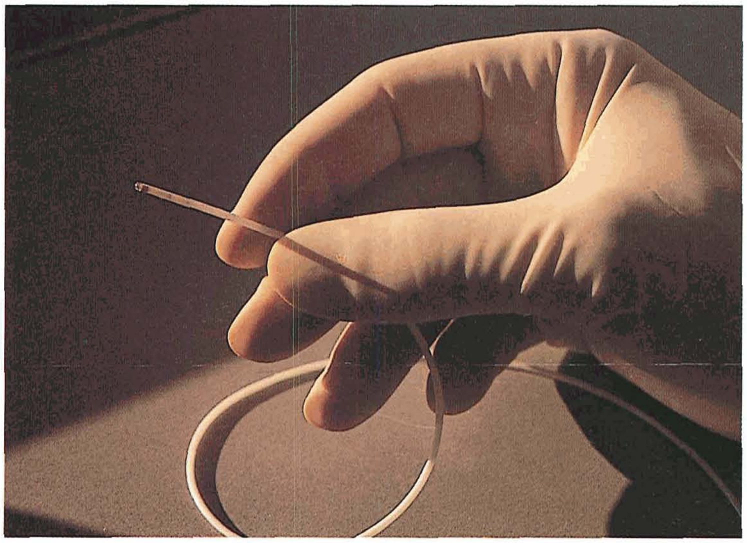


For several years, medical researchers have been exploring another alternative that would help a wider circle of patients than the balloon treatment and entail less risk than bypass surgery: laser angioplasty, in which a laser inserted in a catheter vaporizes the plaque and thus opens the artery. Several types of lasers have been employed in tests on human cadaver and animal arteries. The problem has been that the lasers are too hot. Human tissue can withstand heat up to 154 degrees Fahrenheit; most lasers heat tissue to much higher temperatures, which can cause damage to arterial walls.

Now, however, a research group is on the verge of an exciting development: laser angioplasty with a "cool" type of laser—called an excimer laser—that does not damage blood vessel walls and offers non-surgical cleansing of clogged arteries with extraordinary precision.

The system is the Dymer 200+ Excimer Laser Angioplasty System (top), developed and produced by Advanced Interventional Systems, Inc. (AIS), Irvine, California. The Dymer 200+ is based on NASA-patented technology developed at Jet Propulsion Laboratory (JPL) for satellite-based atmospheric studies. AIS' top management includes the two former JPL scientists who invented the excimer laser to measure gases in Earth's atmosphere: Dr. James Laudenslager,





AIS' vice president–laser development, and Dr. Thomas Pacala. The JPL laser research team also invented a magnetic switching system that is incorporated in the Dymer 200+.

Development of the system began in 1984 when physicians Drs. Frank Litvack, James Forrester and Warren Grundfest started to explore the possibility of using lasers to unclog arteries and went looking for a laser that could do the job without damaging vessels. They recruited Drs. Laudenslager and Pacala, and Dr. Tsvi Goldenberg, a fiber optics researcher at AT&T Bell Laboratories. With funding from NASA, the National Institutes of Health and private donations, the group developed the laser angioplasty system and then, having obtained a NASA exclusive license for the JPL laser technology, founded AIS to commercialize it.

Used in human clinical tests since 1987, the Dymer 200+ system is the first fully integrated "cool" laser capable of generating the requisite laser energy and delivering the energy to target arteries—either coronary arteries or peripheral arteries in other parts of the body. With the JPL-developed technology of magnetic switches, the excimer laser can be made to produce a uniform beam of energy that can be controlled and pulsed in a period as little as 200 billionths of a second. This is longer than most commercial excimer lasers, whose pulse widths are 25 billionths of a second; the system's so-called "stretched" pulse width allows the pulses to propagate through fiber optics.

At far left, Dr. Kenneth Kent and his nurse prepare for laser angioplasty at Georgetown University Hospital, Washington, D.C.; they will monitor the procedure on the video screens above the operating table. In the lower left photo, the physician inserts a flexible catheter into an artery in the groin, then threads it into the blocked coronary artery; a closeup of the catheter is shown at left center.

The laser light source is carried through multiple fiber optic bundles within the catheter. This AIS-patented fiber optic delivery system was developed by Dr. Goldenberg.

Watching the video, the physician spots the area of plaque buildup and vaporizes it by firing short bursts of the excimer laser. It happens so quickly that neighboring tissue is spared from damage. In the top left photo is a before laser-use x-ray image in which the arterial blockage is evident in the narrowed segment of the artery (arrow); at top right is an after-laser view, blockage removed.

Thirteen research hospitals in the U.S. have purchased Dymer 200+ systems and have used them in clinical trials in 121 peripheral and 555 coronary artery cases. The success rate in opening blocked coronary arteries is 85 percent and there have been comparable or fewer complications than in balloon angioplasty. AIS hopes to get Food and Drug Administration approval for general marketing of the system in the latter part of 1990.

Cardiac Imaging System

Balloon angioplasty (see page 74) is a non-surgical procedure for clearing fatty deposits in the coronary arteries that block blood flow and cause heart attacks. The procedure involves insertion of a balloon-tipped catheter, a thin hollow tube, directly into the clogged artery; the cardiologist guides the catheter by viewing fluoroscopic images of the heart area and catheter on a monitor. When the catheter penetrates the blocked segment, he inflates the tiny balloon; that pushes aside the fatty plaque and clears the artery.

Although not available to all patients with narrowed arteries, balloon angioplasty has expanded dramatically since its introduction in 1977—from 12,000 procedures in 1982 to 195,000 in 1987, with an estimated further growth to 562,000 in the U.S. alone by 1992. This growth has fueled demand for higher quality imaging systems that allow the cardiologist to be more accurate and increase the chances of a successful procedure.

A major advance is the Digital Cardiac Imaging (DCI) System (far right top) designed by Philips Medical Systems International, Best, The Netherlands and marketed in the U.S. by Philips Medical Systems North America Company, Shelton, Connecticut. The Philips DCI incorporates image processing technology originally developed for NASA Earth resources survey satellites; it is, the company says, the most widely used digital cardiac imaging system with more than 300 units in operation worldwide, more than 100 in the U.S.

The Philips DCI offers major advantages over earlier angioplasty monitoring techniques. The key benefit is significantly improved real-time imaging and the ability to employ image enhancement techniques to bring out added detail.

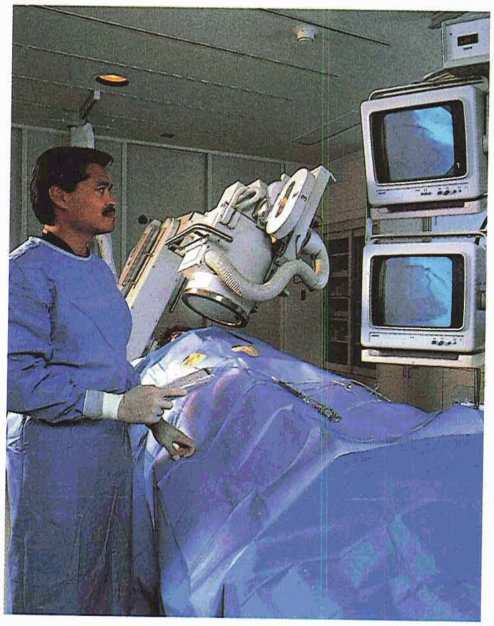
The Philips system gives the cardiologist direct control of "roadmapping," in which freeze-frame images of a section of a blood vessel can be used to guide the progress of the balloon-tipped catheter. Using a cordless control unit like a remote TV channel selector (right center), the cardiologist can manipulate images to make immediate assessment, compare live x-ray and roadmap images by placing them side-by-side on monitor screens, or compare pre-procedure and post-procedure conditions. The photo at lower right illustrates the system's capability for providing simultaneous viewing of the heart from two different planes.

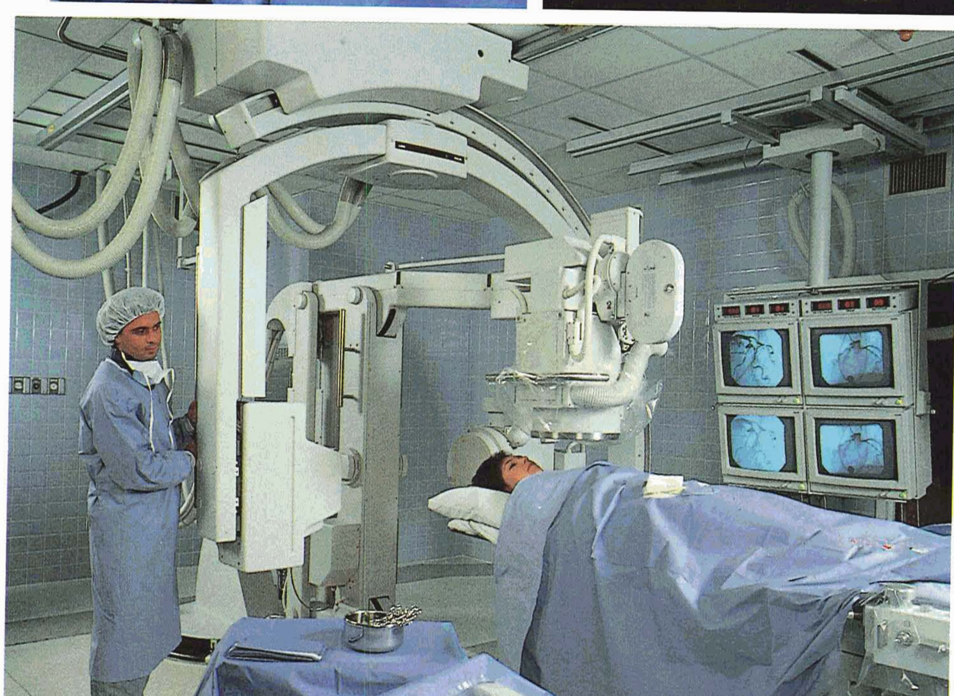
The bottom line is that the Philips DCI improves the cardiologist's precision by expanding the information available to him and enhances his ability to get into the heart and out as quickly as possible, minimizing trauma and maximizing chances of a successful procedure.

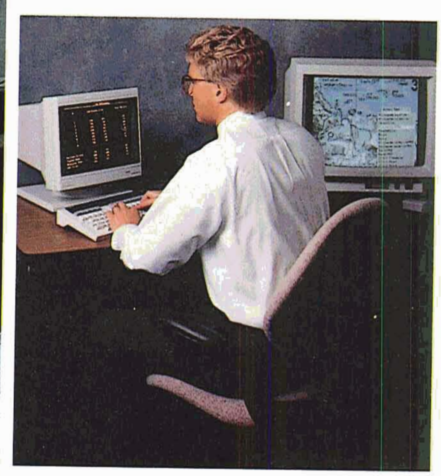
The image processing technology incorporated in the Philips DCI originated some 15 years ago at International Imaging Systems (I^2S), Milpitas, California. I^2S was a pioneer developer of optical, analog and digital image processing equipment for NASA's Earth resources survey satellites, exemplified by the Landsat satellite family.

In the early 1980s, I^2S found emerging interest among the medical industry in such applications as ultrasound, computer aided tomography (CT) and magnetic resonance imaging (MRI) body scanners. I^2S entered into contracts with several medical equipment firms to supply their R&D laboratories with image processing hardware and software identical to that used in Earth resources remote sensing. Subsequently, I^2S broadened its market and developed application-specific products for those companies. In 1984, I^2S developed the M6705 high performance processor for Philips Medical. I^2S engineers worked with Dr. Jos Bakker of Philips Medical Systems International in refining the technology for the Philips DCI application.

In addition to its work on medical applications, I^2S produces a line of workstations which, used in conjunction with System 600 application software, can address a wide variety of remote sensing applications. At far right is the company's low cost image processing workstation with an IVAS 1K display processor and mouse for menu selection and image manipulation.







Body Imaging

In the mid-1960s, as a prelude to NASA's Apollo Lunar Landing Program, Jet Propulsion Laboratory (JPL) developed the technology known as digital image processing to allow computer enhancement of Moon pictures. This technology became the basis for the NASA Landsat series of Earth resources survey satellites, which classify and distinguish among surface features by analyzing Earth objects' radiation signatures.

Digital image processing has found a broad variety of other applications, particularly in the field of medicine, where it is employed to create and enhance images of the organs in the human body for diagnostic purposes.

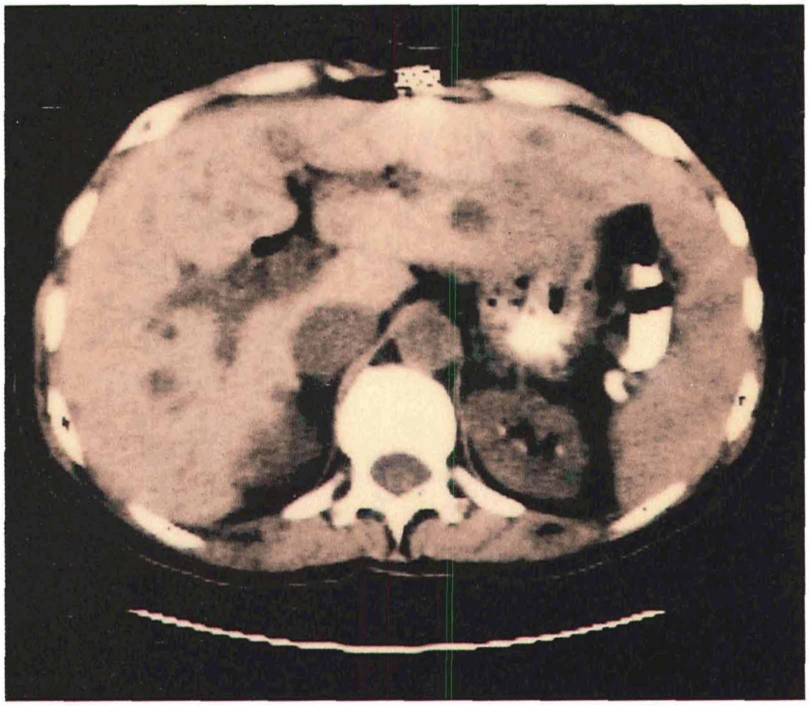
Among advanced body imaging techniques are computer-aided tomography, also known as CT or CATScan, and Magnetic Resonance Imaging (MRI). CT image data is collected by irradiating a thin slice in the body with a fan-shaped x-ray beam from a number of directions around the perimeter of the body; a tomographic (slice-like) image is reconstructed from these multiple views by a computer. MRI is an imaging technique that employs a magnetic field and radio waves to create images, rather than x-rays.

MRI and CT images are often complementary. In most cases, MRI is good for viewing soft tissue but not bone, while CT images are good for bone but not always good for soft tissue discrimination.

Physicians and engineers in the Department of Radiology at the University of Michigan Hospitals, Ann Arbor, Michigan are developing a technique for combining the best features of MRI and CT scans to increase the accuracy of discriminating one type of body tissue from another. One of their research tools is a computer program originally developed to distinguish among Earth surface features in Landsat image processing.

Called HICAP, the program can be used to distinguish between healthy and diseased tissue in body images. At near right is a CT image of a slice of human liver with many lesions; it was analyzed and processed by HICAP to produce the image at far right, in which the false-color red areas represent regions of normal liver. Consecutive liver slices can be processed in this manner to produce a three-dimensional display of the liver.

HICAP was supplied to the Department of Radiology by NASA's Computer Software Management and Information Center (COSMIC)®. Located at the University of Georgia, COSMIC makes available to industrial and other organizations government-developed computer programs that have secondary applicability.



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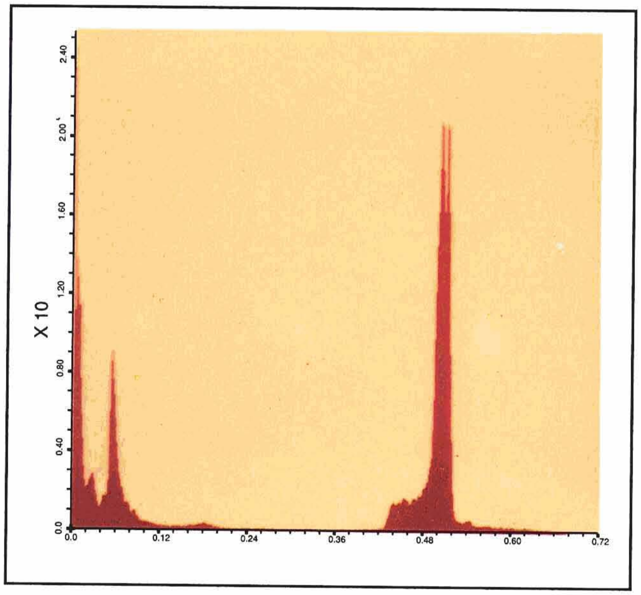

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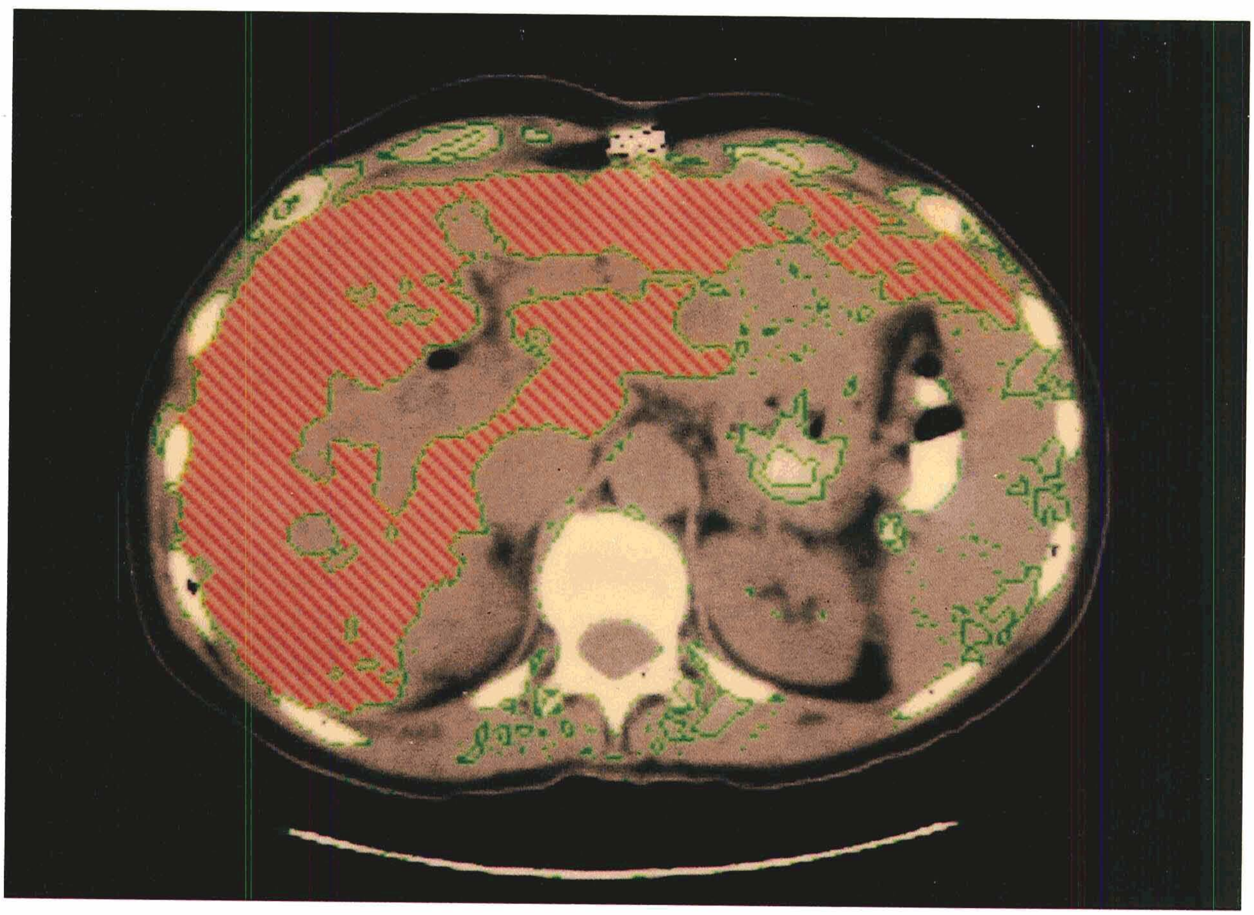
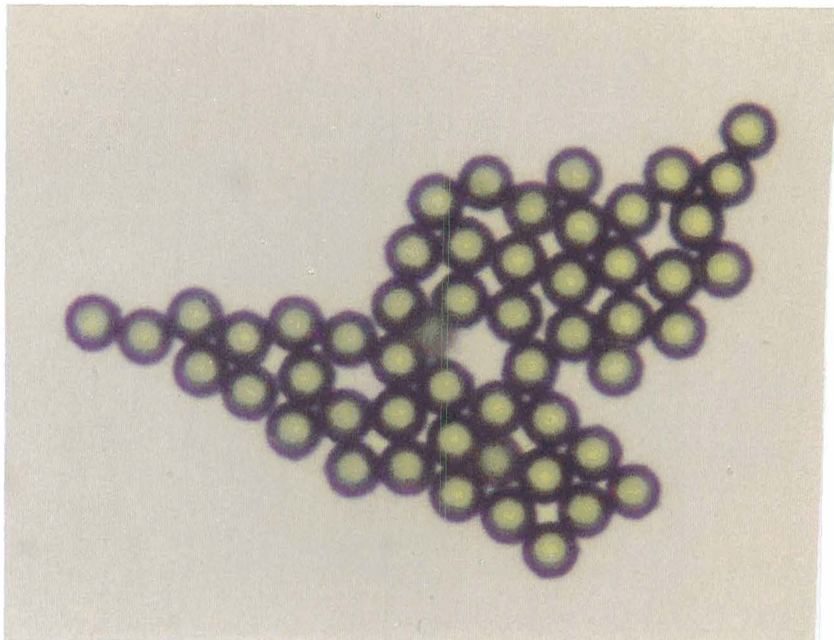


Microspheres

Human blood contains many different types of cells, among them T-cells and B-cells, lymphocytes of the same shape and size that help the immune system protect the body from the invasion of disease. Each has a different function in the immune system.

Vital information on a person's physical condition can be obtained by identifying and counting the population of T-cells and B-cells. At Jet Propulsion Laboratory (JPL), beginning in 1976, a team of scientists led by the late Dr. Alan Rembaum developed a method for identifying the cells. Dr. Rembaum is pictured at right (seated) as he was presented by JPL director Dr. Lew Allen a NASA Career Award in 1986, in recognition of his 52 patented contributions to the field of polymer chemistry, biology and medicine. One of NASA's most distinguished scientists, Dr. Rembaum was twice recipient of the NASA Exceptional Scientific Achievement Award.

The method developed by the Rembaum group involved tagging the T-cells and B-cells with microspheres of different fluorescent color. At lower right are a group of microspheres used for cell identification, shown at 800X magnification; each cell has a diameter of seven microns, or seven millionths of a meter.



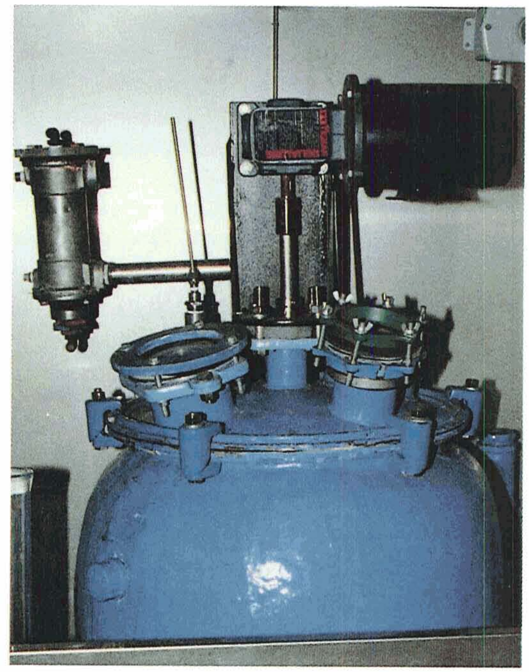
The microspheres, which have fluorescent dye embedded in them, are chemically treated so that they can link with antibodies. With the help of a complex antibody/antigen reaction, the microspheres bind themselves to specific "targets," in this case the T-cells or B-cells. Each group of cells can then be analyzed by a photoelectronic instrument at different wavelengths emitted by the fluorescent dyes.

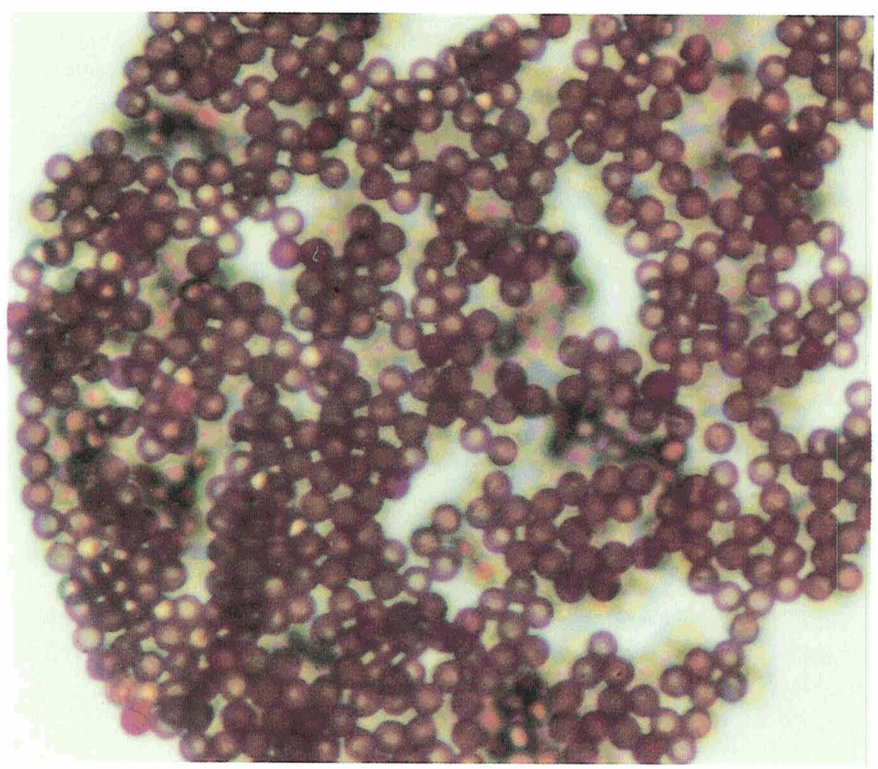
This same concept was applied to the separation of cancer cells from normal cells. The microspheres were also used to conduct many other research projects, among them cell labeling in microbiology research and immunoassays, analyses of bodily substances by testing their reactions with antibodies.

Among the scientists of several disciplines in the Rembaum group was Dr. Manchium Chang,

the polymer chemist who was in charge of preparing the microspheres. In 1988, Dr. Chang obtained patent licenses for the JPL technology from California Institute of Technology, JPL's parent organization, and formed Magsphere, Inc., Pasadena, California to commercialize the technology; he is now president of the company.

Above, Dr. Chang is examining a batch of microspheres in his Magsphere laboratory. At right is the reactor for creating microspheres and below is a sample of the product, a batch of red-dyed microspheres typically used in such immunoassays as one-step pregnancy tests. Having expanded the original JPL technology with the company's in-house proprietary technology, Magsphere is producing a wide spectrum of microspheres on a large scale and selling them worldwide for such applications as immunodiagnostics, cell labeling, instrument calibration, high performance liquid chromatography and other biomedical and chemical uses.





Computer Reader for the Blind

Twenty years ago, Telesensory, Mountain View, California was formed to develop and market technological aids for blind people. Its initial product was a spinoff device called the Optacon, an innovation that permitted the blind and the deaf-blind to read—not just braille transcriptions but anything in print. The Optacon combined optical and electronic technology and incorporated research performed at Stanford Research Institute under the sponsorship of NASA's Ames Research Center.

Last year TeleSensory introduced an even more exciting aid for the blind, a second generation spinoff that not only permits the user to "read" printed words but also provides access to the electronic information available on most personal computers. Called Optacon II, it is a joint development of TeleSensory and Canon, Inc., Tokyo, Japan. The two companies have had a close relationship since 1974 when Canon invested the time and money to introduce the original Optacon to Japan.

The Optacon was invented by Professor John Linvill and Dr. James C. Bliss, who were cofounders of TeleSensory; Linvill is now board chairman and Bliss president. The operation of the print Optacon is illustrated at upper right. The young user is passing a mini-camera over a printed page with his left hand; a control unit processes the camera's picture, translates it into a vibrating image of the words the camera is viewing, and the user senses the tactile image with his other hand. The original Optacon, which can be used with virtually any alphabet or language, provided a new level of independence for thousands of blind persons in more than 70 countries.

Optacon II employs the same basic technique of converting printed information into a tactile image, but it goes much further in that it can be connected directly to a personal computer, opening up a new range of job opportunities for the blind.

Optacon II consists of a hand-held camera with a silicon integrated circuit of 100 light sensitive transistors; a microprocessor control unit that processes information from the camera; and a tactile array, driven by the control unit, consisting of 100 vibrating rods. The camera's "retina" sends the shape of what it is viewing to the control unit and the corresponding rods in the tactile array vibrate. Moving the camera with one hand, the blind operator perceives the vibrating image with the index finger of the other hand. Optacon II is not limited to reading printed words; it can convert any graphic image viewed by the camera.

Optacon II obviously demands extensive training for blind operators. TSI provides 60-hour training courses at its Mountain View headquarters and at training centers around the world. A revolutionary RS-232 interface feature not only provides access to computer information, it also allows the computer to accomplish much of the training that formerly required a teacher. For example, the computer can assist in letter and word recognition drills and speed reading exercises, offering efficiencies in teacher time. At right below, TSI's Optacon II Training Software allows students and their teachers to use Apple and IBM personal computers for training.

IBM and Apple PCs can be used by blind people because their screen information is presented in a format that can be converted to braille or synthetic speech. Until now, however, there have been barriers to use of the Macintosh family because it was generally believed that the blind could not use an input device such as a mouse or trackball. A new development—inTouch™ software developed by Berkeley System Design Inc.—allows Optacon II to display tactually the information on a Macintosh screen. With the Macintosh system, the Optacon II camera is not used; instead, inTouch drives the computer interface and causes the Optacon sensor to show a portion of the Macintosh screen, which the blind operator reads by touch (far right).

™ inTouch is a trademark of Berkeley System Design Inc.

Advanced Pacemaker

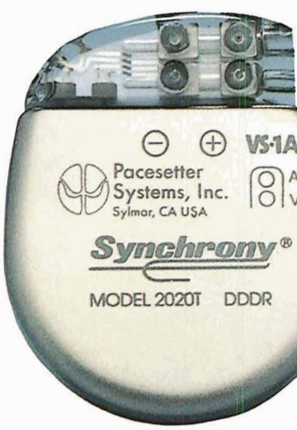
At right is Synchrony®, an advanced state-of-the-art implantable pacemaker that closely matches the natural rhythm of the heart. At right below is the companion element of the Synchrony Pacemaker System, the Programmer Analyzer APS-II, which allows a doctor to reprogram and fine tune the pacemaker to each user's special requirements without surgery.

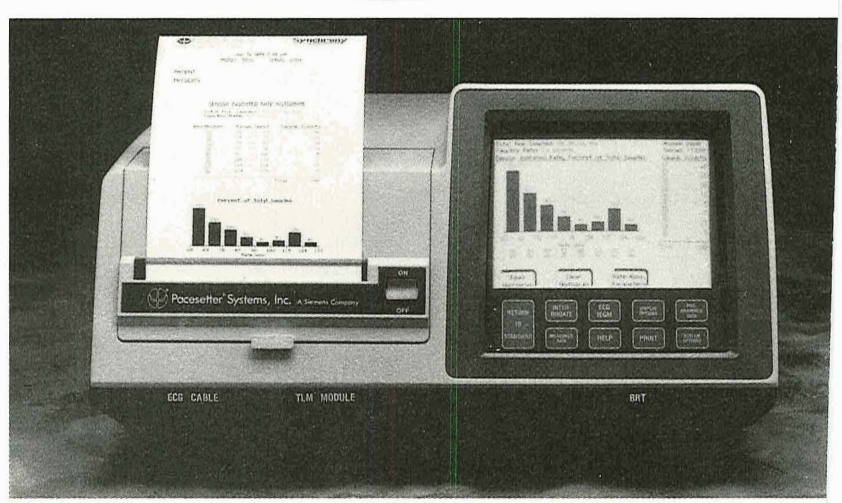
The Synchrony Pacemaker System, developed and produced by Siemens-Pacesetter, Inc., Sylmar, California, won Food and Drug Administration approval for general marketing in August 1989 after clinical trials involving more than 750 implants in more than 90 hospitals. The two-way communications capability that allows the physician to instruct and query the pacemaker is accomplished by means of the space technology known as bidirectional telemetry, which NASA developed for communication between Earth stations and orbiting satellites.

The people pictured, who span a wide age and activity spectrum, were among the first recipients. In the upper photo, opposite page, is Gary Norgan, 39, a Hemet, California life science teacher who enjoys backpacking, tennis and basketball; he became the first Synchrony recipient in the United States in March 1988. A July 1988 recipient is Deborah Rurik (right center), 33, vice president of a Columbus, Ohio real estate firm who participates in aerobics with her six-year-old daughter. Retired Bakersfield, California dentist Charles Linfesty (far right), 80, a December 1988 recipient is an avid fisherman who also does extensive walking and weight training.

These patients are able to pursue such activities because of Synchrony's dramatic technological advance: a rate-modulated, dual chamber device that synchronizes the upper and lower chambers of the heart. A uniquely designed activity sensor allows Synchrony to respond to body movement or activity; Synchrony then increases the heart rate, which boosts the supply of oxygen to the body. This feature opens up to pacemaker patients a whole range of activities—jogging, dancing, swimming or other athletic pursuits—from which they were previously barred.

