Spinoff

1987

NASA

On the cover:

Winner of the 1987 America's Cup competition in Australia, the 12-meter racing yacht Stars & Stripes *was helped by a NASA technology originally developed to improve aircraft fuel efficiency: drag-reducing "riblets," tiny grooves in the yacht's hull that contributed to increased boat speed (the blue/gray lines in the cover backdrop are highly magnified riblets).*

Spinoff

1987

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

As the U.S. civil space program approaches its 30th anniversary, NASA is preparing for a new era of unprecedented challenge—the challenge of space accomplishment, the challenge of international competition, the challenge of regaining lost ground and making the space program a renewed source of pride to the nation.

The people of NASA are working hard to meet those challenges. We have reshaped the agency to make it stronger, more tightly organized and more effective. We are moving forward steadily toward resumption of Space Shuttle flights. We are taking steps to fill critical gaps in our space technology base. NASA continues to conduct vigorous aeronautical and space programs for peaceful purposes for the benefit of mankind.

Among major endeavors, NASA is pioneering development of technologies for the National Aerospace Plane, which has the potential for significant advancements in both space and aeronautical technology. We have entered into the effort to design and build a permanently manned Space Station, a facility that will expand our operational flexibility, provide a singular vantage point for scientific observations, and enhance opportunities for realizing commercial benefits from space. We are pursuing a broad program of space science that embraces comprehensive investigations of the distant universe, the solar system and, most particularly, Earth and the near-Earth environment. Finally, we are charting an agenda of exciting options for the future of the space program. We will continue to work to expand our knowledge of Earth, the solar system and the universe, and to expand the human presence in space.

Consequently, I believe that NASA is well positioned to meet the challenges we see ahead. It is vital that we do so and thus maintain the technological leadership the nation has so long enjoyed. Aerospace achievements are highly visible indicators of a nation's prestige and important factors in international relations. Space and aeronautical goals "drive" major advances in science and technology, and they in turn affect our national productivity and competitiveness, and our capacity for innovation.

In short, aerospace activities play a key role in determining our standing in the community of nations, our national economic growth and our standard of living. And we are entering an era in which such activities will, in all likelihood, exert even greater influence on human affairs. I believe that NASA is ready for that era. With vision, competence and dedication, we will lead the way in exploring and developing the aerospace frontier.

James C. Fletcher

James C. Fletcher
Administrator
National Aeronautics and Space Administration

Introduction

The classic example of "spinoff" is the wheel. A Bronze Age invention intended to allow draft animals to move greater loads, it found countless secondary applications in such ancient innovations as the grindstone, the pulley, the spinning wheel and the windlass; in such relatively new developments as gears, rotating shafts, propellers and turbines; and in a great range of minor conveniences from casters to doorknobs.

The evolution of wheel-derived contrivances serves to underline the fact that contemporary technology can similarly be applied to uses different and often remote from the original purpose. Technology is simply knowledge, and like other forms of knowledge it is transferable.

NASA research programs have proved particularly productive of technology transfers because they are extraordinarily demanding of technological advance and because the innovations they generate are exceptionally diverse. Thus, the wealth of technology NASA has developed to meet the aeronautical and space goals of the past three decades represents an important national resource, a bank of technical knowledge available for reuse. The bank has been well utilized; more than 30,000 secondary applications—spinoffs—have emerged to the benefit of the nation's lifestyle and economy.

By Congressional mandate, it is NASA's responsibility to promote further expansion of spinoff in the public 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 program's aim is to broaden and accelerate the technology transfer process and to realize thereby additional dividends on the national investment in aerospace research in the form of new products, new processes and new jobs.

This publication is an instrument of the Technology Utilization Program. Its purpose is to heighten awareness of the technology available for transfer and its potential for economic and social benefit. *Spinoff 1987* is organized in three 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 and processes that resulted from secondary application of technology originally developed to meet mainline goals.

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

James T. Rose

Assistant Administrator for Commercial Programs

National Aeronautics and Space Administration

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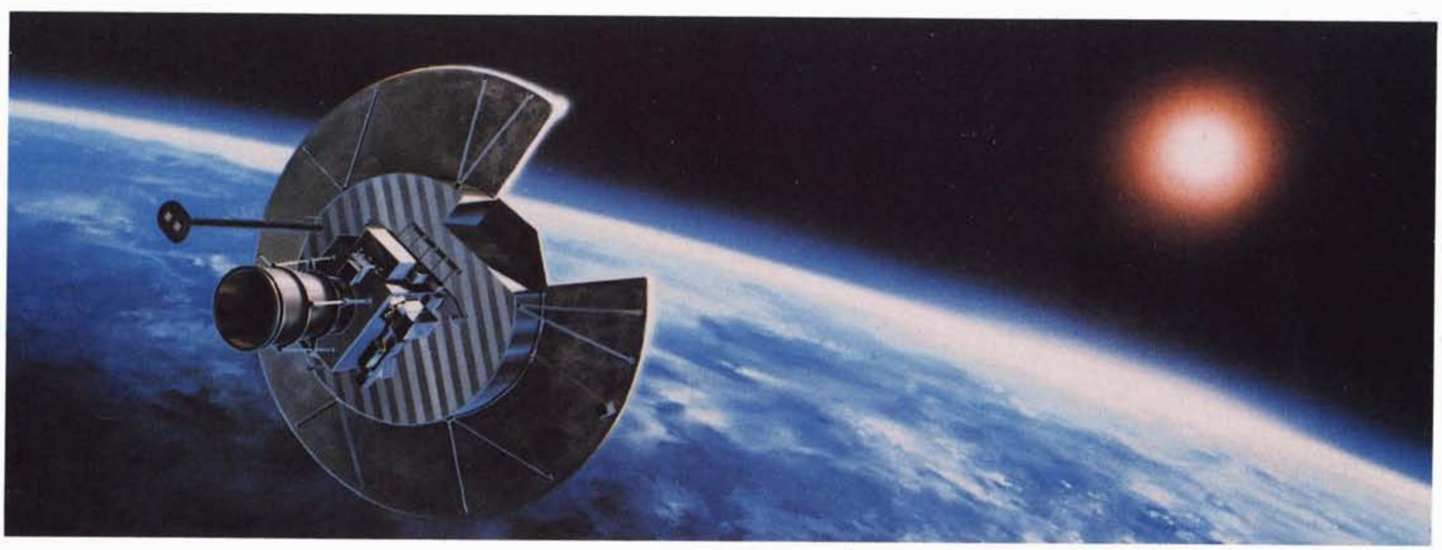
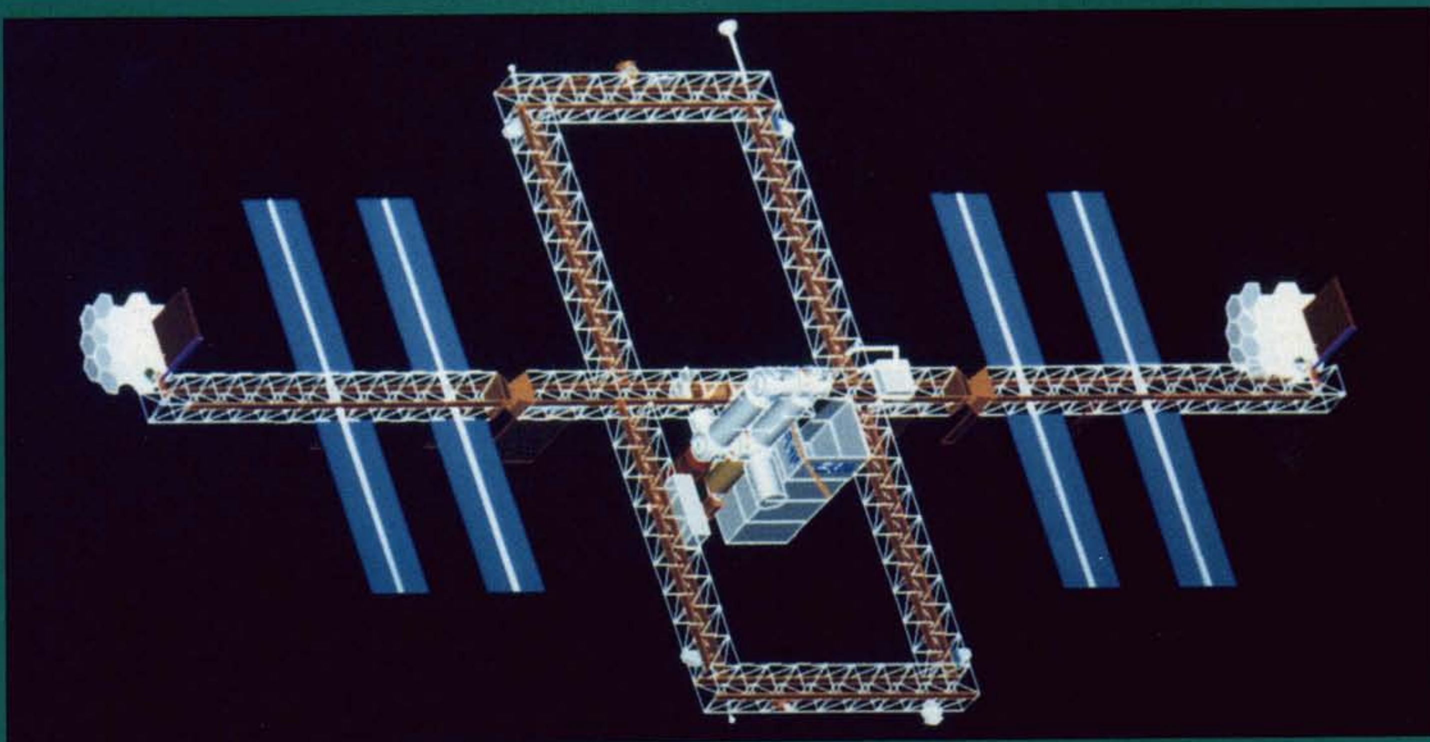


Aerospace Aims



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 benefits

1988: A New Beginning

NASA girds for resumption of Space Shuttle operations as the permanently manned Space Station moves a step nearer

On May 27, 1987, a Space Shuttle Solid Rocket Motor (SRM) was put through a full-scale test at the Brigham City, Utah facility of Morton Thiokol, Inc., SRM manufacturer. The 126-foot Engineering Test Motor-1A, mounted in a horizontal position, fired for 120 seconds, the time it would be required to operate during a Shuttle launch.

The test motor did not represent the final configuration of the redesigned SRMs that will power the next Shuttle flight. The purpose of the test was to evaluate a number of improvements that may be incorporated in the final redesign. Among new features tested were different types of O-rings (the seals for the joints between rocket motor segments) and electric heaters to keep the O-rings warm during cold weather launches (investigators of the January 1986 accident to the Shuttle Orbiter *Challenger* suggested that low temperatures at launch time might have caused the O-rings to lose resiliency and leak).

The May firing, preceded by a lengthy series of subscale, component and laboratory tests, was regarded as a major milestone on the road to resumption of Shuttle flights. It was the first of a series of full-scale firings planned.

Redesign and certification of the SRM is the principal among many Shuttle enhancement projects under way in response to recommendations for safety and performance improvements proposed by the Presidential Commission on the Space Shuttle *Challenger* Accident and the House Committee on Science and Technology. Among major efforts are changes to increase the operating life and the margins of safety and reliability of the Space Shuttle Main Engines, the three liquid-fuel power plants that fire in concert with the two solid rocket boosters during a Shuttle launch. NASA is also developing for consideration a rocket-assisted crew escape system in which an astronaut would be extracted through an Orbiter hatch, the rocket thrust providing the velocity necessary for the crew member to clear the Orbiter in the event of an emergency bailout.

Landing safety will be improved by a number of measures, including modifications to the brakes and addition of a system that will advise the crew and mission controllers of tire pressure prior to deorbit and landing. Also being considered is an arresting barrier capable of safely stopping a 260,000 pound Orbiter traveling at 100 knots on its landing roll. In addition, the Orbiter will have an inflatable crew egress slide, like those on commercial airliners, for rapid post-landing departure from the Orbiter should that become necessary.

Other changes include modifications to the Orbiter's thermal protection system, the tiles that insulate the vehicle against the searing heat of reentry; the fuel cells that supply electrical power; the auxiliary power system; and the Orbiter's flight software. There will also be extensive revision of the complex procedures that govern Shuttle maintenance, processing, prelaunch and launch operations, along with an upgraded capability for forecasting launch site weather conditions. With the assistance of the National Academy of Science, NASA is developing ways of instrumenting Kennedy Space Center to provide a capability for a 90-minute high confidence level forecast.

These examples are representative of literally hundreds of system modifications and procedural improvements that have been made or will be made over the next several months. If the changes can be effected and validated on schedule, Space Shuttle Mission 26, Orbiter *Discovery*, will be rolled out to the launch pad in April 1988 in preparation for flight in June. The tar-

A major step on the road to resumption of Space Shuttle flights, the first of a series of full-scale tests of the Shuttle's Solid Rocket Motor, conducted in May 1987.

get date is flexible; full assurance of flight safety is the priority factor.

Assuming a June launch, there will be two other flights in 1988 and seven in 1989. For the early years of the 1990s, when NASA will be operating only three Orbiters, the maximum annual flight rate will be 12 missions. After 1992, when the replacement Orbiter joins the fleet, NASA will work up to 14 Shuttle flights a year, considered to be the maximum for the foreseeable future. ▲

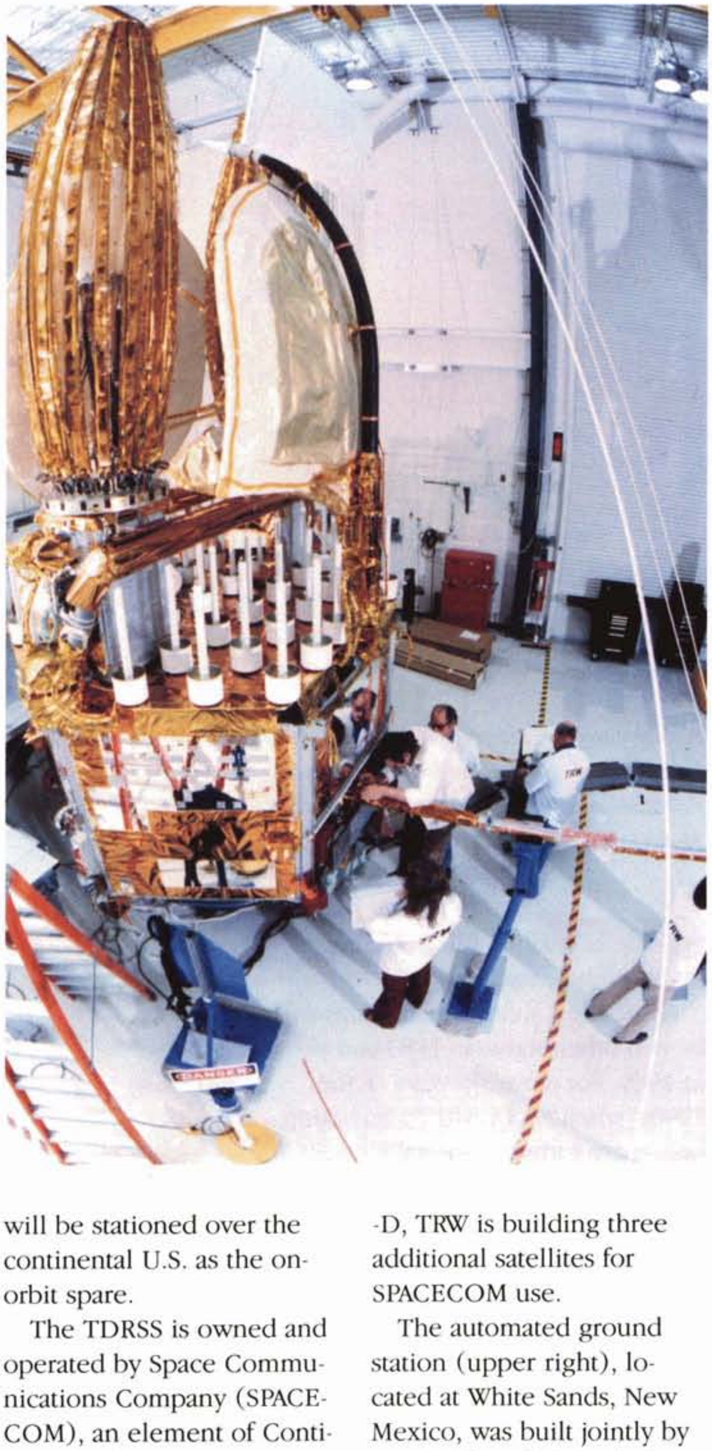
Tracking and Communications System

Radio transmissions from satellite to Earth travel on a line-of-sight path. For this reason, NASA has maintained a network of surface stations around the world to increase the time available for Earth/spacecraft contact. Even so, there are periods when a satellite is not "in sight" of any station; the surface network provides approximately 20 percent of the optimum contact during a spacecraft's orbit of the Earth.

In April 1983, NASA launched the first element of a Tracking and Data Relay Satellite System (TDRSS) intended to effect a significant improvement in communications efficiency. An operational TDRSS, consisting of a ground station, two active satellites in geosynchronous orbit 22,500 miles high and an orbiting spare, would allow near-continuous coverage because the ground station would always be in contact with the TDRSS satellites and they, in turn, would be able to "see" nearly all other spacecraft in orbit. They would collect communications signals from as many as 40 other satellites or manned Shuttle Orbiters and relay them to the ground station. In this manner, the TDRSS can provide 85 percent coverage for each orbit of a satellite operating at low altitude and up to 100 percent coverage for spacecraft in higher orbits. This expansion in coverage will allow NASA to close a number of expensive Earth stations while achieving dramatic gains in data acquisition time and data rates.

The initial TDRSS satellite, designated TDRS-1, demonstrated the potential of the system in September 1983. During Space Shuttle flight STS-8, the satellite provided tracking and communications coverage through 50 percent of a typical Shuttle orbit and delivered, for the mission as a whole, more coverage than had been provided by the surface network on all prior Shuttle missions combined.

The loss of a second TDRS and the temporary cessation of Shuttle operations delayed completion of the TDRSS network, but among the first payloads scheduled for delivery to orbit when Shuttle flights resume are two TDRS spacecraft. Tentatively designated TDRS-C and -D (they will become TDRS-2 and -3 when in service), these satellites will round out the space segment of the TDRS system. TDRS-C, shown above undergoing tests at the manufacturer's plant, will go into geosynchronous orbit above the Pacific Ocean, joining TDRS-1, which is still operating from a geosynchronous position over the Atlantic. TDRS-D



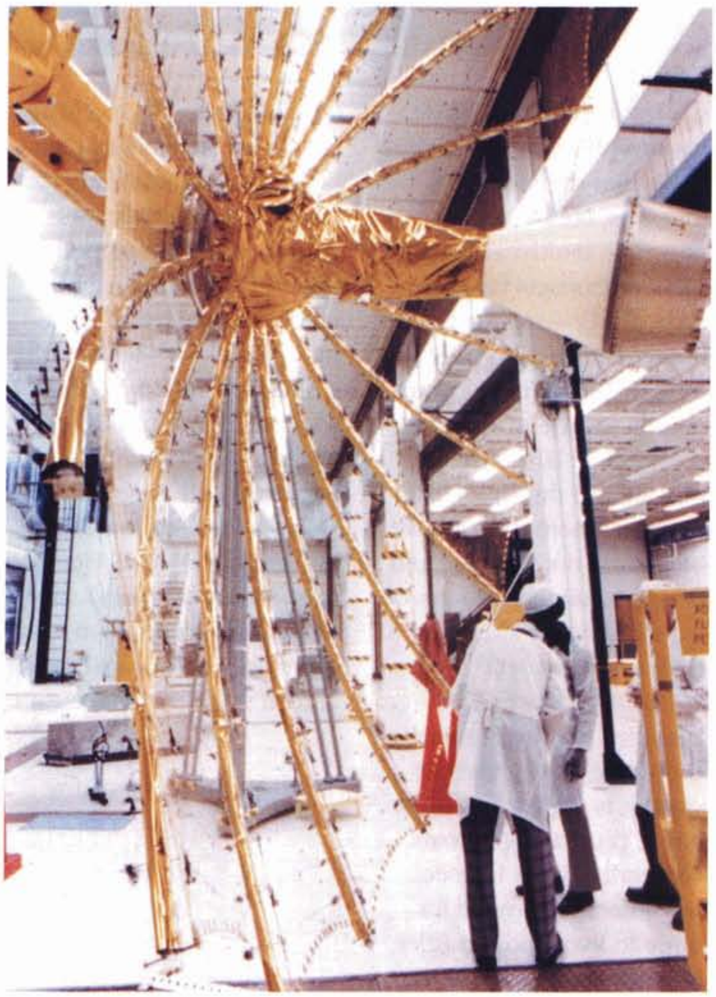
will be stationed over the continental U.S. as the on-orbit spare.

The TDRSS is owned and operated by Space Communications Company (SPACECOM), an element of Continental Telecom Inc.; NASA leases TDRSS services on a full-time basis. The satellites are built by the Space Technology Group of TRW Inc. In addition to TDRS-C and -D, TRW is building three additional satellites for SPACECOM use.

The automated ground station (upper right), located at White Sands, New Mexico, was built jointly by SPACECOM, TRW and Harris Corporation; it will eventually replace NASA's global system of satellite tracking and data acquisition facilities. One of the largest and most complex satellite communication and control facilities ever built, it will relay communications traffic—through the TDRS satellites—between all other

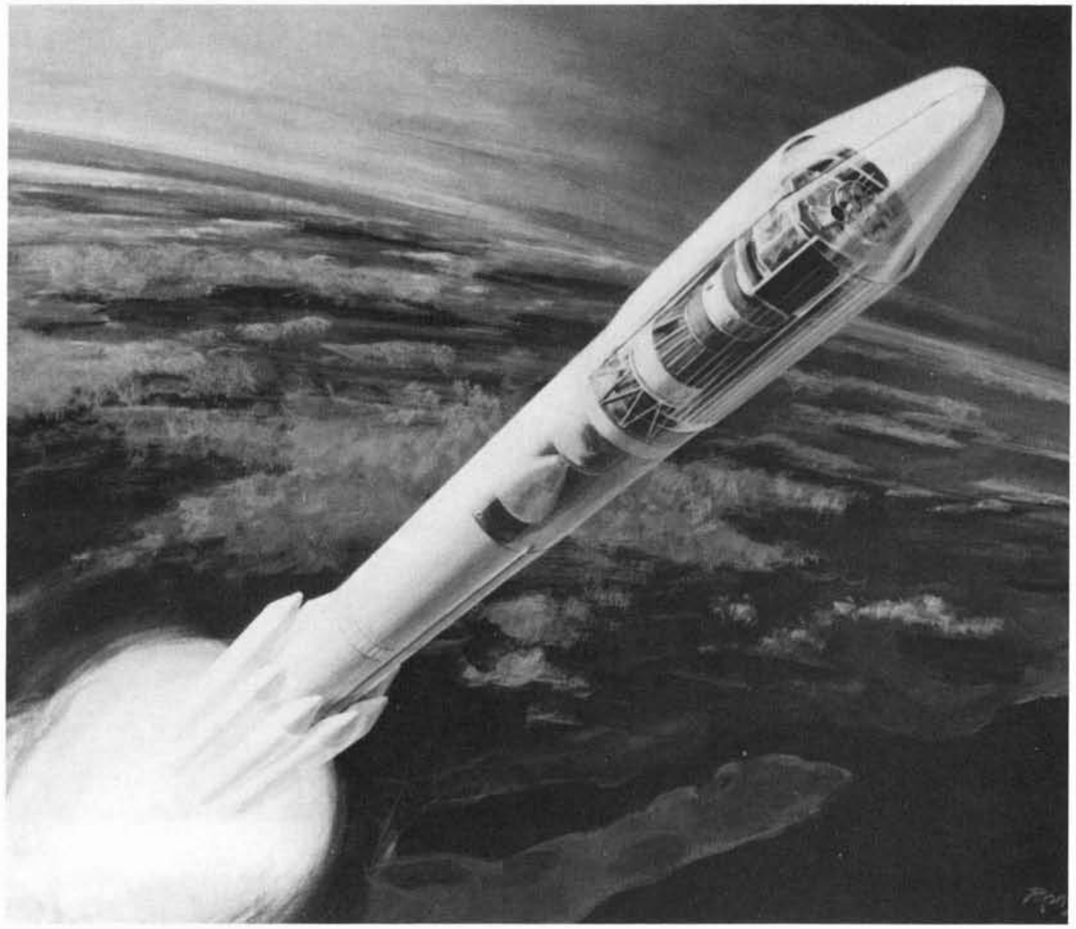
NASA spacecraft and their respective control centers. The ground station will also control the orbiting TDRS satellites.

Spanning 57 feet from tip to tip and weighing some 2½ tons, the TDRS spacecraft are among the largest communications satellites ever built and the first with simultaneous three-band frequency service capability. They will be Shuttle-delivered to low Earth orbit, then boosted to geosynchronous orbit by a solid fuel Inertial Upper Stage (IUS). On attainment of the proper orbit, the IUS will separate and maneuver away and the solar array panels will deploy automatically, as will the



large umbrella-like parabolic antennas, one of which is being inspected at left. The solar arrays are designed to generate 1,700 watts of electrical power for 10 years; nickel cadmium batteries store the energy and supply full power while the TDRS is in Earth's shadow. ▲

Expendable Launch Vehicles



For the decade of the 1990s and beyond, NASA plans to employ a mixed fleet of launch vehicles in which the Space Shuttle will be complemented by expendable launch vehicles (ELVs). The latter vehicles will not be purchased for NASA operation; NASA will contract for launch services with aerospace companies or procure such services through the Department of Defense (DoD).

The intent of the plan is to reduce dependence on the Space Shuttle, add flexibility to the space program, and free the Shuttle for manned scientific, Shuttle-unique and important national security missions. A major objective is to accelerate deployment of space science missions backlogged by the Shuttle's temporary removal from service.

In the first phase, NASA plans to acquire launch services without benefit of competition, in order to make the best match of available ELVs with already-designed payloads. For this phase, NASA is considering five missions scheduled for launch in Fiscal Years 1990-91. Final approval will depend on funding availability.

Beyond the initial five missions, NASA plans to negotiate multiyear launch service contracts for each class of ELV—medium, intermediate, large—beginning in 1989. These contract awards will be made on a competitive basis where possible, or through DoD in cases where competitive bidding is not possible and DoD has launch vehicles or launch services already under contract.

The number of ELV launches required annually cannot be fixed precisely since it is dependent upon future program approvals. Generally, NASA foresees possible annual need for three to five medium ELVs, one or two each in the intermediate and large classes, and an undetermined number in the small vehicle category. The vehicles available or being developed in these categories are the medium ELV Delta II (pictured), built by McDonnell Douglas Corporation; the intermediates Atlas Centaur (General Dynamics Corporation) and Titan III (Martin Marietta Corporation); and the large Titan IV (also Martin Marietta). LTV Aerospace Corporation manufactures the standard small launch vehicle, the Scout. ▲

Orbital Maneuvering Vehicle

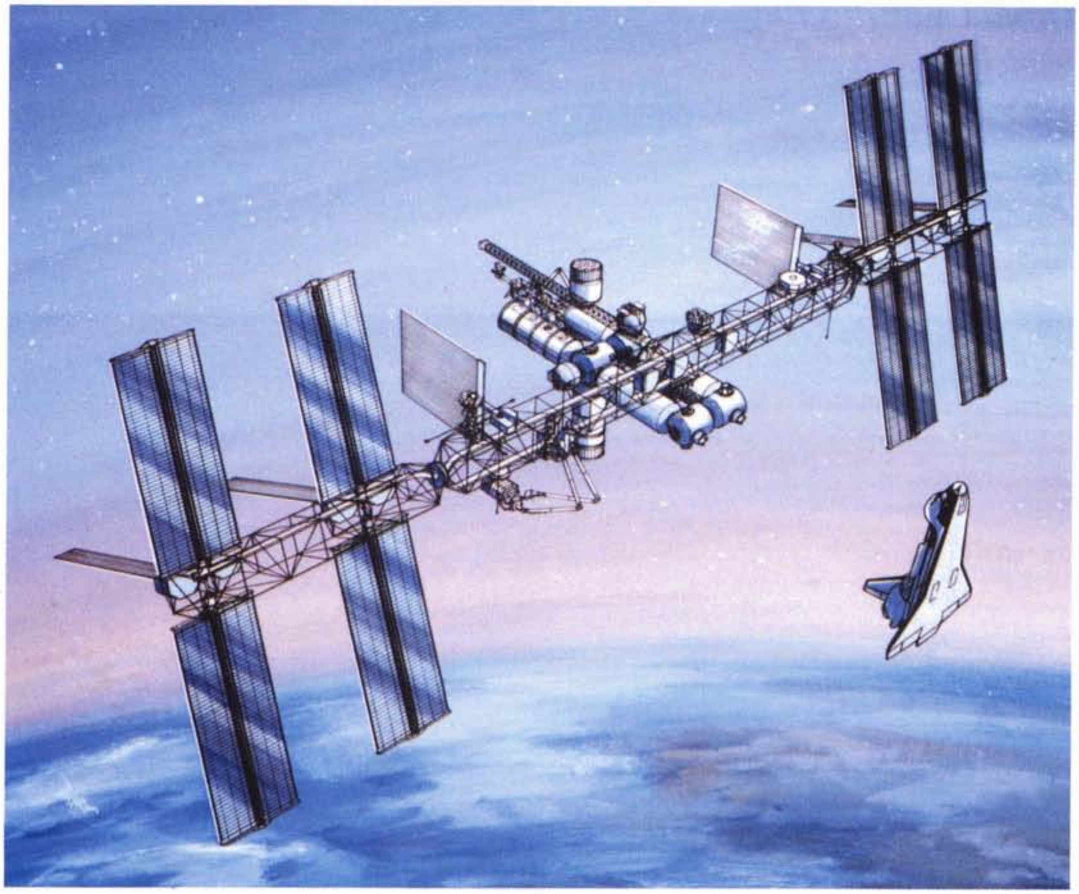
The next planned addition to the Space Transportation System is the Orbital Maneuvering Vehicle (OMV), a "smart space tug" capable of moving satellites and other objects from one orbit to another. Intended for use with the Space Shuttle, the OMV will be remotely controlled by ground-based astronauts employing television and other sensors to guide OMV operations.

Shown in the accompanying artist's concept, the reusable OMV will afford a considerable extension of the Shuttle's reach by delivering payloads to altitudes not attainable by the Shuttle Orbiter; it can propel a payload as far as 1,200 miles after deployment from an Orbiter flying at normal Shuttle altitudes of 150-300 miles. The OMV can handle routine on-orbit servicing, maintenance or changeout of payloads—or it can retrieve the payload and deliver it to the Orbiter for repair, then return it to its operational orbit. The tug will also be useful in construction of large space structures. By use of modification kits, the versatile system can be configured to perform many different types of space tasks.

No provisions have been made for basing an OMV at the initial "baseline" Space Station, but the OMV could evolve later into a station adjunct, performing such tasks as station assembly operations, positioning Shuttle-delivered resupply modules or deploying satellites from the Space Station.

First flight is targeted for 1991. Marshall Space Flight Center is OMV project manager; TRW Inc. is development contractor. ▲

Space Station



In April 1987, NASA issued requests for proposals (RFPs) to industry for detailed design and construction of a permanently manned Space Station to be operational in the mid-1990s. This represented a milestone in the Space Station program, a step toward actual construction after more than three years of government/industry study and technology development.

The Space Station is to be built on a phased basis, starting with a baseline configuration and evolving into an enhanced capability configuration. Intended to operate for several decades, the station will be capable of further growth, in both size and capability, in the 21st century. The RFPs asked industry to submit proposals for each of two options, Option One the phased program and Option Two, proceeding immediately to the enhanced capability version.

The accompanying drawings show representative views of what the initial Space Station manned base may look like. Above is a concept developed by McDonnell Douglas Corporation, at right one by Martin Marietta Corporation.

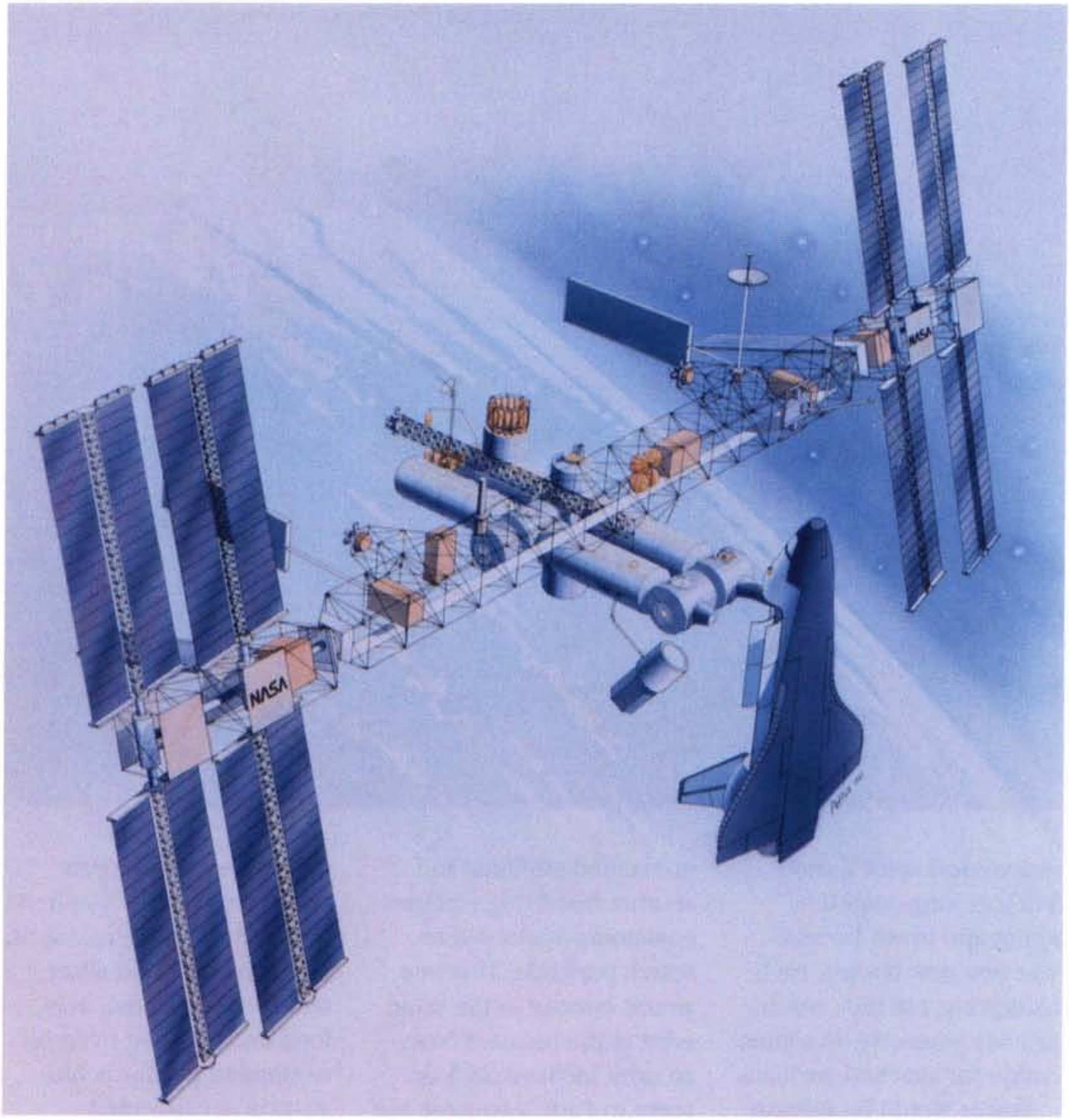
The basic Space Station structural element is a horizontal boom some 445 feet long, flanked at either end by solar cell arrays generating a total of 75 kilowatts of electrical power. In the middle of the boom are four pressurized modules, one of them a habitat providing living quarters for as many as eight astronauts, the others laboratory facilities built separately by the U.S., the European Space Agency (ESA) and Japan. Linking the laboratory modules are pressurized "resource nodes." Intended simply as passageways in earlier station designs, the resource nodes in the new baseline configuration contain equipment to expand the available working/living space.