With the two-way communications capability, the doctor can adjust the device to best suit a patient's needs, which may change over time with changes in physical condition. He can send signals to the pacemaker to alter its rate, for example, and receive signals from the implanted device informing him of the status of its interaction with the heart. The Programmer Analyzer APS-II features 28 pacing functions and thousands of programming combinations to accommodate diverse lifestyles. The microprocessor unit also records and stores pertinent patient

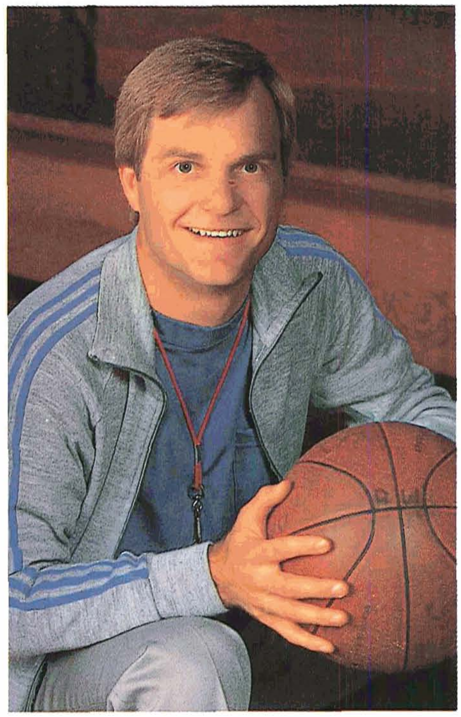




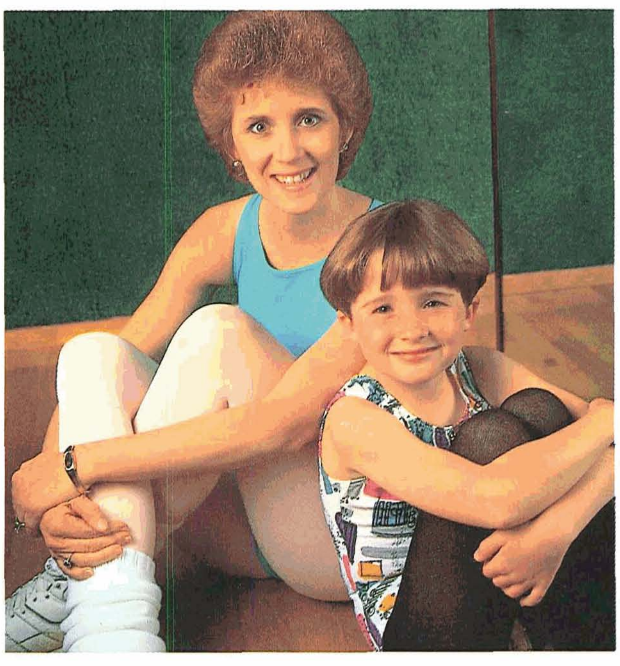
data for up to a year.

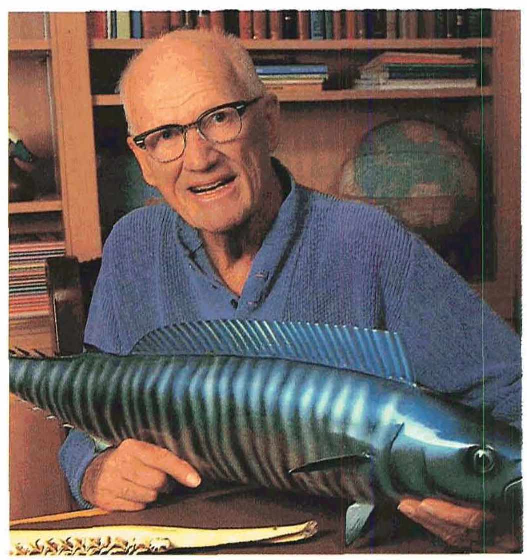
Siemens-Pacesetter resulted from a 1985 merger of the U.S. Pacesetter Systems, Inc. and Siemens-Elema AB, Solna, Sweden, a merger that created Siemens Worldwide Pacing Operations. The merged company is one of the world's two largest manufacturers of cardiac pacemaker system and accessories; together they produce some 70,000 pacemakers a year.

Siemens-Elema developed the world's first pacemaker, implanted in 1958. Pacesetter Systems, formed in 1969 in a joint effort with the Applied Physics Laboratory of The Johns Hopkins University, was the first to apply aerospace technology to the medical sector. Pacesetter Systems introduced the first long-life cardiac pacemaker in 1973, employing technology developed for spacecraft electrical power systems. In 1979, Pacesetter was first to utilize bidirectional telemetry, which allows physicians to monitor noninvasively and modify the interaction of the heart and a cardiac device.



®Synchrony is a registered trademark of Siemens-Pacesetter, Inc.

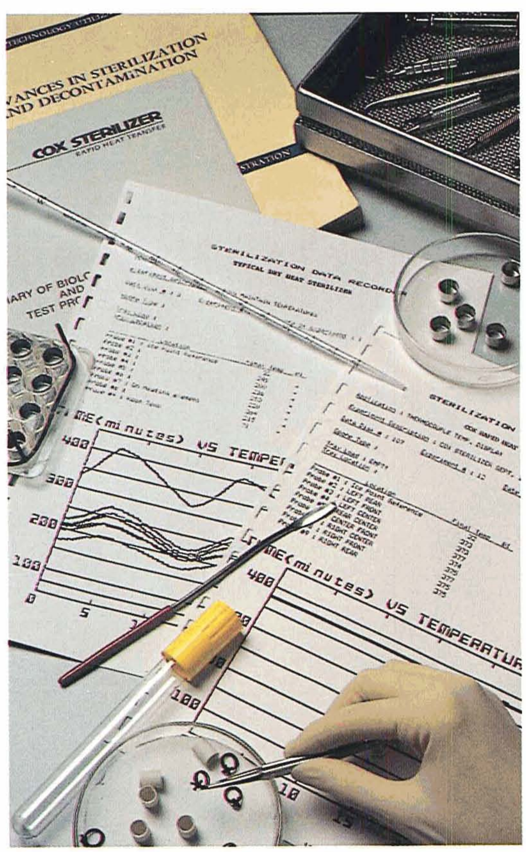




Sterilization System

At right, dentist Dr. M. Keith Cox, president of Cox Sterile Products, Inc., Dallas, Texas, displays the Cox Rapid Heat Transfer Sterilizer™ he developed with the help of NASA technology. Intended for fast, effective, economical sterilization of dental and medical instruments, the system employs dry heat technology that NASA used to sterilize and decontaminate two Viking Lander spacecraft that sought evidence of living organisms on Mars in the 1970s.

The sterilizer's big advantage, according to Dr. Cox, is reduced sterilization time—as little as six minutes, far less time than steam autoclave and chemical vapor sterilizers need and about one-tenth the time required by a conventional dry heat oven. Rapid sterilization eliminates excessive heating, the prime cause of instrument damage, and allows sterilization between patients. That makes possible a reduction of more than 80 percent in instrument inventory, says Dr. Cox, which can mean savings of thousands of dollars.



Dr. Cox became interested in sterilization when he worked his way through dental college as a scrub nurse in a hospital operating room. That experience, coupled with the dentistry profession's emphasis on infection control, prompted him to consider development of an improved instrument sterilization system for the dental office.

Much of the information he needed was available in a NASA publication. In planning the Viking Mars missions, NASA had gone to extraordinary lengths in studying ways to sterilize the Viking Landers and thus protect the Mars environment from contamination by Earth organisms or particulate matter that might erroneously influence the Lander's analytical instruments. NASA explored and evaluated every form of thermal and chemical sterilization before settling on the dry heat approach, which offered minimal corrosion and obviated the use of toxic chemicals.

This exhaustive research was summarized in a 1978 survey entitled *Advances in Sterilization and Decontamination*, prepared for Langley Research Center by The Bionetics Corporation,

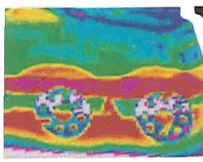
™ Cox Rapid Heat Transfer Sterilizer is a trademark of Cox Sterile Products, Inc.

Hampton, Virginia. Dr. Cox used the survey as the primary information source for his sterilizer development. He credits as particularly useful a chapter on heat sterilization, which aided development of his own technique; a chapter on sterilization materials and compounds, which identified manufacturers of compatible products; and a chapter on analytical models, which helped him develop computer programs for efficacy testing in conjunction with the Food and Drug Administration (FDA). The lower photo, opposite page, illustrates the varied tests involved in certification by the FDA and the American Dental Association, principally tests of microbe survivability after a sterilization run.

The Cox Rapid Heat Transfer Sterilizer that emerged from the R&D program and went into production in 1988 employs a heat exchange process that induces rapid air movement—to 3,000 feet per minute—and the air becomes the heat transfer medium, maintaining a uniform temperature of 375 degrees Fahrenheit. It features pushbutton controls for three timing cycles for different instrument loads as pictured at left above: a six-minute cycle for standard unpackaged instruments (low corner of the photo), eight minutes for certain specialized dental/medical instruments (top corner) and 12 minutes for packaged instruments (right center), which can then be stored in a drawer in sterile condition.

The system will stay at 375 degrees all day, so there is no need to wait for temperature buildup on each cycle. An insulated jacket keeps heat within the unit and prevents its radiation into the room. Continuous operation is not expensive, says the company, because of the sterilizer's very low power requirements, which provide a bonus advantage: the system can operate for long periods off a generator such as the one contained in the disaster relief vehicle shown at left. This allows use of sterile techniques in disaster areas where they are not otherwise possible, because electric power service is usually disrupted in major emergencies such as floods or earthquakes.

A New Continent of Ideas



What happens if an astronaut on a space station of tomorrow needs an emergency appendectomy—and there is no surgeon on board?

Telesurgery is one possibility—surgery performed by a robot whose movements are precisely guided by a surgeon on Earth. He conducts the operation by a combination of computers, television and advanced sensors. The stereoscopic view entirely surrounds the doctor so that he feels he is actually a part of the space station scene, and he is able, through instrumented glove technology, to direct the robot's hand movements to correspond exactly to his own hand movements.

Way out? Not really, according to scientists at Ames Research Center's Aerospace Human Factors Research Division. Telesurgery is not now available, of course, but it is considered feasible for a 21st century time frame, say two to three decades from now. And it is only one of an infinite number of exciting potential applications for a burgeoning new technology called "virtual reality."

The technology is still at the "ground floor" level, still somewhat crude, requiring a great deal of development and refinement. But one of its basic components—3D computer graphics—is already in wide commercial use and expanding explosively. Other components that permit a human operator to "virtually" explore an artificial environment and to interact with it are being demonstrated routinely at Ames and elsewhere. Some of them, in fact, are already commercially available, albeit expensively, and the technology developed for one of Ames' artificial reality research tools—the instrumented glove—has even found its way into a video game.

Virtual reality (VR) might be defined as an environment capable of being virtually entered—telepresence, it is called—or interacted with by a human. One reason for NASA's interest is an anticipated need for large scale remote control of robotic space systems. Robots are becoming more and more sophisticated, more and more dextrous, and there is need for corollary development of devices, displays, skills and techniques that will allow telepresence and effective telerobotic control.

Since the mid-1980s, Ames' Aerospace Human Factors Research Division has been developing experimental systems that permit human/computer interaction. For example, the VIEW system. VIEW stands for Virtual Interface Environment Workstation. It is a head-mounted stereoscopic display system in which the display may

Photo by Wade Sisler

Above, a NASA scientist is conducting a test of Ames Research Center's "virtual reality" headset. She sees a computer-generated 3D scene or a real environment remotely relayed by video cameras; the stereo imagery suggests that she is actually part of the scene.

Topping a selection of spinoffs in computer technology are hardware/software systems for advancing the exciting concept of virtual reality

be an artificial computer-generated environment or a real environment relayed from remote video cameras. The operator can—virtually at least—"step into" this environment and interact with it.

He wears a headset whose centerpiece is a display box containing two small (3.9-inch) television screens, one for each eye so that the TV image appears three dimensional. The scene is accompanied by appropriate sound effects delivered to the headset. The headset bars view of anything but the imagery, thus helps create the illusion that the user is part of the scene pictured. One example of an important practical application: a design engineer can virtually become part of the fuel flow of a rocket engine and travel with the flow, noting places where it slows, speeds up or becomes turbulent; he can learn a great deal about system design that he could not in 2D simulation.

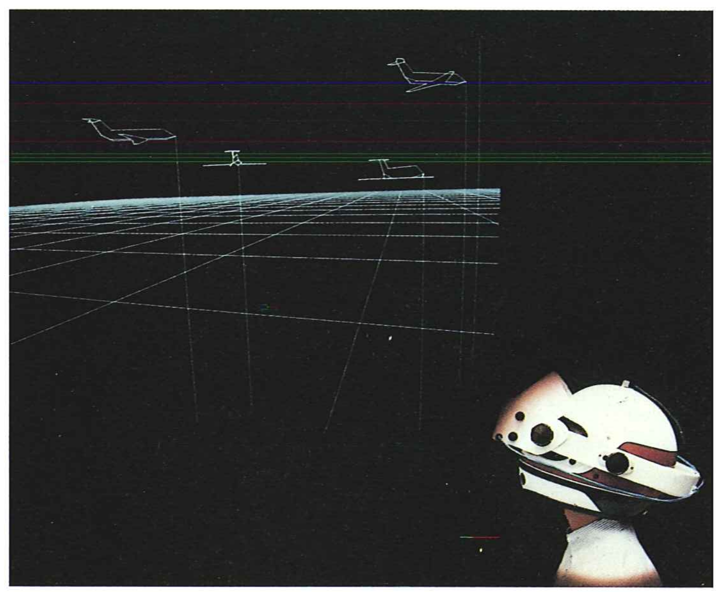
The scene might be a room. If the operator turns his head, the scene shifts just as it would in the real world; a headset-mounted sensor tracks the position of the user's head and communicates this knowledge to the computer. By pointing in a given direction, the operator virtually moves in that direction so he can explore any part of the room. Ames is developing a library of software for various scenes and the operator can select a menu option by a word or gesture, because the system is trained to recognize voice and gesture commands.

An important addition to the Ames system is the DataGlove™, an experiment in telepresence control of advanced robotic hands or fingers. Developed for Ames by VPL Research, Inc., Redwood City, California, the glove has a series of fiber optic cables and sensors that detect any movement of the wearer's fingers and transmit the information to a host computer; a computer-generated image of the hand will move exactly as the operator is moving his gloved hand. With appropriate software, the operator can use the glove to interact with the computer scene by grasping an object, for example, moving a virtual chair within the simulated room; the computer will dutifully move the chair in the TV display. Not only that, the operator can "feel" the virtual chair through tiny vibrators in the fingertips of the DataGlove.

It is possible, Ames and other VR researchers feel, to replicate almost any environment or activity, so VR has immense potential, both as a research tool and an operational system for telepresence/telerobotics.

The possibilities for practical applications of VR in everyday life are even broader, thinks Jaron Z. Lanier. Lanier is chief executive officer of VPL Research, developer of the DataGlove and other systems for creating virtual reality, which he describes as "a new continent of ideas."

(Continued)



A possible future application of virtual reality: an air traffic controller wearing a helmeted version of the headset monitors aircraft from a virtual viewpoint in the airspace.

™ DataGlove is a trademark of VPL Research, Inc.

A New Continent of Ideas

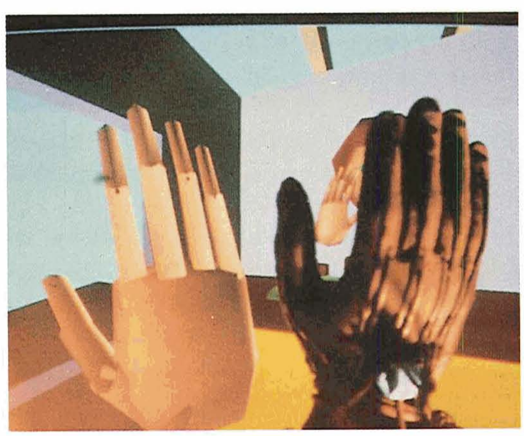
(Continued)

Jaron Lanier, 29, originally planned to be a professional musician, got sidetracked into computers and software, then into designing video games. In 1984, he met Tom Zimmerman, who was developing a wired glove with which to play an imaginary "air guitar." Lanier recognized the virtual reality potential of Zimmerman's concept, persuaded Zimmerman to join him and founded VPL Research to pursue the glove idea and related VR systems.

In April 1986, VPL won a contract for its first product, the NASA DataGlove. Made of thin Lycra, the gloves have sensors at 15 points that monitor flexion and extension of the fingers, the position and orientation of the hand and thus permit hand/computer interaction. The first glove was delivered to NASA in May 1986.

During the NASA contract, Lanier and VPL scientists worked closely with NASA virtual reality principal investigator Scott S. Fisher and his telepresence/telerobotics researchers at Ames' Aerospace Human Factors Research Division. It was a mutually beneficial arrangement; NASA gained an important research capability with development of the DataGlove and VPL learned from extensive use of the technology incorporated in Ames' VIEW system.

In a remarkably short span, VPL has expanded its research and product line. A natural follow-on to the DataGlove was the DataSuit™, a sensor equipped full body garment that greatly increases the sphere of performance for virtual reality simulations by reporting to the computer the motions, bends, gestures and spatial orientation of the wearer—in other words, it makes possible full body interaction with the computer generated virtual world. The absolute position sensors for the DataGlove and DataSuit—and also for the head tracker in Ames' VIEW system—are provided by Polhemus Inc., Colchester, Vermont. The DataSuit has already found a commercial application, an unusual one: it is worn by film actors to give fluid, realistic motion to animated characters in computer-generated movie special effects.



At top is the DataGlove developed for NASA by VPL Research, a computer input device for manipulating 3D environments. In the lower photo the movements of the gloved hand are duplicated on the screen by a computer-generated graphic hand.

The VPL Research EyePhone is a headset in which the viewer can't see the physical world, instead sees a computer generated VR world in color and 3D. With the DataGlove, the goggled VPL engineer shown can virtually grasp and pick up objects in the VR world as if they were real.

After DataSuit, VPL created its own version of the eye display in NASA's helmet system, the EyePhone™, a head-mounted stereo display. VPL has developed a line of software for virtual reality applications. The company offers a complete package, the RB2 Virtual Environment, that includes one DataGlove, the EyePhone, a design control workstation with processor and associated software, cables, transceivers and connections, for $45,000. With the computers, which are made by Silicon Graphics, Mountain View, California, the whole system goes for $200,000 for a single user, $400,000 for two users.

That's costly, to be sure, but VR enthusiasts are counting on continuance of the dramatic drop in computer costs that made personal computers available to all and may similarly broaden VR applications.

The DataGlove alone sells for about $9,000. Among immediate applications are Computer-Aided Design and Manufacturing (CAD-CAM), wherein the glove serves as an input device for manipulating 3D environments; the user can grasp objects on the screen to change an environment without lengthy keyboard stroking. In robotics, robot arms and grippers can be manipulated in real time by the gloved hand, for training or telemanipulation. In animation, computer-generated characters can be puppeted by mapping DataGlove sensor values to the characters' limbs or actions.

The glove has medical applications, too, for example, it can be used for sign language research or as a tool for assessing hand function and performance; these applications are being developed by Greenleaf Medical Systems, Palo Alto, California. And, of course, it can be used to interact with simulated environments for a variety of purposes; already on the market is Mattel Toys' simplified version of the glove for use in Nintendo video games.

With improvements contemplated for the next few years, VPL sees such additional uses for the RB2 system as allowing an architect's clients to inspect and perhaps alter a building design before the structure is built by virtually walking through a graphic replication of it; similarly, the system makes it possible to walk through dynamic models of communication networks, large databases and traffic control systems. VR offers three-dimensional scientific visualization, particularly useful in chemistry, geology and aerodynamics. In medicine, it offers an additional increment of information-gathering capability when used as an image enhancement tool in diagnostic body imaging.

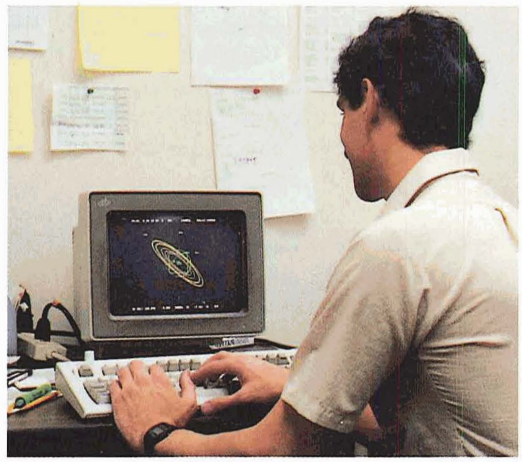
VR has broad potential for training in a number of fields. As for education, it permits virtual travel in time; a student can virtually *be* a pharaoh in ancient Egypt, a tyrannosaurus hobnobbing with other dinosaurs or a comet soaring past planets and moons and asteroids at a million miles an hour. And entertainment? Says VPL: "We leave that to your imagination. . ."

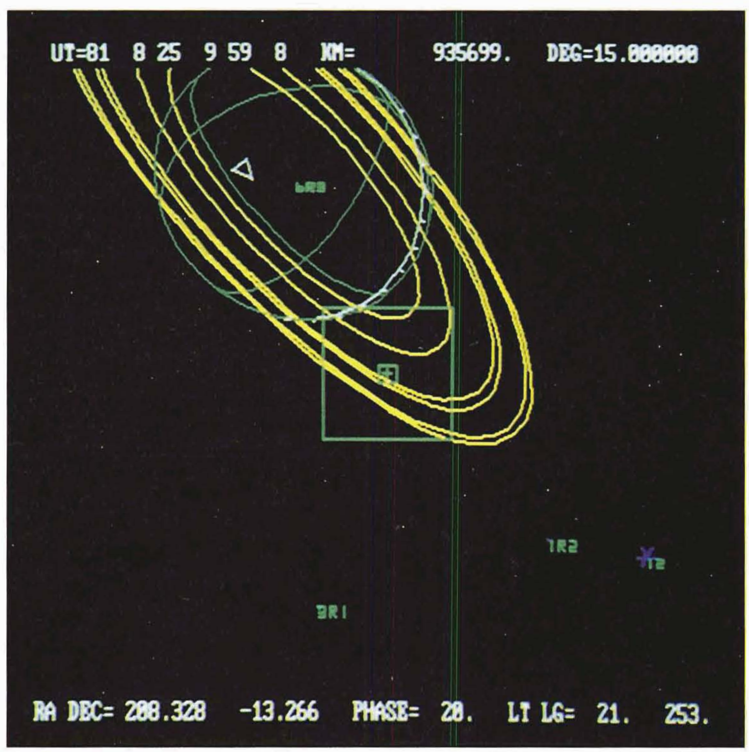
"VR is shared and objectively present like the physical world," company literature states, "composable as a work of art and as unlimited and harmless as a dream. When VR becomes widely available, it will not be seen as a medium used within a physical reality, but rather as an additional reality. VR opens up a new continent of ideas and possibilities."

Wearing sensor-equipped DataGloves and a full-body DataSuit, a technician can virtually become part of a computer-generated environment. Sensor signals are picked up by the computer and the suit-wearer's motions, bends and gestures are replicated in the artificial environment.

™ DataSuit and EyePhone are trademarks of VPL Research, Inc.

Space Software





In the mid-1980s, Jet Propulsion Laboratory (JPL) developed a computer program called MIP, for Multimission Interactive Picture Planner. It was designed as an aid in analyzing science and optical data collected on such missions as the Voyagers' grand tour of the solar system (1977-90) and the Giotto rendezvous with Comet Halley (1986).

Through an agreement with NASA, XonTech, Inc., Van Nuys, California is offering a commercial version of the program to the general public. Called XonVu (Zon-view), the software package simulates the missions of Voyager 1 at Jupiter and Saturn, Voyager 2 at Jupiter, Saturn, Uranus and Neptune, and Giotto in close encounter with Comet Halley.

At right above, John D. Callahan of XonTech, who designed the program when he was an astronomer at JPL, is checking out XonVu. The representation on the screen, shown in closeup below, is a simulation of Saturn, its rings and two of its moons, as viewed by Voyager 2 on its 1981 approach to the planet.

With the program, the user can generate scenes of the planets, moons, stars, or other solar system objects seen by the Voyagers, or Halley's nucleus and tail as seen by Giotto, all graphically reproduced with high accuracy in wireframe representation. The program takes the viewer along the actual paths flown by the Voyagers and Giotto; he cannot invent a new flight path. He can, however, zoom in on an object, rotate the field of vision, or change perspective; for example, it is possible to view a space scene from the perspective of the spacecraft, from Earth, or from a point in space that provides a view of both the spacecraft and its encounter target.

The program can be used on a wide range of computers, including PCs. User friendly and interactive, with many options, XonVu can be used by a space novice or a professional astronomer. With a companion user's manual, it sells for $79.

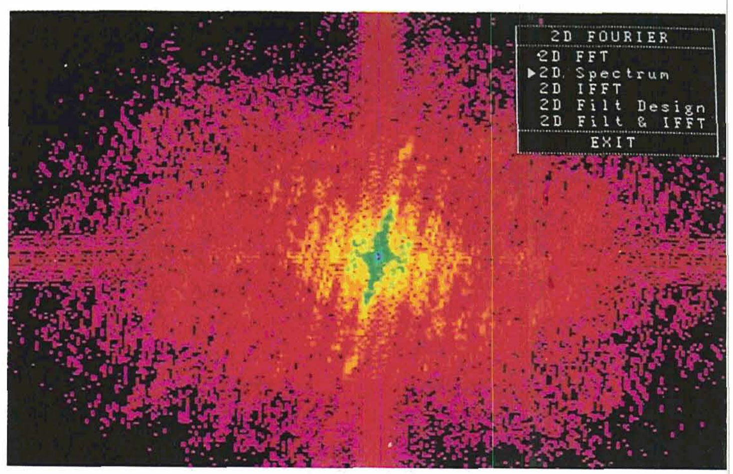
Image Processing Software

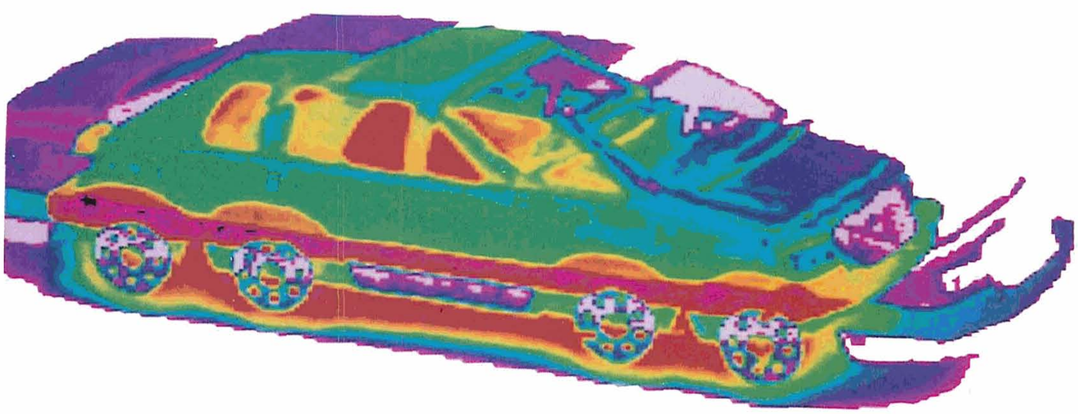
Working with a personal computer linked to a Cray supercomputer, Dr. Y.C. Cho of Ames Research Center developed a new method for measuring motion with multiple exposure images. He captured such images by pointing a camera at a scene, triggering a strobe light several times with the shutter open, and digitizing the resulting exposures on a PC. He then transferred the digitized images to the supercomputer and computed the two-dimensional fourier spectrum of the image. Cho showed that the speed of the object pictured can readily be determined from the width of the stripes that appear in the spectrum image as a result of the object's motion.

The Ames digital image velocimetry technology has been incorporated in a commercially available image processing software package that allows motion measurement of images on a PC alone. The software is IMAGELAB FFT, marketed by Werner Frei Associates, Venice, California.

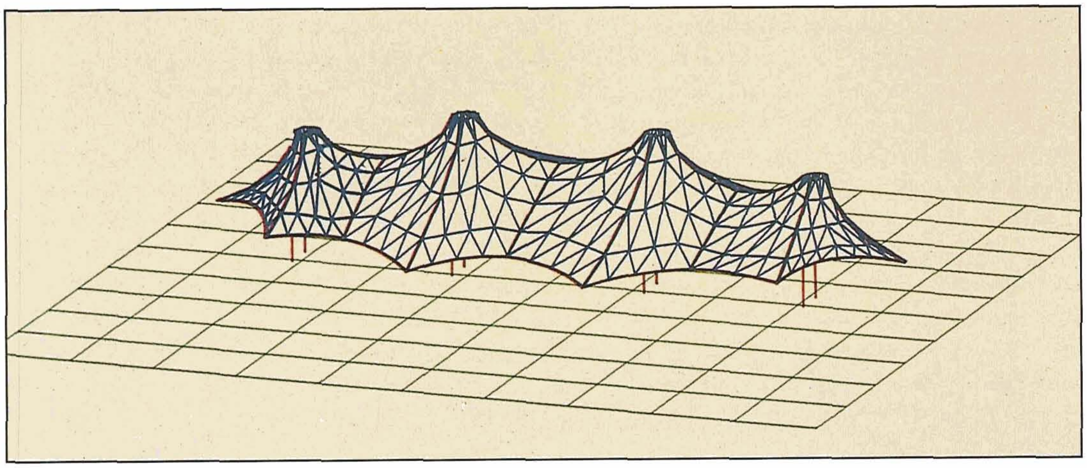
The images shown were produced on an IBM PC. Shown below is a double exposure of a moving car; at right is a fourier spectrum of the moving car's image. In the center of the latter image are a series of yellow/green stripes that provide a key to easy calculation of the moving car's speed; the speed is inversely proportional to the width of the stripes, the time interval between exposures and the magnification of the imaging lens.

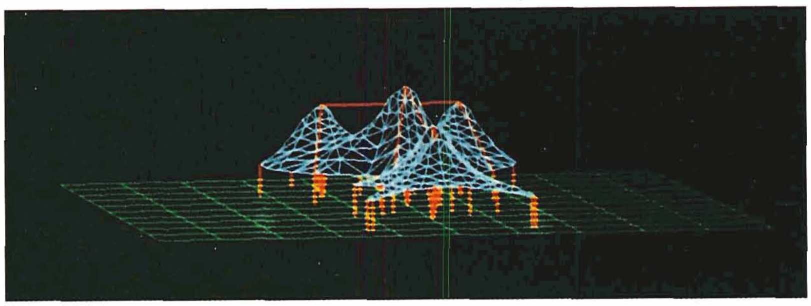
IMAGELAB FFT is a general purpose image processing system with a variety of other applications, among them image enhancement of fingerprints and use by banks and law enforcement agencies for analysis of videos run during robberies. Werner Frei Associates' customers are for the most part researchers who use the software to analyze, restore or enhance imagery.





Design Graphics





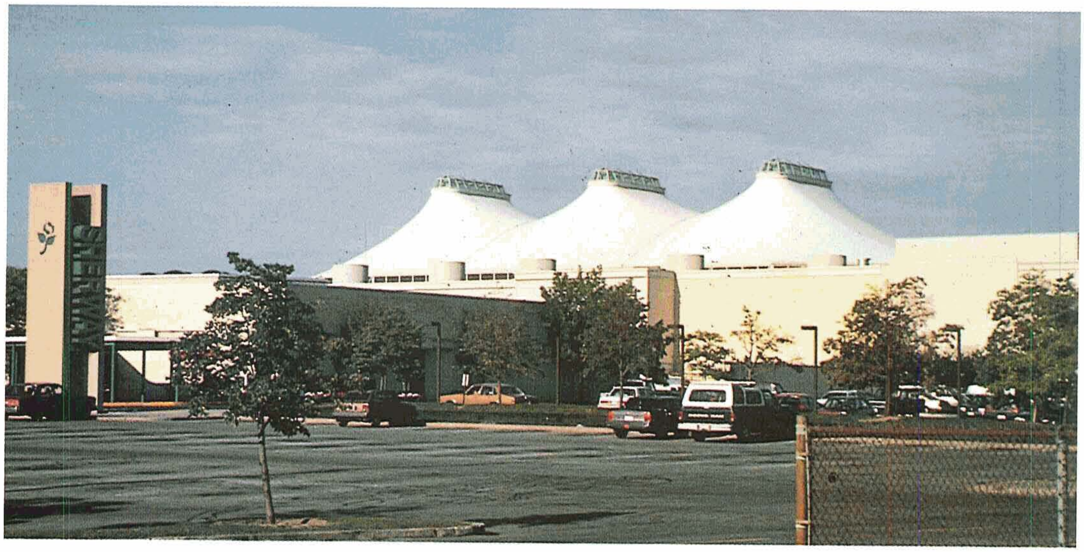
Originally an aerospace innovation, the use of computer-generated graphics as a design tool has long been employed in such other fields of design as architecture, metallurgy and auto development. But until 1982, use of this technique posed a problem.

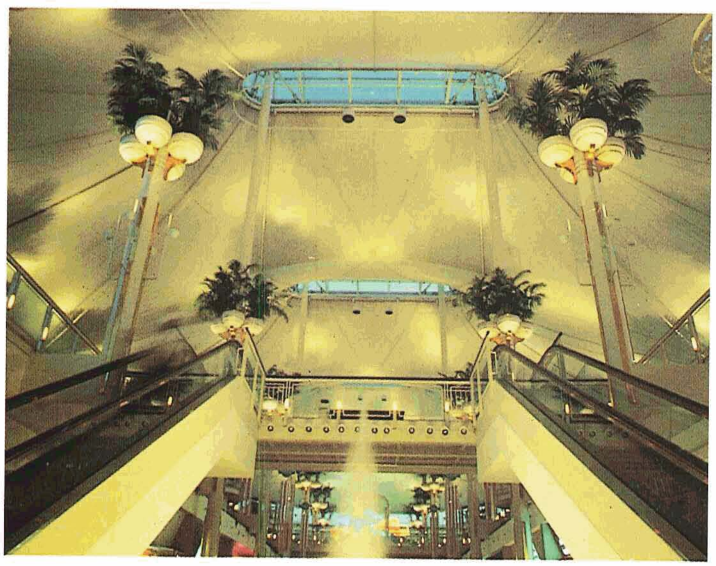
The problem was that a computer could not "see" a solid object as the human eye sees it; the computer defines the whole object without regard to perspective. For example, if a human looks at a desk, he sees the top surface and one or two sides, depending on his viewing angle. But a computer asked to produce a picture of the desk would show all the desk's surfaces, angles and curves, including all the parts a human viewer could not see. This resulted in a cluttered, confusing graphic representation that complicated the design process.

A mathematician at Ames-Dryden Flight Research Facility, David R. Hedgley, Jr., came up with a solution after two years of effort: a computer program that considers whether a line in a graphic model of a three-dimensional object should or should not be visible. Known as the Hidden Line Computer Code, the program automatically removes superfluous lines and displays an object from a specific viewpoint, just as the human eye would see it.

In April 1982, the Hidden Line Computer Code was made available to public users through NASA's Computer Software Management and Information Center (COSMIC)®, which supplies government-developed programs adaptable to secondary uses for industrial and government customers. It was an immediate best seller and the number of users has grown each year.

An example of how one company uses the program is the experience of Birdair, Buffalo, New York, which specializes in production of fabric skylights and stadium covers. The fabric —called SHEERFILL®—is a Teflon®-coated fiberglass material developed in cooperation with DuPont Company, Wilmington, Delaware. SHEERFILL structures are translucent, lightweight, energy efficient and immune to attack by pollutants and ultraviolet radiation.





SHEERFILL glazed structures are either tension structures, employed in all types of skylighting, or air-supported tension structures, sometimes used as stadium domes. Both are formed by patterned fabric sheets supported by a steel or aluminum frame or a cable network.

Birdair uses the Hidden Line Computer Code, obtained through COSMIC, to illustrate a prospective structure to an architect or owner. The program generates a three-dimensional perspective with the hidden lines (those that would not be visible to the observer) removed.

The fabric structure is plotted as a mesh of triangles (opposite page, top). This finite element model is color coded according to a program modification developed by Claude Frenette, Birdair senior systems analyst/engineering programmer. The fabric proper, the supporting cables and a ground-level planar grid are each plotted in a different color (opposite page, lower photo) to aid in the proper visualization of prospective structures. Examples of completed structures are shown on this page; all are views of the Sherway Gardens Mall, Toronto, Canada.

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® SHEERFILL is a registered trademark of Chemical Fabrics Corporation.

® Teflon is a registered trademark of DuPont Company.

Pressure Analysis

FluiDyne Engineering Corporation, Minneapolis, Minnesota is one of the world's leading companies in design and construction of wind tunnels. The company designed NASA's National Transonic Facility at Langley Research Center and a number of other NASA facilities; it has also designed and built wind tunnels for other U.S. agencies, for foreign governments and for a number of commercial operators.

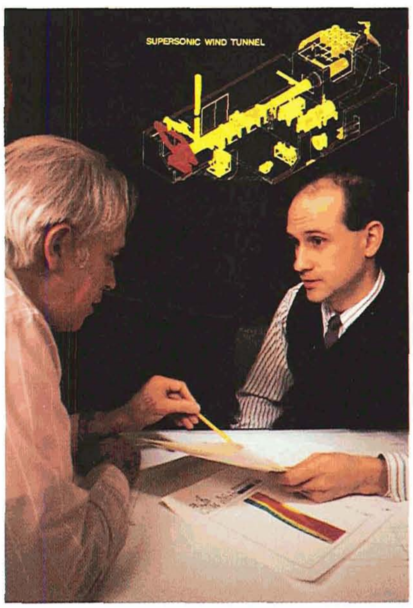
In its design work, FluiDyne uses a computer program called GTRAN, which was supplied to the engineering firm by NASA's Computer Software Management and Information Center (COSMIC).

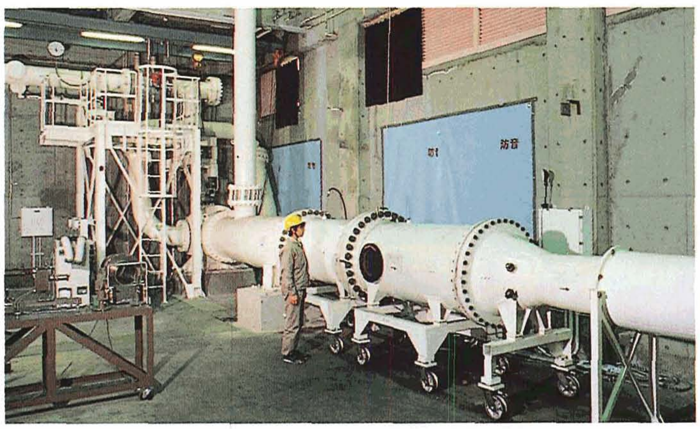
In the photo below, FluiDyne senior engineer Dr. Dean Long and a co-worker discuss use of GTRAN in an industrial wind tunnel being designed. With GTRAN, engineers create a design and test its performance on the computer before actually building a model; should the design fail to meet criteria, the system or any component part can be redesigned and retested on the computer, saving a great deal of time and money. At lower right is a FluiDyne-designed wind tunnel at a research facility in Komatsu, Japan.

Transonic wind tunnels consist of a main chamber surrounded by a larger volume, known as the plenum, which is designed to accept the surplus airflow associated with pressure changes in the main flow. As the system rushes to reestablish equilibrium, the wall of the plenum must be able to withstand the pressure, hence must be monitored.

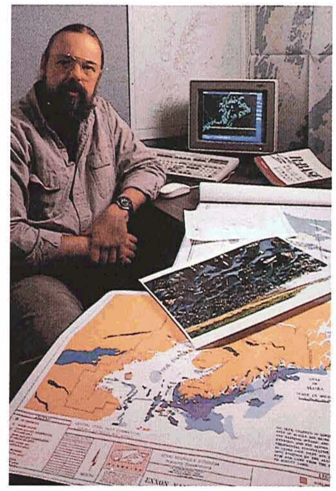
The GTRAN program was originally developed to solve transient problems in flow piping systems. Valves and pipes that connect volumes must be able to withstand pressure changes associated with fluid flow toward equilibrium; GTRAN plots pressure and density changes in such connecting elements. Thus the program was readily adaptable to FluiDyne's need for a means of monitoring the pressure changes in wind tunnels and air supply systems.

Located at the University of Georgia, COSMIC routinely supplies to government and industry customers software packages that can be adapted to uses other than those for which they were originally developed by NASA and other technology generating agencies of the government.





Database Management System



A decade ago, Boeing Computer Services developed for NASA a database management system to store the voluminous data for analyzing the heat shield tiles on the Space Shuttle Orbiter. Called RIM (for Relational Information Manager), the system was developed by a team of scientists led by Wayne Erickson and Dennis Comfort.

In 1981, Erickson founded Microrim®, Inc., Redmond, Washington, a company originally focused on marketing a microcomputer version of RIM; Comfort joined the firm and is now vice president-development.

The team developed an advanced spinoff from the NASA system they had originally created, a microcomputer database management system known as R:BASE 4000, introduced in 1983. Subsequently, Microrim added many enhancements and developed a series of R:BASE products for various environments. R:BASE is now the second largest-selling line of microcomputer database management software in the world.

Here is one of many examples of its utility:

On March 24, 1989, the tanker *Exxon Valdez* struck a reef and spilled millions of gallons of oil into Alaska's pristine Prince William Sound. Alaska's Department of Environmental Conservation (DEC) was on the scene quickly with a computerized system to track and map the spill. The system—called GeoREF—links a spatial database with Microrim's R:BASE so that topographical data can be combined with data from aerial flyovers, sampling station instruments and individual sitings to produce graphic displays of information needed to allocate manpower and equipment in emergencies.

Within hours of the spill, DEC had in operation a system that tracked the thickness, size and movement of the spill and the land areas and animal populations affected; it also provided information for deployment of spill response equipment. In the top photo, DEC's Jim Slocomb is surrounded by the hard copy information available from GeoREF and other programs. The lower sequence of computer images shows three representative views of the spill's growth over a two-month span; regular updates were produced daily, allowing DEC to keep close track of the spill and alert conservationists to wildlife habitats most seriously threatened.

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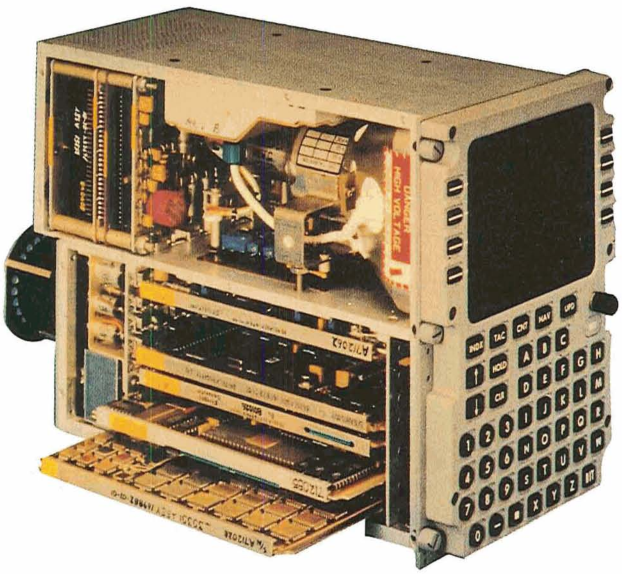
Thermal Analysis



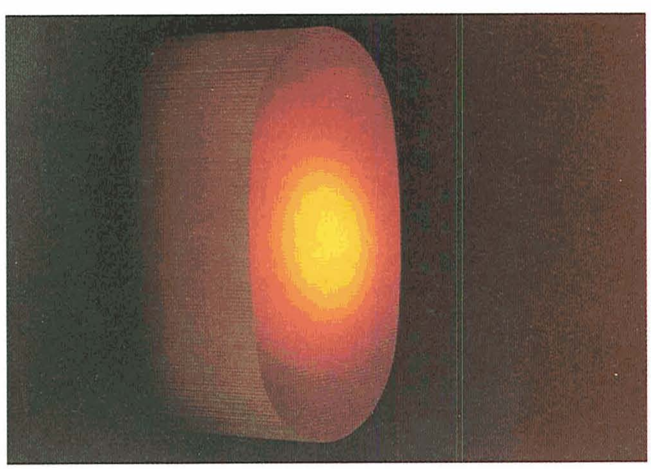
Designing reliable aviation electronic equipment requires precise predictions of the unit's thermal performance. Packaging engineers can avoid unnecessary and costly redesign of the product through use of tools such as the SINDA '85/FLUINT software system for predicting thermal performance. SINDA is made available to industrial and government clients by NASA's Computer Software Management and Information Center (COSMIC).

SINDA '85/FLUINT is an acronym for Systems Improved Numerical Differencing Analyzer and Fluid Integrators. It is a program for solving the physical problems governed by flow and diffusion type equations and is most widely used as a general thermal analyzer. An example of a SINDA user is the packaging and engineering group of Smiths Industries, Grand Rapids, Michigan division, which designs navigational aides and other avionics for commercial and military aircraft.

A 20-year user of SINDA, the division has applied the upgraded design tool to a fiber optic gyro and in the Integrated Display Computer (above) for a Navy aircraft. By applying finite modeling techniques to develop a model of the structure, engineers can obtain thermal predictions typically within two degrees Centigrade of measured values. When an abnormality, such as a localized hot spot, is predicted, a change in the product design can be made early to eliminate potential problem areas.

Another SINDA '85/FLUINT user is Corning Inc., a Corning, New York specialty glass and ceramics firm. One application of the program is modeling the heat flow in catalytic converters; shown below is a catalytic converter during heat-up. The hotter a converter gets, heated by engine exhaust, the better it is at removing hydrocarbons, hence more efficient in controlling emissions. A SINDA '85/FLUINT thermodynamic model can be used to predict the time necessary for optimum converter functioning during a standard Environmental Protection Agency test cycle.

Corning has also found SINDA '85/FLUINT valuable in research on glass forming processes; the program models the thermal behavior of molten glass during shaping and cooling. Additionally, company researchers are studying the visco-elastic behavior of glass by stretching furnace-heated fibers; SINDA '85/FLUINT helps in modeling the elongation of the fibers.

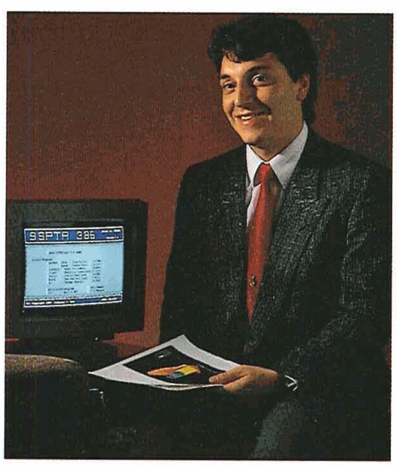


Thermal Analysis Software

Depending on their orientation to the Sun, payloads in orbit are subjected to heat and cold over a range of several hundred degrees. To assure that spacecraft perform properly over the entire temperature range, extensive thermal analyses are conducted during the payload design phase.

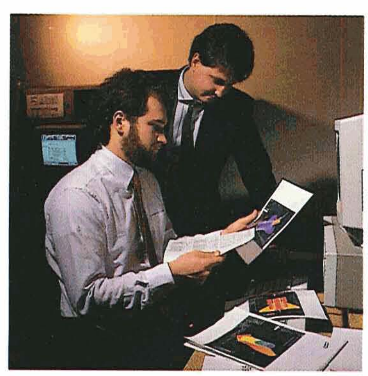
To meet a need for an easier-to-use and less costly way of doing thermal analyses, Goddard Space Flight Center contracted with Arthur D. Little, Inc. for development of a software package that simplified the complex procedures involved. The resulting product was the Simplified Space Payload Thermal Analyzer, or SSPTA, essentially an integration of several computer programs used independently in thermal analysis of spacecraft. Goddard successfully used SSPTA for years on a VAX computer and the software has proved an effective thermal analysis tool for many other government and industry users.

A former Goddard engineer has taken the simplification process a step further. Nicholas M. Teti, an engineer who worked in Goddard's Thermal Engineering Branch (1985-89) and is now with Swales and Associates, a Beltsville, Maryland engineering consulting firm, developed a new version of SSPTA that can be used on a 386 personal computer. Thus a small business can use the modeling software at a fraction of the investment a VAX computer would entail. At lower left, Teti is pictured with his software installed on a 386 PC.



SSPTA/386, as Teti calls his software package, includes the programs that Goddard has traditionally used in thermal design and analysis. The original programs were modified to run on the 386 system and automatic data transfer between programs was improved. SSPTA/386 includes all the features available in Goddard's VAX version of SSPTA. SSPTA/386 is designed to meet the needs of experienced thermal engineers, who may or may not have computer experience, as well as the needs of junior engineers and computer specialists who have little thermal analysis experience.

Teti's software package is highly flexible in that it allows the user to run the programs interactively or in batch mode. It provides a menu system that allows the user to select a program or a combination of programs. Below, are two of Teti's associates, S. Bruffey, at left, and Edward J.M. Colbert, who worked to make the menu system and database manager more user friendly. Teti originally developed SSPTA/386 solely for his own use, but it has met with such interest he is now offering the package commercially.



Longer Life for Steel Structures

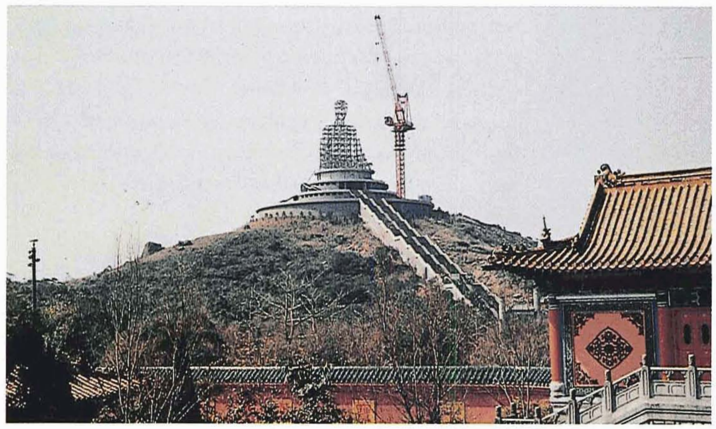
Kennedy Space Center (KSC), NASA's principal space launch base, is located on Florida's Atlantic Coast, and because of constant exposure to salt spray and fog, its steel structure facilities need greater protection from corrosion than is needed at locations farther from the ocean.

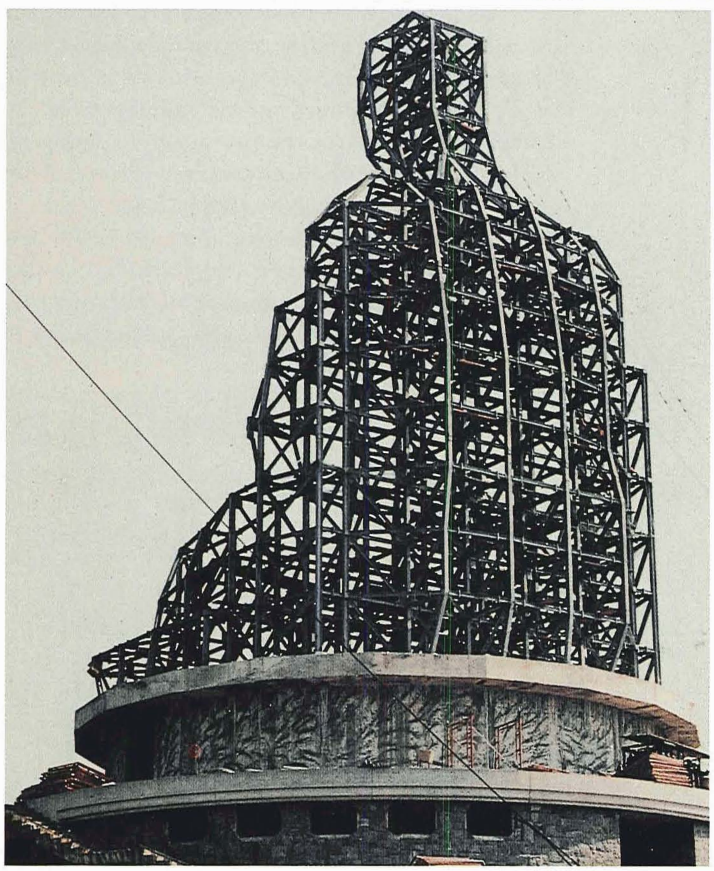
NASA decided that there was need for a new type of coating to reduce maintenance cost for gantries, the steel frameworks that provide multi-level access to launch vehicles, and other KSC facilities. Goddard Space Flight Center initiated a research program aimed at development of a superior coating that would not only provide long term resistance to salt corrosion but would also protect KSC launch structures from the very hot rocket exhaust and from the thermal shock created by rapid temperature changes during the first seconds of a launch.

Goddard researchers focused on water-based zinc silicate coatings, which had been available for years; they offered good protection but they required extensive curing. Looking for maximum cost-effectiveness, Goddard sought to improve zinc silicate formulations by boosting the ratio of potassium to silicate while maintaining stability of the formula.

That line of research proved successful and Goddard's effort was hailed as a breakthrough in inorganic chemistry. The high ratio formula eliminated the cure process and provided an answer to KSC's maintenance problem: an easy-to-mix, easy-to-apply, zinc rich coating with a water-based potassium silicate binder that would provide long term protection with a single application. It offers cost advantages in materials, labor hours per application and fewer applications over a given time span.

In 1981, NASA granted a license for the coating process to Shane Associates, Inc., Wynnewood, Pennsylvania. In 1982, Inorganic Coatings, Inc. (IC), Malvern, Pennsylvania signed an agreement to become sole manufacturer and sales agent under the Shane license. IC is now marketing the





At top and in closeup above is Hong Kong's mammoth Po Lin Buddha, shown under construction. The interior structure was coated with a spinoff IC 531 product that provides superior protection against corrosion and offers cost and environmental bonuses.

Among spinoff products that enhance public safety is a NASA-developed coating with superior corrosion resistance for structural security

product under the trade name IC 531 and has developed a number of new coating concepts.

In eight years of commercial use, IC 531 has demonstrated exceptional performance in single-coat applications and as a primer in multi-coat systems where it is combined with epoxy, acrylic and other topcoat formulations. Because IC 531 is water-based, it provides an environmental bonus: it is non-toxic, non-flammable and it generates no volatile organic compounds nor hazardous chemical waste. The high ratio formulation bonds to steel and in about 30 minutes dries to a very hard finish with superior adhesion characteristics. When topcoating is specified, IC 531's no-cure chemistry allows topcoating in two hours or less; that's a big plus, because it allows application of two, even three coats in a single shift.

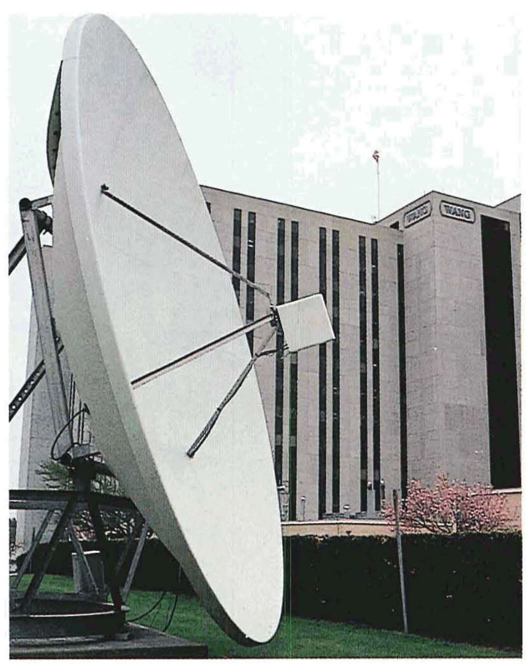
IC 531 came to public attention in 1984 when, after a seven-month study of various coatings, it was selected by the National Park Service and the Statue of Liberty Foundation as the best formulation for protecting Miss Liberty in her second century of service to America. It was also chosen as the protective system for Panama Canal rehabilitation.

A tractor trailer frame is coated with IC 531 zinc silicate; the coating's fast cure to ceramic-like hardness allows movement of the frame directly from the coating shop to the assembly line.

More recently, the coating was applied to the interior structure of a huge Buddha, roughly the size of Miss Liberty, at Po Lin Temple on Hong Kong's Lantau Island. The coating is used on a great variety of outdoor structures, vehicles and vessels, such as bridges, military tanks, shipboard equipment, dock equipment, buoys, municipal water facilities, power stations, antennas and tractor trailer frames.

How long is IC 531's effective lifetime? No one can say for sure because it hasn't been around long enough to be tested to its limit. At least 14 years, because some of the original Goddard test applications of 1976 are still going strong after lengthy exposure to the Sun, salt and moisture. Probably a lot longer than that. Says IC in company literature: "IC 531 offers virtually permanent protection for steel. We predict it will protect structures for well beyond 25 years. If necessary, it is infinitely maintainable; if damaged, it can easily be touched up with more IC 531."

Versatile Coating



At right and in closeup at far right is a large radome at Logan Airport, Boston, Massachusetts; the lower photo shows a large parabolic antenna at the Wang Building in Lowell, Massachusetts. These facilities are protected from weather, corrosion and ultraviolet radiation by a coating, specially designed for antennas and radomes, known as CRC Weathertite 6000 and produced by Boyd Coatings Research Company, Inc., Hudson, Massachusetts.

The CRC 6000 line represents a multiyear Boyd Coatings development, aided in part by NASA technology described in *NASA Tech Briefs* and other technical reports. *NASA Tech Briefs* is a monthly publication intended to let potential users know what new NASA developed technologies are available for transfer (see page 150).

On occasion, *Tech Briefs* reports contain sufficient information by themselves to inspire and guide development of a spinoff product or process. More often, *Tech Briefs* provides an initial lead; prospective users can follow up by requesting of NASA a Technical Support Package (TSP) that supplies more detailed information about a particular innovation.

Boyd Coatings used both approaches, using *Tech Briefs* information by itself over a period of years and sometimes following up with a request for a TSP. Says Boyd Coatings president Pedro A. Diaz:

"First work started 13 years ago and since then information and data generated by NASA has contributed on a steady basis to the development of the product. A small company such as ours could not have developed such a sophisticated coating without basic data on the performance of many materials, data supplied to a large extent by *NASA Tech Briefs.*"

Diaz mentioned as particularly useful a *Tech Briefs* report that described development of a stable thermal control coating with low solar energy absorption and another detailing a survey investigation of several high performance solar-selective coatings. In addition, Boyd Coatings development effort benefited from use of the NASA Handbook on Passive Thermal Control

Coatings, prepared for Marshall Space Flight Center by Teledyne Brown Engineering, Huntsville, Alabama.

The CRC 6000 line that emerged from Boyd Coatings' development work is a solid dispersion of fluorocarbon polymer and polyurethane that yields a tough, durable film with superior ultraviolet resistance and the ability to repel water and ice over a long term. Additionally, it provides resistance to corrosion, abrasion, chemical attacks and impacts.

The material can be used on a variety of substrates, such as fiberglass, wood, plastic and concrete in addition to steel and aluminum. A single coat is adequate for most applications. The coating has been on field trials for five years and has shown no significant loss of properties over that span.

In addition to its use on radar and antennas, Boyd Coatings sees CRC 6000 applicability as an anti-icing system coated on the leading edge of aircraft wings.

PUBLIC SAFETY

Aircraft Icing Sensor

Aircraft icing is a severe weather hazard. The buildup of ice changes the shape of the aerodynamic surfaces, which can alter the flow of air around critical components, particularly wings and engine inlets.

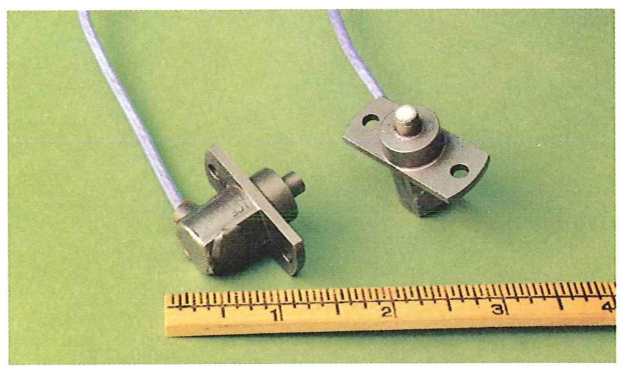
Aircraft are equipped with various devices to remove ice from critical components, including pneumatic boots, ice-melting heaters and other systems. A further need is for a system that alerts a pilot to the fact that ice is building up and can be used to automatically control the ice protection system. Generally, two types of detectors have been employed for that purpose, one that detects a differential pressure effect when ice forms over exposed holes, another that measures the changes in resonance of a vibrating probe as ice collects on it. These techniques have certain disadvantages: ice tends to build up on the probe areas more than it does on critical surfaces, and the probes protrude into the airstream, thus must be mounted on the fuselage rather than the wing.

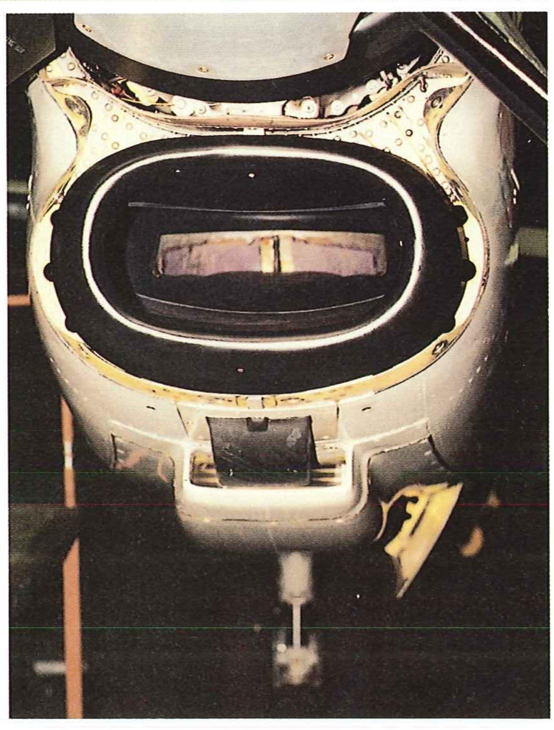
Looking for improved safety and fuel economy, Simmonds Precision Products, Inc., a subsidiary of Hercules Incorporated located at Vergennes, Vermont, undertook to develop a highly accurate, reliable ice detection system utilizing the latest advances in ultrasonics. The Simmonds Precision system is based on technology developed under a NASA grant by researchers at Massachusetts Institute of Technology (MIT) and on tests of the MIT-developed system, in a wind tunnel and in flight, at Lewis Research Center. Simmonds Precision is producing the system under license from MIT.

The Simmonds system consists of an ultrasonic sensor (above) and a signal conditioner. The sensor has a piezoelectric ceramic crystal (PCC) that sends an ultrasonic pulse into an ice layer and detects an echo returning from the ice; the time elapsed in the pulse-echo round trip provides a basis for calculating ice thickness.

Simmonds offers an alternative system with two PCCs, one a transmitter and the other a receiver for picking up the return echo. This technique offers detection of ice at much smaller thickness values, but at the cost of some ability to detect thicker ice.

Among the advantages of the Simmonds system are the small size of the sensor (an exposed diameter of half an inch), which allows its placement in areas previously inaccessible; it can be flush-mounted directly on surfaces, including airfoils, with no disturbance of airflow. In the photo below, the sensor (white dot) is mounted within the engine inlet of a turboprop aircraft. Other sensor advantages include high accuracy and insensitivity to salt spray, fog, chemicals and abrasion. Both sensor and signal conditioner offer high reliability, light weight and low power consumption.

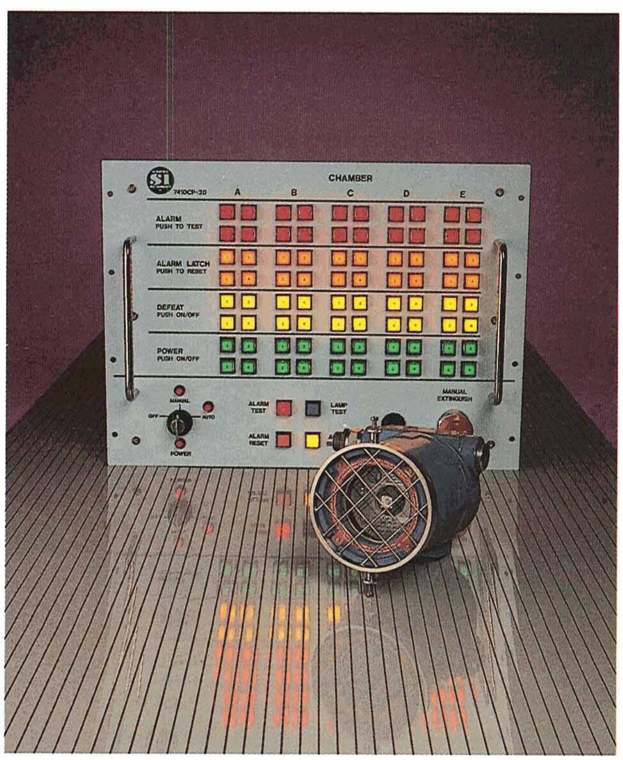




Flame Detector

At Kennedy Space Center (KSC), NASA stores hydrogen fuel for the Space Shuttle in large spherical tanks and feeds it through a pipeline to the launch pads. The hydrogen must be handled with care; it is easily ignited and is particularly troublesome because it burns with an invisible flame.

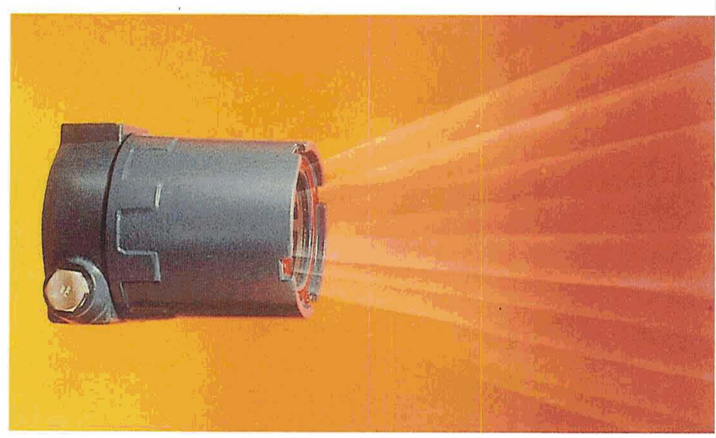
As a safety aid for KSC personnel, Scientific Instruments, Inc., West Palm Beach, Florida, developed a device capable of detecting the ultraviolet emissions in a hydrogen flame. Later the company expanded the utility of the device by adapting it to detection of flames from hypergolic propellants (those that ignite on contact with an oxidizer) in ground tests of the Space Shuttle's orbital maneuvering system and reaction control system. Subsequently, the detector went into service with the Air Force to monitor hypergolic fuel storage tanks, and with the Navy for use in hyperbaric chambers where deep underwater dives are simulated.