With the modules and nodes, the baseline Space Station will have 31,000 cubic feet of pressurized volume. Work in the laboratories will focus on microgravity experiments—for example, pharmaceutical research or research on flawless crystals for advanced supercomputers—and on life sciences investigations, such as study of the fundamental behavior of living cells.

The baseline design includes provisions for "attach points" for mounting major experiments externally on the horizontal boom. Examples of systems that might be boom-mounted are a contemplated high resolution solar observatory for long duration studies of the Sun and an instrument for monitoring tropical rainfall, providing information toward an understanding of the periodic variability in Earth's weather patterns.

Additional experiments will be accommodated by two unmanned platforms operating separately from the manned base, one to be built by the U.S., the other by ESA. Operating in polar orbit, these platforms will be devoted primarily to acquisition of Earth resources data and scientific information about planet Earth.

Submitted in July, industry proposals cover only the U.S. segments of the Space Station; the international partners will fund their own



design and development work in coordination with NASA. The U.S. portion of the program is divided into four "work packages," each managed by a NASA field center and each to be accomplished by a team of contractors selected before the end of 1987. Each work package involves detailed design, construction, test and evaluation of a range of station components, broken down this way:

Work Package One, Marshall Space Flight Center, two U.S. pressurized modules, four resource node structures, three logistic transport systems, the environmental control and life support system, and certain internal systems.

Work Package Two, Johnson Space Center, the structural framework, resource node outfitting, two airlocks and a variety of subsystems, such as propulsion, navigation and control, communications and tracking. In addition, this package includes interface between the Space Station and the Space Shuttle, assembly and external systems maintenance, and provisions for extravehicular activity.

Work Package Three, Goddard Space Flight Center, the free-flying U.S. platform, along with provisions for instruments and payloads to be attached externally to the Space Station. Not part of this work package but under Goddard management is the Flight Telerobotic System, a robot manipulator that will be employed in assembly of the station and used thereafter in servicing operations.

Work Package Four, Lewis Research Center, system for generating, conditioning, storing, controlling and distributing electric power.

Other NASA centers involved in Space Station work include Kennedy Space Center (prelaunch and flight operations, logistics support, launch facilities and ground support equipment); Jet Propulsion Laboratory (program requirements and assessment); and Langley Research Center (Space Station evolution planning).

Although the possibility exists that an advanced heavy lift launch vehicle might be available in time for Space Station construction, NASA is basing the assembly plan on use of the Space Shuttle. The target date for the first launch is March 1994, when the Shuttle will deliver to an orbit 250 miles high an initial group of components for assembly in space. Over the following three years, there will be 18 additional flights, 11 of them delivering manned base segments, six bringing up logistics modules for resupply and outfitting, and two sending the unmanned platforms into polar orbit. Permanently manned capability for a crew of four will be achieved on the 11th flight in early 1996. Full crew capability (eight astronauts) will be attained on the 13th flight in late 1996.

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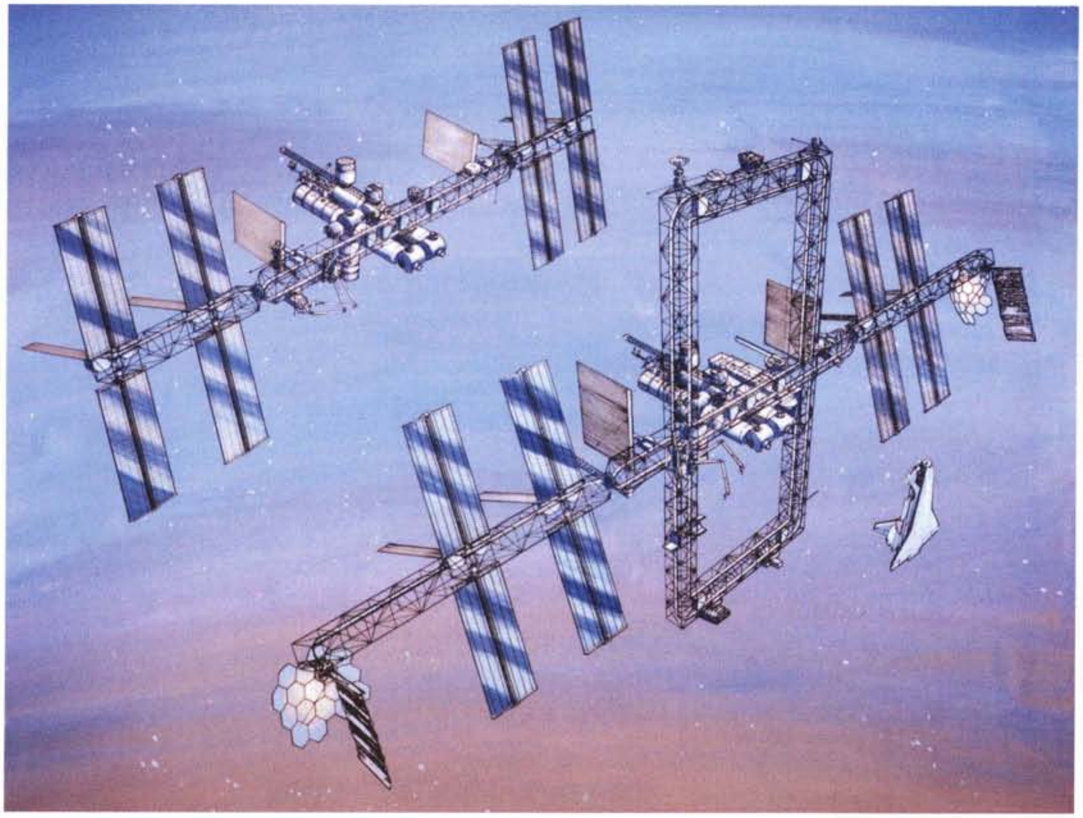


Under the phased approach to Space Station construction, NASA would initiate the second phase—development of the enhanced capability configuration—about 1991, when hardware fabrication for the initial station is well along.

The ultimate design of the enhanced capability version has not, of course, been determined, but the round of studies completed early this year has enabled NASA to outline one way the Space Station's capability might be expanded. This direction is illustrated by the accompanying artwork. At right is a McDonnell Douglas comparison view of the contemplated baseline and enhanced configurations. On the opposite page are Langley Research Center computer-generated representations of the baseline station (top) and the enhanced capability configuration.

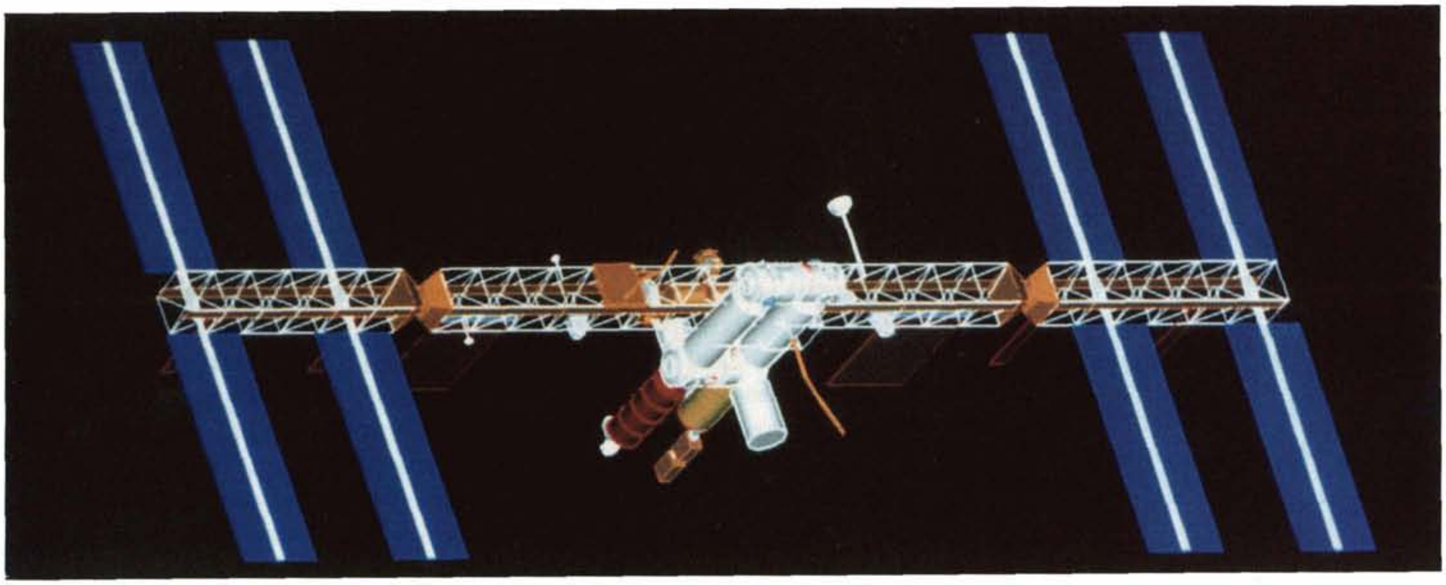
The enhanced capability design builds upon the baseline configuration, retaining the central horizontal boom and pressurized module complex, to which are added a rectangular mid-structure composed of two vertical spines, each 345 feet long, joined by upper and lower booms. The two new booms, each measuring 148 feet, would provide extensive accommodation for attached payloads.

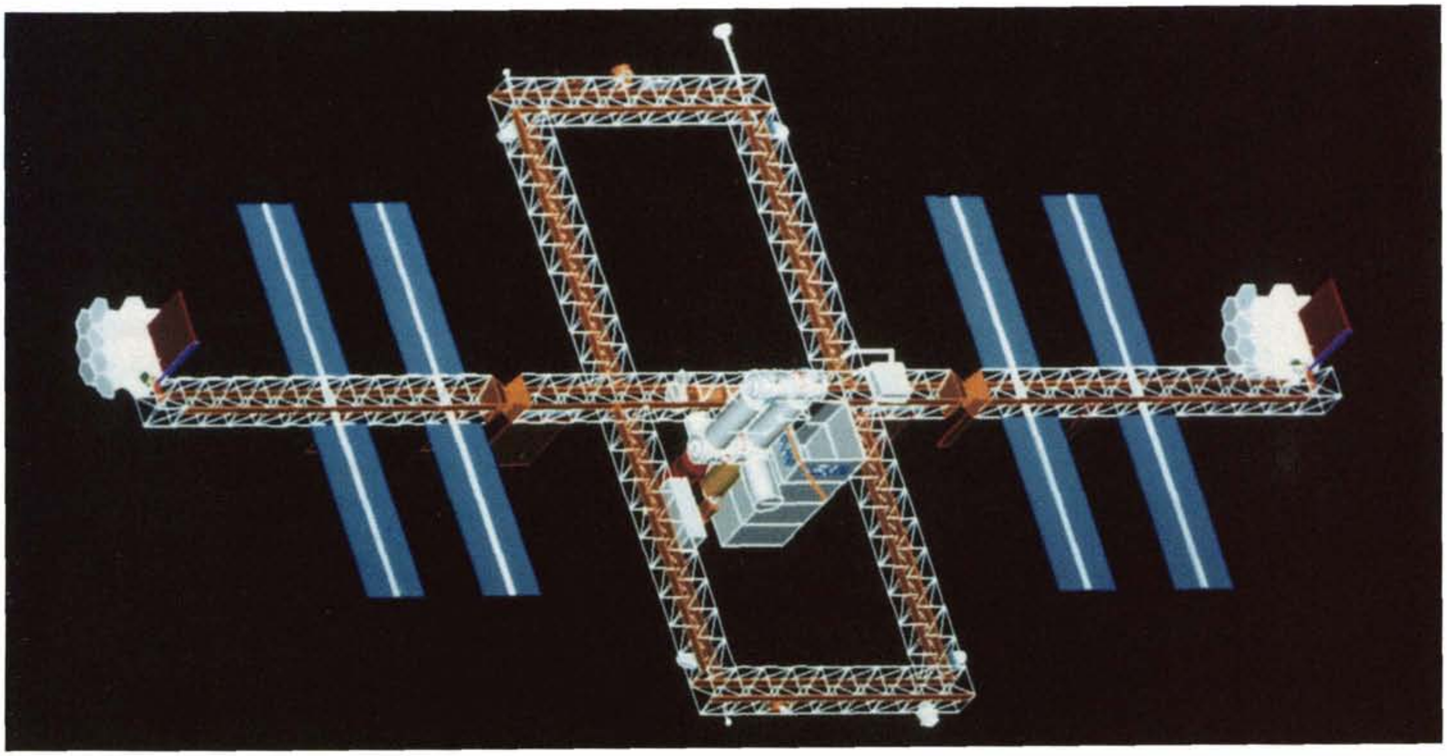
Power would be substantially increased in the enhanced capability configuration, which would retain the 75 kilowatt solar cell arrays of the baseline station and have, in addition, a new solar dynamic power system capable of generating 50 kilowatts. This would allow a significant expansion of the amount of research work that can be accomplished. The "dishes" shown in the illustrations at either end of the horizontal boom are heat collectors for the solar dynamic system.

Other major enhancements envisioned are a U.S.-supplied servicing bay that would permit servicing of unmanned satellites and another free-flying platform containing additional research payloads. This one would operate in the same orbit as the manned base, an orbit inclined 28.5 degrees to Earth's equator, but some distance removed from the main base to avoid disturbances or contamination from main station activities. Like the polar orbiting platforms, the co-orbiting platform would be powered by solar cell arrays.

The hub of the Space Station, the central complex of pressurized modules and nodes, would be essentially the same in the enhanced capability version as in the baseline station. Astronauts will live and work there under the same atmospheric pressure they experience on Earth. Both air and water will be regenerated; only food and nitrogen need be resupplied insofar as life support is concerned.

The principal advantage of the Space Station is that it will allow research expansion and continuity through permanent manned presence in orbit, where all U.S. human space activity to date has been intermittent. With several free-flyers complementing the manned base, the Space Station will offer the advantages inherent in both manned and unmanned systems, providing new versatility and flexibility for performing useful work in space. In its initial (baseline) configuration, the station will be a laboratory for scientific research and development of new tech-





nologies, a facility for development and possibly manufacture of new products, an observatory with an undistorted view of the universe, and a platform for observation of Earth to the benefit of resources management, meteorological advance and Earth science in general.

The enhanced capability station would significantly expand the facility's utility as a research and observation base through the greater electrical power supply available. In addition, the enhanced station would become a servicing facility for maintenance and repair of satellites, thus extending the useful lives of expensive assets; a storage depot in space; and a place to assemble large space structures, an essential follow-on step in space capability. As the Space Station evolves further, it could become an orbiting transportation hub for assembly, checkout and departure of 21st century spacecraft bound for geosynchronous orbit, the moon, the planets and destinations beyond the solar system. ▲

Probing The Universe

Scientists are learning more about Earth through study of the near-Earth environment, the planets of the solar system and the galaxies beyond

Over the past 30 years, a span that coincides with the Space Age, man has learned more about the Earth he inhabits—the solid Earth, the fluid Earth, the biological Earth—than in all prior years. But this great expansion of knowledge has only served to underline the fact that there is a great deal more to be learned about the complex processes that govern Earth, and that greater understanding of these processes is essential to improving, even maintaining, the quality of life on Earth.