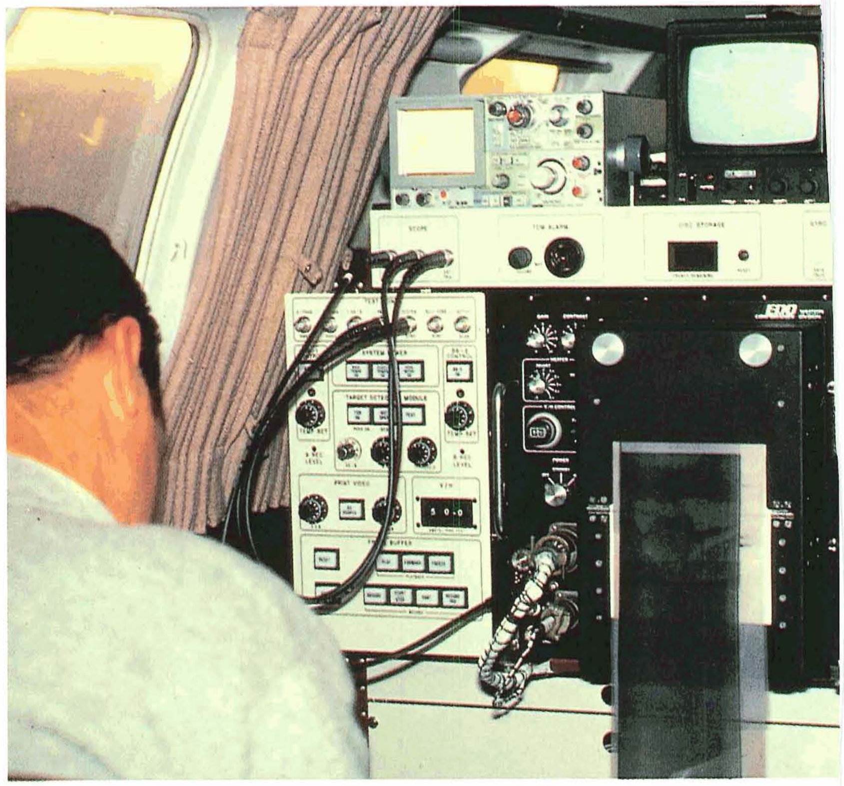
Scientific Instruments has now developed a second generation, commercially available instrument to detect flames in hazardous environments, typically refineries, chemical plants and offshore drilling platforms. The Model 74000 UV Flame Detector is pictured in the foreground at left below, along with the Model 7410CP annunciator control panel. The latter is designed to enhance the detector's utility by making available a complete selectable fire detection and alarm system.

The Model 74000 detector incorporates a sensing circuit that detects UV radiation in a 100-degree conical field of view extending as far as 250 feet from the instrument (below). It operates in a bandwidth that makes it virtually "blind" to solar radiation while affording extremely high sensitivity to ultraviolet flame detection. A "windowing" technique accurately discriminates between background UV radiation and ultraviolet emitted from an actual flame—hence the user is assured of no false alarms.

The Model 7410CP is a combination controller and annunciator panel designed to monitor and control as many as 24 flame detectors. When it receives an alarm condition signal from the detector, the controller will automatically activate external fire extinguishing equipment or fire precautionary systems such as valves or door closing devices.



Forest Fire Mapping



At right is a view of the Fire Logistics Airborne Mapping Equipment (FLAME) system mounted in a twin-engine airplane operated by the U.S. Forest Service (USFS) of the U.S. Department of Agriculture (USDA). An airborne instrument for detecting and pinpointing forest fires that might escape ground detection, FLAME was developed by Jet Propulsion Laboratory in collaboration with the USFS and jointly sponsored by NASA and the USDA.

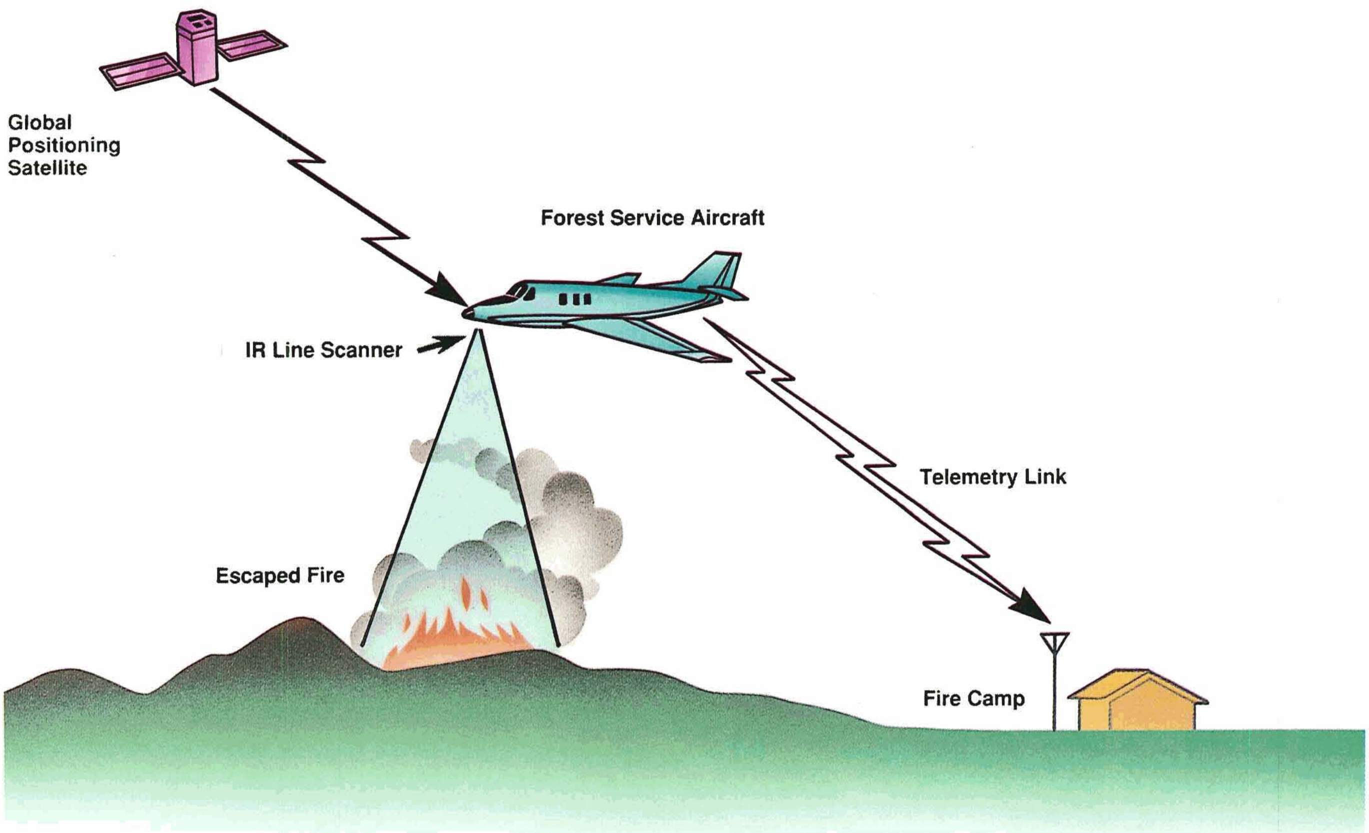
The FLAME equipment rack includes the operator interface, a video monitor, the system's control panel and film output. FLAME's fire detection sensor is an infrared line scanner system that identifies fire boundaries. The sensor's information is correlated with the aircraft's position and altitude at the time the infrared imagery is acquired to fix the fire's location on a map.

The FLAME system can be sent to a fire locale anywhere in the U.S. at the request of a regional forester. Operational since 1984, it has provided considerable improvement in getting wildland fire information to USFS firefighters; it has, says USFS, exceeded the original design and operational requirements.

However, the FLAME development was based on technology of an earlier vintage. For example, it requires manual image interpretation to process the infrared output, and it employs standard navigational means for aircraft position determination rather than the more precise satellite reference method now available. USFS felt a need for a more advanced system to deliver timely fire information to fire management personnel in the decade of the 1990s.

JPL conducted a study, jointly sponsored by NASA and USDA, on what advanced technologies might be employed to produce an end-to-end thermal infrared fire detection and mapping system. That led to initiation of the Firefly system, currently in development at JPL and targeted for operational service beginning in 1992. Firefly will employ satellite-reference position fixing and provide performance superior to FLAME in terms of increased timeliness of data delivery, accuracy, data consistency, reliability and maintainability.

The Firefly system is shown schematically at right above. The system consists of the aircraft unit, with a special purpose dual band infrared sensor for locating forest fire perimeters and high-intensity "hot spots," and a ground terminal located at the fire camp and linked to the aircraft unit by telemetry. The aircraft flies over an area designated by the Fire Incident Commander on a flight path designed to enable the infrared sensor to cover the entire perimeter area. The airborne system images the ground scene, computes fire perimeter and hot spot locations, and correlates fire data to geographic coordinates.



The "georeferencing" procedure—determining fire locations relative to a geographic base for plotting onto a map—is aided by use of the Department of Defense's satellite based navigation system, the Navstar Global Positioning System (GPS) now being deployed in orbit. GPS will allow fixing the aircraft's position—in three dimensions—within 25 to 100 meters, thus permitting Firefly georeferencing accuracy of plus or minus 500 feet. At the completion of the data gathering portion of the flight, the aircraft flies to a point within line-of-sight of the ground terminal, allowing transfer of mission results between the aircraft and ground terminal computers via the telemetry data link.

Space Technology for the Iron Foundry

More than three decades ago, NASA began developing spacecraft to carry man into space. Among the many challenging design requirements was a means of protecting astronauts returning to Earth from the searing heat of re-entry into the atmosphere. Designers came up with a heat shield in which part of the material was allowed to burn off, thus absorbing heat energy and protecting the rest of the spacecraft from friction heat. This type of shield was subsequently used in NASA's Mercury, Gemini and Apollo programs.

As an essential prelude and complement to flight testing of the shield, Langley Research Center—then man-in-space manager—planned an extensive series of ground tests. Because no adequate equipment existed to simulate re-entry temperatures, Langley contracted with Westinghouse Electric Corporation for development of a superheating system capable of subjecting heat shields to re-entry temperatures and even greater heat for safety margin.

Westinghouse responded with an electric torch in which a gas—such as nitrogen or air—is ionized by a high voltage power supply. The ionized gas, or plasma, superheats incoming gas and the gas exits the torch at high velocity and at temperatures as high as 10,000 degrees Fahrenheit.

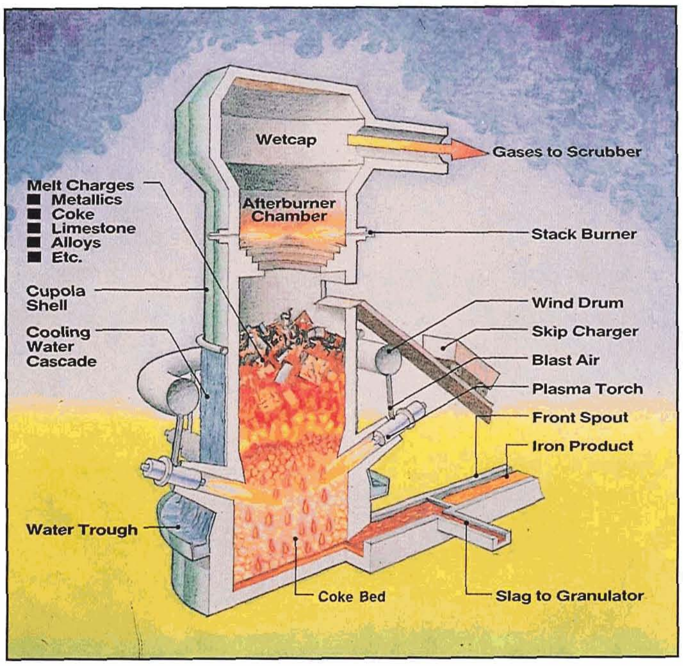
After its use by NASA, the technology was not used extensively for a quarter century until 1983 when the Electric Power Research Institute (EPRI) initiated development of a plasma melter intended to solve a major problem in the U.S. foundry industry. Based in Palo Alto, California, EPRI is a non-profit organization that manages research and development for some 600 electric utility member companies. For the plasma melter program, EPRI enlisted as co-sponsors Westinghouse Electric's Environmental Systems and Services Division, Pittsburgh, Pennsylvania; General Motors Corporation's Central Foundry Division, Saginaw, Michigan; and Modern Equipment Company, Fort Washington, Wisconsin, supplier of equipment and services to the foundry industry.

The problem was this: international competition and environmental constraints threatened the survival of U.S. foundries employing coke-burning cupolas, or melting furnaces, used to melt metal for castings. Foundries sought to reduce operating costs by using scrap iron as "charge" material, or feedstock, in place of expensive pig iron—but use of scrap materials in a conventional cupola can cause operating and metal chemistry problems. Additionally, use of cheaper high-sulphur fuels to cut costs was restricted by environmental regulations. Mounting operating costs and ever increasing international competition caused the number of U.S. foundry cupolas to drop from 3,000 in the 1950s to fewer than 850 in the late 1980s.

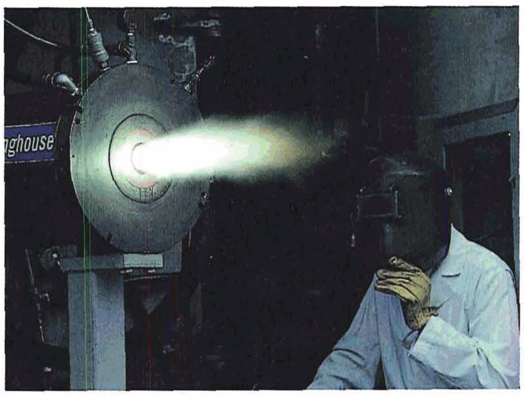
Seeking to make cupola operation more efficient and more competitive, the development team designed a plasma melter, using the decades-old plasma torch technology as the primary heat source, and built a pilot-scale test cupola at a Westinghouse facility near Pittsburgh. A three-year pilot program demonstrated conclusively that plasma melters can effectively melt scrap iron and thereby lower operating costs. General Motors then rebuilt a cupola at its Defiance (Ohio) foundry to incorporate six Westinghouse plasma torches in the cupola base where incoming air is directed to the combustion area to burn the coke. A portion of the incoming air is superheated by the torches, thus reducing the combustion energy required from coke. It also reduces the air volume needed in the cupola and that is the feature that allows operators to use lower-cost scrap iron as feedstock. The system offers an environmental bonus in reduced cupola emissions. In mid-1989, after a stringent three-month test program, the new melter was accepted for on-line casting production.

The plasma torches increase GM's electric bill at Defiance, but that cost is more than compensated by the savings in charge material, the major item of operating cost. For the Defiance

A melting torch for more efficient foundry operation exemplifies spinoffs in industrial productivity and manufacturing technology



Shown in cutaway view is General Motor's plasma melter, first in the U.S., at the company's Defiance (Ohio) foundry. It is an advanced technology system designed to improve the efficiency of coke-burning cupolas that melt iron to produce automotive castings. The key elements are six Westinghouse plasma torches (two visible in lower cutaway).



The electrically-powered plasma torch creates an ionized gas that superheats air entering the cupola to 10,000 degrees Fahrenheit. That great heat, three times higher than that attainable by oil or natural gas systems, is the key to making iron cheaper, cleaner and faster.

Employees at the Defiance foundry inspect castings manufactured from iron melted in the plasma melter. The Defiance plant annually produces 400,000 tons of castings for GM cars and trucks.

project, Toledo Edison—the local electric utility—worked closely with GM to develop an incentive package that further enhances the economic benefit of the plasma melter.

On the basis of early operation, Michael Hamilton, manager of the Defiance foundry that annually manufactures 400,000 tons of automotive castings for GM cars and trucks, feels that the spinoff technology has substantially brightened the facility's future in an increasingly competitive world marketplace. "Clearly," he says, "the plasma melter is producing the desired results."

If long term experience confirms the advantages, the whole U.S. foundry industry stands to benefit. And the potential benefit may extend beyond iron casting manufacture. The EPRI-sponsored Center for Materials Production (CMP), located at Carnegie Mellon University in Pittsburgh, serves as a project office to encourage broader application of the plasma melter. In a project jointly funded by EPRI and Westinghouse, CMP is evaluating the potential of plasma cupola technology for economical, large-scale recovery of usable iron from waste products generated by the steel industry.

Flow Meter

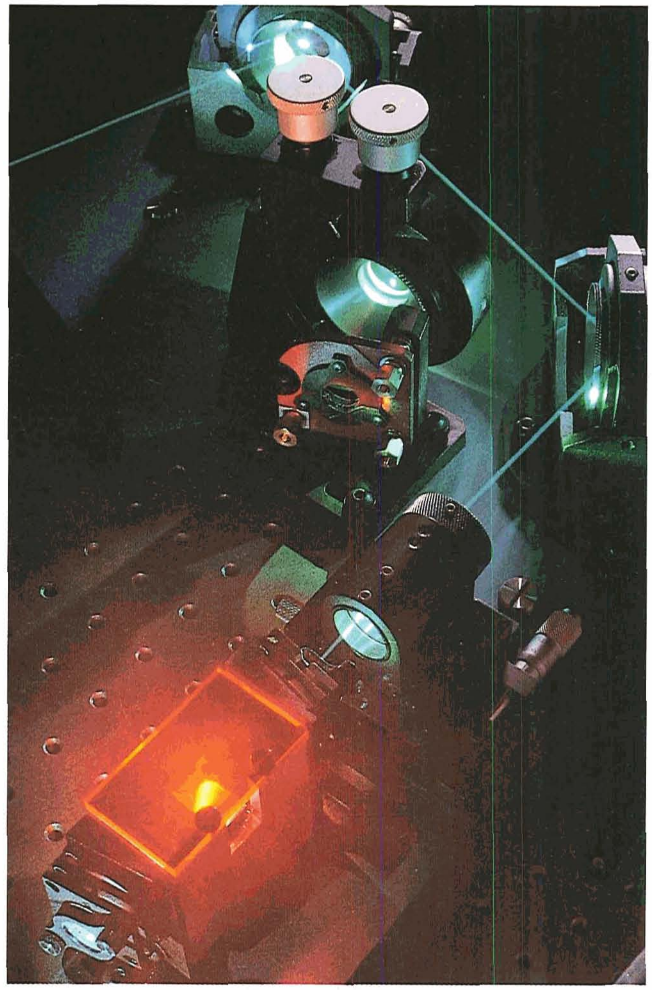
Below, an engineer is conducting a quality control test of a Hedland Stainless Steel In-line Flow Meter, manufactured by Hedland, Division of Racine Federated Inc., Racine, Wisconsin.

The $1\frac{1}{4}$-inch series of flow meters monitor in-line hydraulic fluids or other liquids under continuous operating pressures up to 5,000 pounds per square inch with a 3:1 safety factor at temperatures from 35 to 250 degrees Fahrenheit. This type of meter is a commercial adaptation of a $1\frac{1}{4}$-inch series originally designed to monitor the hydraulic systems of a liquid fuel rocket engine test stand at Marshall Space Flight Center.

Hedland manufactures a complete line of flow meters used in industrial operations to monitor the flow of oil, water or other liquids, air and other compressed gases, including caustics or corrosive liquids/gases. The company produces more than 1,000 types of flow meters featuring rugged construction, simplicity of installation and the ability to operate in any position. A sampling of the product line is shown at right; the different housing colors indicate the use for the particular meter, the type of liquid or gas it is intended to monitor.

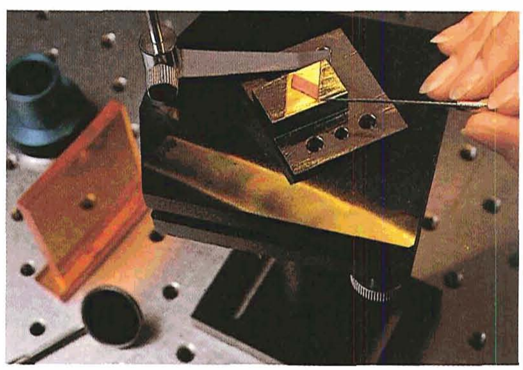
Solid-state Laser

At right is a Titan-CW Ti:sapphire (titanium-doped sapphire) tunable laser, an innovation in solid-state laser technology jointly developed by the Research and Solid State Laser Divisions of Schwartz Electro-optics, Inc. (SEO), located in Concord, Massachusetts and Orlando, Florida, under NASA contract. The red area in the photo is the location of the titanium sapphire crystal, shown in closeup below. SEO is producing the laser for the commercial market, an outgrowth of a program sponsored by Langley Research Center to develop Ti:sapphire technology for space use.



Where dye lasers use dye solutions to emit light, the solid-state laser employs exotic crystals, in this case sapphires doped with titanium. Although solid state lasers generally have a limited range of wavelengths, the Ti:sapphire laser offers a broad wavelength range with an important bonus: it is relatively maintenance-free, thus an attractive candidate for long term space use. In satellite research, laser wavelengths are absorbed by chemical substances in the atmosphere; measurement of the amount of absorption provides data on chemical concentrations in the atmosphere for environmental studies.

The Langley Ti:sapphire program, which is generating other advances in solid-state laser technology, began in 1982 with basic research by Langley in concert with California's Stanford University and Christopher Newport College in Virginia. Later, Langley contracted with Union Carbide, Washougal, Washington for materials development, and with SEO and other companies for laser engineering.



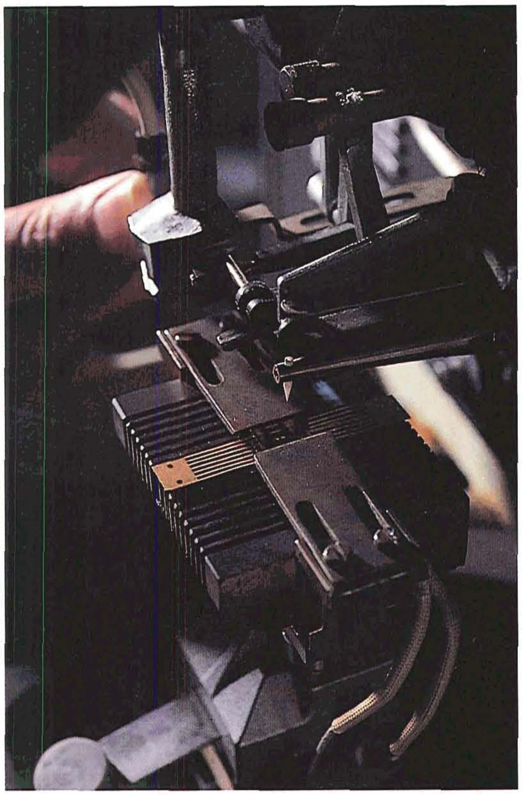
SEO's Titan-CW series of Ti:sapphire tunable lasers have applicability in analytical equipment designed for qualitative analysis of carbohydrates and proteins, structural analysis of water, starch/sugar analyses, and measurements of salt in meat. Further applications are expected in semiconductor manufacture, in medicine for diagnosis and therapy, and in biochemistry.

Gas Sensor

In 1983, after 12 years as an engineer with Martin Marietta Corporation, Ralph M. Mindock founded High Technology Sensors, Inc. (HTS), Longwood, Florida to develop and market microelectronics products.

In the photo below, an HTS technician is assembling a sensor under a microscope, using pure gold wire many times finer than human hair to solder connections. At lower right, company president Mindock holds a finished carbon dioxide detector, part of the HTS Model SS-250 miniature gas sensor designed to measure carbon dioxide concentrations.

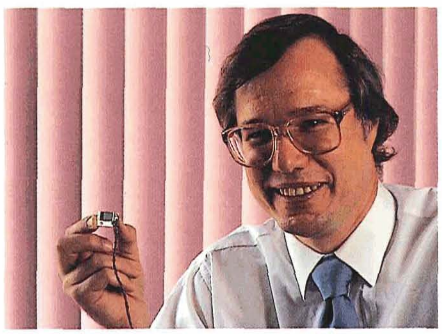
The SS-250 uses a patented semiconductor optical source that efficiently creates infrared radiation, which is focused through an airway on a detector. Carbon dioxide passing through the airway absorbs the radiation, causing the detector to generate a signal. The small size—roughly 2 x 2 x 2 inches—and low power requirements of the SS-250 make it attractive for incorporation in a variety of medical instruments.



The experience of Ralph Mindock and HTS exemplifies the benefits available to industry through a network of NASA assistance centers that provide information retrieval services and technical help. In this case, the assistance was provided by the Southern Technology Applications Center, (STAC), Alachua, Florida.

Mindock met a STAC official at a trade show, learned of STAC's literature searches and other services, and began to use STAC regularly as an information resource. STAC conducted searches for HTS in several areas, including investigation of the market for gas and vapor detection sensors. STAC also provided extensive information helpful to HTS in preparing proposals for Small Business Innovation Research (SBIR) awards.

Confirming that STAC saved HTS considerable time and money, Mindock says: "The search on sensor markets gave us data to use in the long range business plan, including an estimate of total market, our potential market penetration, and our competition." Mindock adds that a literature search can make or break an SBIR proposal. "The search results are much more complete than I could collect manually. STAC goes further back into the literature and locates sources I didn't know existed."



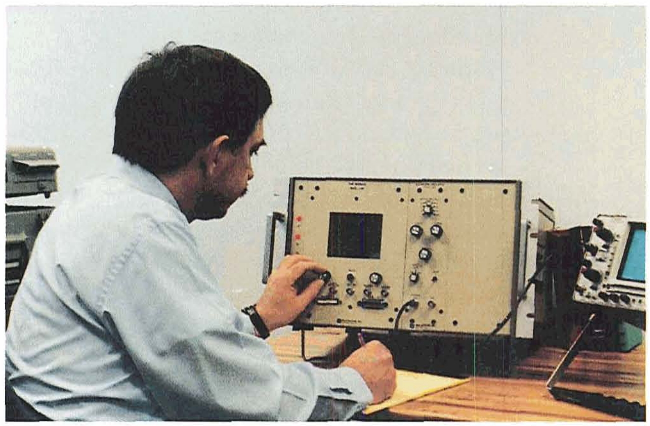
Signal Processor

At right, a researcher is using a Model 3100 Frequency Domain Processor, an innovative instrument that significantly increases the amount and accuracy of information available from laser velocimeter flow measurement systems. The Model 3100 is shown in closeup at lower right; it is a commercial version of a system invented by a team of scientists from Langley Research Center and Old Dominion University Research Foundation, Norfolk, Virginia.

The system is manufactured by Macrodyne, Inc., Clifton Park, New York. In 1986, Macrodyne received a Small Business Innovation Research award for development of a proof-of-concept prototype of the processor. In mid-1989, the company delivered the first units to Ames and Langley Research Centers for evaluation and use. In August 1989, Macrodyne was granted a NASA license to use the technology in commercial manufacture of the Frequency Domain Processor. The innovation permits use of laser velocimetry in industrial applications where extremely precise measurements are required; it has applicability in industrial controls and in improvement of transmission standards in the automotive industry.

The benefits of the Model 3100 stem from patented digital signal processing techniques. Laser velocimetry is a method of measuring the velocities of micron-size particles in fluids or microscopic flaws in surfaces, utilizing a system of crossed laser beams by creating a "fringe pattern" of lighted bands. Particles passing through the fringe scatter light from the lighted bands. A burst of the oscillating light about a microsecond long is captured and converted to an electrical signal.

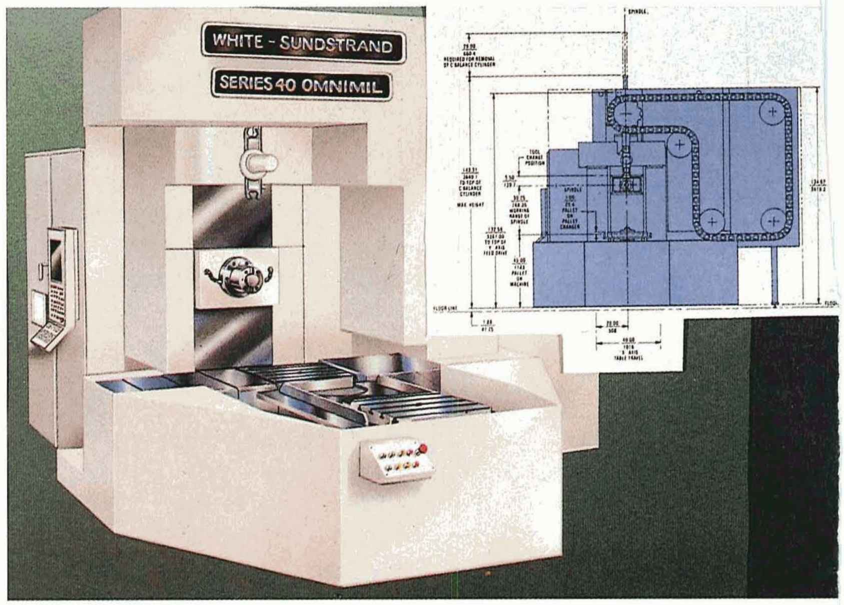
As with any measurement sensor, a major factor in the success of the technique is the signal processor. The principal utility of the Model 3100 signal processor is determination, by means of digital signal processing, of the oscillating frequency of the captured burst. This allows accurate computation of the velocity of the particle passing through the lighted bands. In comparison with conventional techniques, digital signal processing offers an eightfold increase in measurable signals and fivefold gain in measurement accuracy.

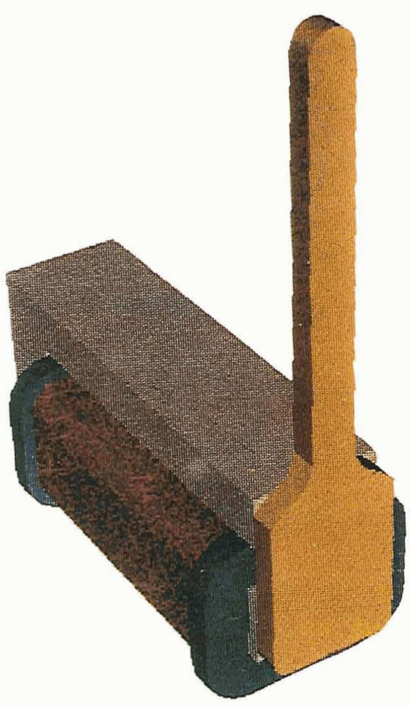


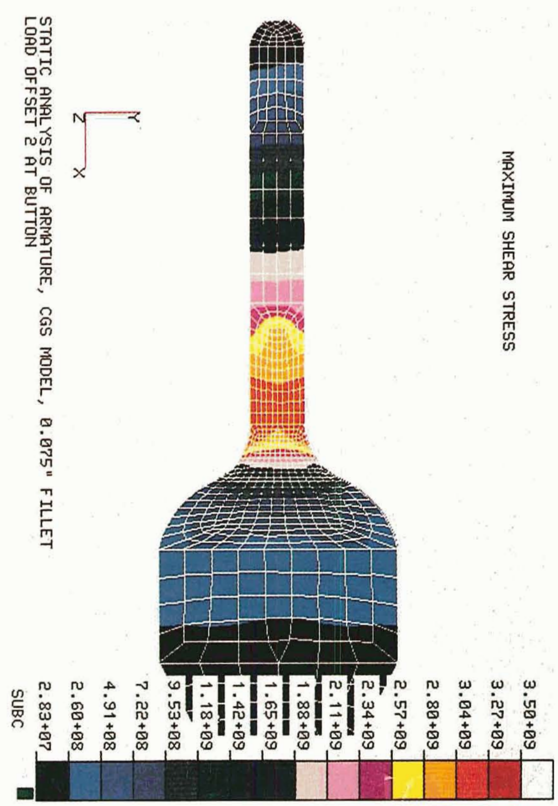
Structural Analysis

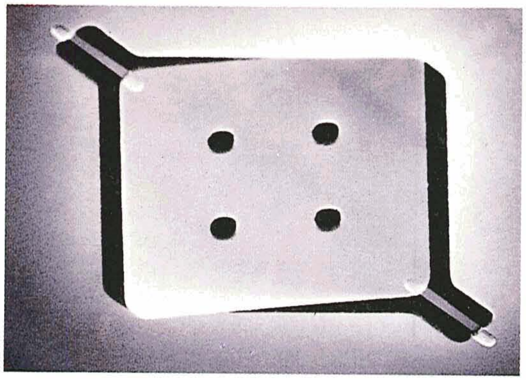
One of the most widely used NASA computer programs is NASTRAN®, an acronym for NASA Structural Analysis Program. Originally developed by Goddard Space Flight Center as an aid to aerospace vehicle design, NASTRAN has been used in hundreds of non-aerospace applications. Basically, it performs complex analyses of a structural design and predicts how various elements of the design will react to many different conditions of stress and strain.

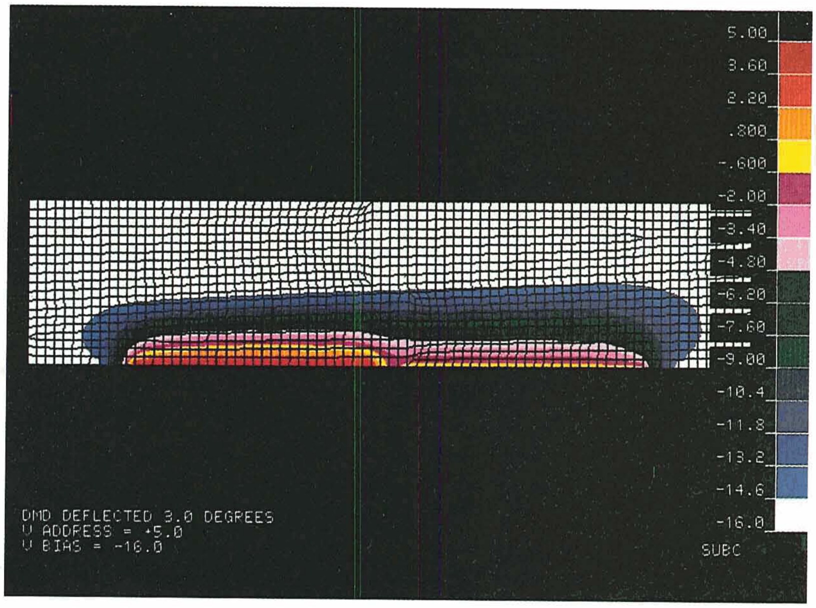
Over the years, NASA has improved NASTRAN to broaden its range of utility. NASTRAN applications include almost every kind of structure and construction, and the program's substructuring capability allows different segments of a structure to be modeled jointly after having been modeled separately. NASTRAN permits the effects of control systems, aerodynamic transfer functions and other nonstructural problems, such as static response to thermal expansion, to be incorporated in the solution of the structural problem.











An example of industrial use of NASTRAN is its employment by DeVlieg-Sundstrand, Belvidere, Illinois, a company which manufactures machine tools that produce parts for other machines; shown at left above is the company's horizontal machining center. These machine tools must be able to maintain a certain rigidity during temperature and load changes associated with the manufacturing process; their rigidity determines their accuracy and prevents production errors in the machine parts. NASTRAN is used in the design of machine tools to predict the design's rigidity.

Another NASTRAN user is Texas Instruments (TI), Temple, Texas, which uses the program as an aid in designing impact and non-impact printers.

Dot matrix impact printers form characters by means of a series of actuator mechanisms that fire needles at an ink ribbon to transfer ink dots to paper. Each actuator mechanism has a tiny magnetic core and an actuator coil, an armature and a print needle. The printhead is a circular arrangement of a large number of such assemblies; in operation, the printhead moves across the paper to produce characters.

Generation of a magnetic field causes the armature to propel the needle toward the ribbon. To optimize the design of the printhead, it is necessary to maximize the magnetic force propelling the armature—and that requires extremely accurate calculations of the magnetic field. TI used NASTRAN for that purpose and was able to develop the optimum geometry for a new printhead entirely by NASTRAN simulation. At far left is the printhead cone and armature of TI's impact printer; at left is a NASTRAN analysis of the armature and the magnetic field.

NASTRAN predictions were proved accurate by testing of the first prototype, which sharply reduced the very substantial prototyping costs of conventional test models. NASTRAN was then employed to develop all of the mechanical and structural parts of the printhead, such as the needles, wire guides and housing.

TI's Central Research Laboratories also used NASTRAN in designing a deformable mirror device (DMD) that has several applications in non-impact printing, where it can replace the laser and the rotating mirror of conventional laser printers. TI was unable to predict accurately the behavior of the DMD (top photo), which was dependent upon the electric field and mechanical properties. Researchers employed NASTRAN to model the DMD and, with the combined results of various analyses, were able to predict the voltages required for operation and indicate ways in which efficiency might be increased. At left above is a NASTRAN analysis of electric potential in the DMD. Here again, NASTRAN allowed accurate prediction of the effect of design changes without the large expense of prototype production.

NASTRAN is available to private industry through NASA's Computer Software Management and Information Center (COSMIC)®. Located at the University of Georgia, COSMIC maintains a library of computer programs from NASA and other technology-generating agencies of the government, and offers them for sale at a fraction of the cost of developing a new program.

® NASTRAN and COSMIC are registered trademarks of the National Aeronautics and Space Administration.

Wood Products Analysis

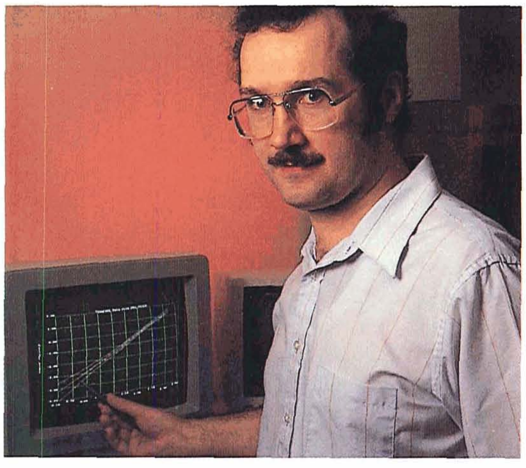
A committee of the American Society of Civil Engineers (ASCE) plans to review a draft of a new standard for engineered wood construction and submit the standard for ballot late in 1991. In the interim, the committee has published a pre-standard report, Load and Resistance Factor Design for Engineered Wood Construction, a segment of which incorporates NASA technology related to statistical distribution. This technology quantifies wood product reliability with a high degree of confidence, accounting for sampling variability.

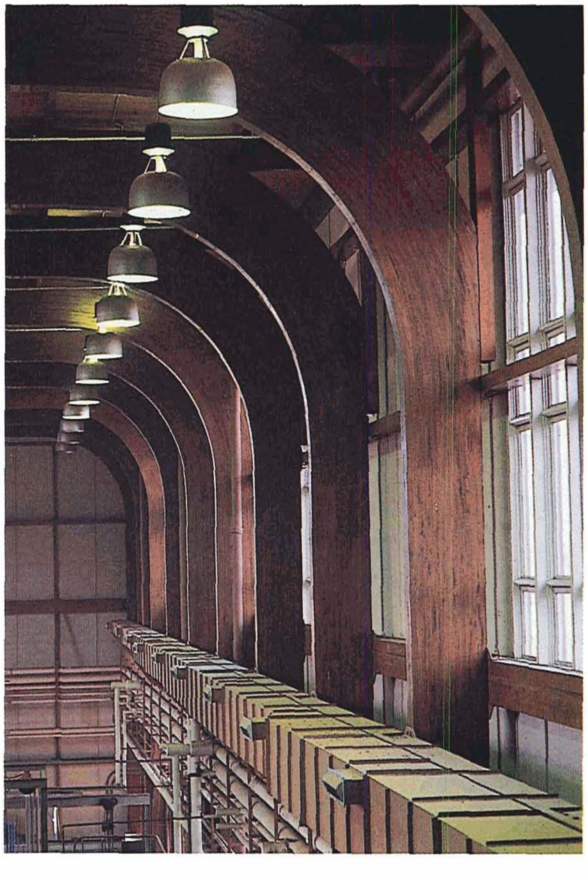
Additionally, Dr. Joseph F. Murphy, chairman of the ASCE committee and president of Structural Reliability Consultants, Madison, Wisconsin, made use of the same technology in developing a computer program for analyzing the distribution of wood resistance. Below, Dr. Murphy is shown with a representation of his computer program, which creates graphic plots showing the statistical parameters of glue laminated timbers, or "glulam." At right is an example of such products, the huge curved glulam beams of the U.S. Department of Agriculture's Forest Products Laboratory (also in Madison) that extend across a wide ceiling and allow uninterrupted interior space in the facility.

Dr. Murphy read in *NASA Tech Briefs*, a publication that describes NASA technology available for transfer, about work related to analysis of Space Shuttle surface tile strength performed for Johnson Space Center by Rockwell International Corporation. The analysis led to a theory of "consistent tolerance bounds" for statistical distributions, applicable in industrial testing where statistical analysis can influence product development and use.

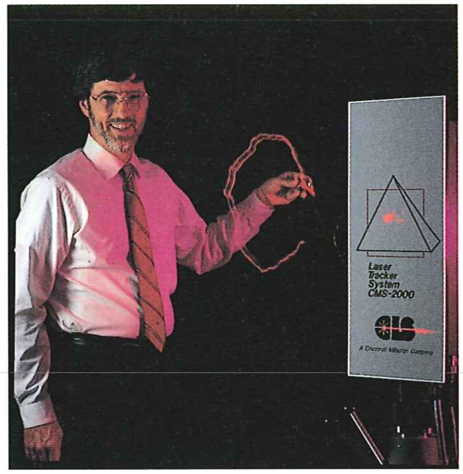
Dr. Murphy obtained from NASA a Technical Support Package (TSP) that covers the subject in greater detail than the Tech Briefs report. The TSP provided information used by the ASCE task committee in compiling its pre-standard report, and it also became the basis for Dr. Murphy's computer program PC-DATA™, which he is marketing commercially.

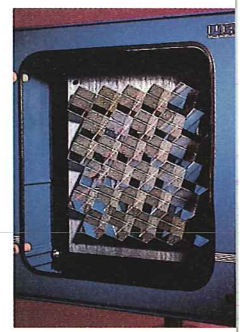
™ PC-DATA is a trademark of Structural Reliability Consultants.

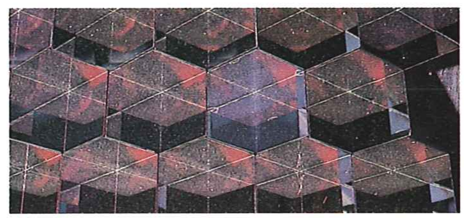




Optical Instruments







Among the experiments of the 1975 joint U.S./USSR Apollo-Soyuz orbital mission was one involving measurement of gases in the atmosphere by an advanced optical system. A key element of the equipment used was a device called a retroreflector, a mirror-like instrument that reflects light and other radiation back to its source. With the spacecraft at a fixed distance apart, Apollo sent a beam of ultraviolet radiation to a retroreflector array on Soyuz, and the beam was reflected back to an instrument on Apollo that measured the amount of radiation absorbed; that offered clues to the densities and concentrations of atmospheric gases at low Earth orbital altitudes.

The hollow retroreflector used on Apollo-Soyuz was developed for NASA by Precision Lapping & Optical Company, Inc., Valley Stream, New York, manufacturer of high technology precision optical equipment. That experience made Precision Lapping a pioneer company in retroreflector development. In the years since, Precision Lapping has developed a wide variety of hollow retroreflector systems for applications involving the entire optical spectrum; they are, according to company literature, cheaper, more accurate, lighter and capable of greater size than solid prisms.

Precision Lapping's major customers are aerospace and defense companies, government organizations, R&D and commercial instrument companies. For example, Precision Lapping supplies hollow retroreflectors for the laser fire control system of the Army's Abrams tank, and retroreflectors have been and are being used in a number of space tests relative to the Air Force's Strategic Defense Initiative (SDI) research program.

An example of a customer/user of Precision Lapping's products is Chesapeake Laser Systems, Lanham, Maryland, producer of the Laser Tracker System CMS-2000, which has applications in SDI research and in industrial robotics (for tracking the movement of robot arms). The CMS-2000 employs a retroreflector to lock onto a laser beam and track the source of the beam. At top left above, Chesapeake Laser president Brad Merry shows the system's utility; holding a retroreflector, he makes a circular motion with his hand and creates a laser pattern that demonstrates the Laser Tracker's ability to follow any movement.

Another Precision Lapping customer is MDA Scientific, Inc., Norcross, Georgia, manufacturer of a line of toxic gas detection systems used to monitor the hazardous gases present in oil fields, refineries, offshore platforms, chemical plants, waste storage sites and other locations where gases are released into the environment. The product line is based on the fact that each gas has a unique absorption spectrum; by carefully choosing light sources that can be tuned and filtered to produce specific wavelengths, the systems can selectively identify and monitor specific gases without interference from atmospheric conditions or other background gases. Retroreflectors are employed to reflect the light back to its source; measurement of the changes in light between source and receptor determines the presence of a specific gas and its concentration. At top right is a 30-retroreflector array employed by MDA Scientific in an infrared light source detection system; the retroreflectors are shown in closeup in the lower photo.

Diamond Coatings

Still the hardest substance known to man, diamond is resistant to wear, the best thermal conductor, an excellent electric insulator, immune to attack from most chemicals, relatively friction-free, and transparent not only to visible light but also to infrared and ultraviolet. These characteristics would make diamond the ideal material for a wide range of industrial applications were it not for its extremely high cost.

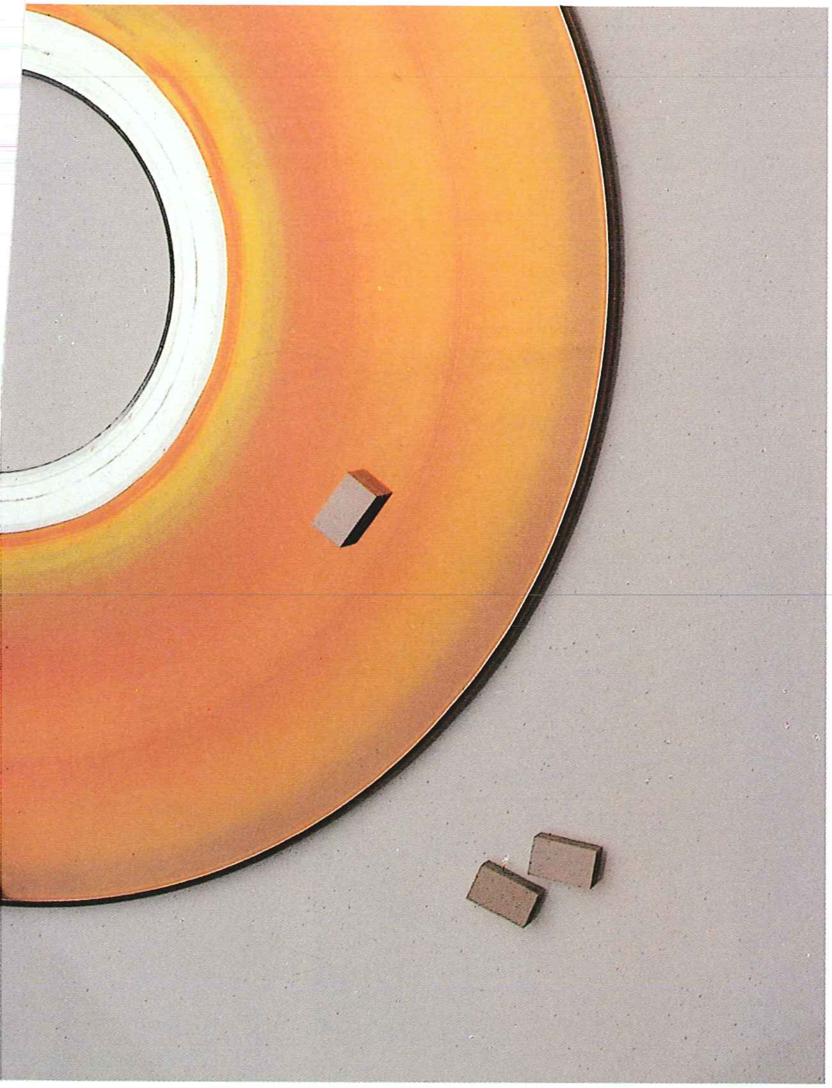
However, advances in materials technology have demonstrated that it is possible to get the advantages of diamond in a number of applications without the cost penalty—by coating and chemically bonding an inexpensive substrate (supporting material) with a thin film of diamond-like carbon (DLC). Diamond films offer tremendous technical and economic potential in such advances as chemically inert protective coatings; machine tools and parts capable of resisting wear 10 times longer; ball bearings and metal cutting tools; a broad variety of optical instruments and systems; and consumer products ranging from wristwatch crystals to eyeglasses. In the U.S., Japan and Europe, there are growing diamond-coating industries competing to bring forth the first of a stream of commercial applications and get a foothold in a new market that is predicted to reach $500 million–$1 billion in this decade and expand far beyond that in the 21st century.

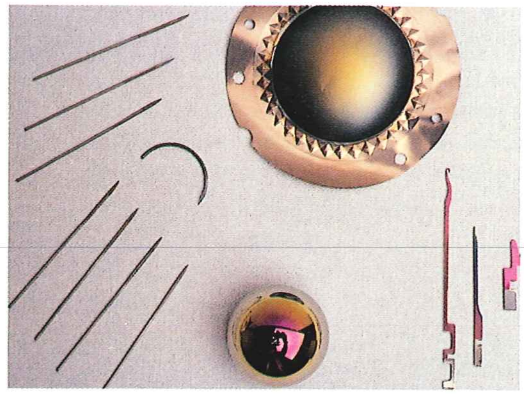
Among the American companies engaged in DLC commercialization is Diamonex, Inc., a diamond coating spinoff of Air Products and Chemicals, Inc., Allentown, Pennsylvania. Along with its own proprietary technology for both polycrystalline diamond and DLC coatings, Diamonex is using, under an exclusive license, NASA technology for depositing DLC on a substrate.

Interested in the aerospace potential of synthetic diamond coatings, Lewis Research Center has, for more than a decade, conducted extensive research on the properties of DLCs, including investigations of a variety of different ways to deposit them on many different types of substrates. Among the coating methods researched is a technique known as direct ion beam deposition, in which an ion generator creates a stream of ions from a hydrocarbon gas source; the carbon ions impinge directly on the target substrate and "grow" into a thin DLC film. Lewis' research has generated patents related to a dual ion approach. This low pressure, low temperature approach—as opposed to high-temperature, high-pressure processes normally used in making synthetic diamond—allows coating substrates that cannot tolerate high temperatures—plastics, for instance.

Lewis is providing technical assistance to Diamonex on a major step that would significantly expand the DLC market: scratch-resistant coatings for plastic prescription eyeglasses. The critical technical problem is making the hard DLC coating thick enough to provide scratch resistance yet maintain optical clarity for clear vision; that is not a problem with sunglasses, where color and light attenuation are desirable. Diamonex plans to form a joint venture with a lens manufacturer to commercialize this technology.

The photos illustrate some of the applications of diamond coating. At near right are a magnetic data storage disc and several read/write head sliders; disc and sliders are coated to reduce friction and increase disc life. At upper far right are some typical applications for non-optically-transparent DLC coatings: at top center is a speaker diaphragm which is coated to provide a higher frequency response from the speaker; moving clockwise in the photo are needles used in weaving cotton cloth, coated to reduce friction and snagging; at bottom photo is a diamond-coated ball for an artificial hip joint, whose wear resistance and durability is increased by coating; and at left photo are surgical needles, coated to promote reduced patient recovery time by minimizing needle puncture damage. At lower right are several optical applications; at top, prescription eyeglasses; at the three o'clock position, a polycarbonate blank for sunwear; at four o'clock, two coated polycarbonate lenses; at bottom photo, a lens with iridescent diamond coating for fashion; and at upper left photo, sunglasses.





Diamonex is developing, and offering commercially—under the trade name Diamond Aegis™—a line of polycrystalline diamond-coated products that can be custom tailored for optical, electronic and engineering applications.

Additionally, Diamonex is engaged in a collaboration with Seiko Instruments, Inc. of Japan involving development and commercialization of diamond coating technologies. Diamonex brings to the partnership its own proprietary technologies, plus the Lewis ion beam technology. Seiko will contribute its own microwave coating technology and has access to coating technologies developed by Japan's National Institute for Research in Inorganic Materials and licensed from the Research Development Corporation of Japan.

Diamonex' initial focus is on optical products and the first commercial product is expected in late 1990. Other target applications include electronic heat sink substrates, x-ray lithography masks, metal cutting tools and bearings.

™ Diamond Aegis is a trademark of Diamonex, Inc.

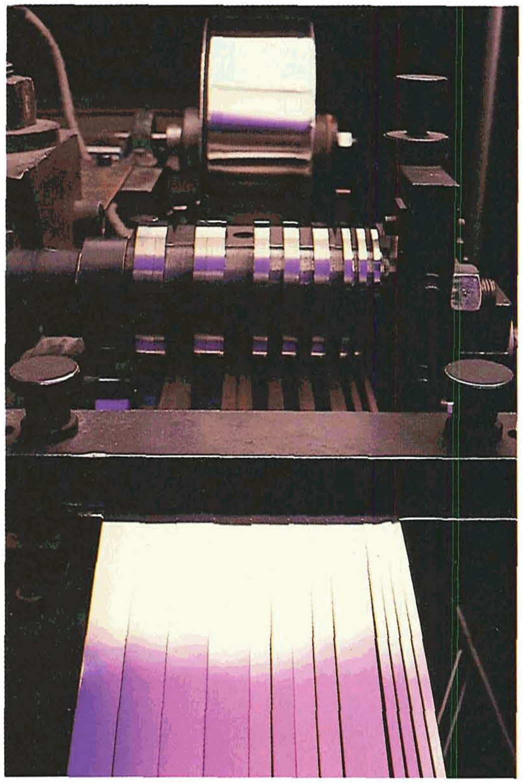
Composite Cores

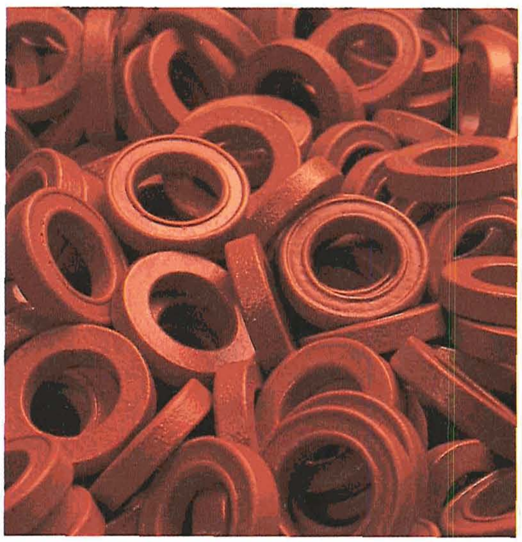
At right, an automatic machine at Magnetics, Division of Spang and Company, Butler, Pennsylvania is slitting strips of magnetic nickel-iron alloy tape prior to winding them into composite cores for use in the transformers of electronic systems. At right center, a Magnetics employee is assembling ring-shaped segments into complete cores, which go to an oven for application of a baked-on epoxy protective coating (below).

The composite toroidal (doughnut-shaped) core was developed by the Electric Power System Section of Jet Propulsion Laboratory (JPL) in response to a problem—failure of the switching transistors of a voltage converter—experienced in a spacecraft. Investigation showed that "saturation"—a power surge—of the core of the converter transformer sometimes causes a large voltage "spike" that often destroys the switching transistors.

JPL's solution was to redesign the cores of converter transformers to provide an air gap with a powerful demagnetizing effect. The term "composite" here means that the new configuration is a composite of gapped and ungapped cores assembled together in concentric relationship. The net effect of the composite design is to combine the protection from saturation offered by the gapped core with the lower magnetizing requirement of the ungapped core. The uncut core functions under normal operating conditions and the cut core takes over during abnormal operation to prevent power surges and their potentially destructive effect on transistors.

Magnetics manufactures the cores under NASA license. Principal customers are aerospace and defense manufacturers who use the cores in power supplies for high reliability space and military applications. The cores also have applicability in commercial products where precise power regulation is required, as in the power supplies for large mainframe computers.





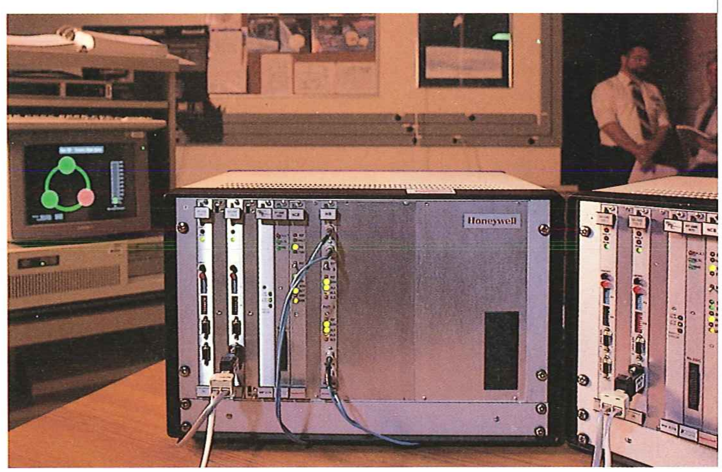
Communications Network

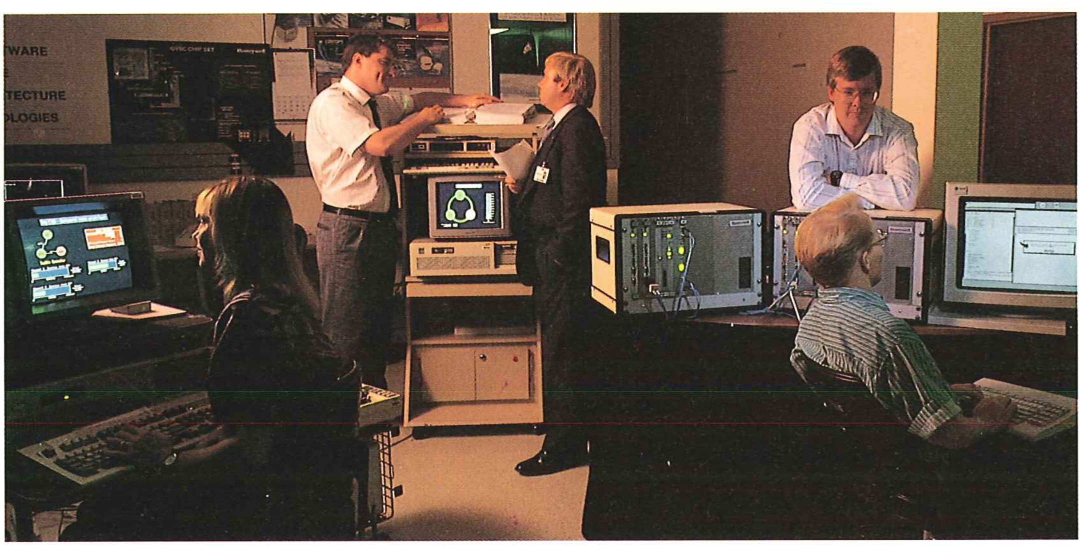
At right is the Multi-Compatible Network Interface Unit (MCNIU) system, a high performance, 100-megabit-per-second fiber optic communications network for linking the various systems on board Space Station *Freedom*.

Developed for NASA's Johnson Space Center by Honeywell Inc., Minneapolis, Minnesota, the MCNIU is intended to connect the space station's communications and tracking, guidance and navigation, life support, electric power, payload data, hand controls, display consoles and other systems, and also communicate with diverse processors. In the lower photo, members of Honeywell Space Systems Operations design team are conducting a test of MCNIU's ability to exchange information between IBM, VAX and Sun Unix computers, a capability analogous to a person speaking three languages fluently and simultaneously.

The MCNIU system includes a complete seven-layer International Standards Organization open systems interconnection architecture. Designed to interface between low-speed digital electronics and extremely high-speed fiber optics, the system runs at 10 times the speed of conventional fiber optics and has been tested above 1,000 messages a second; at this rate, the MCNIU could transmit the entire text of Encyclopedia Britannica in less than one minute. It also features a dual counterrotating ring architecture, which automatically recovers from fault conditions in milliseconds and thus ensures continuous operation in the event of a system failure.

Honeywell is now marketing MCNIU commercially. It has applicability in certain military operations, such as interconnection of multicomputer shipboard networks, or civil control centers, such as the Federal Aviation Administration's air traffic control network. It has nongovernment utility among large companies, universities and research organizations that transfer large amounts of data among workstations and computers.





Pressure Measurement Systems

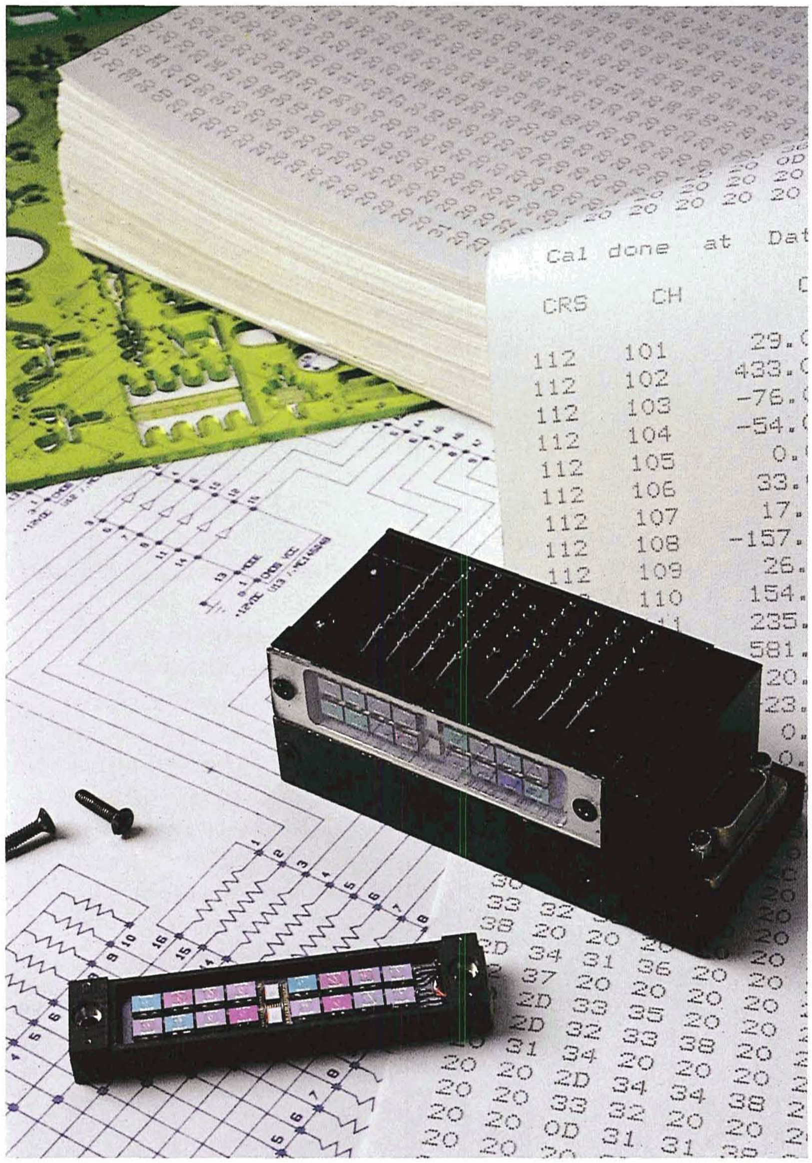
Shown at right is the processor unit of System 8400, an advanced system for measurement of gas and liquid pressure, along with a variety of other parameters, including voltage, frequency and digital inputs. At far right is an exploded view of the whole system. System 8400 offers exceptionally high speed data acquisition through parallel processing, and its modular design allows expansion from a relatively inexpensive entry level system by the addition of modular Input Units that can be installed or removed in minutes.

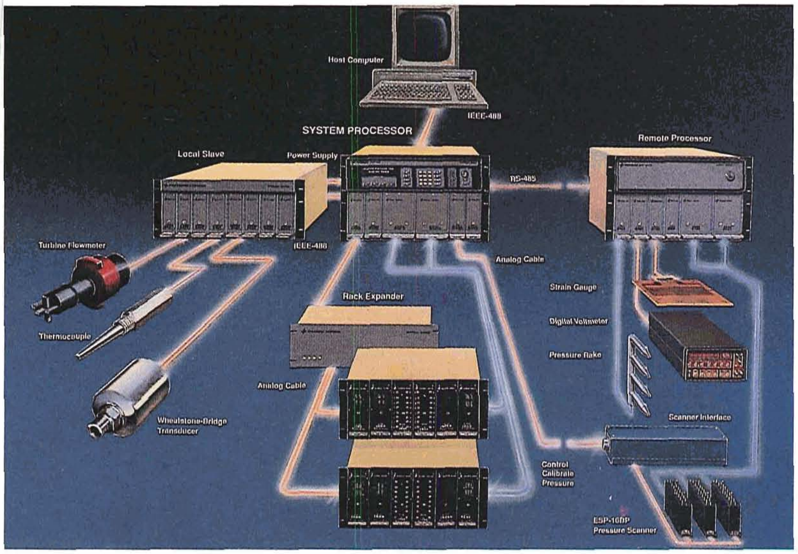
Typically used by aerospace firms for wind tunnel or flight test pressure measurement, or by industrial firms for scanning control loop pressures that govern plant processes, System 8400 is the latest advancement produced by Pressure Systems, Inc. (PSI), Hampton, Virginia, a thriving company whose business, and much of its product line, evolved from a single spinoff development.

PSI began life in 1977, its "plant" a single room in the home of founder and president Douglas B. Juanarena, its sole product an innovative pressure sensing device developed at Langley Research Center. Today, PSI manufactures 20 distinct products within four basic product lines and has annual sales of $8 million, exports accounting for about 25 percent of it.

The PSI success story began in the early seventies when Langley Research Center was looking for a way to obtain better acccuracy and higher data rates in measuring airflow pressure at many points around a wind tunnel model. Mechanical systems then in use had a maximum capability of 10 measurements a second. To get the hundreds of measurements needed in a typical test, it was necessary to conduct many repetitive tunnel runs.

Additionally, inaccuracies were induced because test conditions changed over the lengthy period required to make the measurements. And there was the energy factor: energy costs were soaring in those crisis years and wind tunnels consume enormous amounts of energy. Langley embarked on an effort to get higher data





rates with greater accuracy while simultaneously shortening tunnel operating times.

The solution, developed by a team of engineers that included Douglas Juanarena, was a new technology known as ESP—electronically scanned pressure. The Langley ESP measurement system was based on miniature integrated circuit pressure-sensing transducers that communicated pressure information to a minicomputer. These sensors were capable of being calibrated while in use, an innovation that greatly increased accuracy. The high data rate was achieved by using one transducer for each pressure port in a wind tunnel, which would have been impractical with mechanical systems. The basic system, capable of making 10,000 measurements a second, was small, relatively low in cost and highly reliable.

In 1977, Juanarena formed PSI to exploit the NASA technology. In 1978 he left Langley, obtained a NASA license for the technology, and introduced the first commercial product, the 780B pressure measurement system, which quickly captured a large part of the pressure scanning market among U.S. government and industrial wind tunnels. Subsequently, the French and West German governments standardized on PSI instrumentation for their wind tunnels. PSI systems are also used for pressure measurements in flight; at left below an engineer is adjusting a wing-mounted unit that gathers data from a dozen sensors along the leading edge of the wing.

Looking to the broader potential of the technology in industrial applications, PSI developed a pressure scanner for automation of industrial processes where there is a need for making multiple pressure measurements quickly and with high accuracy. Now in its second design generation, the DPT-6400 is capable of making 2,000 measurements a second and has 64 channels that can be expanded to 256 channels by addition of slave units.

The new system 8400, which can handle up to 400,000 measurements a second, represents PSI's bid to further exploit the $600 million U.S. industrial pressure measurement market. The system is geared to provide a turnkey solution to physical measurement for both aerospace and general industrial applications. Its configuration is determined by the customer's need; a wide selection of Input Units allows the user to tailor the system to his own specific measurement and performance requirements.

PSI is still growing. In 1985, the company moved into a new 15,000 square foot plant, but outgrew it by 1989, when an 8,800 square foot addition was constructed. PSI is now projecting additional plant expansion in 1992. Sales are expanding not only in the U.S. but abroad; in 1988, PSI won U.S. Department of Commerce recognition as Virginia's Exporter of the Year.

CONSUMER/HOME/RECREATION

Space-Spurred Metallized Materials

Metallization is the art of coating a material with a fine mist of vaporized metal to create a foil-like effect. It's not a space age invention; in fact, the concept is a century old.

However, metallization is a prime example of how use of an existing product or process to meet a space need sometimes triggers a chain reaction: the space requirement serves to create a market, the existence of a market inspires further development, which expands the range of applications, and eventually a once commercially obscure product becomes a booming commodity. In the case of metallization, the space need proved to be the catalyst that transformed a small scale manufacturing operation producing decorative-use metallized plastics into a flourishing industry marketing many different types of materials for scores of applications.