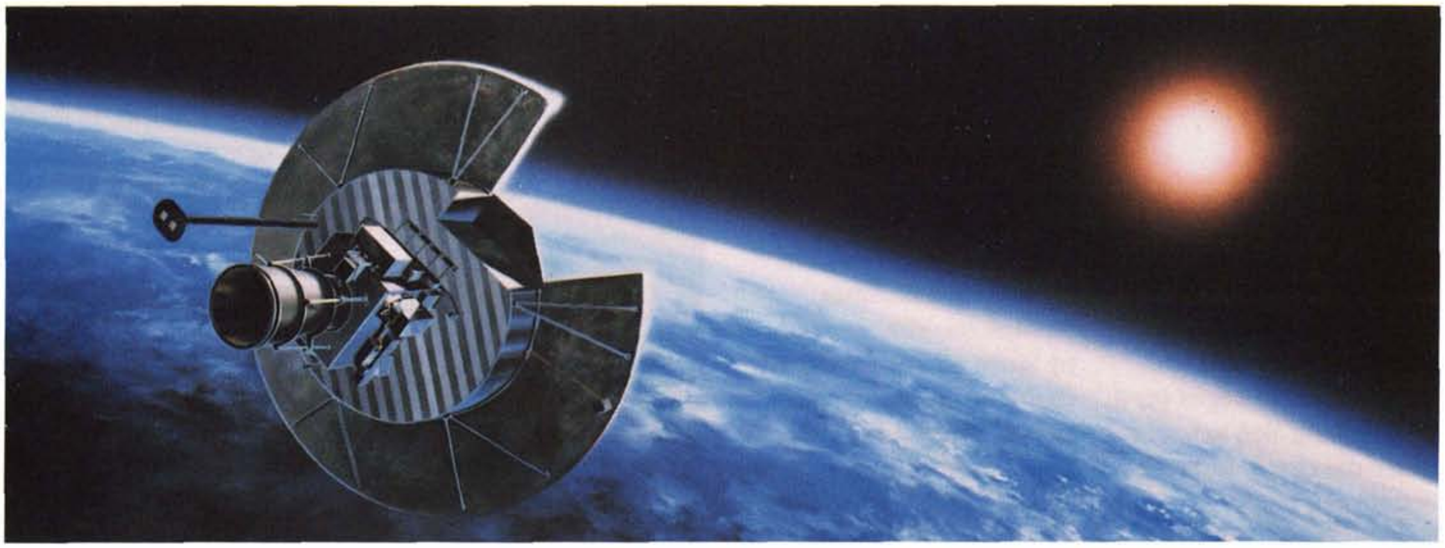
Space offers a unique vantage point for Earth investigations, and such investigations will continue to be one of the principal areas of effort in the U.S. space program. Additionally, expanded study of Earth's atmosphere, oceans, crust, the near-Earth environment and Sun/Earth relationships have become matters of priority interest among other spacefaring nations. The need for truly global perspective has sparked a number of agreements for international Earth study programs. One such, initiated this year, is the Global Geospace Science (GGS) program, a cooperative solar terrestrial research effort whose participants include NASA, the European Space Agency (ESA) and the Japanese Institute for Space and Aeronautical Sciences.

The GGS program will be the most comprehensive study ever attempted of Earth's magnetosphere, a region extending thousands of miles outward from Earth that expands and contracts as Earth's magnetic field interacts with the solar wind. A high-velocity electrified gas emitted by the Sun, the solar wind transfers energy from the Sun to Earth through a chain of complex reactions with Earth's magnetic fields, its ionosphere and its upper atmosphere.

How this incoming energy is transported, distributed, stored and released is a most important area of space science research, and it also has underlying practical implications for Earth's climate, weather and other life-influencing factors. Over the past several years, NASA has employed several spacecraft in a study of the physical processes that link Earth and the Sun. The GGS program will build upon the knowledge base provided by those spacecraft and greatly expand it by "multipoint" study—the employment of several different spacecraft, operating in widely different orbits with different instrumentation, to make simultaneous and sequential measurements intended to establish cause and effect relationships among magnetospheric phenomena.

To start in 1992 and continue through the 1990s, the international program involves a fleet of eight spacecraft: two U.S. spacecraft yet to be developed; a Japanese mission called GEOTAIL; and five ESA-built spacecraft for which the U.S. will supply instrumentation. The latter include a Solar and Heliospheric Observatory that will study the solar wind from an orbit between Earth and the Moon, and a four-spacecraft team of small spacecraft, collectively called CLUSTER, that will operate in orbit around Earth's poles. Goddard Space Flight Center will control and coordinate the activities of all the spacecraft.

NASA's participation in the GGS exemplifies one aspect of the agency's broad research effort known as the space science and applications program. The applications segment of the program involves use of space technology to generate direct Earth benefit; examples include the now-operational communications, weather and Earth resources survey satellites, which NASA pioneered in the 1960s and 1970s. Among more recent examples are a space-based system designed to aid search and rescue opera-



tions (see page 29) and an ocean dynamic survey satellite of importance to maritime operations.

The space science program embraces four main avenues of research: solar system exploration, or investigation of the planets, moons, comets and other phenomena in the solar system; astrophysics, the study of distant stars and galaxies; life sciences research, aimed at greater understanding of the origin and distribution of life in the universe, and at using the space medium to improve knowledge of biology and medicine; and solar terrestrial research, the study of the Sun's energy processes and their interactions with Earth's environment.

This comprehensive program has many goals, but they can be reduced to a common denominator: fitting the tiny planet Earth into the cosmic puzzle of how the universe began, how it evolved and how it is structured. The volumes of new scientific knowledge being generated represent an incalculably valuable resource, not just for scientists but for everyone, because science is the foundation of advancing technology, the informational base for tomorrow's practical applications. ▲

A primary quest of space science research is knowledge of how energy from the Sun is transported to Earth and how it drives Earth's environment. Among many NASA spacecraft that have investigated the Sun/Earth relationship are the Solar Mesosphere Explorer (top) and two Dynamics Explorers (above). To amplify the information acquired by these and other spacecraft, NASA—with European and Japanese partners—is launching a comprehensive, multiyear, multi-spacecraft study of the physical processes that link Earth and the Sun.

Great Observatories

Astronomers who view the heavens through Earth-based telescopes say it is something akin to trying to see the clouds from the bottom of a muddy pool, because Earth's veil of atmosphere blurs the visible light rays coming from distant space. The advent of space flight provided a great boon to the sciences of astronomy and astrophysics by making it possible to place instruments *above* the distorting layer of atmosphere and thus get a clearer visible light picture of the universe. It also provided opportunity to observe not only in visible light but in other forms of radiation that are scientifically very important yet are largely invisible to ground observatories because they are absorbed or filtered by the atmosphere—ultraviolet, infrared, x-rays and gamma rays, for example. This latter capability significantly increased the space observatory's value to science, because each segment of the electromagnetic spectrum offers a different set of clues to the origin and evolution of the universe.

Over the remaining years of this century and into the next, space astronomy will take another giant step forward with the on-orbit operation of NASA's four "Great Observatories." These very large spacecraft, designed for extended lifetimes through on-orbit servicing by Space Shuttle crews, will enable scientists to look back in time further than has previously been possible and study the cosmic happenings of the early years of the universe. Each observatory is designed to observe in a special segment of the electromagnetic spectrum; thus they will open entirely new vistas on the universe, collectively producing a comprehensive picture of the cosmos that no single observatory could provide.

The first of the Great Observatories to go into service will be the Hubble Space Telescope (HST), one of NASA's highest priority scientific spacecraft, which will be among the earliest projects launched when Space Shuttle flights resume. Capable of observing in both visible and ultraviolet wavelengths, the HST (above) has been termed the most important scientific instrument ever designed for use on orbit. It will literally be able to look back in time, observing the universe as it existed early in its lifetime and providing information on how matter has evolved over the eons. The system will enormously expand the viewable volume of the universe, will return images of unprecedented clarity, and will detect very

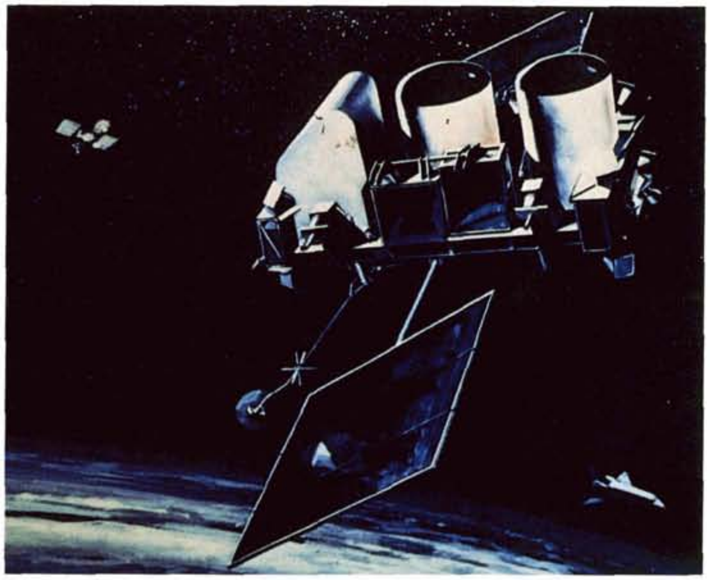
dim objects that have never before been observed.

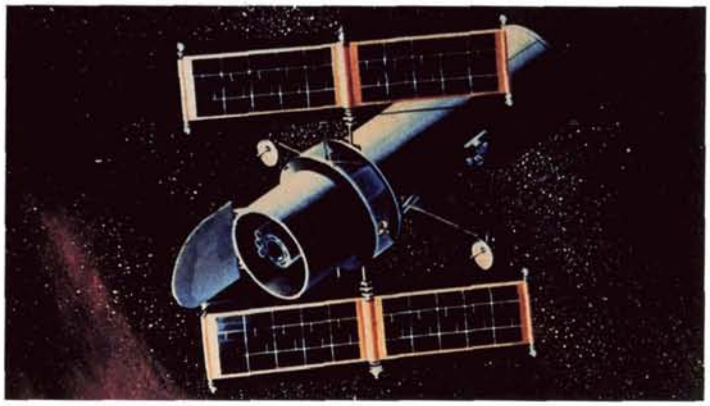
The largest scientific payload ever built, the 12½-ton, 43-foot HST was developed by Lockheed Missiles & Space Company, spacecraft prime contractor, and Perkin-Elmer Corporation, prime contractor for the optical assembly. The European Space Agency furnished the power generating solar array and one of the system's five major instruments. Marshall Space Flight Center manages the HST project; Goddard Space Flight Center will be responsible, when the spacecraft is in orbit, for controlling the telescope and processing the images and instrument data it returns.

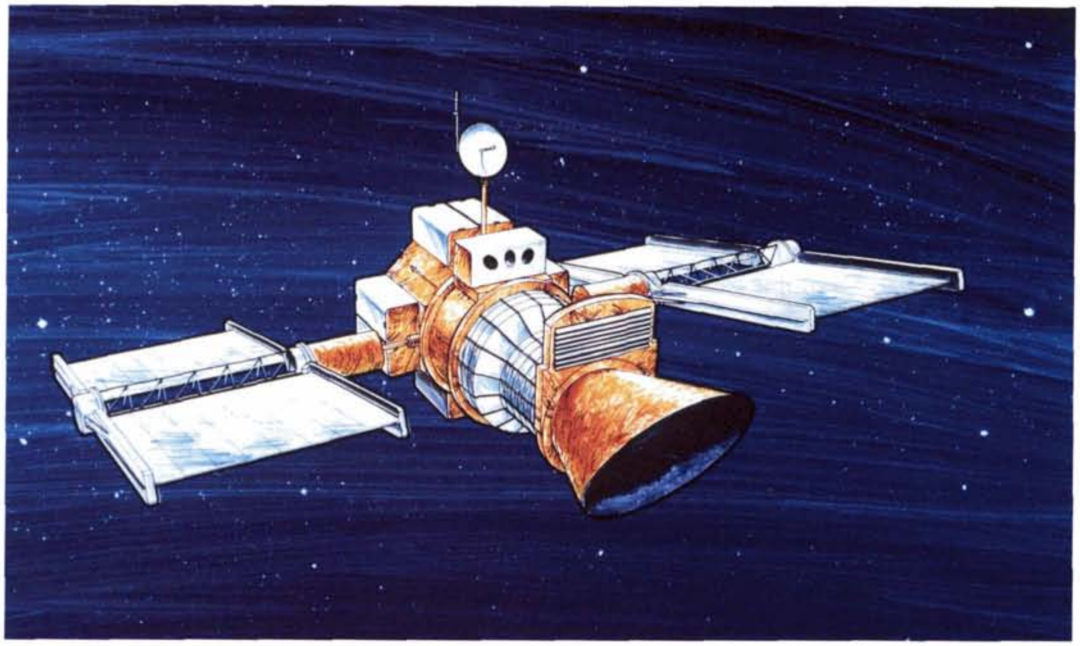
Second of the Great Observatories, planned for Shuttle launch about 1990, is the Gamma Ray Observatory (GRO) (top right). Managed for NASA by Goddard Space Flight Center, GRO is a joint development of the U.S., West Germany, The Netherlands and the United Kingdom; the U.S. prime contractor is TRW Inc. The gamma rays that GRO will investigate are the most energetic form of radiation known; a gamma ray unit packs a million to a trillion times as much energy as a comparable unit of visible light. These rays offer insight into the violent aspects of the universe—explosive, high energy and nuclear phenomena—that are found in such puzzling celestial objects as pulsars, quasars, black holes and supernovae. GRO will carry a six-ton instrument package for investigating the full range of gamma ray energies, from 60,000 to 30 billion electron volts. The observatory is expected to provide volumes of new information about the creation, nature and distribution of matter in the universe and expand knowledge about the center of our own Milky Way galaxy, which is obscured at visible wavelengths by clouds and dust.

Third of the series is the Advanced X-ray Astrophysics Facility (AXAF), not yet a fully funded program but a candidate for an early new start. Managed by Marshall Space Flight Center, AXAF (middle right) is a 10-ton observatory, capable of being serviced in orbit, that will build upon the successful work of HEAO-2, a High Energy Astronomical Observatory that provided the most comprehensive data yet acquired about celestial x-ray sources. AXAF, however, will have instruments 100 times more sensitive than those of HEAO-2. AXAF will study the most distant quasars and investigate one of the great mysteries of the universe, the "missing mass." About 90 percent of the matter in the universe is invisible; its presence is known only through the gravitational force it exerts on stars, galaxies and other visible objects. What is the missing mass, scientists want to know. Data from GRO, combined with that from other Great Observatories, may supply some answers.

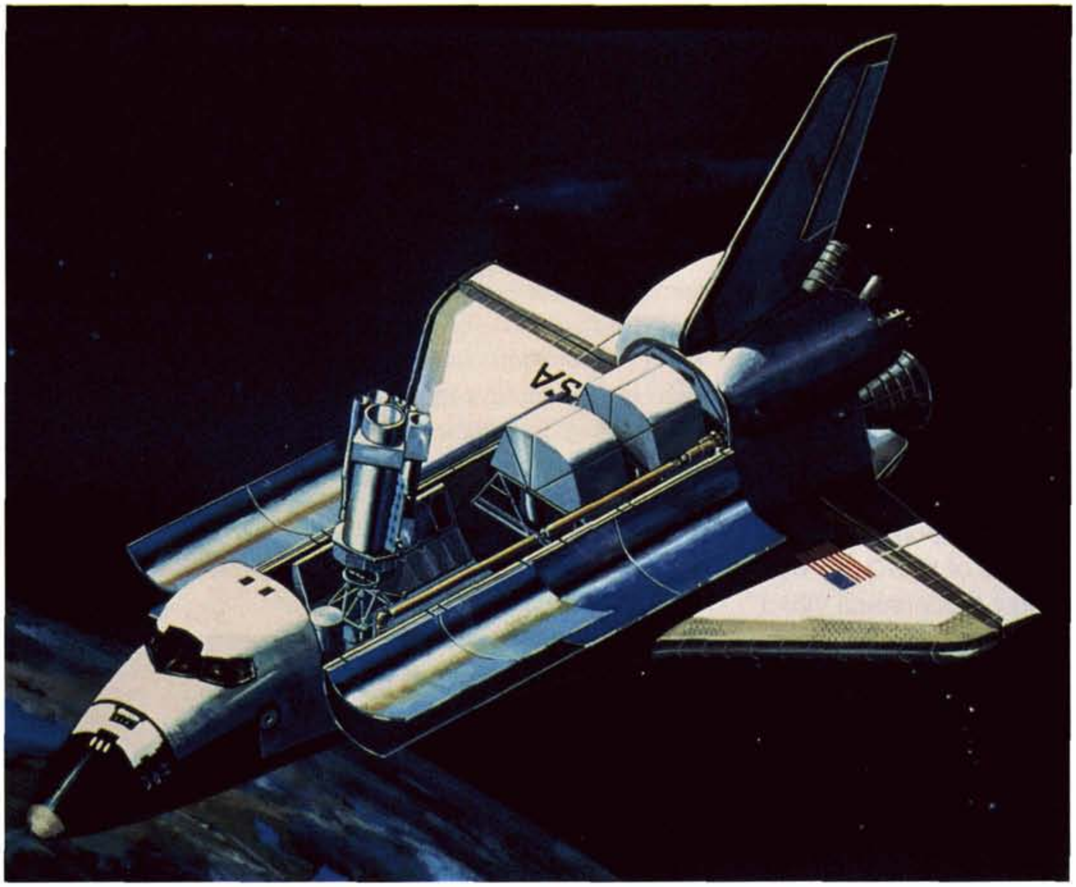
The fourth of the Great Observatories is the Space Infrared Telescope Facility (SIRTF), again not yet a fully funded development but envisioned as a 1990s follow-on to the Infrared Astronomical Satellite (IRAS), which made the first all-sky survey of infrared emissions in 1983, mapping some 100,000 sources. With instruments 1,000 times more sensitive than those of IRAS, SIRTF (below) will study areas of high interest identified by IRAS, ranging from bodies within the solar system to galaxies at the edge of the universe. One exciting assignment for SIRTF will be a search for planets around the nearest stars; the observatory's infrared spectra could provide clues to the composition of the atmosphere around a detected planet, allowing determination of whether it might sustain life similar to Earth's, and thus providing focus for the ongoing Search for Extraterrestrial Intelligence. ▲







Shuttleborne Observatory



Most stars are relatively "cool" bodies that emit much of their radiation in visible light. Hotter stars—typically very young and very old stars—emit ultraviolet radiation that does not penetrate Earth's atmosphere, hence is not visible to us. If we could view the sky in ultraviolet—rather than visible—light, we would get a very much different picture of the universe in which the stars we normally see would fade in prominence and the hotter parts of star clusters and galaxies would be highlighted.