It started in the early days of the space program when NASA was experimenting with large balloon-satellites as orbital relay stations for reflecting communications signals. NASA needed a special material for the balloon skin—something highly reflective for "bouncing" signals, something exceptionally thin and lightweight so it could be folded into a beachball-size canister for launch from Earth. The need was filled by development of a new type of plastic film coated with a superfine mist of vacuum-vaporized aluminum.

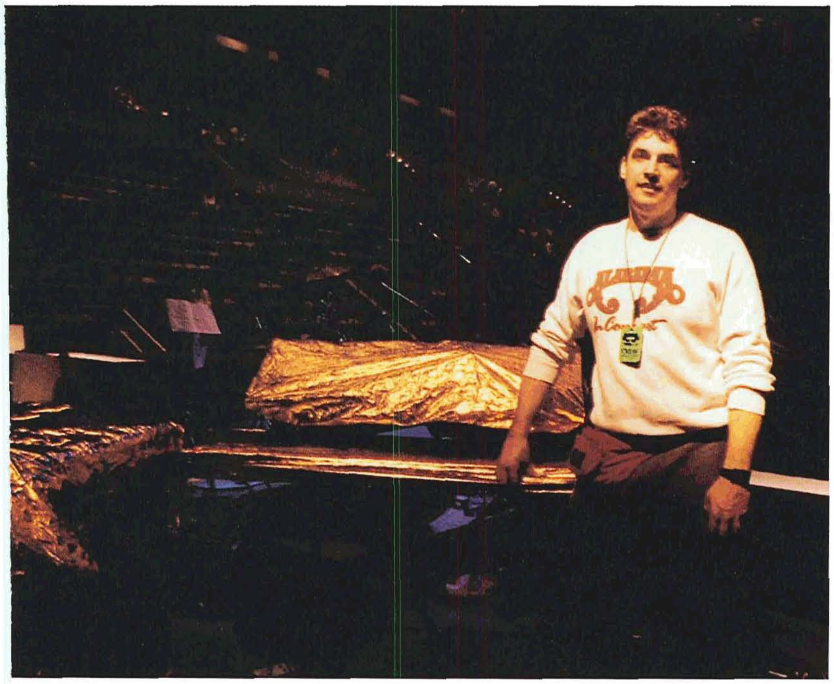
NASA subsequently found a broader use for the material thus developed: as a reflective insulator for protecting astronauts from solar radiation and sensitive spacecraft instruments from extremes of temperature. Initial success in that application brought an ever-expanding role for metallized materials, used as insulating "thermal barriers" in virtually every U.S. spacecraft. The impetus thus provided gave manufacturers a market, spurred R&D toward improved vacuum metallizing techniques and led to an extensive line of commercial products, from insulated outdoor garments to packaging for foods, from wall coverings to window shades, from life rafts

In the top photo, fishing boat captain Kurt Barlow of Islamorda in the Florida Keys is deploying an S.O.S Signal Kite, a highly reflective distress signal that can be elevated to 200 feet for best visibility. Barlow is wearing a reflective cap for protection from the Sun. Both products are made of a spinoff TXG material by Solar Reflections, Inc., a Florida family business. In the lower photo, displaying their kites and hats, are company vice president Kathryn Holmes (seated); her husband David G. Holmes, president and kite designer; and daughters Cathryn Carlson (left) and Jessica Beerli.

to candy wrappings, reflective blankets to photographic reflectors.

Metallized Products, Inc. (MPI), Winchester, Massachusetts was one of the companies that worked with NASA in development of the original space materials. It has been a productive partnership for MPI; the company continues to supply metallized materials for space use, but it has developed an even broader line of industrial and consumer-oriented metallized film, fabric, paper and foam. MPI markets its own metallized products and supplies materials to other manufacturers.

One of the most widely used MPI products is TXG laminate, once employed by NASA as a reflective canopy for visual and radar detection of the inflatable rafts in which returning Apollo astronauts awaited pickup by ships or helicopters of the recovery fleet. New uses for this material are still cropping up regularly.



In the upper photo is Dan Leach of Pro-Tektion, Inc., who formed a small business to provide covers for musical instruments, made of gold reflective TXG, that protect sensitive electronic components from heat, dust or rain. A closeup of a covered bass guitar and amplifier is shown above.

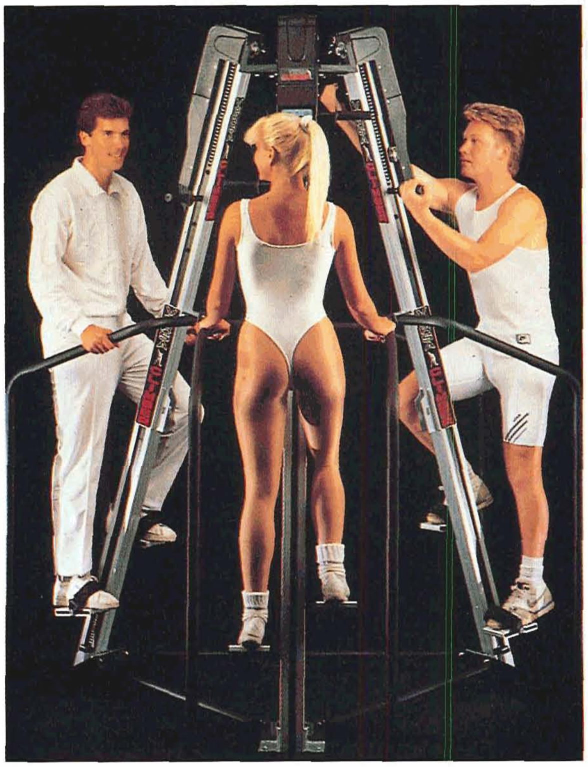
An example is an application similar to the reflective raft canopy: a reflective kite of gold TXG intended to provide a highly conspicuous distress indicator in an emergency. The S.O.S. Signal Kite can be flown as high as 200 feet to enhance radar and visual detectability. It offers a boon to campers, hikers and mountain climbers, who have need for a lightweight, easily portable emergency signaling device, and to boaters as a more convenient substitute for the bulky dish devices employed as signalling systems in an emergency at sea. Made of metallized nylon, the kite spans six feet but weighs only six ounces. It is produced by Solar Reflections, Inc., Fort Lauderdale, Florida; the company also markets a solar reflective hat for protection from the Sun.

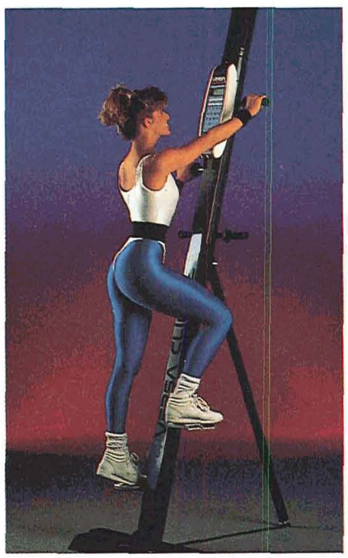
Another example is the novel use of TXG by Pro-Tektion®,Inc., Nashville, Tennessee, a small business operated by Dan Leach to provide protection for expensive musical equipment—keyboards, guitars, amplifiers, audio and lighting consoles—that have sensitive electronic components subject to damage from the heat of stage lights, dust in auditoriums, or rain at outdoor concerts.

Leach, a professional audio technician, saw the need for safeguarding instruments and designed a "fitted sheet" type of instrument cover. He researched fabrics available for the covers and found only one—TXG—that met requirements for protecting against all of the hazards. MP supplied the material and, in the budding stage of the new business, acceptance of the covers by the sound industry has been excellent. Pro-Tektion reports that "some of the biggest entertainers on tour are implementing the covers on their equipment, as are sound production companies and manufacturers of audio and lighting consoles."

® Pro-Tektion is a registered trademark of Pro-Tektion, Inc.

Heart Rate Monitors



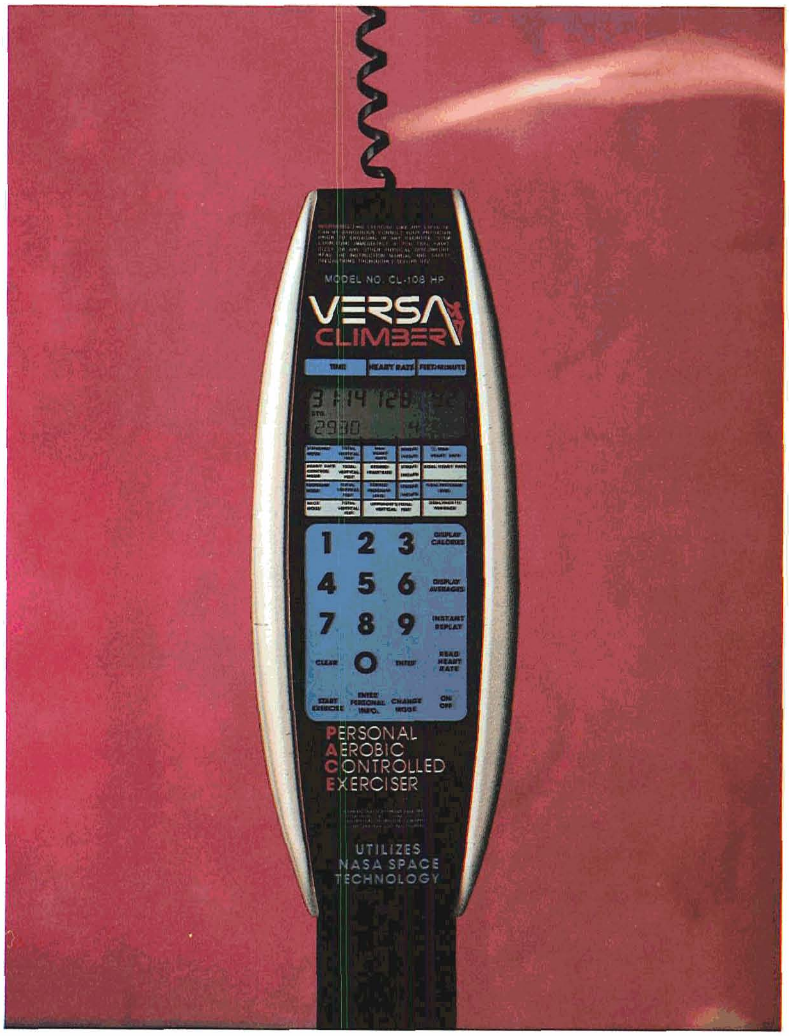


In the mid-1970s, looking ahead to the era of very long duration space flight, NASA saw a need for a new type of electrode for astronaut monitoring. The conventional conducting electrode, which made contact with the skin through a paste electrolyte, had disadvantages for long term use. For example, the paste can irritate skin and it eventually dries, causing unacceptable distortion of the data sensed. Other types of electrodes, which directly contact the skin without paste, posed different problems for longtime use in space, principally the "motion artifact," wherein movement of the subject causes electrode movement and signal-distorting noise of the conductively acquired signal.

Under a NASA grant, Dr. Robert M. Davis and Dr. William M. Portnoy of Texas Technical University came up with a new type of electrocardiographic electrode that would enable long term use on astronauts. Their invention was an insulated capacitive electrode constructed of a thin dielectric film. The dry reusable electrode functions immediately on contact with the skin and is not affected by ambient conditions of heat, cold or light, nor by perspiration, rough or oily skin conditions; the insulative film prevents motion artifact during exercise.

NASA subsequently licensed the electrode technology to Richard Charnitski, inventor of the VersaClimber, who founded Heart Rate, Inc., Costa Mesa, CA, to further develop and manufacture personal heart monitors and to produce exercise machines using the technology for the physical fitness, medical and home markets.

At right above is a Hi-Tri Health Club Model VersaClimber, one of eight models of a stepping/ full body climbing exercise machine designed to make use of all the major skeletal muscle groups during aerobic and strength conditioning. Therapy models, with a built-in seat for pedaling, are used for cardiac rehabilitation and orthopedically impaired patients. These machines, along with models for professional sports, schools, hotels, firemen, and the military services, incorporate the heart rate monitoring system based



on NASA electrode technology. At lower left, opposite page, is the Home Model VersaClimber 108H; the display module, which shows such information as calorie burn rate, exercise time, climbing speed and distance climbed, is shown in closeup at left.

The same technology is on both the Home and Institutional Model VersaClimbers. On the Home Model an infrared heart beat transmitter is worn under exercise clothing. The transmitted heart rate is used to control the work intensity on the VersaClimber... using the heart rate as the speedometer of the exercise. The ability to accurately read heart rate and set work intensity levels offers advantages to a full range of users from the cardiac rehab patient to the high level physical conditioning requirements of elite athletes.

The company manufactures and markets five models of the 1*2*3 HEART RATE™ monitors that are used wherever people exercise to accurately monitor their heart rate (bottom). They permit periodic or constant readings of heart rate to assure that the person exercising is within his proper heart rate training zone.

The company is developing a talking heart rate monitor that works with portable headset radios. The person exercising will be able to hear his heart rate announced in the headset without interrupting his exercise activity. A version of the heart beat transmitter will be available to the manufacturers of other aerobic exercise machines.

™ 1*2*3* Heart Rate is a trademark of Heart Rate, Inc.

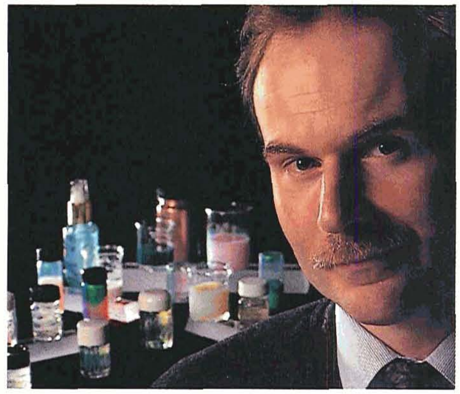
Liquid Crystals

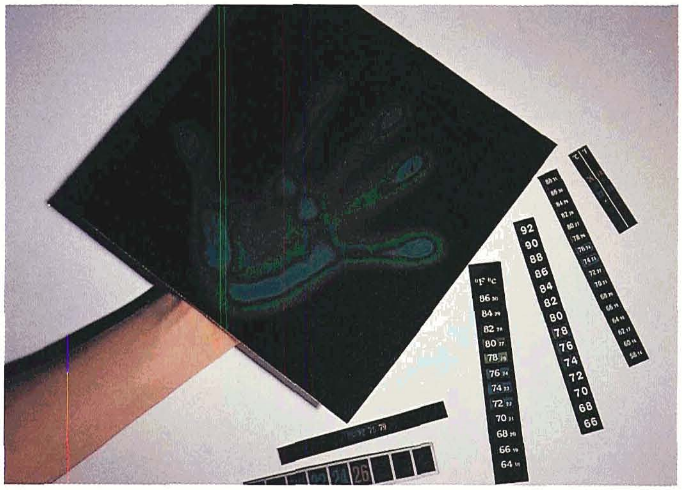
Liquid crystals are a form of matter in between solids and liquids. They appear as oily liquids, but they have certain properties of solid crystals; they also possess their own unique properties not found in either solids or liquids. They have familiar applications in everyday life, for example, in the displays of digital watches or pocket calculators and in a wide range of novelty products.

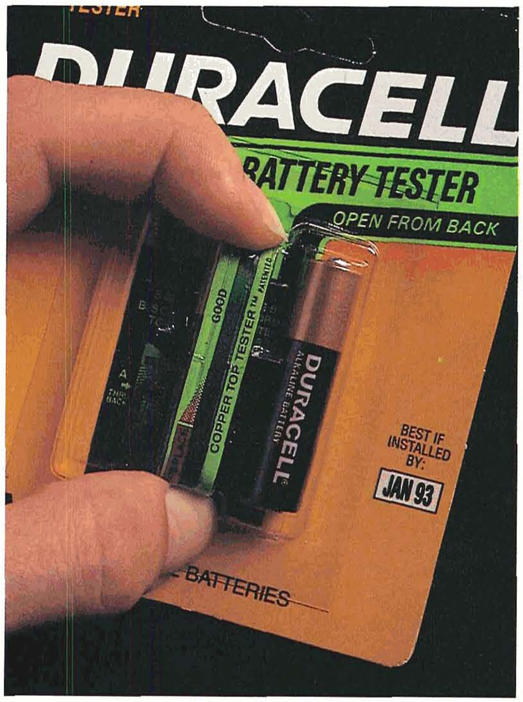
Thermochromic liquid crystals (below), or TLCs, are a type of liquid crystals that react to changes in temperature by changing color. Most TLC mixtures turn from colorless to red at a low temperature, then pass through other colors of the visible spectrum as temperatures increase. This color change characteristic offers a wide range of applications for TLC as temperature indicators, to mention just a few, digital thermometers, hot/cold warning indicators, disease diagnosis, industrial non-destructive testing, thermal imaging, chemical and gas detectors and advertising specialties.

Hallcrest, Glenview, Illinois has pioneered TLC technology since the beginning of the industry in 1973 and is now one of the world's leading manufacturers of temperature indicating devices. Hallcrest is continually seeking to expand existing markets and generate new markets through an aggressive program of research and development. Toward that end, Hallcrest collaborated with Langley Research Center in a mid-1980s R&D effort whose success provided NASA with an improved aerodynamic testing capability and allowed Hallcrest to develop a new market.

The Hallcrest/NASA collaboration involved development of a new way to visualize boundary layer transition in flight and in wind tunnel testing of aircraft wing and body surfaces. The boundary layer is the layer of air immediately adjacent to the aircraft skin (or, in hydrodynamics, the flow of water immediately adjacent to a vessel's hull). In flight, when the boundary layer is laminar—smooth—it yields very low skin friction drag, but when it becomes turbulent with increased speed, drag is similarly increased. In aerodynamic research, it is important to determine exactly where the boundary layer transition from laminar to turbulent flow occurs on a particular aircraft. Since air turbulence increases skin friction and also raises the temperature of the boundary layer at the transition point, the color change characteristic of







TLCs offered a new and potentially better method of visualizing the boundary layer transition in flight.

Hallcrest provided a liquid crystal formulation technique that afforded great control over the sensitivity of the liquid crystals to varying conditions. For flight research, for example, the Hallcrest/Langley team used a TLC formulation that would change color over a wide temperature range because the air temperature varies at different altitudes and the researchers wanted a technique that would allow transition measurement over a broad range of altitudes in a single flight. The solution was applied like paint over the surfaces of a test aircraft and the resulting color changes photographed in flight. TLC successfully indicated the transition points and the test results correlated closely with transitions indicated by other methods.

"Liquid crystal flow visualization provides a unique new testing capability for providing boundary layer transition data in some cases previously unavailable by practical means in wind or water tunnels and in flight test," said Dr. Bruce J. Holmes, who led the Langley test group. "The method is of great use to industry, government and universities for aerodynamic and hydrodynamic testing, saving significant cost and time."

This work enabled Hallcrest's establishment of a broad new market for TLC products in government/industrial aeronautical research, flow visualization and heat transfer studies, and for consulting or contract services on such programs. Hallcrest also supplies training kits designed to educate potential TLC users in the new technique, which is finding wide acceptance.

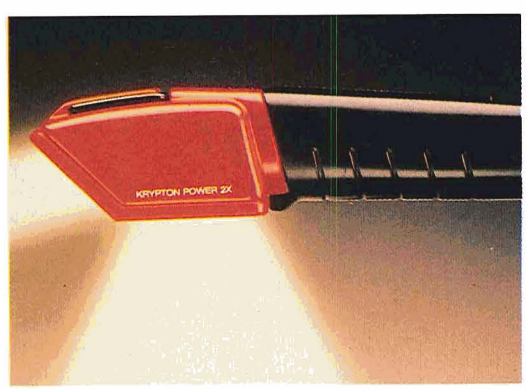
Among other subdivisions of Hallcrest's workload, the company's principal line is temperature indicating devices for industrial use, such as non-destructive testing and flaw detection in electric/electronic systems; for medical application, such as diagnostic systems; for retail sale, such as room, refrigerator, baby bath and aquarium thermometers (In the top photo are a sampling of thermometers with an illustration of the TLC's ability to display the temperatures of a human hand resulting from the thermal radiation of the hand); and for advertising and promotion specialties, decorations, jewelry, badges, etc. Additionally, Hallcrest manufactures TLC mixtures for cosmetic applications; at top left is Hallcrest technical marketing director Dr. Michael Parsley with a selection of liquid crystals used in a preparation manufactured by Estée Lauder Cosmetics. At lower left is a new Duracell battery that comes complete with a liquid crystal battery tester whose color change indicates the battery's condition.

Combination Light

At right is the Rayovac TANDEM™, an advanced technology combination work light and general purpose flashlight that incorporates several NASA technologies.

Produced by Rayovac Corporation, Madison, Wisconsin, the TANDEM functions as two lights in one. It features a long range spotlight (up to 50 feet) and wide angle floodlight (up to six feet in diameter); simple one-hand electrical switching changes the beam from spot to flood.

The TANDEM developers made particular use of NASA's extensive research in ergonomics (man/machine relationships) in the TANDEM's angled handle, convenient shape and different orientations that allow the user to shine either floodlight or spotlight or both from different angles. The shatterproof, water resistant plastic casing, similar to football helmet material, also draws on NASA technology, as does the shape and beam distance of the square diffused flood (right below).



The TANDEM's heavy duty magnet that permits the light to be affixed to any metal object borrows from NASA research on rare earth magnets that combine strong magnetic capability with low cost; the magnet's cost factor was very important to a high volume product, according to Rayovac officials. Finally, the Rayovac developers used a NASA-developed ultrasonic welding technique in the light's interior.

Rayovac was made aware of the NASA technologies by NERAC, Inc., Tolland, Connecticut, one of the 10 NASA-sponsored Industrial Applications Centers that offer clients access to the NASA data bank and some 400 other computerized databases. Since 1983, Rayovac engineers have been using NERAC's problem solving services as an extension of their own technology development capability. Rayovac reports that it has realized continuing savings in time, labor and expenditures from NERAC's work, which has provided direct assistance to the company on a wide range of projects.

™TANDEM is a trademark of Rayovac, Inc.

Catamaran Nets

In the 1970s when the Space Shuttle was being developed, NASA's Shuttle prime contractor Rockwell International saw a need for a new type of personnel safety net; several such nets would protect workers building the Shuttle Orbiter, preventing a fall through an open cavity to the ground.

Rockwell turned to West Coast Netting Inc. (WCN), Cucamonga, California, an established firm with 30 years experience in developing nets for sports and circus performers or other specialized nets. Rockwell wanted something more than an ordinary net; it had to have a tensile strength twice the government standard for safety nets, and it also had to be fire resistant and ultraviolet resistant.

WCN met the requirement with a net of Hyperester™ twine, made of three strands of fiber twisted together by a company-invented sophisticated twisting machine and process that maintain precisely the same tension on each strand. The resulting twine offers higher strength and improved abrasion resistance.

The WCN nets met all specifications and went into service with Rockwell. The technology that created the Hyperester supertwine has found spinoff applications, first as an extra-efficient seine for tuna fishing, then as a capture net for law enforcement agencies. Now there is a new one: as a deck for racing catamarans.

In the past, various materials were used to support the area between a catamaran's two hulls. In racing, netting was preferred because it allowed water to pass through and offered no solid surface that the wind could lift. As catamarans became larger and the span between the hulls wider, the nets' ability to support the crew became a problem. The Hyperester twine net became the solution; it has been used on most of the high performance racing catamarans of recent years, including the America's Cup Challenge boats. In the top photo is a view of the net from the mast down on a catamaran and in the bottom photo is a view looking from one hull toward the other.

Gino Morrelli of Gino Morrelli Design, one of the leading U.S. competition sailcraft designers whose boats are among the most competitive in the world, has been using Hyperester nets for the past three years. "We have had great success with these nets," he says, "and we specify them for use on cats from 20 feet to 70 feet long. They are tough and hold up well in the continual exposure to sunlight and saltwater."

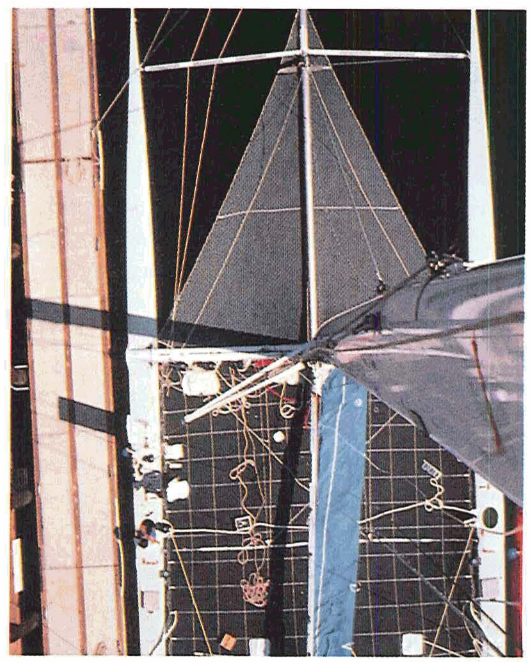
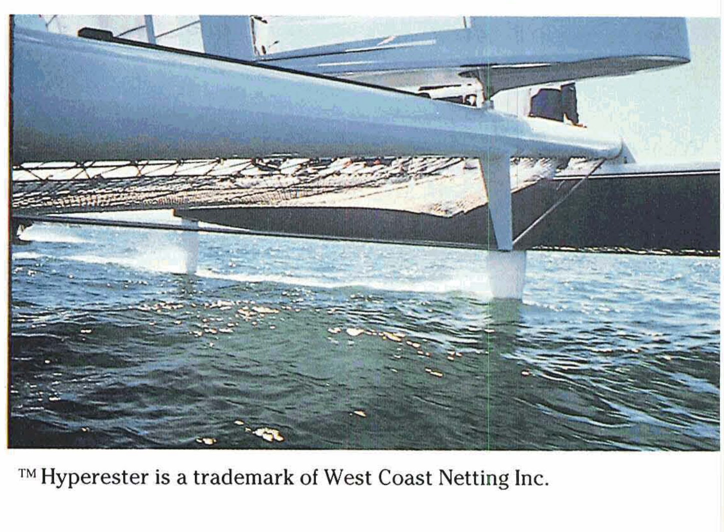


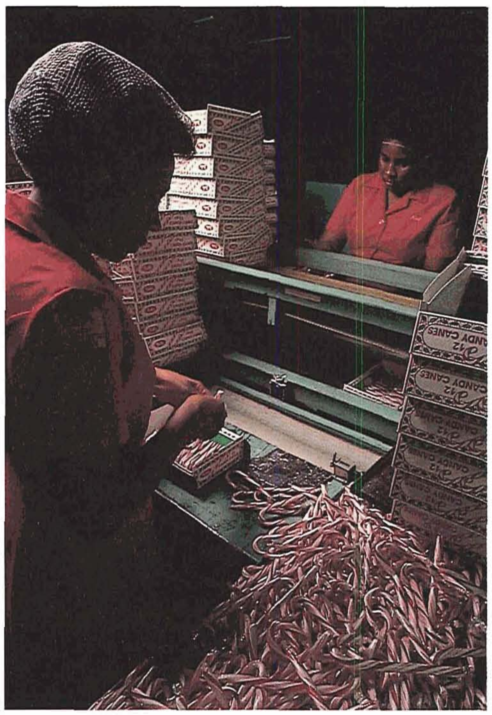
Photo by Mickey Munoz



™ Hyperester is a trademark of West Coast Netting Inc.

Heat Pipes

Bobs Candies, Inc., Albany, Georgia produces some 24 million pounds of candy a year in more than 200 different varieties, much of it "Christmas candy"—striped peppermint sticks, canes and balls. At right, kitchen workers pull the hot liquid sugar, add peppermint extract and red coloring to make stripes; below, candy canes moving very rapidly along a conveyor belt are just as rapidly bundled into hand-packaged boxes of 12.



The company makes 75-80 percent of its sales during the Christmas season, but to meet Christmas demand it must produce year-round. That means that thousands of cases of candy must be stored a good part of the year in two huge warehouses. The candy, of course, is very sensitive to temperature, for example, heat and humidity make the candy canes and sticks soft and runny, causing the red stripes to bleed into the white.

To bar that possibility, the warehouses must be maintained at temperatures of 78-80 degrees Fahrenheit with relative humidities of 38-42 percent. Such precise climate control of enormous buildings covering acres of floor space can be very expensive. In 1985, energy costs for the single warehouse then operated ran to more than $57,000 for the year and Bobs vice president-operations Don Bravaldo decided to do something about it.

Bravaldo learned of a cooperative project wherein NASA and the Florida Solar Energy Center (FSEC) were adapting heat pipe technology—originally developed for temperature control of sensitive space electronic systems—to control of humidity in building environments. FSEC was investigating ways to curb the high energy losses incurred in extracting excess moisture from superinsulated buildings in very humid climates.

In moderately humid climates, a conventional air conditioner cools air and lowers humidity with normal cooling coil operation. In a highly humid environment, however, the same air conditioner must operate longer and use more energy to lower humidity to an acceptable level.

Then, in the process of lowering humidity, it overcools the room air; that necessitates reheating the air to get it back to a comfortable temperature—and that takes additional energy.

The NASA/FSEC approach to the problem involves use of heat pipes, which transfer heat without expenditure of energy, to precool the air before it reaches the air conditioner's cooling coil. The coil removes the remaining heat and humidity, then the heat pipes reheat the overcooled air to proper temperature. In other words, the heat pipes handle the jobs of precooling and reheating without using energy, leaving the air conditioner free to operate for a shorter period of time. This approach obviously affords significant energy savings.

Bobs felt that this technique might be the answer to his warehouse control problem. The company contacted FSEC systems engineer Mukesh Khattar and from that contact there eventually emerged a cooperative test project to install a heat pipe system at Bobs' warehouses, operate it for a period of time sufficient to determine accurately the cost benefits, and gather data applicable to development of future heat pipe systems potentially beneficial to a wide range of users. At left, a warehouse engineer is servicing a roof-level air conditioning unit. Below, a Bobs/FSEC conference with, left to right, Bravaldo, Khattar, FSEC director Dr. David Block and Bob McCormack, Jr., Bobs chairman of the board.

The installation was completed in mid-1987 and data collection is still in progress. Costs of the project are shared by Bobs Candies, Kennedy Space Center, FSEC and Georgia Power Company.

Bobs Candies is more than pleased with the results so far. Using 1985 as a control year, energy costs for that year are estimated at $115,000 (only one of two warehouses was then operating so the figure represents a doubling of the actual energy cost of that year). In 1989, total energy cost for the *two* warehouses, with the heat pipes complementing the air conditioning system, was $28,706—and that figures out to an effective cost reduction from the control year of more than 75 percent. Bobs Candies is adding another 98,000 square feet of warehouse space and, needless to say, the new building will be heat-pipe controlled.

Fallout from the Shuttle Robot Arm

Painting railway hopper cars can be an expensive and time-consuming job, particularly if you have 11,500 of them, as does Canadian National (CN) Railways. That's why CN went looking for a better way to do it, and found one: the Robotic Paint Application System, now operating at the company's Transcona repair and overhaul facility in Winnipeg, Manitoba.

Developed for CN by Vadeko International Inc., Mississauga, Ontario, the robotic paint shop has two parallel paint booths, allowing simultaneous painting of two hopper cars, which are covered, tanklike carriers of such materials as coal, grain and potash. Each booth has three robots, two that move along wall-mounted rails to spray-paint the exterior, a third that is lowered through a hatch in the railcar's top to paint the interior. A fully computerized system controls the movement of the robots and the painting process.

CN, which prides itself on innovative ways to improve services and rates, was looking for a system that would speed up and lower the cost of painting hopper cars. Vadeko's answer met the approval of CN officials, who call it a "key advancement." The robotic painters can do a car, inside and outside, in four hours; the job formerly took 32 hours. This dramatic reduction in hopper car out-of-service time provides an economically important gain in equipment utilization.

And there are bonuses. The robotic system applies a more thorough coating, particularly to the car interior, that CN expects will double the useful life of its hoppers and improve cost-efficiency. Additionally, human painters no longer have to handle the difficult and somewhat hazardous job; CN paint shop employees have been retrained to operate the computer system that controls the robots and to handle such other jobs as paint selection, inspection and the logistics of moving cars through the robotic facility.

In sum, CN got for its investment in advanced technology a fourfold dividend: productivity gain, cost savings, improved working conditions, and significantly enhanced utilization of much in demand hoppers.

The system that made all this possible traces its technological ancestry to the Space Shuttle Remote Manipulator System (RMS), the robot arm used to deposit payloads in space or retrieve them from orbit. A robotic counterpart of the human arm, the RMS—or Canadarm as it is known in Canada where it was developed—has shoulder, elbow and wrist joints, plus a series of electric motors that serve as "muscles." Its "hand" is a cylindrical grappling fixture, which grasps a metal prong on the payload to be maneuvered. The Canadarm is controlled by an operator on the Shuttle Orbiter's flight deck, aided by sensors in the robot arm that send control information to a flight deck computer display. The system can handle any payload the Orbiter can carry; in coming years, it will also serve as a tool for space assembly and construction tasks.

Canadarm was developed by the National Research Council of Canada; prime contractor is Spar Aerospace Limited, Toronto, Ontario. The project was funded by the Canadian government as Canada's contribution to the Shuttle program, with the conviction that the technology would generate important Earth-use spinoffs and establish Canadian industry as a leader in robotics.

Canada's Vadeko International, manufacturer of large robotic systems, was founded by Dr. Graham D. Whitehead (left), shown with Canadian Defense Minister William McKnight (center) and Ben Torchinsky, board chairman of Agra Industries, Vadeko's parent company.

Robotic systems for railcar maintenance head technology transfers in the field of transportation

The investment has paid off; in fact, Spar formed a division specifically dedicated to development of robotic spinoffs. The first was a robot arm not unlike Canadarm that was designed to remove, inspect and replace large components of Ontario Hydro's CANDU nuclear reactors. A second major spinoff was development of remote-controlled mining equipment that increased productivity fourfold and removed miners from a hazardous operation. Spar is exploring other robotic systems for remote material handling in such operations as nuclear servicing, chemical processing, smelting and manufacturing.

Vadeko International represents an extra dividend on the Canadian investment, because Vadeko is a spinoff company, a fallout from Spar Aerospace. It is an example of a personnel-type technology transfer, wherein aerospace personnel move to other industries, bringing with them aerospace-acquired skills and know-how that have potential for non-aerospace applications.

In this case, the principal instrument of technology transfer is Dr. Graham D. Whitehead, president of Vadeko International. Dr. Whitehead was a member of the original Spar Aerospace Canadarm design team; he also worked on the initial spinoff, the CANDU project. In 1981, he left Spar to found Vadeko International. Among his associates are many of the other Vadeko engineering, project management and technical personnel who worked at Spar on Canadarm and CANDU.

Still a young company and relatively small, Vadeko has already built a solid reputation for advanced systems engineering. It has good financial backing, with 50 percent of its stock owned by the industrial conglomerate Agra Industries of Saskatoon, Saskatchewan. It is a partnership that benefits both companies; two of Agra's divisions are involved in joint ventures with Vadeko. Besides the headquarters in Mississauga, Vadeko operates three other facilities in Toronto, Winnepeg, and Ottawa, plus sales offices in Minneapolis, Minnesota and Seattle, Washington.

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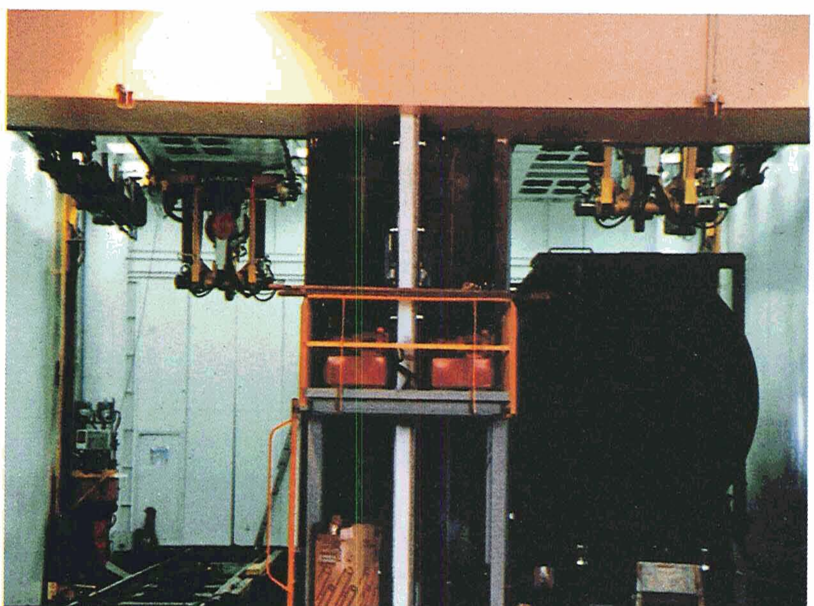
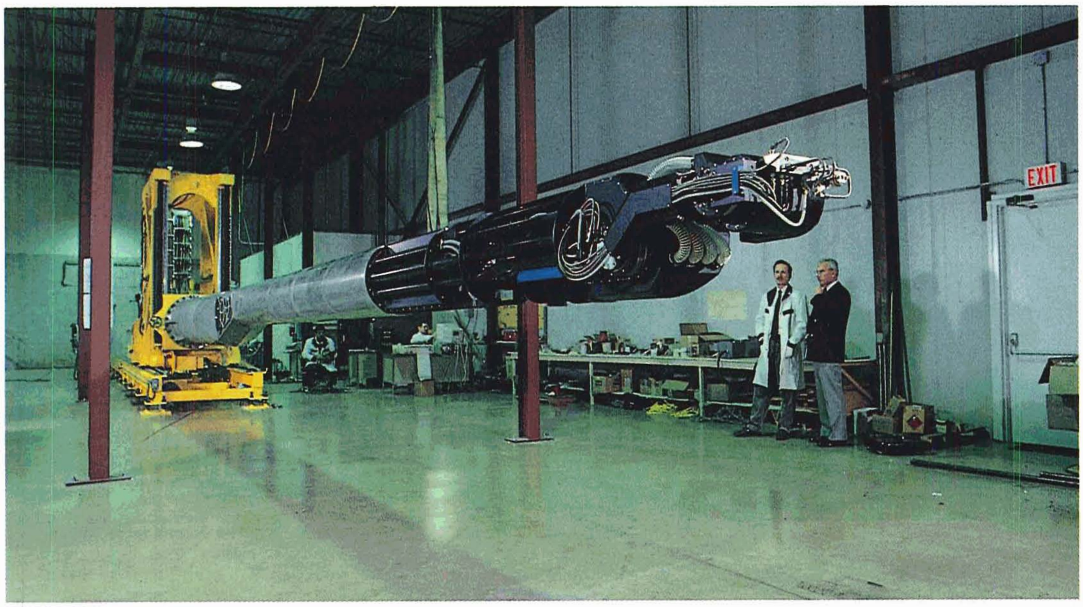


Shown above is Canadian National Railways' Robotic Paint Shop, two parallel paint booths with a hopper car ready for painting in the right hand booth. Each booth has three robot painters, two to handle the railcar's exterior and a third that drops through a roof hatch to paint the hopper. The photo at right shows the ceiling-mounted inside robot and, in red at left photo, one of the wall-mounted exterior painters. The robots can do in four hours a job that formerly took 32 hours.

Fallout from the Shuttle Robot Arm

(Continued)



Vadeko designed and built for rocket manufacturer Hercules Aerospace this 50-foot-long Rolling Cantilever Robot, used to clean, degrease and apply coatings on large solid rocket motors.

In addition to large scale robotic systems, Vadeko International is engaged in such other areas of technology as flexible automation, nuclear maintenance, underwater vehicles, thin film deposition and wide band optical monitoring.

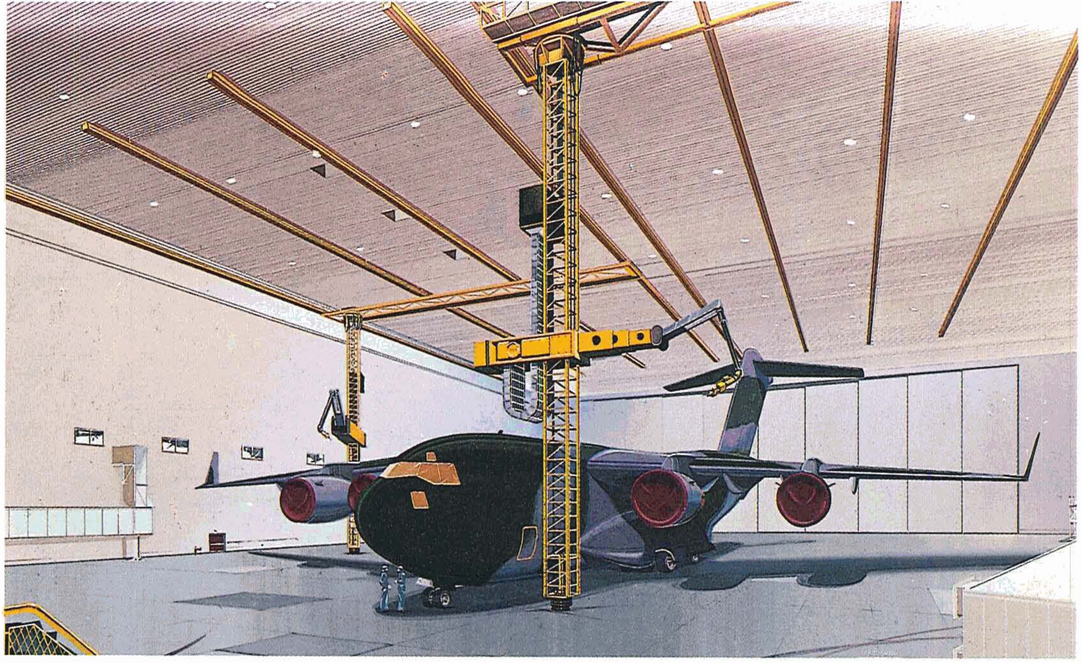
Among the company's major recent projects are two performed for U.S. space contractors. The first, under a contract from Hercules Aerospace, Salt Lake City, Utah, called for construction of the world's largest robot arm, a 50-foot long system that weighs 35,000 pounds. Hercules is using the Rolling Cantilever Robot to do automatically a painting job on large rockets that would be difficult to accomplish with human painters. The rockets are large solid fuel motors used as boosters on U.S. expendable launch vehicles. Before the motors are filled with solid propellant, it is necessary to clean and apply special coatings to the cylindrical motor casings inside and out, and to apply the coatings uniformly. This assignment called for a rather complex robot system that incorporates six major assemblies and provides five axes of motion. Despite the complexity, Vadeko designed, built and delivered the robot arm in just seven months.

Vadeko also won a contract from Thiokol, Inc., Wasatch, Utah to produce the controls and software for a similar large robotic system. Called the Bore Inspection Tool System, its job is inspection and repair of the volatile propellant surfaces of the Space Shuttle's Solid Rocket Boosters, which are manufactured by Thiokol. So the technology transfer has come full cycle: one Shuttle system—Canadarm—spawned a series of spinoffs, one of which will help improve the Shuttle.

Another Canadarm descendant of enormous potential is waiting in the wings: a robotic rail cleaning system, an offshoot of the Canadian National Robotic Paint Application System.

Over time, grease and debris build up on the undersides of railway and subway cars. Periodic cleaning is necessary to prevent fires and ease access for maintenance. That's a difficult job by conventional methods.

Vadeko has designed a Robotic Undercar Cleaning System that employs two robots mov-



One of the largest robotic systems ever built is Vadeko's Automated Preparation and Paint Application System, designed and fabricated for McDonnell Douglas Corporation to apply all exterior coatings to large aircraft. The aircraft pictured is the C-17 military airlifter still in development.

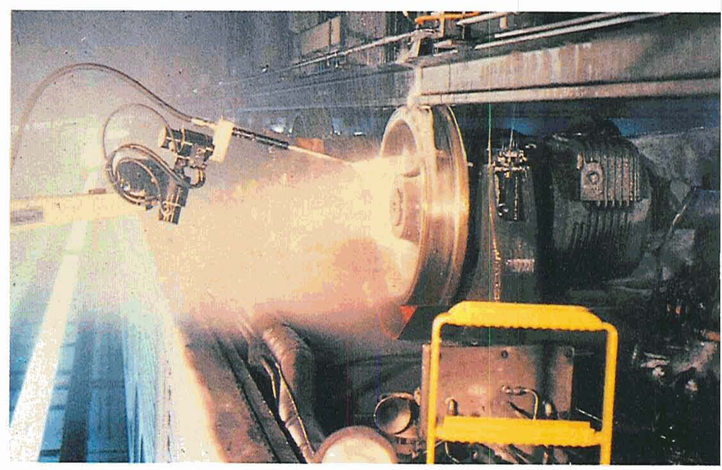
ing along a 180-foot section of track. The fully automatic facility identifies the type of railcar and directs the movement of the robots without human intervention; the robots perform delicate cleaning operations on the complex undercar equipment, using a combination of water and compressed air. The system increases the efficiency of railcar maintenance while allowing removal of humans from a hazardous and unpleasant environment.

Vadeko designed the cleaning facility for Long Island Rail Road (LIRR), a major New York Commuter line; LIRR is considering full scale implementation of the facility. Rail services in Toronto, London and New York are also interested.

Among other Vadeko robotic systems are a Press Unloading System for automatically removing aluminum castings from an injection molding press, and a fully automatic system for assuring the correct removal of vials from an inventory of more than 1,300 possible vial selections.

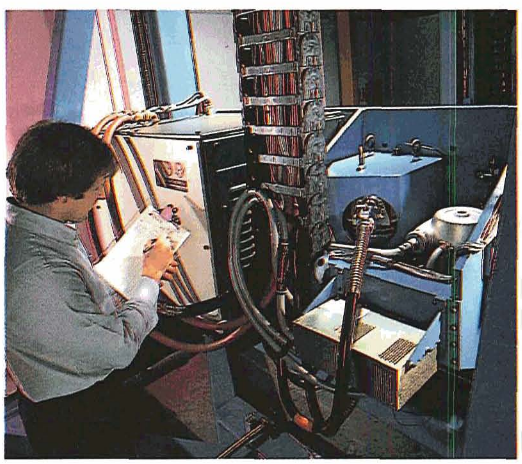
Vadeko also has a major project in retail level automation, a joint venture with 20/20 Recycling Centers, an Agra division. Legislative actions in California created a need for retail recycling services capable of receiving aluminum cans, glass bottles and plastic containers in exchange for a monetary incentive. A major player in this market, 20/20 recognized that automation of the scrap acquisition process could improve throughput while reducing costs. So 20/20 called on Vadeko to utilize its extensive background in flexible automation to design an intelligent, reliable and adaptable Reverse Vending Machine. The system is in development.

One other Vadeko Project merits special note: the company's work for the Bank of Canada and the National Research Council of Canada in anticounterfeiting measures. New technologies, such as laser scanning and high fidelity color copying, pose a threat to the security of multicolored Canadian money. Vadeko's approach to foiling counterfeiters draws on its thin film technology expertise to develop a "revolutionary" currency protection process – but Vadeko can't elaborate for security reasons. The Bank of Canada has permitted Vadeko to partially commercialize the technology and it could find a big market. Other nations have expressed interest in the currency protection process and the process is adaptable to many other security applications, such as drivers' licenses, identification cards, securities, passports and police documents.



For the difficult railroad job of cleaning complex undercar equipment, Vadeko has designed a twin-robot system that automatically moves along a track beside the car and sprays a combination of water and compressed air.

Non-destructive Testing Scanner



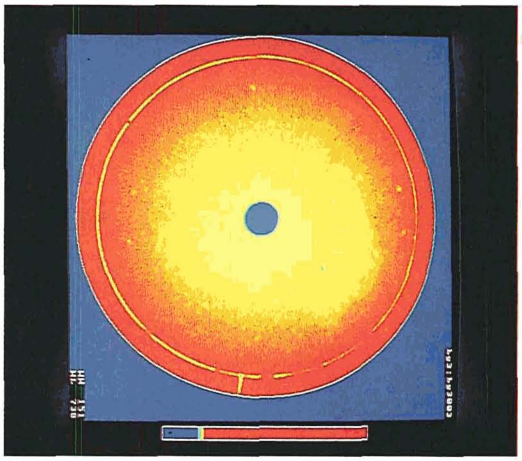
Computed tomography, also known as CT or CATScan, is an established medical diagnostic technique for comprehensive body scanning. It incorporates digital image processing technology that traces its origin to NASA research and development performed as a prelude to the Apollo Lunar Landing Program.

The technology that originated in an aerospace program has come full circle with a new aerospace—or general industrial—adaptation called the Advanced Computed Tomography Inspection System, or ACTIS. Where the medical version of CT scans the human body for tumors or other abnormalities, the ACTIS system finds imperfections in aerospace structures and components, such as castings, assemblies, rocket motors and nozzles.

Developed for Marshall Space Flight Center by Bio-Imaging Research, Lincolnshire, Illinois, ACTIS is described by its developer as the most versatile CT scanner available for non-destructive testing applications. Marshall is using its system to test rocket motor assemblies and other critical components. Boeing Aerospace & Electronics, Kent, Washington purchased the first industrial use model and is using it to learn more about materials and processes, particularly in the field of composite materials.

ACTIS is a variable geometry system. Where most large scanners have fixed distances between the radiation source and the detectors, ACTIS source and detectors can be moved closer together or farther apart to optimize the geometry for different sizes of test objects. In addition, ACTIS can support three separate radiation sources operating over a wide range of voltages; it also has a large number of detectors in unique focusing assembly, which provides greater x-ray collection efficiency and more image data. This combination—variable geometry, three sources and focusing detectors—makes ACTIS cost-effective for a broad range of applications. The system can scan anything from very small turbine blades to large rocket assemblies.

At top right is the ACTIS console, from which the user can set scan parameters, initiate scan-



ning, create, retrieve and store data, and control the display and analysis of images. In the middle photo, opposite page, is the gantry control processor, which provides local control of the scanner gantry while test objects are being loaded and unloaded. The bottom photo opposite illustrates the three separate radiation sources. At immediate left is a CT color image (ACTIS also provides monochrome imagery) of a cross section of a rocket motor gas generator; the bright yellow spots in the orange background (near the perimeter) are small voids that indicate anomalies.

Photo below illustrates one of a number of Boeing applications of the ACTIS system: it is being used in non-destructive evaluation of aircraft components. Boeing's special use of the system is in analysis of composite materials, crucial to the company's advances in missile and aircraft design. Computerized tomography bids to become increasingly important with industry's anticipated expansion of composite use.

ACTIS has already proved important to Boeing Aerospace & Electronics. The company has won several NASA/USAF research and development contracts for component inspection and test due to the expertise of the ACTIS-equipped Physics Group.

Boeing's interest in CT was sparked by a problem early in the development of the company's Inertial Upper Stage (IUS), used by NASA and the Air Force to boost satellites to higher orbits after their initial delivery to low Earth orbit. When concerns arose over IUS' nozzle exit cones, Boeing technicians purchased inspection time at medical facilities to examine suspect exit cones with CT scanners. That led to the company's purchase of its own ACTIS system. All IUS cones are routinely scanned to verify product quality when they leave the factory.

Stress Analyzer

At top right is the SPATE 900 Dynamic Stress Analyzer, manufactured by Ometron Limited, London, England and distributed in the U.S. by Ometron Inc., Herndon, Virginia. SPATE is an acronym for Stress Pattern Analysis by Thermal Emission, a title that embraces its purpose and *modus operandi*: it detects stress-induced temperature changes in a structure and indicates the degree of stress.

SPATE is widely used to analyze structural stress in research studies and manufacturing operations involving a wide range of structures, among them air, rail and automotive transportation vehicles, propulsion systems, earth moving equipment, composite materials, transmission towers, mechanical gears, nuclear power plants and marine structures. SPATE 9000 systems, says Ometron, "have established a proven record for cost reduction in product design and testing; an increasing number of everyday products owe their improved performance and structural integrity to the SPATE analyzer."

The SPATE system is based on technology developed under NASA contract a quarter century ago, when Langley Research Center sponsored a study of infrared stress measurement. The study was proposed by Milo H. Belgen, an engineer with the Columbus (Ohio) Aircraft Division of North American Aviation Inc. (later Rockwell International). For his company, Belgen had explored the feasibility of using sensitive infrared radiometers then becoming commercially available to scan aircraft structures for stress concentrations while they were being subjected to repeated oscillating loads that simulated actual flight; it was hoped such research would reduce the cost of developing aircraft structural designs.

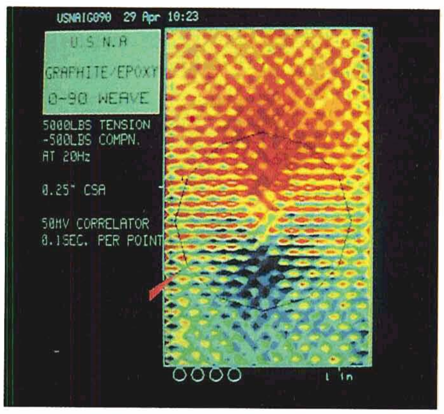
Belgen's follow-on work under the NASA contract was essentially a demonstration of a principle postulated more than a century earlier by the British mathematician and physicist William Thomson Kelvin. Lord Kelvin theorized that a material subjected to stress experiences a conversion between mechanical and thermal energy that results in changes of temperature in the material, and that there was a correlation between the degree of stress and the change in temperature. Lord Kelvin's theory of thermoelastic stress analysis temperature changes remained an intellectual curiosity until the availability of sensitive radiometers.

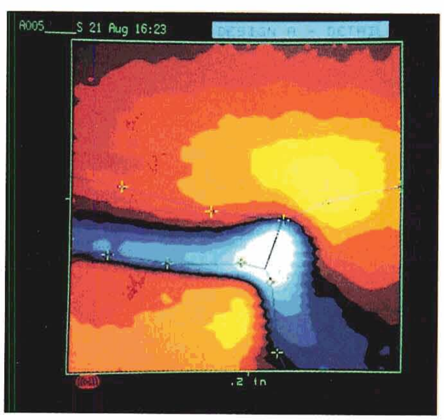
Belgen's work was a milestone in that he showed the feasibility of using *non-contacting* instrumentation—the infrared radiometer—to make stress measurements, overcoming the skepticism of that time that a system could map stresses in a structure without anything actually attached to the structure. Belgen's work established a departure point for later development of SPATE systems by providing a technology base of technical literature that detailed the basic aspects of infrared stress measurement. This stimulated research on practical applications of the technology.

More than a decade later, when temperature measurement technology had advanced, SIRA Ltd., Chiselhurst, England developed—in 1977—the first practical SPATE system under contract to the British Ministry of Defence. SIRA is the parent company of Ometron Inc. Ometron general manager David E. Oliver, who participated in the SPATE development at SIRA, acknowledges that "Belgen's work in the sixties for NASA helped us have a strong start in a technology that is now revolutionizing experimental stress analysis."

Ometron's SPATE 9000 consists of a scan unit and a data processing console with a keyboard and a visual display. The scan unit contains an infrared channel focused on the test structure to collect thermal radiation, and a visual channel used to set up the scan area and interrogate the stress display; stress data is produced by detecting minute temperature changes—down to one-thousandth of a degree Centigrade– resulting from the application to the structure of dynamic loading. The electronic data processing system correlates the temperature changes with a reference signal to determine stress level.

At near left is a typical visual display showing a fault (blue area) in a composite material; impact damage, not visible under normal visual in-

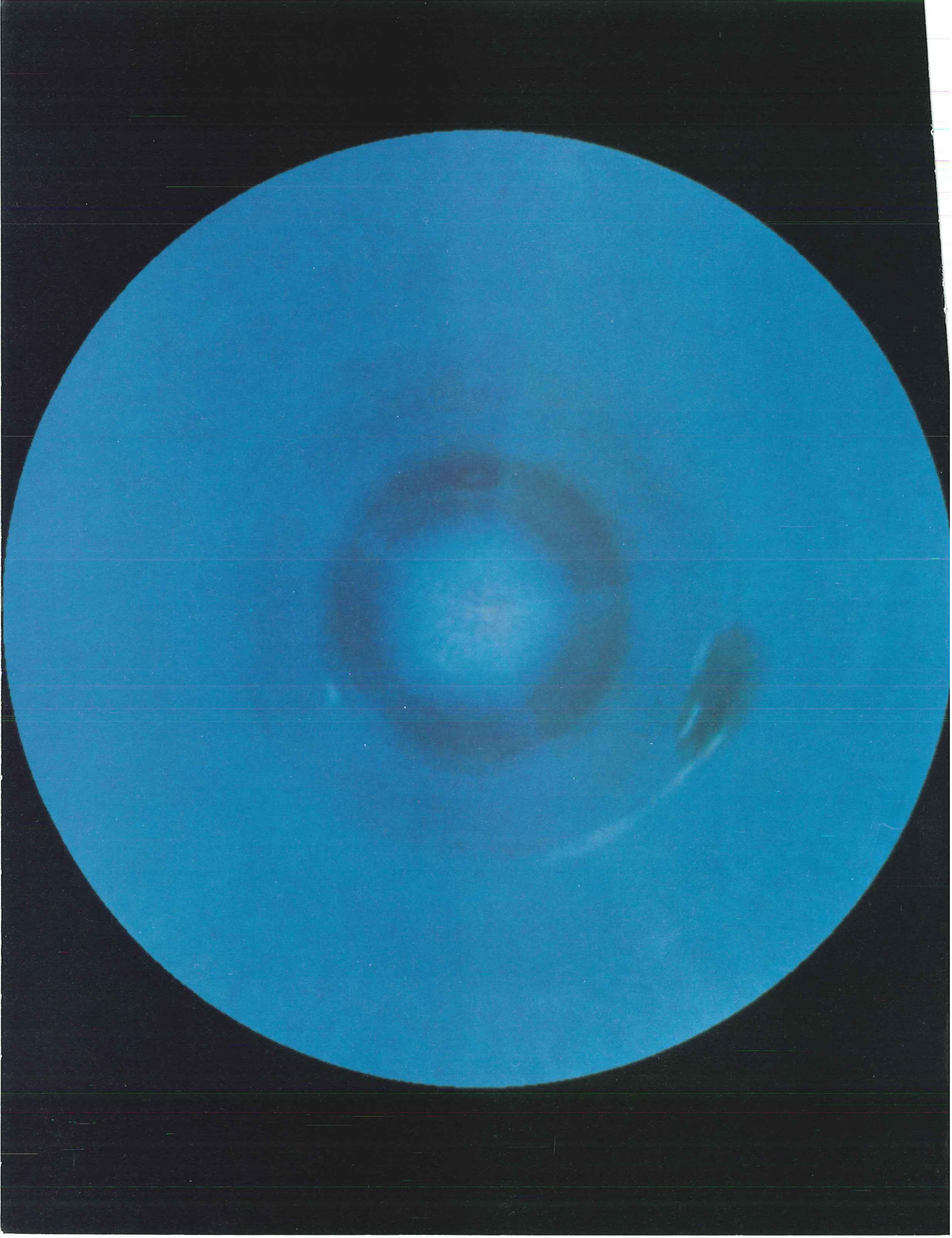




spection, is readily detected by SPATE 9000. The bottom photo is a scan of a truck frame weld showing stress areas in red (tension) and blue (compression). A wide range of software is available for the great variety of applications; some software programs have been developed in association with Deere & Company.

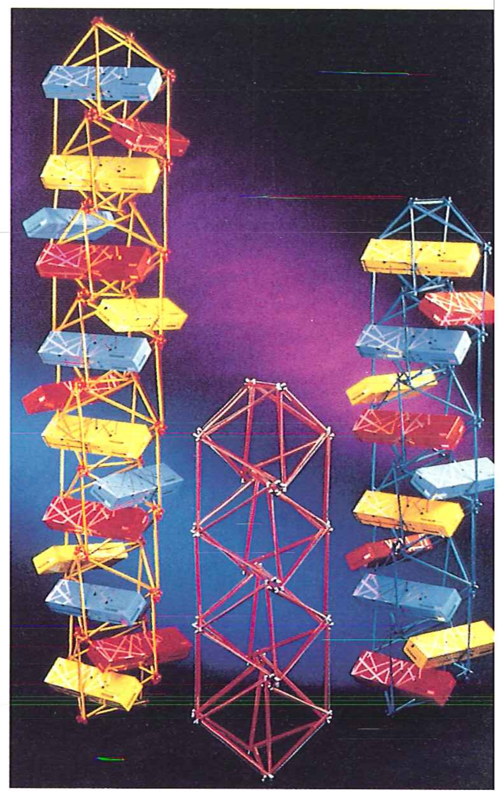
At left center is Brad Boyce of Deere's Horicon Works, chairman of the U.S. SPATE Users Group. Deere & Company uses SPATE for measuring stress in agricultural, lawn and garden equipment.

The roster of SPATE 9000 users reads like a who's who of industrial research; among them are such familiar names as Ford, Chrysler, General Motors, BMW, Nissan, Honda, Toyota, Renault, Boeing, Rockwell, General Electric, Aeritalia, Pratt & Whitney, and such government research facilities as the USAF's Wright-Patterson Air Force Base, Britain's Admiralty Research Establishment and the Royal Aircraft Establishment, Japan's Research Institute of Industrial Safety and National Aerospace Laboratories, the Royal Military College of Belgium and the Technical University of Denmark.



Technology Utilization

A description of the mechanisms employed to encourage and facilitate practical application of new technologies developed in the course of NASA activities.



Neptune's south pole, encircled by concentric bands, is at the center of this composite projection, made from five color images acquired by Voyager 2 in the course of one Neptunian day—about 18 hours.

TECHNOLOGY UTILIZATION

Putting Technology to Work

By their challenging nature, NASA programs are especially productive of technology advancements. This wealth of technology is an important national asset in that it can be reused to develop new products and processes, to the benefit of the U.S. economy in increased productivity, frequently in new companies, new jobs and a resulting expanded contribution to the Gross National Product.

NASA's instrument for promoting broader use of the technology bank is the Technology Utilization Program, which employs several types of mechanisms to stimulate the transfer of aerospace technology to other sectors of the economy. The program is managed by the Technology Utilization Division, a component of NASA's Office of Commercial Programs. Headquartered in Washington, D.C., the division coordinates the activities of technology transfer specialists located throughout the United States.

A key element of the program is the Technology Utilization Officer, or TUO. Located at each of NASA's nine field centers and at one specialized facility, TUOs are technology transfer experts who serve as regional managers for the Technology Utilization Program.

The TUO's basic responsibility is to stay abreast of R&D activities at his center that have significant potential for generating transferable technology. He assures that the center's professional people identify, document and report new technology developed in the center's laboratories and, together with other center personnel, he monitors the center's R&D contracts to see that NASA contractors similarly document and report new technology, as is required by law. This technology, whether developed in house or by contractors, becomes part of the NASA bank of technical knowledge that is available for secondary application. Such availability is reported in the publication *NASA Tech Briefs*. (See page 150)

The TUO also serves as a point of liaison among industry representatives and personnel of his center, and between center personnel and others involved in applications engineering

Research scientist Dr. Stuart Rogers (seated, foreground) briefs Ames Research Center's Technology Utilization staff on the use of the aerospace-developed Computational Fluid Dynamics (CFD) technique in studies of the human heart's complex blood flow field. The use of the CFD technique in heart research, involving solution on supercomputers of complicated mathematical equations describing blood flow behavior, is a step toward computer-aided design of artificial hearts.

A nationwide technology utilization network seeks to broaden and accelerate secondary application of NASA technology in the public interest

projects, which are efforts to solve public sector problems through the application of pertinent aerospace technology. On such projects, the TUO prepares and coordinates applications engineering proposals for joint funding and participation by federal agencies and industrial firms. Additionally, the TUO coordinates his center's activities relative to the conferences, seminars and workshops NASA sponsors to encourage broader private sector participation in the technology transfer process.

Support for the TUOs—and for all the other elements of the NASA technology utilization network—is provided by the Technology Utilization Office at the NASA Scientific and Technical Information Facility (STIF). This office executes a wide variety of tasks, among them maintenance of the subscription list for *NASA Tech Briefs*; maintenance and mailout of Technical Support Packages, which requires a reproduction effort of more than 1.5 million pages a year; and responding to requests for information, an activity that entails processing some 120,000 letters and other inquiries and mailout of more than 200,000 documents annually.

The TUO/STIF is also responsible for research, analysis and other work associated with this annual *Spinoff* volume; for distribution of technology utilization publications; for retrieval of technical information and referral of highly technical requests to appropriate offices; for developing reference and bibliographic data; and for public relations activities relative to media, industry and trade show interest in technology utilization matters.

In addition to the TUOs, other mechanisms of the Technology Utilization Program include a network of 10 Industrial Applications Centers that offer clients access to a great national data bank; a software center that provides, to industry and government clients, computer programs applicable to secondary use; publications that inform potential users of technology available for transfer; and applications engineering projects. These mechanisms are amplified in the following pages.

Dean C. Glenn, Technology Utilization Officer at Johnson Space Center (dark jacket), discusses an applications engineering project with two members of his staff.

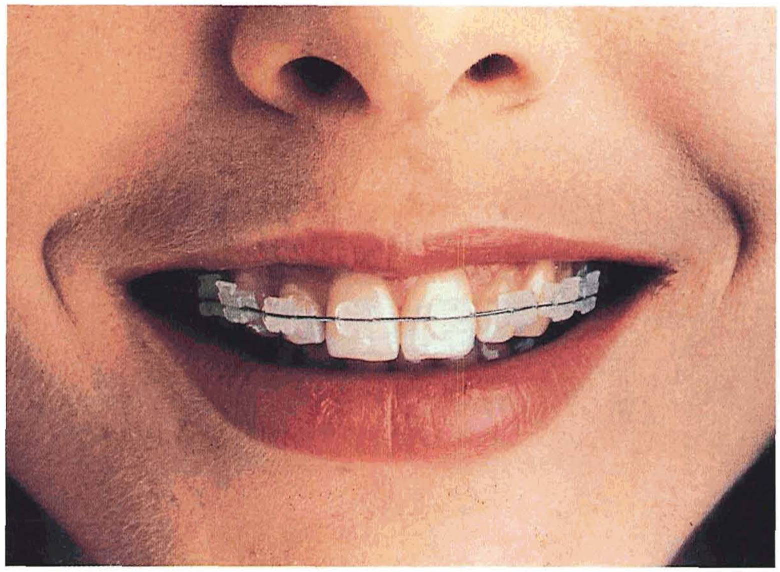
Applications Centers

To promote technology utilization, NASA operates a number of user assistance centers whose job is to provide information retrieval services and technical help to industrial and government clients. There are 10 Industrial Applications Centers (IACs) affiliated with universities across the country. The centers are backed by off-site representatives in many major cities and by technology coordinators at NASA field centers; the latter seek to match NASA expertise and ongoing research/engineering in areas of particular interest to clients.

In the latter 1980s, the IAC network was expanded by agreements linking the IAC system with technology-oriented assistance centers sponsored by state governments. The IACs bring to this partnership access to a great national storehouse of accumulated technical knowledge, along with their broad expertise in retrieving information and applying it in support of clients' needs. The state-sponsored centers, closer to much of U.S. industry than the IACs, offer special assistance tailored to the needs of firms in their service areas. Thus, the linkage significantly expands the capability of the combined network for serving industry. There are now 21 state-sponsored centers designated Industrial Applications Center Affiliates.

Through the applications centers, clients of the combined network have access to nearly 100 million documents in the NASA databank and more than 400 other computerized databases. The NASA databank includes reports covering every field of aerospace-related activity, plus the continually updated, selected contents of some 15,000 scientific and technical journals. Clients in many areas have access to this vast data storehouse through a Remote Interactive Search System (RISS). Clients at personal computers hundreds of miles distant can watch as an IAC representative formulates a strategy for solution of the client's problem and conducts a preliminary search of the databanks to start the process of getting the client the specific help he needs from the best source.