Acquiring such different views of the universe is the assignment of a new NASA astronomical system known as the Astro Observatory, which is designed to provide extended duration observations from the Space Shuttle Orbiter. The sky has been viewed in ultraviolet by instruments aboard balloons, aircraft, sounding rockets and spacecraft, but the total time expended in ultraviolet imaging to date amounts to only a few hours. As a result, much of the sky has yet to be imaged in the ultraviolet and this range of the spectrum is considered a prime scientific target, because studies indicate that the solar system, the Milky Way Galaxy and the universe are rich in ultraviolet radiation. Astro's observations can furnish scientists a great deal of new information about the origin, structure and evolution of many different kinds of celestial objects.

To be used in concert with the Hubble Space Telescope (see page 20), which views in both visible and ultraviolet light, Astro consists of three distinct instrument systems: the Hopkins Ultraviolet Telescope (HUT), designed and built by The Johns Hopkins University Center for Astrophysical Sciences; the Ultraviolet Imaging Telescope (UIT), developed by Goddard Space Flight Center; and the Wisconsin Ultraviolet Photopolarimetry Experiment (WUPPE), developed by the University of Wisconsin.

The Johns Hopkins HUT is to study faint astronomical objects, such as quasars, and normal galaxies in the far ultraviolet range. Goddard's UIT is for imaging faint objects—such as hot stars and galaxies—in broad ultraviolet wavelengths and with a wide field of view. Wisconsin's WUPPE will study the polarization of hot stars, galactic nuclei and quasars; light is said to be polarized when the radiation is oriented in a particular plane and the polarization of a celestial object offers clues to the object's shape and structure.

The three instruments will be mounted and coaligned—installed so that all will point in the same direction at the same time—on two platforms in the Shuttle Orbiter's payload bay, thus creating a Shuttleborne observatory that can operate for a week at a time and provide 200 to 300 observations per mission. Astro can simultaneously gather ultraviolet imagery, spectroscopy and polarimetry; that cannot be done by any other observatory or space payload. Marshall Space Flight Center is Astro project manager. ▲

Big Bang Investigation

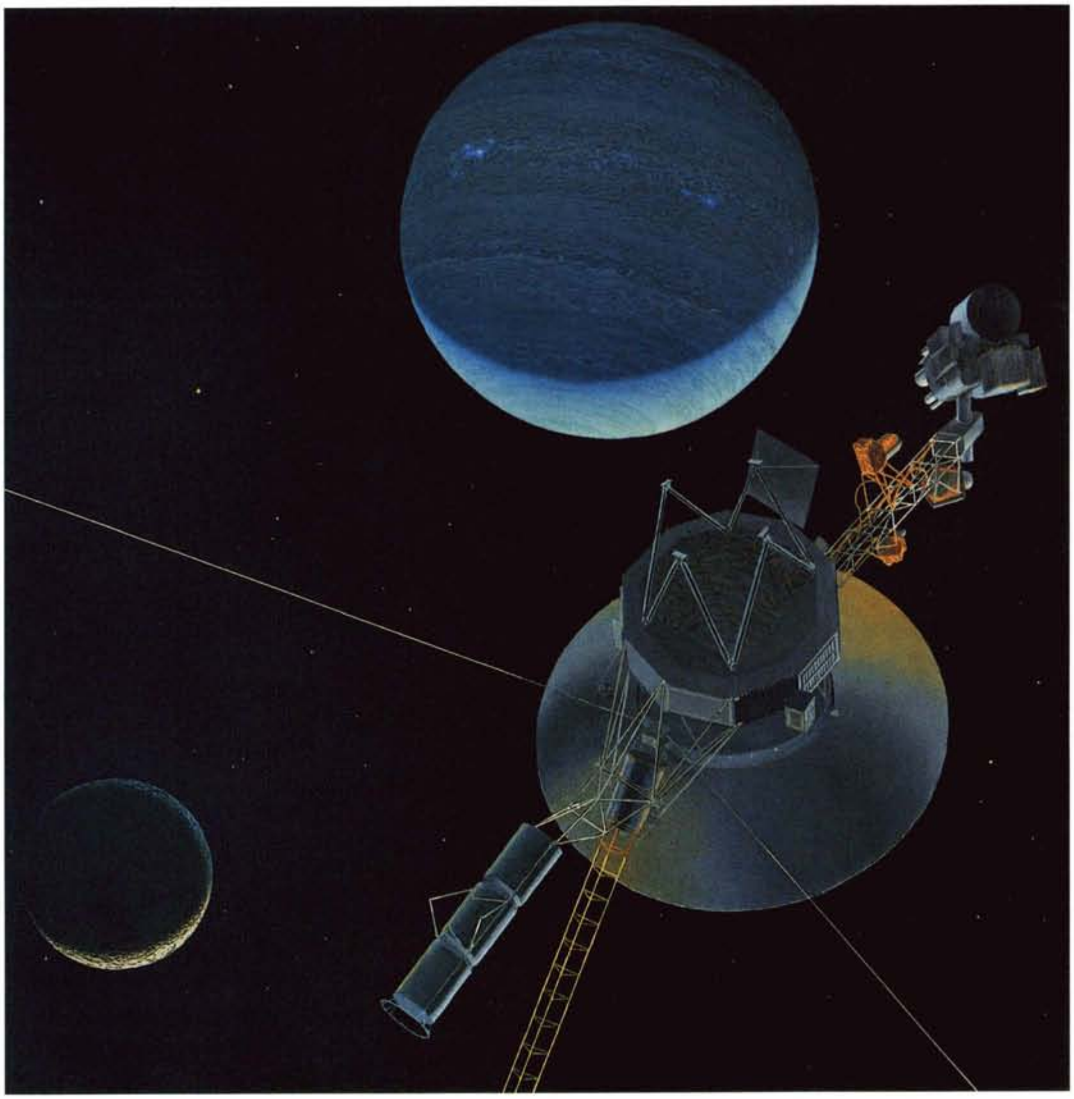
Among cosmologists—scientists who specialize in the study of the earliest beginnings and structures of the universe—there is a high degree of agreement on the Big Bang theory of the origin of the universe. This theory holds that the universe began, some 15 billion years ago, with a monumental explosion and that the explosion triggered a uniform expansion of the universe that has continued ever since.

Early in 1989, NASA will launch a spacecraft designed expressly to investigate the Big Bang theory. It is called the Cosmic Background Explorer (COBE), a designation that indicates the primary purpose of the mission: study of cosmic background radiation that is the strongest evidence supporting the Big Bang theory. The existence of such radiation was discovered in 1964 by radio telescope scientists at Bell Telephone Laboratories. Using a new, highly sensitive microwave receiver and antenna, they detected signals coming from space, not just from one object but equally from all directions. This phenomenon cannot be explained except as a remnant of the primeval explosion.

COBE will map the sky at many different wavelengths and measure the radiation emitted by a variety of celestial objects, in addition to its primary investigation of cosmic background radiation. An experiment of special interest involves detection of the first stars and galaxies, never before possible because Earth's atmosphere interferes with measurements and because the dust in the solar system and the Milky Way Galaxy confuses analysis. COBE will use an advanced instrument called the Diffuse Infrared Background Experiment to search for light from the earliest galaxies.

COBE is a 5,000 pound observatory measuring eight feet in diameter. It will be launched by a Delta expendable launch vehicle into a Sun-synchronous orbit 559 miles high. Goddard Space Flight Center is responsible for design, integration and test of the spacecraft. Goddard will also process scientific data returned by COBE and relay it by computer links to members of the science team located at NASA centers and universities across the country. ▲

Visit to Neptune



With the successful reconnaissance of Uranus in 1986, there remained only two planets in the solar system that had not been visited by NASA spacecraft—the outermost planets Neptune and Pluto. The number will be reduced to one with the 1989 encounter of Neptune by the Voyager 2 spacecraft (in the illustration, Neptune at top and its moon Triton at lower left).

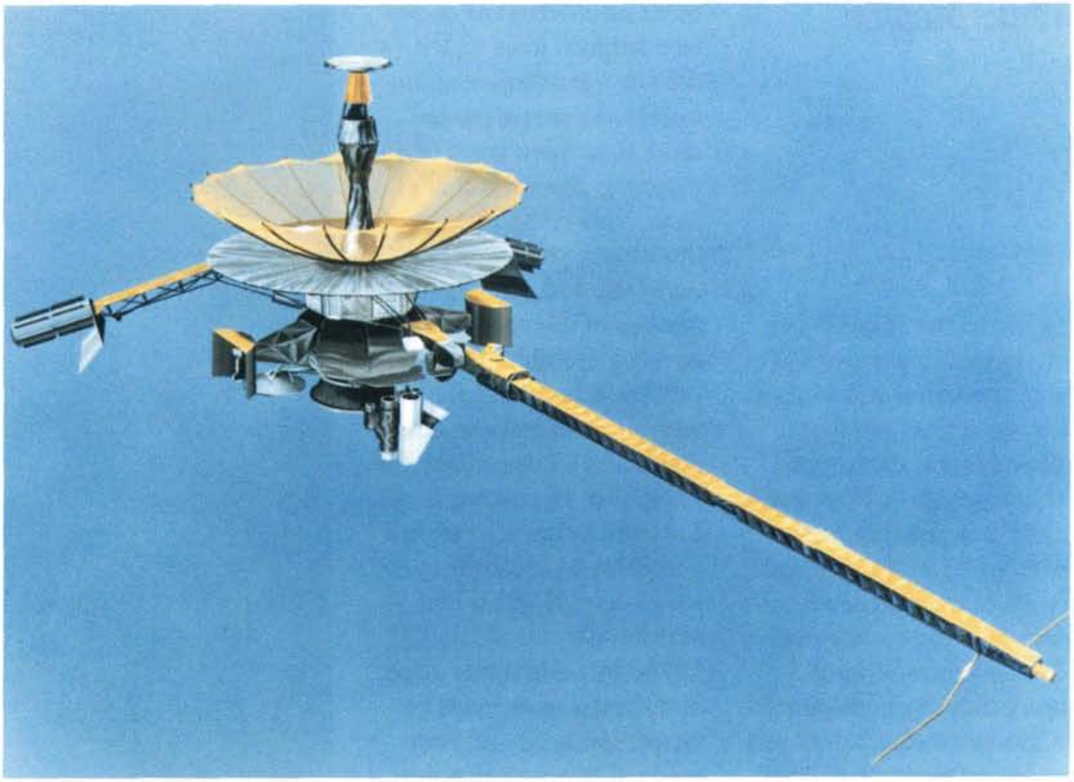
Now more than a decade out of home port Earth, Voyager 2—along with its companion Voyager 1—was launched in 1977. Both made highly successful encounters with Jupiter in 1979 and with Saturn in 1981, returning some 70,000 images of those planets. Voyager 2 continued on to Uranus, seventh planet of the solar system, two billion miles from Earth, making its closest approach to the planet on January 24, 1986. During a 113-day Uranus encounter, Voyager 2's instruments sent to Earth volumes of data and thousands of images of incalculable scientific value. Because the great distance makes Uranus detail visible only to the most powerful Earth telescopes and then only dimly, little was known about the planet and from Voyager 2 scientists learned far more than had been learned in all the years since the planet's discovery.

That is also expected to be the case when Voyager 2 reaches Neptune, because very little is known about that planet, a billion miles farther from Earth than is Uranus. Neptune is nominally the eighth planet from the Sun, but it is now, and will be at the time of the Voyager encounter, the outermost planet of the solar system; that's because Pluto, normally the ninth and outermost planet, has an elongated orbit around the Sun and it is currently "inside" the orbit of Neptune, and will be for another seven years.

Neptune is the third largest of the planets (after Jupiter and Saturn) with a diameter estimated at 31,500 miles. It is a gas planet that takes 165 years to make a revolution of the Sun. Neptune has two known moons: Triton, comparable in size to Earth's moon, and tiny Nereid, perhaps only 200 miles in diameter.

Voyager 2 is scheduled to make its closest approach to Neptune on August 25, 1989, when the planet will be 2.8 billion miles from Earth. The images Voyager returns will provide man's first real look at Neptune, since it is invisible to the unaided eye, and even to large telescopes it shows up as a small, greenish disc in which no surface detail is discernible. The Voyager program is managed by Jet Propulsion Laboratory. ▲

Galileo



Targeted for launch in November 1989 is a mission that will provide the most comprehensive investigation yet conducted of a planet other than Earth—the Galileo mission to Jupiter, named for the Italian astronomer, physicist and mathematician who is credited with construction of the first complete, practical telescope in 1620. A cooperative program with the Federal Republic of Germany, the Galileo mission is intended to meet a need for long term, detailed studies of Jupiter, amplifying the information acquired by the two Voyager spacecraft in their brief flybys. The Galileo spacecraft (right) is a two-element system that includes a Jupiter-orbiting observatory and an entry probe.

Galileo, affixed to an Inertial Upper Stage (IUS) rocket, will be deposited in low Earth orbit by the Space Shuttle. The solid fuel IUS will then boost the spacecraft into a trajectory that will take it close to Venus, whose gravity will be employed in the "slingshot" technique of accelerating Galileo on a path to Jupiter. Even with the planetary gravity assist, the trip will take six years.

As it approaches Jupiter in mid-1995, Galileo will release the five foot diameter entry probe which will proceed on an independent course to Jupiter and descend into the Jovian atmosphere. A parachute will slow the descent and a forward heat shield will deploy to absorb the heat of entry, estimated to be as high as 14,000 degrees Fahrenheit. The probe will report data—relayed to Earth through the primary spacecraft—on temperatures, pressures and the composition of the atmosphere. Its lifetime in the extreme heat and crushing pressure is estimated at about 60 minutes, but in that brief span the probe can provide volumes of exceptionally important scientific data—important because Jupiter's gaseous atmosphere is believed to contain remnants of the original material from which the solar system was formed, hence offers clues to the origin of the universe.

The main spacecraft, meanwhile, will swing into orbit around the giant planet, in effect becoming a man-made moon of Jupiter, transmitting high quality images and instrument data about the planet and its natural moons. As a long term observatory, returning data for two years from a great variety of vantage points, Galileo is expected to amplify enormously the existing body of knowledge about Jupiter. Jet Propulsion Laboratory is Galileo project manager and builder of the main spacecraft. Ames Research Center has responsibility for the entry probe, which was built by Hughes Aircraft Company and General Electric Company. ▲

Venus Mapper

The planet Venus is permanently cloud-shrouded, thus it is impossible to view its surface directly from Earth-based observatories or from spacecraft. It is possible, however, to create images and maps of the never-seen surface by radar measurements from a Venus-orbiting spacecraft. Such imagery is important to the continuing comparative study of Earth and Venus, two planets that have evolved in strikingly different manner although they are very similar in size, age, mass, density and orbital distance from the Sun.

From flyby missions, from instrumented probes sent into the Venusian atmosphere, and from Venus-orbiting spacecraft of both the U.S. and the Soviet Union, scientists have learned a great deal about Venus' atmosphere, temperatures, pressures, winds and other elements of the planet's weather system. To complement this information for study of Venus' evolution, scientists need accurate data on the planet's topography.

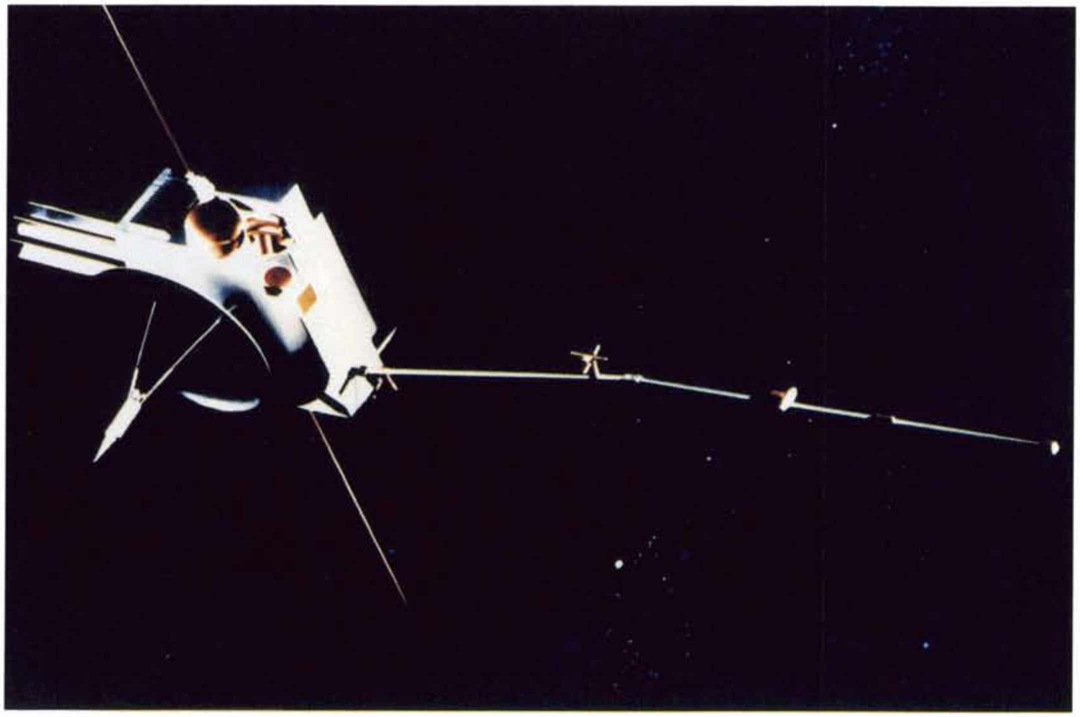
NASA's Pioneer Venus Orbiter, launched in 1978, used a radar altimeter to acquire measurements of surface heights, from which the first Venus topographic maps were prepared. In more than three years of mapping, the spacecraft's radar covered 93 percent of the surface. The resulting maps showed that some 60 percent of the surface is relatively flat, rolling plain; 24 percent is highland area with some mountains taller than Earth's Everest; and the remaining 16 percent is lowland, below a reference point that would correspond to sea level if Venus had oceans.

The Pioneer Venus maps, and similar ones made by Soviet spacecraft, allowed study of Venus from a new informational plateau, but much remains to be learned about the planet, and particularly its detailed surface contours. Specifically, there is need for topographic measurements at great resolution, which would enable identification of such small scale surface features as volcanos, craters, lava flows, faults, erosion channels and possibly the remnant shorelines of long-ago oceans. Such measurements will help identify geological processes and establish a geological history of the neighbor planet. That information is not only scientifically important, it has an underlying practical aspect: expanded knowledge of Venus may provide clues to greater understanding of the many factors that influence Earth's complex environment.

The quest for detailed measurements will be undertaken by a new NASA spacecraft named Magellan,

for the 16th century Portuguese explorer. Targeted for launch in April 1989, Magellan (above) will orbit Venus about once every three hours, acquiring radar data for 37 minutes of each orbit when it is closest to the surface. Using an advanced instrument called a synthetic aperture radar, it will map more than 90 percent of the surface with resolution 10 times better than the best obtained by prior spacecraft. Magellan is managed by Jet Propulsion Laboratory; Martin Martin Aerospace is developing the spacecraft and Hughes Aircraft Company the advanced imaging radar. ▲

Solar Polar Mission



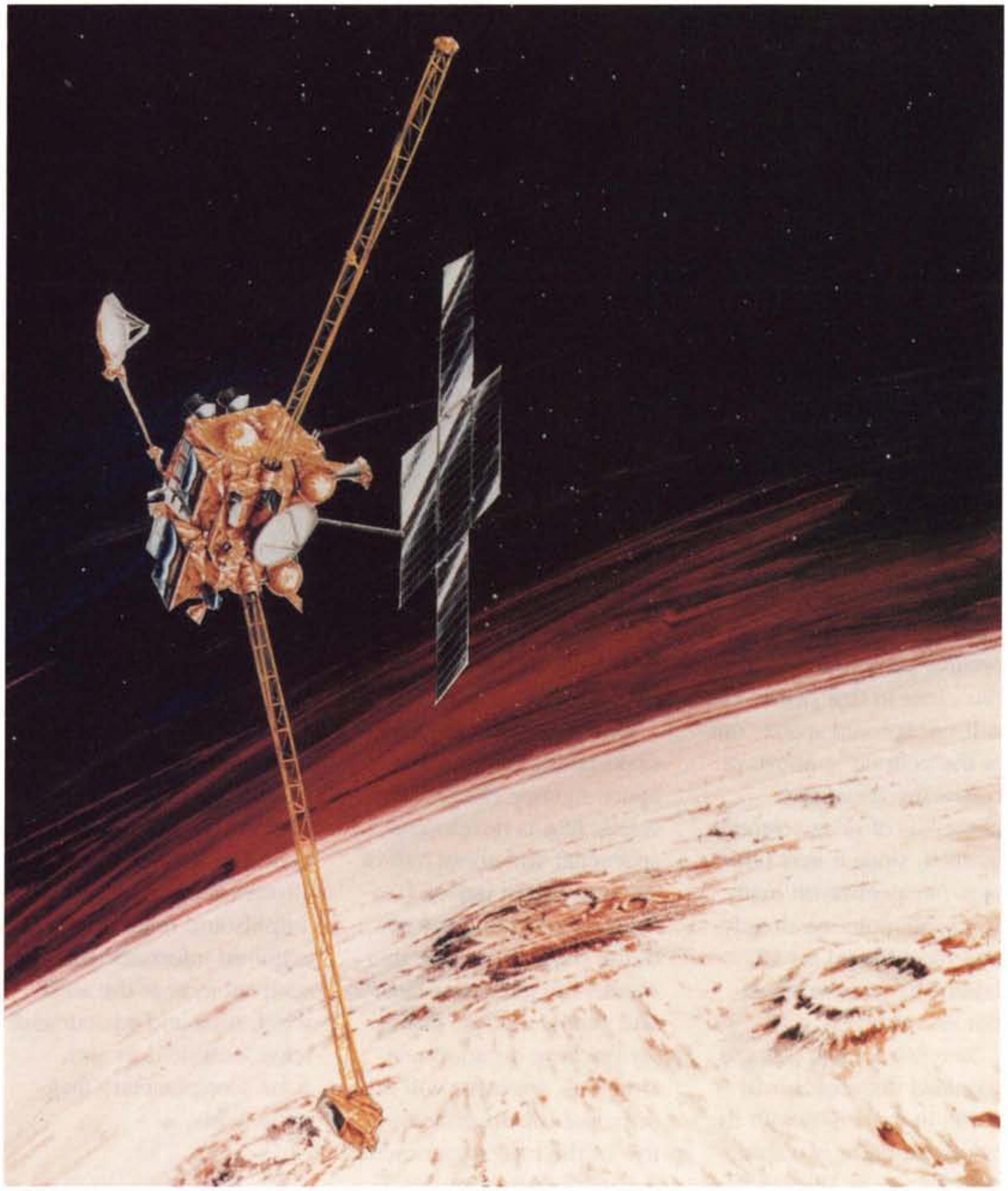
Although almost 3,000 spacecraft have been launched by all the world's spacefaring nations over the past 30 years, all have operated in a relatively thin band of solar system space near the ecliptic, an imaginary plane that approximates an extension of the Sun's equator; Earth and all the planets revolve about the Sun in orbits close to that plane. The still unexplored space "out of the ecliptic"—above or below the imaginary plane—is of great scientific interest, since it may offer new perspective on many space phenomena already investigated and reveal other phenomena as yet not encountered.

The first look at this spatial third dimension will come in the 1990s with the multiyear flight of a spacecraft known as Ulysses, aptly named for the mythological hero who—in Florentine poet Danté's *Divine Comedy*—sought to explore the "world behind the Sun." The spacecraft Ulysses will explore a new "world" by flying around the poles of the Sun.

Ulysses is a cooperative undertaking of the European Space Agency (ESA) and NASA. ESA is developing the spacecraft and about half of the instrument payload; NASA is providing the rest of the payload and the thermoelectric generator that will supply electric power for the long duration mission. U.S. scientists will be principal investigators for five of the nine experiments to be conducted and co-investigators on some of the ESA experiments. NASA will also provide Space Shuttle launch and tracking/data acquisition services. Jet Propulsion Laboratory is NASA's project manager.

Ulysses will be directed initially into a trajectory that will take it to Jupiter, whose immense gravity will be utilized as a "slingshot" to hurl the spacecraft out of the ecliptic and into a new trajectory that will swing Ulysses over the Sun's polar region; it will then orbit the Sun in a path perpendicular to the Sun's equator, or around the poles. From its new vantage points en route to and in solar polar orbit, Ulysses is expected to amplify and refine earlier acquired information on such subjects as the solar wind, solar and galactic radiation, cosmic dust and solar/interplanetary magnetic fields. ▲

Mars Observer



The planet Mars is closely linked to Earth in terms of its volcanic, erosional and climatic phenomena. Study of Mars, in particular comparative study of the Earth-Venus-Mars triad, offers clues to understanding the evolution of Earth and the inner solar system.

NASA has sent eight spacecraft to Mars, four of them flyby reconnaissances by Mariner spacecraft, four of them more detailed explorations by a team of Viking Orbiters and Landers. The latter spacecraft, which operated from 1976 to 1982, photographed and mapped the surface, studied the atmosphere and climate, and conducted chemical and biological tests of the Martian soil in a search for evidence of rudimentary life forms.

Along with the Magellan mission to Venus (see page 26), the next step in the continuing study of the inner planet triad is a long term investigation of Mars that will build upon and amplify the findings of the Viking team. Called the Mars Observer (above), the spacecraft is the first of a planned series of Observer Class flights to the planets and small bodies of the solar system. To be launched in 1992, the Mars Observer will be directed into a circular orbit approximately 200 miles above Mars' surface. Operating as a Martian moon for two years, the spacecraft will obtain images of the planet's surface with the highest resolution yet attained, and report data in two general areas: geoscience and climatology.

Among geological matters to be investigated are the elemental and mineralogical composition of the Martian surface and the global distribution of the different elements and minerals; Mars topography and gravity; magnetic field characteristics; tectonic stresses in the planet's crust; the composition of Mars' volcanos and the nature of their evolution. Climatology studies to be performed include investigations of the daily and seasonal variations of the atmosphere; the composition of clouds; the nature of the upper atmosphere and ionosphere and how they interact with the solar wind and solar radiation; and the history of the atmosphere. Jet Propulsion Laboratory is manager of the Mars Observer program; RCA Corporation is developing the spacecraft. ▲

Search and Rescue System

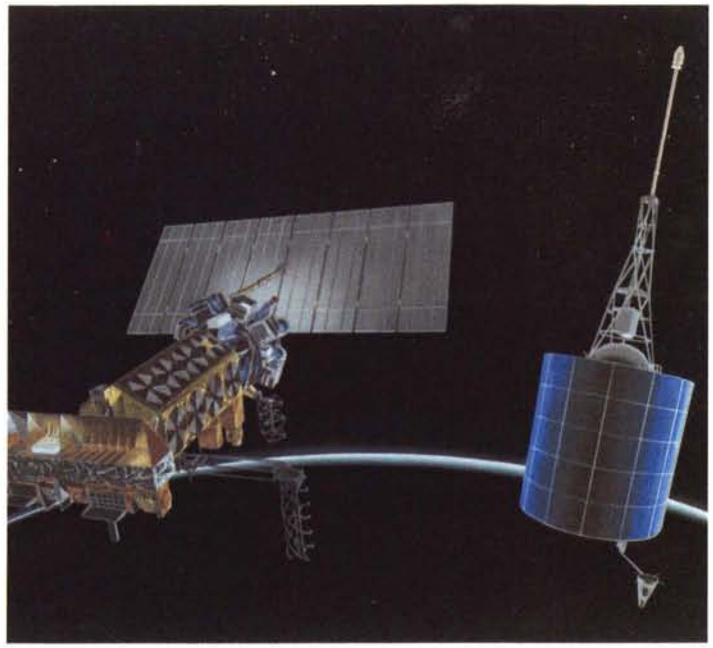
The accompanying photo shows a U.S. weather satellite (left) operated by the National Oceanic and Atmospheric Administration (NOAA) and a Soviet navigation satellite of the Kosmos class. They share a common feature: each has an electronic package, carried as a secondary payload, that is part of a global search and rescue system. The antennas protruding from the side of the NOAA satellite are part of the search and rescue payload, as is the antenna at the lower edge of the Soviet satellite.

Called COSPAS/SARSAT, the search and rescue system is marking the fifth anniversary of its first lifesaving operation, which took place on September 10, 1982. Since then, COSPAS/SARSAT has been instrumental in saving more than 750 lives in maritime, air and ground emergencies. SARSAT is an acronym for Search and Rescue Satellite Aided Tracking; COSPAS is the Soviet equivalent.

COSPAS/SARSAT was developed to meet an important need. Ships and commercial aircraft, and many private aircraft, carry radio beacons to signal emergencies and to provide a homing beam to help rescuers locate a craft in distress. The problem that existed before COSPAS/SARSAT was that there was no international system for *continuous* monitoring of beacon signals, thus no assurance that a signal for help would be heard.

The answer was provision of a beacon monitoring payload aboard satellites routinely concerned with other operations, such as weather/environment data reporting or providing space-based navigation signals. These monitors "listen" continuously on emergency frequencies used by ships and aircraft. When a monitor picks up a signal from an emergency beacon, it notes the direction of the signal source and relays that information to a ground receiving station. The ground station processes the monitor's information and within minutes the station's computers provide a position fix, within five to 10 miles, of the emergency locale. The ground station then notifies the appropriate rescue agency, in the U.S., the Air Force or Coast Guard. Survivors are usually found within four hours; time is vital, since the survival rate declines sharply with increased rescue time.

The space portion of the system, a cooperative program involving Canada and France as well as the U.S. and the U.S.S.R., consists of search and rescue payloads aboard three NOAA and three Soviet satellites. Other nations participating include Brazil, Bulgaria, Denmark, Finland, Norway, Sweden



and the United Kingdom. There are 11 regional ground stations for receiving and processing satellite signals, four of them in the U.S., three in the U.S.S.R. and one each in Canada, France, England and Norway.

Goddard Space Flight Center is responsible for research and development toward improvements in the system. Goddard is currently developing a lightweight, battery-powered, waterproof locator beacon that emits a strong signal although it weighs only 1½ pounds. Two prototype units have been extensively tested; one of them, though not needed, was aboard the December 1986 round-the-world nonstop flight of the Rutan Voyager lightplane. ▲

Toward Future Flight

Propfan progress highlights NASA's aeronautical research program, which is providing new technology for coming generations of more efficient aircraft

In the oil glut of 1986, the price of jetliner fuel plummeted to 50-60 cents a gallon, less than half of its cost only three years earlier. It was a welcome respite for the world's airlines, who burn billions of gallons of fuel annually and therefore had encountered some rough financial weather in the wake of the global oil crises of the 1970s. But even at its 1986 "bottom" price, fuel still cost five times as much as it had in 1972 and constituted a significant portion of an airline's total operating costs.

Airline executives feel that fuel prices will inevitably edge upward again. Looking at the longer term, they are concerned about the uncertainties of future supply and the possibility that another crisis might send fuel costs even higher than the $1.40-a-gallon peak. That's why they are noting with great interest progress in development of a new aircraft propulsion system that promises fuel savings of 30 percent, a NASA-pioneered system known variously as the propfan, unducted fan, open rotor or ultra high bypass engine. In the U.S. three different types of propfans are being flight tested or readied for flight, and two leading aircraft manufacturers have based their next generation airliner designs on propfan propulsion.

The propfan had its origin in NASA's Aircraft Energy Efficiency program, begun in 1975 to combat rising fuel costs by reducing fuel consumption in a variety of ways. Propfan work started as an investigation of combining the best features of the turbofan engine and the aircraft propeller, which has inherently better fuel consumption characteristics. Used in most modern airliners, the turbofan is a type of jet engine in which *some* of the air taken in is compressed, burned in a combustion chamber and expelled at high velocity as thrust, but a far greater amount of air bypasses the combustion process; pushed rearward by a large diameter, multibladed internal fan, this slower moving unburned air mixes with the hot exhaust gas. The result is a very large gain in overall thrust with minimal expenditure of fuel. Propulsion engineers use the term "bypass ratio" to indicate how much air bypasses the combustion chamber; for example, a bypass ratio of six to one means six times as much cold (unburned) air as hot. Generally speaking, the higher

The NASA Propfan Test Assessment propulsion system (above) was ground tested last year in preparation for 1987 flight testing aboard a Gulfstream II business jet, modified to permit installation of the test system (left).

the bypass ratio, the greater the efficiency of the engine at subsonic airliner cruise speeds.

NASA's propfan concept of the mid-1970s envisioned use of a large *external* fan—in effect a reincarnation of the propeller—to move great amounts of air and thereby effect a dramatic increase in the bypass ratio. But to drive aircraft at jetliner speeds, the propfan blades would have to have supersonic tip velocity. Therefore, the new "fan" would little resemble its ancestor, the propeller; it would have to be much thinner, yet stronger, and differently shaped to allow faster rotation.

Lewis Research Center and its principal contractor—Hamilton Standard Division of United Technologies—began extensive computer design and wind tunnel testing of model propfan systems. What emerged from several years effort was a new type of rotary thruster with 8-10 extremely thin blades, made of composite material for requisite strength and "swept back" to slice through the air more efficiently. A further advantage of the propfan is that it is not encased by a large, heavy duct, as is the turbofan. The beneficial effect of the turbofan duct increases its efficiency; but the propfan can be made larger to gain back the lost efficiency of ductless operation and still provide substantial weight saving.

Research indicated that such a system, driven by an advanced engine, could provide propulsion at jetliner speeds with fuel savings of 30 percent or more. By 1980, NASA was making sufficient progress to release the results of its initial work to engine manufacturers, who subsequently started their own propfan programs.