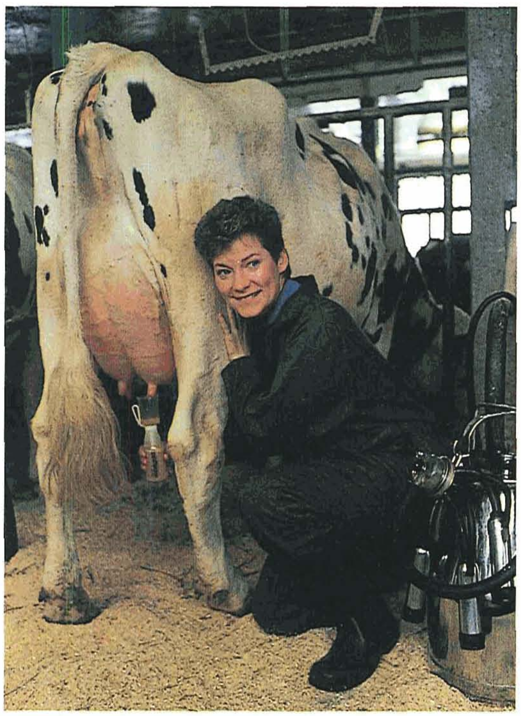
An example of how the industrial assistance network operates is the help provided Ceradyne, Inc., Costa Mesa, California and Unitek® Corporation/3M, Monrovia, California by the NASA Industrial Applications Center, University of Southern California (NIAC/USC).



The two companies jointly developed new type dental braces that are virtually invisible at normal contact distances (right); only in close-up, as above, are the translucent braces detectable. Called Transcend Brackets®, the ceramic braces are made of a material known as translucent polycrystalline alumina, or TPA. The material came to orthodontics by an indirect route and NIAC/USC played an important part.

Ceradyne, a leader in advanced ceramics for aerospace, defense, electronics and industrial uses, was looking for a special material to be used in infrared radomes employed by the military services in tracking heat-seeking missiles. At Ceradyne's request, NIAC/USC conducted an extensive literature and patent search to provide a technology base for Ceradyne's production of TPA.

Later, Unitek contacted Ceradyne in quest of a transparent material of sufficient tensile strength to be used in orthodontic treatment. Ceradyne suggested TPA as the answer and the



two companies embarked on a program of development and clinical trials. Transcend Brackets were introduced in 1987 in what the developers say was the most successful orthodontic product introduction in history.

Another example involves the work of NERAC, Inc., Tolland, Connecticut, another of NASA's IACs, in behalf of Alcide Corporation, Norwalk, Connecticut. Alcide's founders developed a formulation—later named Alcide® compound—for sterilizing ultrasonic cleaning tanks and found that it could kill bacteria, viruses or fungi on or shortly after contact, yet was non-toxic to humans, animals and plants—and therefore had a very wide range of potential applications.

Alcide Corporation was formed to commercialize the technology and the new company sought NERAC's aid in identifying applications and the types of businesses that might have a need for such a product. NERAC conducted a computer search of more than a dozen databases and uncovered scores of applications, among them treatment of viral, fungal and bacterial infections in animals; treatment of human skin diseases; disinfection and sterilization of medical facilities; as a sterilant for food production machinery and food preservation; as a preservative for cutting oils and paints; and as a deodorant/disinfectant for carpets, chemical toilets, public conveyances and meeting places.

Alcide Corporation developed and tested specific compounds for some of these applications and some of them are now commercially available. The company found a broad new market when research disclosed that Alcide could destroy mold as well as bacteria, viruses and fungi. This opened the door for a product—Ren New Air Conditioning Disinfectant—for disinfecting and removing mold from auto air conditioners (above left) without removing them from the auto (which is costly) and without leaving lingering toxicity. In 1987, Alcide concluded agreements with major U.S. automakers for distribution of the disinfectant, and with others for disinfecting contact lenses, for mouthwash and toothpaste, and for a barrier teat dip that helps prevent mastitis in dairy herds (left). Still other applications are in development.

® Transcend Brackets and Unitek are registered trademarks of Unitek Corporation/3M.

® Alcide is a registered trademark of Alcide Corporation.

Software Center

In the course of its varied activities, NASA makes extensive use of computer programs in such operations as launch control, analyzing data from spacecraft, conducting aeronautical design analyses, operating numerically controlled machinery and performing routine business or project management functions.

To meet such software requirements, NASA and other technology generating agencies of the government have of necessity developed many types of computer programs. They constitute a valuable resource available for reuse. Much of this software is directly applicable to secondary applications with little or no modification; most of it can be adapted to special purposes at far less than the cost of developing a new program.

Therefore, American businesses can save a lot of time and money by taking advantage of a special NASA technology utilization service that offers software capable of being adapted to new uses. NASA's mechanism for making such programs available to the private sector is the Computer Software Management and Information Center (COSMIC)®.

Located at the University of Georgia, COSMIC gets a continual flow of government developed software and identifies those programs that can be adapted to secondary usage. The center's library contains more than 1,400 programs for such tasks as structural analysis, design of fluid systems, electronic circuit design, chemical analyses, determination of building energy requirements, and a great variety of other functions. COSMIC customers can purchase a program for a fraction of its original cost and get a return many times the investment, even when the cost of adapting the program to a new use is included.

An example of how this service aids industry is the use of a COSMIC-supplied NASTRAN® program by Honda R&D Company, Ltd. of Japan. The Honda Acura Legend Coupe pictured at top right is representative of a number of Honda vehicles designed with the aid of the NASTRAN (NASA Structural Analysis) program.

Developed by Goddard Space Flight Center, NASTRAN is a general purpose predictive tool applicable to structural analysis of air and space vehicles, automotive vehicles, railroad cars, ships, nuclear power plants, steam turbines, bridges, office buildings—and that's just the beginning of a lengthy list.

One of the most widely used of all aerospace spinoffs, the NASTRAN program takes an electronic look at a computerized design and predicts how the structure will react under a great many different conditions. Quick and inexpensive, it minimizes trial-and-error in the design process and makes possible better, lighter, safer structures while affording significant savings in development costs.

Virtually all U.S. automakers, and many others, now employ the aerospace derived computer design technique and most use NASTRAN in some part of the design process. Honda R&D Company has been using NASTRAN for more than a decade for structural analysis of auto bodies, motorcycles and such components as tires, wheels, engine blocks, pistons, connecting rods and crankshafts.

Another example of the utility of COSMIC-supplied programs is the experience of Ducks Unlimited, Inc., Long Grove, Illinois, an organization dedicated to preservation of the world's waterfowl. Ducks Unlimited makes continuous inventories of wetland resources, crucial to effective waterfowl management. To get continually updated information on the changing conditions of waterfowl habitats, the organization uses data from the Landsat satellites' Thematic Mapper, an advanced Earth-scanning instrument that collects data in seven bands of the spectrum.

Orbiting the Earth, the Thematic Mapper measures and records six values of light reflected from Earth and one value of heat energy. On each orbital sweep, its sensors produce a series of digital "scenes" representing the features of Earth segments, each segment containing about 40 million bits of information. Called picture elements, or pixels, they are computer processed and the resulting mosaic is projected on a digital display device.

To interpret this great flow of information,

Ducks Unlimited uses a computer program—called ELAS—designed especially for analysis of Landsat data. The raw data contains seven values for each pixel. Each of the seven bands of data can be displayed as shades of gray on a monitor (above). Any three bands of raw data can be combined to produce color-coded images such as the one at right. From these images, analysts can extract volumes of information about the ability of the area imaged to support waterfowl, and the information can be updated every 16 days.

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Publications

An essential measure in promoting greater use of NASA technology is letting potential users know what NASA-developed technology is available for transfer. This is accomplished primarily through the publication *NASA Tech Briefs.*

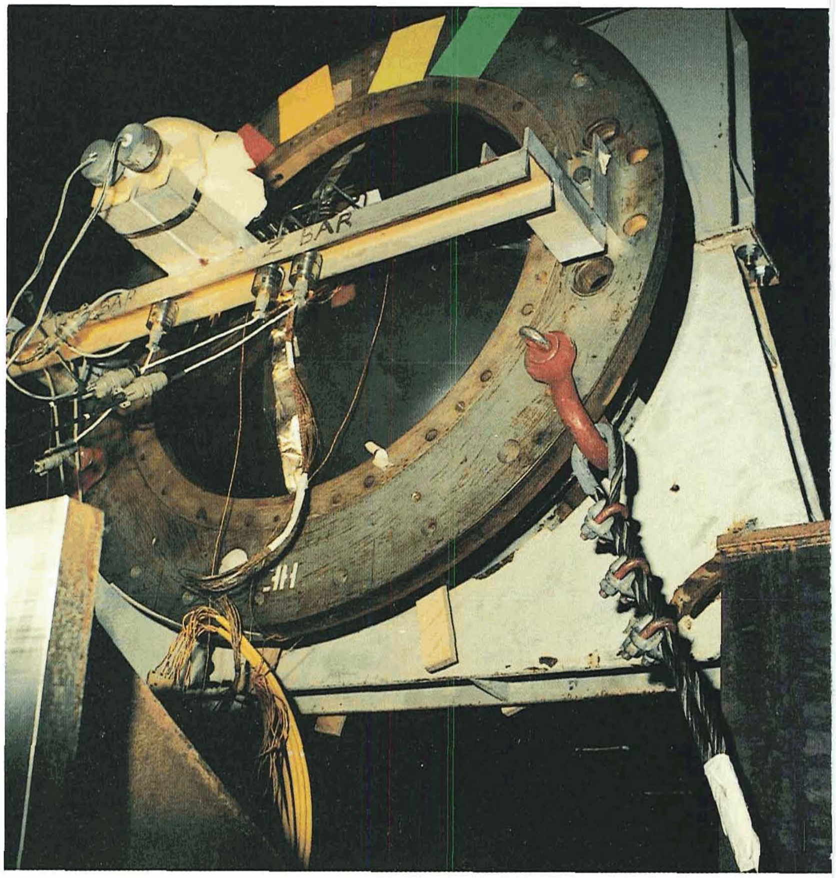
The National Aeronautics and Space Act requires that NASA contractors furnish written reports containing technical information about inventions, improvements or innovations developed in the course of work for NASA. Those reports provide the input for *Tech Briefs*. Issued monthly, the publication is a current awareness medium and problem solving tool for more than 150,000 government and industry readers. It is a joint publishing venture of NASA and Associated Business Publications of New York City.

Each issue contains information on newly developed products and processes, advances in basic and applied research, improvements in shop and laboratory techniques, new sources of technical data and computer programs, and other innovations originating at NASA field centers or at the facilities of NASA contractors. Firms interested in a particular innovation may get more detailed information by requesting a Technical Support Package; more than 120,000 such requests are generated annually.

Here are some examples of how *Tech Briefs* spreads the word and inspires secondary usage of NASA technology:

Tech Briefs carried a report about a research project at Langley Research Center involving use of thermochromic liquid crystals, or TLCs, a type of liquid crystal that reacts to changes in temperature by changing color. Langley used this color-changing characteristic as the basis for a better way of visualizing the boundary layer transition from smooth to turbulent airflow in flight.

The report was read by engineers of Thiokol, Inc./Huntsville Division, who were then engaged in redesigning a rocket motor whose dome had overheated and caused a burnthrough. Because the dome was more than 40 inches in diameter, Thiokol was looking for a new approach to detecting possible overheated areas, or hot spots; the conventional approach of using standard



thermocouples wouldn't do because of their limited local coverage. To the Thiokol engineers, the *Tech Briefs* report sounded like the answer to detecting hot spots: using TLCs, which could be manufactured to show specific colors at specific temperatures.

Thiokol obtained a Technical Support Package from NASA and, after verifying the hot spot detecting capability of the TLCs, applied them to the dome (above) of the rocket motor being redesigned and static tested. The TLCs served the purpose and were thereafter used on all static tests of that type of rocket motor. The tests have been completed and Thiokol/Huntsville is researching other potential uses for liquid crystals.

Another example: Tensegrity Systems Corporation, Tivoli, New York manufactures an erector-set-like toy, or geodesic puzzle, called Tensegritoy. Company president Stuart Quimby read two *Tech Briefs* articles describing deployable geodesic trusses that could be collapsed into small packages for Space Shuttle transport to orbit, then unfolded in space into a space station truss 118 times the volume of the compacted package.

Quimby used the technology to create mini-trusses from Tensegritoy kits that could be deployed into sturdy, lightweight, displays for retailers of the Tensegritoy line. The display columns range from four to 12 feet high (center). Tensegrity Systems was able not only to develop an attractive display that takes up only one square foot of floor space, it also realized substantial savings in freight costs, since the displays are shipped in a package only 18 inches high.

Another example: Sonics Associates, Inc., Birmingham, Alabama, designs, manufactures and installs professional audio-visual-video systems. Installation of complex systems demands a great many cables and connections, and there are hundreds of separate conductors to be assembled and verified before being connected to the equipment. This posed a problem: often the wiring must be done by local labor not totally familiar with proper procedures. Unless each cable connection can be verified, there is high risk of damage to costly equipment. Sonics had for years sought a completely effective way of field testing interconnection cables, but hadn't found one.

Ames Research Center, faced with a similar problem, had developed a simple two-part cable testing device that included an active part which applied a voltage to a cable under test and a passive companion unit that allowed a technician to observe the sequence of the applied voltage and note any discrepancy that would indicate a miswired cable.

Sonics vice president James B. Cawthorn read about the Ames device in *Tech Briefs* and requested the Technical Support Package from NASA. Sonics changed the design to adapt it to its own needs and came up with an inexpensive but highly effective tester. Its two units are shown at left above and at right above Cawthorn is using the device to check a control panel circuit board at a theater. The device, he says, has reduced the time to test a single cable from 12 minutes for two technicians to less than one minute for one technician.

Available to scientists, engineers, business executives and other qualified technology transfer agents in industry or government, *Tech Briefs* is the principal publication of the Technology Utilization Program. Among others are this annual *Spinoff* volume and the *NASA Patent Abstracts Bibliography*, a semiannually updated compendium of NASA patented inventions available for licensing, which now number almost 4,000 (the latter publication can be obtained from the National Technical Information Service, Springfield, Virginia 22101).

Technology Applications

An important facet of NASA's Technology Utilization Program is an applications engineering effort involving use of NASA expertise to redesign and reengineer existing aerospace technology for the solution of problems encountered by federal agencies, other public sector institutions or private organizations.

Applications engineering projects originate in various ways. Some stem from requests for assistance from other government agencies, others are generated by NASA technologists who perceive possible solutions to problems by adapting NASA technology to the need. NASA employs an applications team composed of scientists and engineers representing different areas of expertise. The team members contact public sector agencies, medical institutions, industry representatives, trade and professional groups to uncover problems that might be susceptible to solution through application of aerospace technology.

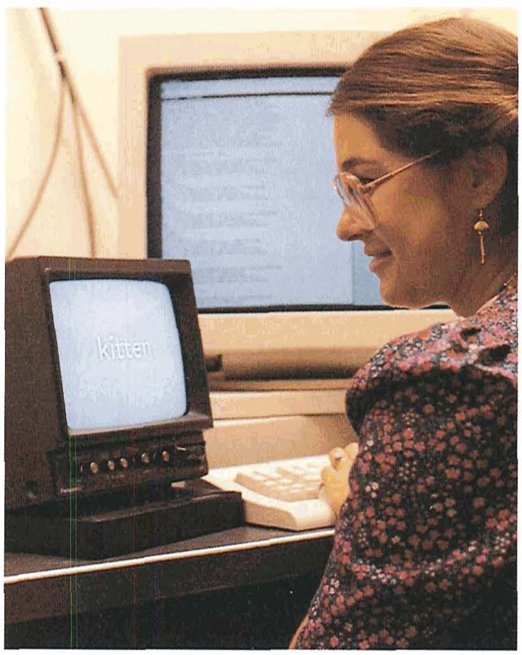
An example of an ongoing applications engineering project is one that draws on technology being developed for space station experimentation, which has clear applicability to cancer detection and treatment. To develop this and other cancer-related applications, NASA has entered into a cooperative program with the Florida Division of the American Cancer Society (ACS). Kennedy Space Center has been designated NASA's lead center for this program.

The initial NASA/ACS project is one involving adaptation of Multichannel Flow Cytometry technology, being developed by Johnson Space Center, to cancer research being conducted at the University of Miami (Florida), and to related research at Los Alamos (New Mexico) and the University of California-San Francisco.

Cytometry is the measurement of cell type and structure. In the cytometry process, specimen cells are marked with a fluorescent dye, suspended in a liquid solution and identified or measured by use of sophisticated lasers and photometers. Existing equipment poses difficulties in performing flow cytometry in both clinical and laboratory settings. The aim of NASA/ACS research is development of an advanced flow cytometry instrument that will surmount the difficulties currently limiting the usefulness of the system and provide a system capable of supporting biomedical experiments aboard Space Station *Freedom* while advancing medical knowledge in cancer detection and treatment. NASA and ACS share many developmental objectives: reductions in system size, power requirements, maintenance and requisite operator skill level, along with multichannel capability. At right, cancer researcher Dr. David Robinson, University of Miami, is conducting a flow cytometry experiment with an existing system; a prototype advanced system is being developed by RATCOM, Inc., Miami, Florida.

Among the cancer-fighting benefits of such an advanced system are the ability to evaluate cancer cells very early and to determine several important features, including the sensitivity of those cells to different chemotherapy drugs, the ability of the cells to grow and their capacity for spread. This is expected to permit development of better and more timely strategies in the fight against cancer.

In April 1990, a second NASA/ACS project was initiated, this one directed at improved detection and treatment of cancer through enhanced Magnetic Resonance Imaging (MRI). The MRI project involves development of computer software capable of analyzing MRI data and generating three-dimensional color-coded images of body tissues, improvements that will make detection of tumors more sensitive. In addition, the technology will help define tumor boundaries with respect to normal tissue and thereby allow more accurate and more precise planning of radiation treatment for cancer patients. The technology being employed is a spinoff from NASA technology developed to analyze Landsat images of Earth's surface. NASA and ACS are providing funding for research by the University of South Florida and additional funding is being provided by a private company, Artificial Cognition Systems, Inc., Tampa, Florida. Support for both the cytometry and MRI projects is being



provided by the NASA Technology Applications Team, Research Triangle Institute, Research Triangle Park, North Carolina.

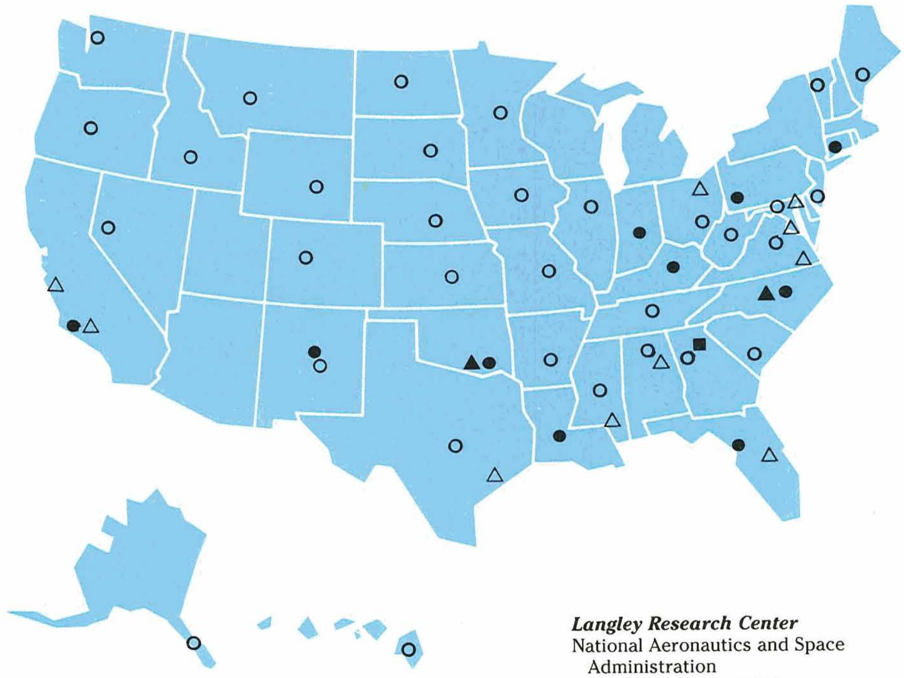
An applications engineering project intended to aid people afflicted with maculopathy, or central spot blindness, is being conducted by Jet Propulsion Laboratory (JPL). The project draws upon digital image processing technology, originally developed by NASA as a means of enhancing Moon pictures in the early days of the Apollo program, and on current robotics/teleoperation technology being developed for Earth-orbital operations and planetary exploration.

Maculopathy sufferers, mostly elderly, can no longer see fine detail or read. Since maculopathy is a degeneration of nerve cells rather than a problem of the lens, it does not respond to corrective lenses or other conventional treatment. But a non-invasive method of alleviating such vision problems is being developed by Dr. Teri Lawton of JPL's Robotics, Teleoperators and Human Factors Research Group, who is shown checking her system at left below.

Dr. Lawton tests a patient's contrast sensitivity function, then designs a customized digital image enhancement formula tailored to the patient's vision. The formula presents enlarged and enhanced printed words on a closed circuit TV (CCTV) screen with the proper amount of brightness to make the words more easily readable by the patient—although they appear blurred to an observer with normal vision. Black and white text is transformed into magnified "grayscale" text that makes use of the low-vision patient's remaining visual function. In tests, patient reading speeds increased two to four times with up to 70 percent less magnification needed for word recognition.

JPL and Dr. Lawton are collaborating with Telesensory/Visualtek, Inc. (TSI/VTEK), Santa Monica and Mountain View, California to carry out the next step. TSI/VTEK will play an active part in supplying (free) test-bed equipment, a CCTV, with which Dr. Lawton will optimize the image enhancement technology for an effective, inexpensive commercial product, planned to be available in three years, pending funding from the National Eye Institute.

NASA's Technology Transfer System



The NASA system of technology transfer personnel and facilities extends from coast to coast and provides geographical coverage of the nation's primary industrial concentrations, together with regional coverage of state and local governments engaged in transfer activities. For specific information concerning the activities described below, contact the appropriate technology utilization personnel at the addresses listed.

For information of a general nature about the Technology Utilization program, address inquiries to the Manager, Technology Utilization Office, NASA Scientific and Technical Information Facility, Post Office Box 8757, Baltimore, Maryland 21240.

△ ***Field Center Technology Utilization Officers:*** manage center participation in regional technology utilization activities.

● ***Industrial Applications Centers:*** information retrieval services and assistance in applying technical information relevant to user needs.

○ ***Industrial Applications Center Affiliates:*** state-sponsored business or technical assistance centers that provide access to NASA's technology transfer network.

■ ***The Computer Software Management and Information Center (COSMIC):*** offers government-developed computer programs adaptable to secondary use.

▲ ***Application Teams:*** assist agencies and private institutions in applying aerospace technology to solution of public problems.

△ Field Centers

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, California 94035
Technology Utilization Officer:
Laurence A. Milov
Phone: (415) 604-4044

Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland 20771
Technology Utilization Officer:
Donald S. Friedman
Phone: (301) 286-6242

Lyndon B. Johnson Space Center
National Aeronautics and Space Administration
Houston, Texas 77058
Technology Utilization Officer:
Dean C. Glenn
Phone: (713) 483-3809

John F. Kennedy Space Center
National Aeronautics and Space Administration
Kennedy Space Center, Florida 32899
Technology Utilization Officer:
Thomas M. Hammond
Phone: (407) 867-3017

Langley Research Center
National Aeronautics and Space Administration
Hampton, Virginia 23665
Technology Utilization Officer:
John Samos
Phone: (804) 864-2484

Lewis Research Center
National Aeronautics and Space Administration
21000 Brookpark Road
Cleveland, Ohio 44135
Technology Utilization Officer:
Anthony F. Ratajczak
Phone: (216) 433-5567

George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Marshall Space Flight Center, Alabama 35812
Director, Technology Utilization Office:
Ismail Akbay
Phone: (205) 544-2223

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91109
Technology Utilization Manager:
Norman L. Chalfin
Phone: (818) 354-2240

NASA Resident Office—JPL
4800 Oak Grove Drive
Pasadena, California 91109
Technology Utilization Officer:
Gordon S. Chapman
Phone: (818) 354-4849

John C. Stennis Space Center
Mississippi 39529
Technology Utilization Officer:
Richard A. Galle (acting)
Phone: (601) 688-1929

● Industrial Applications Centers

Aerospace Research Applications Center
611 N. Capitol Avenue
Indianapolis, Indiana 46204
F.T. Janis, Ph.D., director
Phone: (317) 262-5036

Central Industrial Applications Center
Rural Enterprises, Inc.
P.O. Box 1335
Durant, Oklahoma 74702
Dickie Deel, Ph.D., director
Phone: (405) 924-5094
(800) 658-2823

NASA Industrial Applications Center
823 William Pitt Union
Pittsburgh, Pennsylvania 15260
Robert G. Konecny, acting director
Phone: (412) 648-7000

NASA Industrial Applications Center
Research Annex, Room 200
University of Southern California
3716 South Hope Street
Los Angeles, California 90007
Robert Stark, director
Phone: (213) 743-6132
(800) 642-2872 (CA only)
(800) 872-7477 (toll free, US)

NERAC, Inc.
One Technology Drive
Tolland, Connecticut 06084
Daniel Wilde, Ph.D., president
Phone: (213) 872-7000

North Carolina Science and Technology Research Center
P.O. Box 12235
Research Triangle Park,
North Carolina 27709
H. Lynn Reese, director
Phone: (919) 549-0671

Technology Applications Center
University of New Mexico
Albuquerque, New Mexico 87131
Stanley A. Morain, Ph.D., director
Phone: (505) 277-3622

Southern Technology Applications Center
Progress Center, Box 24
1 Progress Boulevard
Alachua, Florida 32615
J. Ronald Thornton, director
Phone: (904) 462-3913
(800) 354-4832 (FL only)
(800) 225-0308 (toll free, US)

NASA/UK Technology Applications Program
10 Kinkead Hall
University of Kentucky
Lexington, Kentucky 40506
William R. Strong, director
Phone: (606) 257-6322

NASA/SU Industrial Applications Center
Southern University
Department of Computer Science
Baton Rouge, Louisiana 70813-2065
John Hubbell, Ph.D., director
Phone: (504) 771-6272
(504) 771-4950

○ Industrial Applications Center Affiliates

Alabama
Dr. Bernie Schroer
Johnson Research Center
University of Alabama-Huntsville
Huntsville, Alabama 35899
Phone: (205) 895-6361

Alaska
Mr. Patrick Anderson, Director
Alaska Economic Development Center
University of Alaska—Juneau
1108 F Street, Juneau, Alaska 99801
Phone: (907) 789-4402

Arkansas
Mr. Homer Presnall
Industrial Research and Extension Center
University of Arkansas
33rd and University
Little Rock, Arkansas 72204
Phone: (501) 371-1971

Dr. George Marsh
Center for Interactive Technology
Arkansas Center for Technology Transfer
Engineering Experiment Station
University of Arkansas
Fayetteville, Arkansas 72701
Phone: (501) 575-5399

Mr. Alan A. Gumbel
Arkansas Science and Technology Authority
100 Main Street, Suite 450
Little Rock, Arkansas 72201
Phone: (501) 371-3554

California
● See Industrial Applications Center, University of Southern California

Colorado
Ms. Patti Martillaro, Director
Business Advancement Center
University of Colorado
1690 38th Street, Suite 101
Boulder, Colorado 80301
Phone: (303) 444-5723

Florida
● See Southern Technology Applications Center, University of Florida

Georgia
Dr. David Swanson
Economic Development Laboratory
Georgia Institute of Technology Research Institute
Atlanta, Georgia 30332
Phone: (404) 894-3863

Hawaii
Ms. Angela Williams
Pacific Business Center Program
University of Hawaii
2404 Maile Way
Honolulu, Hawaii 96822
Phone: (808) 948-6286

Idaho
Mr. Ronald R. Hall, Director
Idaho Business Development Center
Boise State University
1910 University Drive
Boise, Idaho 83725
Phone: (208) 385-1640

Illinois
Mr. Brian Frost
c/o Technology Transfer Center
Argonne National Laboratory
Argonne, Illinois 60439
Phone: (312) 972-7694
(312) 790-0749

Indiana
● See Aerospace Research Applications Center, Indianapolis Center for Advanced Research

Iowa
Mr. Lloyd Anderson
CIRAS—Iowa State University
205 Engineering Annex
Ames, Iowa 50011
Phone: (515) 294-3420

Kansas
Mr. Kevin Carr
Kansas Technology Enterprise Corporation
112 West 6th Street, Suite 400
Topeka, Kansas 66603
Phone: (913) 296-5272

Kentucky
● See NASA/UK Technology Applications Program, University of Kentucky

Louisiana
● See NASA/SU Industrial Applications Center, Southern University

Maine
Mr. Ivan Most, P.E. Director
Production Technology Center
University of Southern Maine
37 College Avenue
Gorham, Maine 04038
Phone: (207) 780-5439

Maryland
Mr. Travis Walton
Technology Extension Service
Engineering Research Center
University of Maryland
College Park, Maryland 20742
Phone: (301) 454-1941

Minnesota
Mr. Gil Young
Governor's Office of Science and Technology
900 American Center Building
150 E. Kellogg Boulevard
St. Paul, Minnesota 55101
Phone: (612) 297-4368

Mississippi
Dr. James Miller, Director
Mississippi Technology Transfer Office
Stennis Space Center, Mississippi 39529
Phone: (601) 688-3144

Missouri
Mr. Fred Goss
Technology Search Program
304 Harris Hall
University of Missouri-Rolla
Rolla, Missouri 65401
Phone: (314) 341-4004

Montana
Dr. William R. Taylor, Director
University Technical Assistance Program
College of Engineering
402 Roberts hall
Montana State University
Bozeman, Montana 59717-0007
Phone: (406) 994-3812

Nebraska
Mr. Thomas Spilker
Nebraska Technical Assistance Center
W191 Nebraska Hall
University of Nebraska
Lincoln, Nebraska 68588
Phone: (402) 472-5600

Nevada
Mr. Bernard "Gus" Zuzo
Desert Research Institute
P.O. Box 60220
Reno, Nevada 89506
Phone: (702) 673-7388

New England
● See Industrial Applications Center, NERAC, Incorporated

New Jersey
Mr. Thomas Allen, Director of Operations
Southern New Jersey Technology Consortium
236 Doughty Road
Pleasantville, New Jersey 08232
Phone: (609) 641-1008

New Mexico
● See Industrial Application Center TAC, University of New Mexico

Mr. James Ray
Business Assistance and Resource Center
University of New Mexico
1920 Lomas NE
Albuquerque, New Mexico 87131
Phone: (505) 277-3541

North Carolina
● See Industrial Applications Center North Carolina Science and Technology Research Center

North Dakota
Mr. Leonard Christianson, Director
Technical Services Center for Innovation and Business Development
Box 8103, University Station
Grand Fork, North Dakota 58202
Phone: (701) 777-3796

Ohio
Mr. Jeff Schick, Director
Ohio Technology Transfer Organization
65 East Street, Suite 200
Columbus, Ohio 43266-0330
Phone: (614) 466-4286

Oklahoma
● See Central Industrial Applications Center, Rural Enterprises, Inc.

Oregon
Mr. Terry Edvalson, Director
Regional Services Institute
Eastern Oregon State College
8th and K
La Grande, Oregon 97850
Phone: (503) 963-2171

Pennsylvania
● See Industrial Applications Center, University of Pittsburgh

South Carolina
Dr. Ted Gasper
The State Board for Technical and Comprehensive Education
111 Executive Center Drive, Room 103
Columbia, South Carolina 29210
Phone: (803) 737-9320

South Dakota
Mr. LaDell Swiden
College of Engineering, Box 507
South Dakota State University
Brookings, South Dakota 57007-0199
Phone: (605) 688-4184

Tennessee
Mr. T.C. Parsons, Executive Director
Center for Industrial Services
University of Tennessee
226 Capitol Boulevard Building, Suite 401
Nashville, Tennessee 37219-1804
Phone: (615) 242-2456

Texas
Dr. Helen Dorsey, Director
Technology Business Development
Texas Engineering Experiment Station
College Station, Texas 77843-3369
Phone: (405) 845-0538

Vermont
Mr. Graeme H. Freeman
Agency of Development and Community Affairs
State of Vermont
Montpelier, Vermont 05602
Phone: (802) 828-3221

Virginia
Dr. Gene Calvert
Center for Innovative Technology
2214 Rock Hill Road
Herndon, Virginia 22070
Phone: (703) 689-3000

Washington
Dr. Lyle M. Anderson, State Director
Small Business Development Center
Washington State University
441 Todd Hall
Pullman, Washington 99164-4740
Phone: (509) 335-1576

West Virginia
Mr. Donald F. Butcher, President
The Software Valley Association
c/o Department of Statistics and Computer Science
311 Knapp Hall
University of West Virginia
Morgantown, West Virginia 26056
Phone: (304) 293-3607

Science and Technology Center
c/o Dr. David Powers
Vice Chancellor for Academic Affairs
Board of Regents
950 Kanawha Boulevard, East
Charleston, West Virginia 25301
Phone: (304) 348-2101

Wyoming
Ms. Gail Mathews
Institute of Business Management Services
College of Commerce and Industry
University of Wyoming
P.O. Box 3275, University Station
Laramie, Wyoming 82071
Phone: (307) 766-2363

■ Computer Software Management and Information Center

COSMIC
382 E. Broad Street
University of Georgia
Athens, Georgia 30602
John A. Gibson, director
Phone: (404) 542-3265

▲ Application Teams

Research Triangle Institute
Post Office Box 12194
Research Triangle Park, North Carolina 27709
Doris Rouse, Ph.D., director
Phone: (919) 541-6980

Rural Enterprises, Inc.
P.O. Box 1335
Durant, Oklahoma 74702
Tom S. Smith, executive director
Phone: (405) 924-5094

NASA Scientific and Technical Information Facility

Technology Utilization Office
P.O. Box 8757
Baltimore, Maryland 21240
Walter Heiland, manager
Phone: (301) 859-5300 extension 241

Spinoff Team:
Project Manager
Walter Heiland

Technology Associate:
Jane Lynn-Jones

Technology Associate:
Barbara Chapolini

Graphic Services:
Justin Associates

Photography:
Kevin Wilson

NASA
National
Aeronautics and
Space
Administration

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Director, Technology Utilization Division
Office of Commercial Programs
NASA Headquarters
Washington, D.C. 20546