NASA continued ground testing of propfan models in the early 1980s, but it had become apparent that flight testing of a full-scale system would be necessary to get the answers to some important questions: *exactly* what kind of fuel efficiency can be expected; what cabin and community noise levels will result from supersonic rotation of the blade tips; and how the shock waves generated will affect the airplane structure. Accordingly, in 1984, Lewis Research Center initiated the Propfan Test Assessment (PTA), assisted by an industry team that includes prime contractor Lockheed-Georgia Company; Hamilton Standard, which designed and built an eight-bladed, nine-feet-diameter, single rotation propfan; Allison Gas Turbine Division of General Motors, which provided a 6,000 horsepower turbine engine and gearbox; Rohr Industries, which designed the engine nacelle; Gulfstream Aerospace, which modified a Gulfstream II business jet to allow mounting of the PTA engine on a wing; and Lockheed-California Company, responsible for analysis and evaluation of noise and vibration levels.

The PTA effort began in the summer of 1986 with a successfully concluded 50-hour program of static testing to check the compatibility of the engine, fan and nacelle and to measure propulsion system performance. In late 1986, the test system was installed on the Gulfstream II and airworthiness testing of the PTA test bed, a preliminary to propfan flight testing, began in March 1987.

(Continued)

In flight tests on a Boeing 727 (left), the General Electric Unducted Fan is flown as the starboard engine in place of one of the regular three turbofans. First flown in August 1986, the UDF is a pusher-type propfan with two counter-rotating rotors of eight blades each (above).

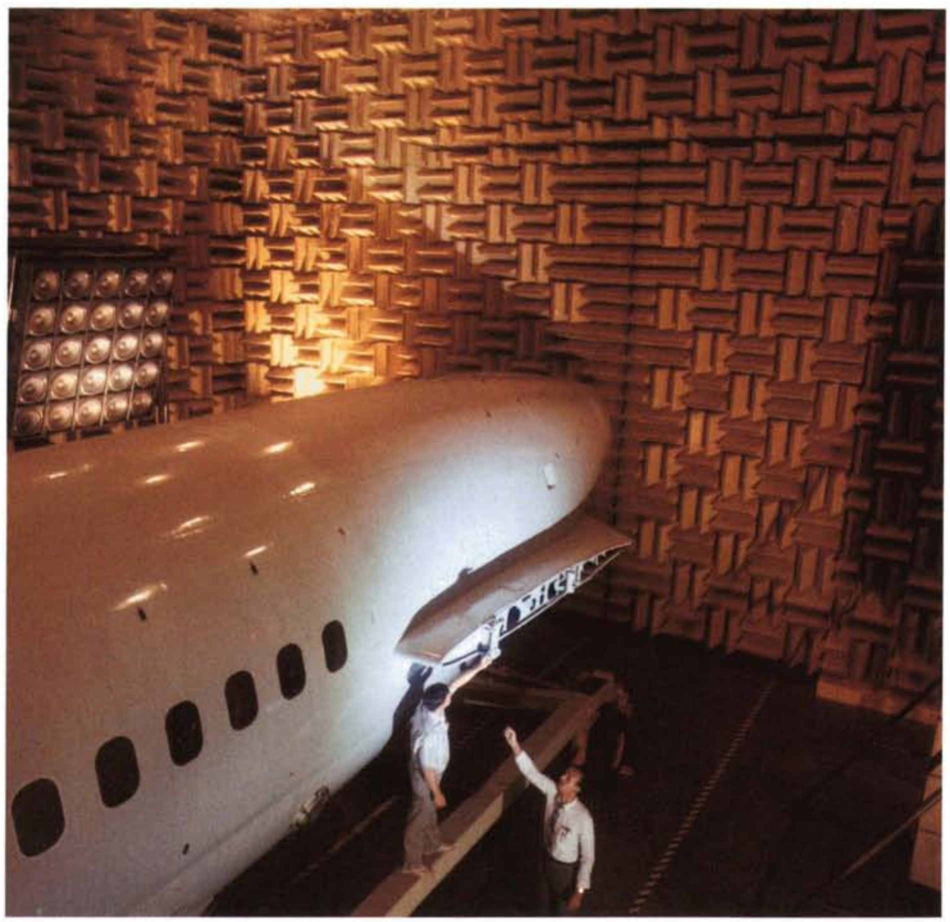
Propfans for the 1990s

(Continued)

While NASA and its contractor team were pursuing propfan technology development in one direction—the single rotation "tractor" or "puller" system—General Electric Company (U.S.A.) used the early NASA technology as a departure point for independent development of a different kind of propfan known as the Unducted Fan or UDF ™. After study and component test work in 1981-82, General Electric started construction in 1983 of a proof-of-concept dual rotation pusher-type UDF. The UDF has two counter-rotating external fans, each with eight sweptback blades. Unlike the NASA PTA system, it has no gearbox; the fans are driven directly by the turbine, a weight-saving measure that eliminates the weight of the gearbox and its oil cooling system.

In a cooperative General Electric/NASA program, the UDF was extensively ground tested in 1985-86 and it demonstrated a fuel consumption rate 20 percent better than modern turbofans. Then General Electric teamed with Boeing Commercial Airplane Company to test the UDF in flight aboard a modified Boeing 727 jetliner. Flight tests began in August 1986 and continued into 1987. General Electric also built a second demonstrator engine for 1987 flight tests

The Allison/Pratt & Whitney Model 578-DX, an offshoot of NASA Propfan Test Assessment technology, is scheduled for flight tests starting in December 1987.



Propfans generate lower frequency sound pressures than do turbofans, and the supersonic blade tip speed greatly increases the acoustical energy propagated. These factors demand extensive research toward reducing community/cabin noise and designing methods of protecting against sonic metal fatigue in aircraft structures. Such research is conducted in facilities like this Douglas Aircraft anechoic chamber, where engineers use a full-scale pressurized section of a DC-9 fuselage to study structural sound transmission under conditions as close as possible to actual cruise flight.

on a McDonnell Douglas MD-80 twinjet. The company's schedule calls for engine certification by the end of 1990 and availability for service in 1991-92.

A new propfan program, a direct offshoot of NASA propfan technology, was launched in 1986 when Allison Gas Turbine Division and Pratt & Whitney Division of United Technologies began a joint venture to pursue commercial—and possibly military—applications of the propfan. The development team includes, in addition to Allison, two other members of the NASA PTA industry group: Hamilton Standard (propfan) and Rohr Industries (nacelle).

The team built a demonstrator engine known as the Model 578-DX, a 10,000 horsepower system in which an Allison turbine drives a counter-rotating pusher propfan of two six-bladed rotors. Wind tunnel tests started in 1986 and continued into 1987. The team has signed an agreement with McDonnell Douglas for flight tests on a modified MD-80 beginning in December 1987. In addition, the group is defining a production-type propfan for projected airliners of the 1990s. Targeted for a fuel consumption rate 30 percent better than the best similarly sized turbofans that will be available in the same time frame, the advanced engine will have a bypass ratio of 50-60 to one. It is expected to be ready for operational use in 1991-92.

The propfan may ultimately be applied to a wide range of airline and military transports, including retrofit installations in aircraft already in service. For now, however, developmental emphasis is on propulsion systems for medium-size airliners being designed for service introduction early in the next decade. The reason: analysts expect that airliners in the 100-180 seat bracket, and in particular the 150-seat category, will constitute the greatest market at that time, due to projected traffic increases and the necessity for retiring more than 3,000 aircraft of that type beginning about 1990.

Boeing Commercial Airplane Company is designing an all-new, 150-seat propfan airliner tentatively designated 7J7. Boeing is aiming for a fuel efficiency rating 60 better than the most efficient turbofan-powered jetliners now flying. That 60 percent is compounded of a number of technological advances in addition to propulsion, such as extralight structural materials, a new high lift/low drag wing and a highly advanced flight control system. Target date for airline operation of the 7J7 is 1992.

McDonnell Douglas Corporation's Douglas Aircraft Company is considering an all-new twin propfan; designated MD-94X, it would be a 160-180 seater available in 1994. Douglas is also planning to offer propfan retrofitting of its MD-80 series now in wide airline service, and additionally is designing two propfan-powered MD-80 derivatives: the 100-110 seat MD-91X that could be in production by 1991 and the 150-seat MD-92X, planned for service beginning in 1992.

A lot of development work remains to realize the dramatic potential fuel economies and to solve problems associated with supersonic fan blade tip rotation. But barring other, unforeseen problems, the propfan airliner could be carrying passengers within five years. ▲

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Projected propfan airlines of the 1990s: above, the McDonnel Douglas MD-94X and, at right, the Boeing 7J7.

High Performance Aircraft

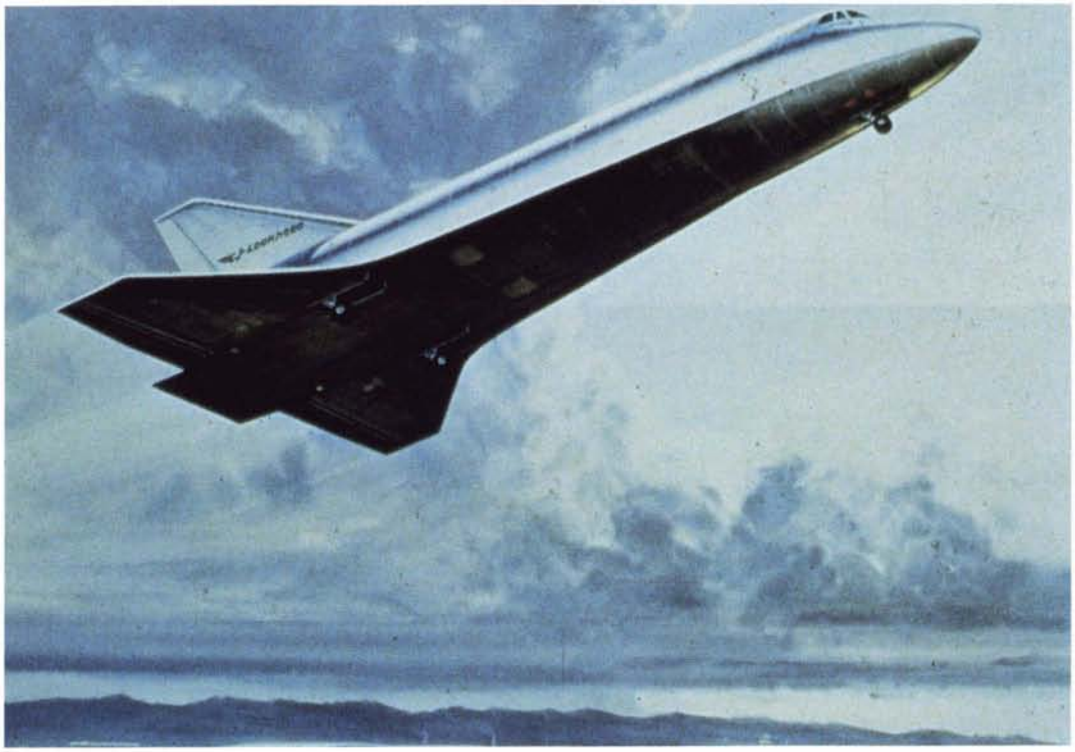
Shown above is the X-29A advanced technology demonstrator being test flown at Ames-Dryden Flight Test Facility. The craft was built by Grumman Aerospace Corporation for a program sponsored by DARPA with NASA and Air Force support. A unique research airplane rather than a prototype fighter aircraft, the X-29A features a thin, forward-swept supercritical wing made of composite materials. Among several other aerodynamic advances incorporated in the demonstrator are a digital control system; flaperons that combine the functions of flaps and ailerons; and forward "canard" wings intended to increase the airplane's agility. At transonic speeds, the forward-swept composite wing offers weight and drag reductions of as much as 20 percent in comparison with the conventional aft-swept metal wing. The flight test program is designed to validate the concept that aircraft can be built smaller, lighter and more efficient for a given mission by integrating the foreswept wing with the other advances in the X-29A.

Another project at Ames-Dryden is flight test of the AFTI (Advanced Fighter Technology Integration) F-111 (above), a NASA/Air Force program that involves investigation of the military potential of the variable camber wing, one whose camber—the fore to aft curve of the airfoil—can be changed in flight. Such a

wing is known as a Mission Adaptive Wing (MAW); it automatically reconfigures, altering its lift characteristics to permit maximum aerodynamic efficiency over the entire flight range.

Built by Boeing Military Airplane Company under Air Force contract, the AFTI/F-111 MAW system changes its shape in flight by means of computer-controlled hydraulic actuators that move a series of smooth-surfaced flaps on the wing's leading and trailing edges. Fully developed, the MAW system could lead to a military aircraft with an automatic flight control system offering several modes of control, providing the wing its optimum shape for a particular flight condition—for example, approach and landing, cruise, maneuvering and maximum speed operation. Equipped with variable sweepback as well as variable camber, the AFTI/F-111 is being tested at subsonic, transonic and supersonic speeds in a variety of simulated combat scenarios. NASA's role, in addition to Ames-Dryden's flight test responsibility, includes wind tunnel studies by Langley Research Center. ▲

Aerospace Plane



The National Aerospace Plane (NASP) is a joint Department of Defense/NASA program to develop and demonstrate the technologies for a revolutionary class of aerospace vehicles, powered by airbreathing "scramjet" engines, that would have the capability to take off and land horizontally on standard runways like a conventional airplane, cruise in the upper atmosphere at hypersonic speed, or fly directly into low Earth orbit. At upper right is one contractor's concept of such a craft.

Successful development of the essential NASP technologies could lead to military or civil single stage runway-to-orbit spaceplanes capable of rapid access to orbit and airplane-like flexibility. Because they would not require the extensive facilities and lengthy countdown operations needed in vertical space launches, such craft promise dramatically lower costs of delivering payloads to orbit. They could be in operational service around the end of the century. The same general "transatmospheric" technology could be applied to hypersonic civil transports that could fly from the United States to Japan in two hours, the "Orient Express" projected by President Reagan.

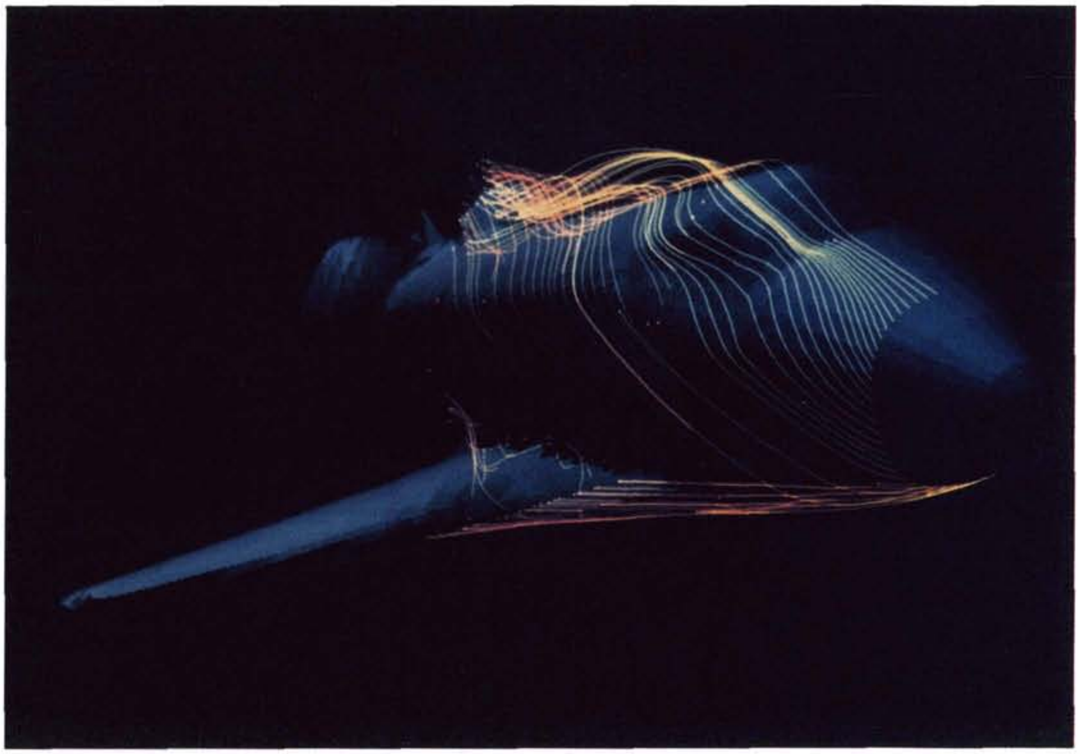
The Air Force is executive agency for the NASP program. Other Department of Defense participants include the Defense Advanced Research Projects Agency (DARPA), the Navy and the Strategic Defense Initiative Organization. A Joint Project Office for NASP has been established at Wright-Patterson Air Force Base, Dayton, Ohio, staffed by personnel from each participating agency.

The current phase of the NASP effort, which began in 1986 and will continue through 1989, involves accelerated development of key technologies in propulsion, aerodynamics, computational fluid dynamics, advanced structures and high temperature materials.

In April 1986, contracts were awarded to General Electric Company and Pratt & Whitney Division of United Technologies for design and development of scramjet propulsion modules and ground testing of their systems up to Mach 8. Simultaneously, five companies—The Boeing Company, General Dynamics Corporation, Lockheed Corporation, McDonnell Douglas Corporation and Rockwell International—were awarded airframe design contracts; the group is to be narrowed in 1987 to two or three contractors, who will fabricate certain critical components and develop preliminary designs for a NASP flight demonstrator vehicle. Final selection of propulsion/airframe contractors for building the flight vehicle is expected in late 1989. The NASP demonstrator would be ready for flight testing in 1992-95.

In a separate effort, NASA awarded parallel study contracts to Boeing Commercial Airplane Company and McDonnell Douglas to survey NASP and other technologies that might be useful in development of future high speed civil aircraft and provide NASA information to guide technology development. The companies will study the economics, size, speed, range and fuel type of possible hypersonic or advanced supersonic cruise transports. ▲

Computer Design Facility



Located at Ames Research Center, NASA's Numerical Aerodynamic Simulation (NAS) Facility is a supercomputer system being developed in building block fashion toward an eventual capability of 10 billion calculations a second. It is intended principally for "computational simulation" in aerospace research and development but it will also permit advances in other areas, such as non-aerospace structural design, materials research, chemistry and weather.

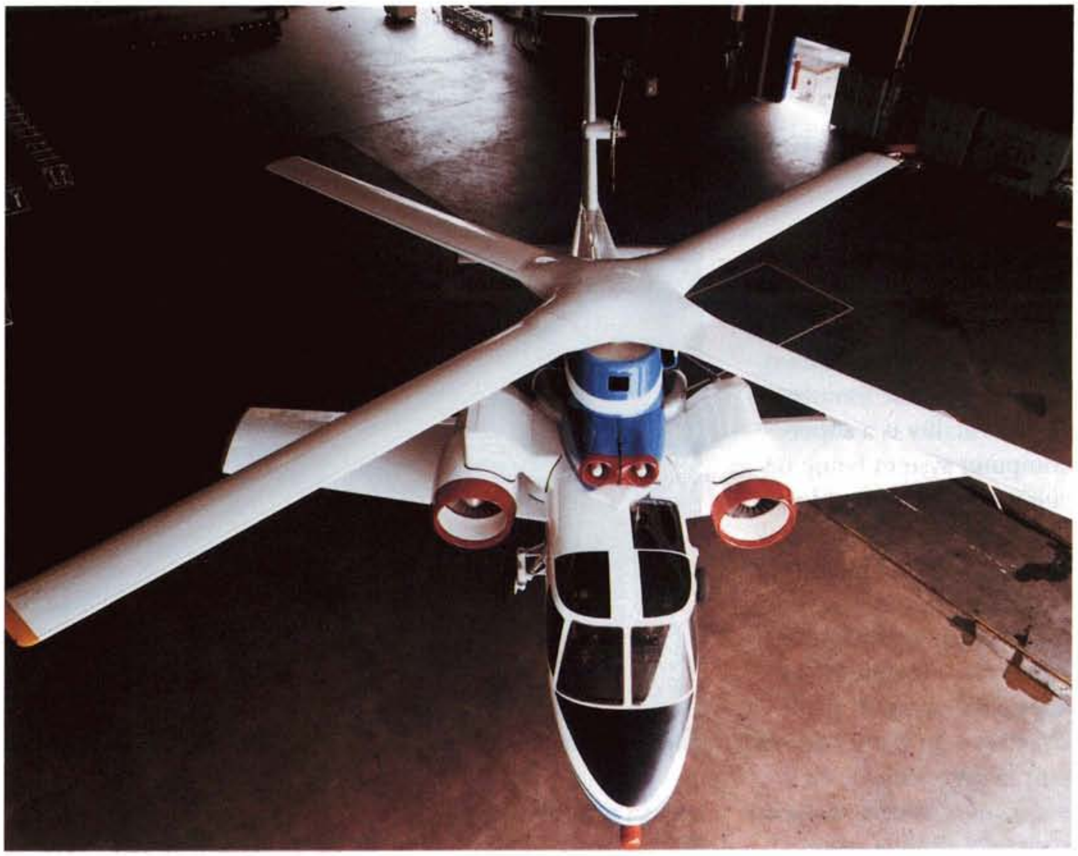
In aeronautics, researchers create mathematical models of flight vehicles and "fly" them by computer simulation; this permits study of the performance and behavior of many different designs before settling on a final configuration. This technique of computational simulation has expanded enormously in recent years to embrace calculation and visual imagery (right above) of many types of forces acting upon a flight vehicle, including phenomena that cannot be realistically simulated in wind tunnels.

NAS is an evolutionary effort to permit realization of a major goal in aeronautical science: the ability to simulate routinely the complex three-dimensional airflow around a complete airplane and its propulsion system. Such a capability will allow solution of many previously intractable problems and make possible many of the calculations required to develop advanced aircraft with greater accuracy and reliability. NAS will not only improve the design process, providing cost savings and aircraft performance gains, it will also reduce the long and expensive wind tunnel and flight testing essential to validation of a design.

The key to attainment of the goal is far greater computer capability than has been available. The NASA plan is to incorporate the latest supercomputing technology as it becomes available, so that NAS will serve as a pathfinder in supercomputing for government, industry and universities. The first building block, a Cray 2 system known as the High Speed Processor-1 (HPS-1), went into service at Ames early in 1986; the fastest supercomputer then operating, it has a 256 million word memory and can perform 250 million calculations a second. In 1987 an even more advanced HPS-2 will boost the NAS computational capability to one billion calculations a second. By 1990, NAS hopes to reach the near-term goal: a NAS memory of one billion words and power for four billion calculations a second. The long-term goal of 10 billion calculations is targeted for a decade hence.

NAS offers scientists and engineers throughout the nation direct access to the world's most powerful computer system via their own personal computers. For example, a scientist a thousand miles from Ames can run complex programs using the full capability of NAS, which is connected to remote locations across the country by high-speed terrestrial and satellite links. NAS went on line to some 150 scientists and engineers from NASA, the Department of Defense, universities and industry in July 1986; the number able to use the system has since doubled. ▲

X-wing Research



Shown in the accompanying photo is the X-wing Rotor Systems Research Aircraft (RSRA), a heavily-instrumented experimental vehicle designed to test a flight concept that combines the vertical lift advantages of the helicopter with the faster forward speed of the fixed wing airplane. Managed by Ames Research Center, the X-wing program is a joint effort of NASA and the Defense Advanced Research Projects Agency.

The test vehicle is a specially modified version of the RSRA, two of which have been operating since 1978 as "flying wind tunnels" for investigations of promising rotorcraft concepts with future commercial or military potential. The X-wing's rotor, made of composite material, has four extremely stiff blades that can be stopped in flight to become fixed wing airfoils. For takeoff, hovering and low speed forward flight, the rotor operates in the spinning mode as a helicopter rotary wing. At a speed of about 215 miles per hour, the rotor is stopped and locked in place, becoming, in effect, two wings—one pair of blades swept forward at an angle of 45 degrees, the other pair swept rearward at the same angle. With the X-wing providing fixed wing lift and two General Electric TF34 jet engines providing 9,725 pounds of thrust, the craft can attain forward speeds of more than 600 miles per hour.

The goal of the flight test program is to demonstrate conversion—stop-ping the rotor, then restarting it—between rotary wing flight and fixed wing flight. The experimental rotor will not permit hovering or speeds exceeding 288 miles per hour (250 knots), the limit of the RSRA flight envelope. A future operational prototype X-wing would be capable of speeds approaching 500 knots in the fixed wing mode and economical hovering in the rotary wing mode.

Flights in the helicopter mode are scheduled for late 1987 and conversion flights will begin in 1988.

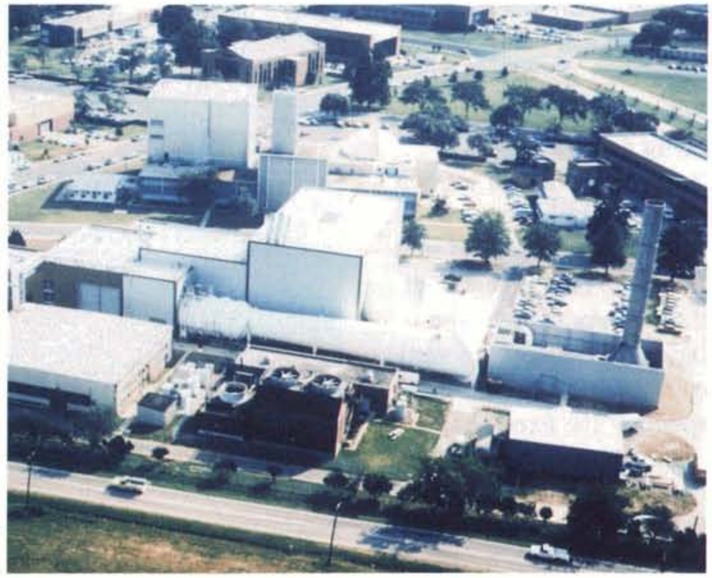
The X-wing concept is considered to have potential for future commercial service—perhaps around the turn of the century—as a short-haul transport. In military service, it has applications in tactical operations, electronic intelligence, antisubmarine warfare and search and rescue. ▲

Tilt Rotor Research

More than a decade old and still contributing flight data, the XV-15 Tilt Rotor Research Aircraft is being flown by Ames Research Center to support military development of tactical tilt rotor craft and studies of the civil potential of the concept, which combines the helicopter's vertical lift flexibility with the speed of the fixed wing airplane. Built by Bell Helicopter Textron, the XV-15 has helicopter-like rotors for vertical takeoff, hovering and landing (above); for more efficient high-speed cruise flight (right), the rotors tilt forward to become propellers. Ames is operating one of the two XV-15s built for a joint NASA/Army research test program; the manufacturer is operating the other as a demonstrator.

The highly successful XV-15 flight test program led to a decision by the Department of Defense (DoD) to design and develop a larger, more advanced tilt rotor craft known as the V-22 Osprey. Now in full scale development by Bell Helicopter Textron and Boeing Vertol Company, the Osprey is slated for first flight in 1988. DoD plans large scale production of the V-22 in the 1990s and its use, for several different missions, by the Marine Corps, Navy, Air Force and Army.

In 1985-87, NASA participated in a study program—with DoD, the Federal Aviation Administration, Bell Helicopter, Boeing Vertol and Boeing Commercial Airplane Company—to identify potential civil benefits of further U.S. tilt rotor development. The study centered on the V-22 and included analysis of civil missions, estimates of the civil market, possible technology spinoffs and the impact on the defense industrial base of advanced tilt rotor development and production. The contractor team produced "first look" designs for civil tilt rotor aircraft ranging in capacity from 10 to 75 passengers, solicited inputs from potential users and evaluated market potential. Among possible tilt rotor applications identified were commuter service, emergency medical service and executive transport. Detailed results of the study were to be presented at a mid-1987 forum. ▲



Ames Research Center's 40 × 80 Foot Wind Tunnel is 43 years old but it is beginning a new life—after extensive reconstruction—as a major element of the National Full-scale Aerodynamics Complex (NFAC). Used since World War II for low speed testing of civil and military aircraft, the "40 × 80", as it was formerly known, is large enough to test full-scale airplanes and therefore plays a special role in aircraft development, because full-scale testing usually produces the most accurate results. But the size of modern aircraft and other developments dictated a need for a more comprehensive full-scale research facility. Thus, the old 40 × 80 was converted to the NFAC complex of two test sections, each capable of handling full-scale aircraft with their engines running.

The modified facility (above) includes a redesigned 40 × 80 segment plus a new 80 × 120 foot test section, both sharing a common drive system of six 22,500 horsepower electric motors, almost four times the original power for blowing air through the test sections. The new drive system boosts the top test speed from 230 to 345 miles per hour.

In August 1986, Ames completed the first phase of the NFAC project with the opening of the 40 × 80-foot closed loop segment. It features a number of improvements, among them an acoustic liner to reduce noise and aid helicopter testing, better airflow characteristics, an upgraded data acquisition system and a new air exchanger that allows the tunnel to operate for longer periods.

The second phase, due for completion in the latter part of 1987, involves addition of a 600 foot long structure housing the 80 × 120 foot test section. This segment is a "straight through" tunnel as opposed to the closed loop 40 × 80. It will receive air through a huge intake 360 feet wide and 130 feet high. Traveling at up to 115 miles per hour, the air will pass through the test section, the tunnel drive section, and be vented to the outside through vanes in a wall of the facility. Since they share a common drive, the two tunnels cannot be operated simultaneously; however, engineers can set up experiments in either tunnel while the other is running.

The NFAC is an example of one of the newer NASA research facilities. This extensive complex of installations constitutes an integral component of the agency's aeronautical research and technology program, a national asset available to industry contractors and other government agencies in the interests of maintaining U.S. leadership in aircraft development. Among other recently activated installations are the National Aerodynamic Simulation Facility

(see page 37) and the National Transonic Facility (NTF).

Located at Langley Research Center, the latter facility (left) represents a significant advance in wind tunnel research capability. As its name indicates, it operates in the transonic speed range, just below and just above the speed of sound, an area of particular importance in designing both commercial transports and military aircraft. It is also an area of special complexity because an airplane's approach to the speed of sound creates airflow patterns very different from those encountered at lower speed: thus the differences between tunnel conditions and free flight conditions are greater and, in the past, it has been very difficult to correlate test results.

In the NTF, a huge fan compressor (above) blows supercooled nitrogen—instead of air—through the tunnel test section (right), simulating flight speeds up to 850 miles per hour. The nitrogen vaporizes into a gas that is much denser and more viscous than air; that offsets scaling inaccuracies due to the use of relatively small models, typically

spanning three to five feet.

The facility also operates at several times the outside atmospheric pressure. These factors and other NTF advancements make it possible to correlate more closely the results of tunnel testing small models and the flow patterns that actually occur as the full scale airplane flies through the air at transonic speed. The correlation factor is called the Reynolds Number; it ties together velocity, air density, air viscosity and model size. The higher the Reynolds number, the better the comparison between wind tunnel values and actual flight. The NTF's greatly improved approximation of the real flight environment permits attainment of the highest Reynolds Numbers ever recorded in ground facilities at transonic speeds. ▲

Commercial Use Of Space

NASA seeks to stimulate interest and investment in space-related ventures to assure U.S. leadership in the promising new field of space/commercial activity

In 1911, Dutch physicist Heike Onnes discovered that the electrical resistance of a metal vanished when the metal was cooled. Later research established that this phenomenon—called superconductivity—occurred in a variety of materials, but only when they were cooled to extremely low temperatures, near absolute zero.

For three quarters of a century, scientists have sought to increase the temperature at which superconductivity occurs, because that could make possible applications of resistance-free electricity long contemplated but impractical in light of the cooling requirement. An example is a supercomputer with speed and capacity several orders of magnitude beyond today's best computing systems; scientists in the U.S., Japan, Europe and China have been vigorously investigating this possible application of superconductors for its enormous economic/trade potential. Among other examples are frictionless, superspeed trains, "levitated" by magnetic force; generators and transmission lines that suffer no power loss through resistance; and supermagnets that could significantly advance the promising medical diagnostic technique of magnetic resonance imaging. The range of potential applications is too broad to catalog, but there is general agreement that the ability to transport electrical current with no resistance on a practical basis would engender profound technological and sociological change throughout the world.

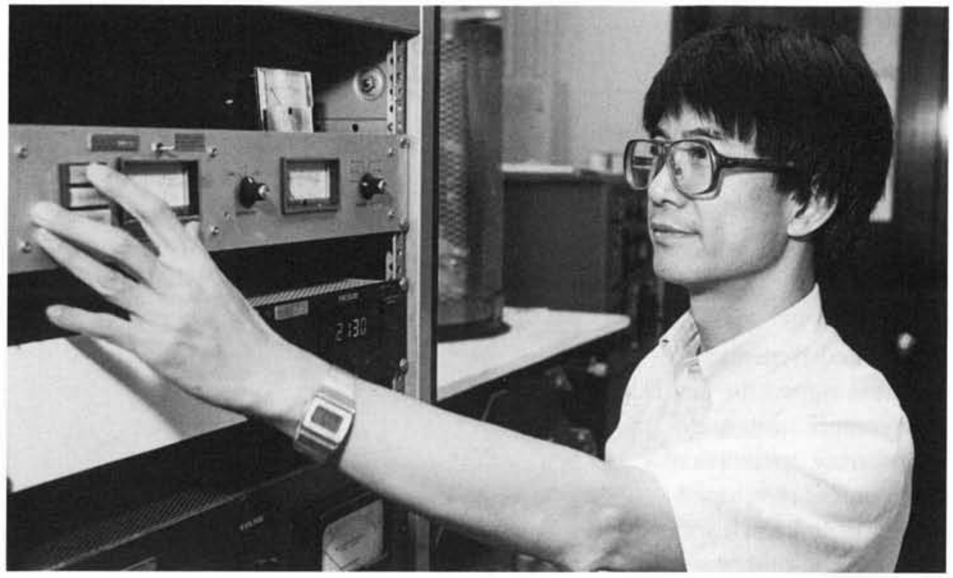
In February 1987, the National Science Foundation (NSF) announced that two teams of physicists, one headed by Dr. Paul C. W. Chu of the University of Houston, the other by Dr. M. K. Wu of the University of Alabama-Huntsville, had achieved superconductivity at 98 degrees Kelvin (minus 283 degrees Fahrenheit). This was described as a breakthrough, since it was the highest temperature ever attained and represented a level more than 20 degrees higher (on the Kelvin scale) than the scientific world had long considered a threshold target for widescale practical use of superconductivity. In addition, Dr. Chu's team discovered that the temperature at which superconductivity occurs increases dramatically with pressure; because there are many ways of mimicking pressure, this offers a host of new approaches to temperature increase. Finally, the Houston/Huntsville teams used liquid nitrogen as the refrigerant instead of liquid helium, formerly the only coolant that could be used; cheaper and more effective, liquid nitrogen's utility as a coolant further increases the potential for practical applications.

The superconductivity research at Houston and Huntsville exemplifies the type of work supported by NASA's Centers for Commercial Development of Space (CCDS). Dr. Chu is director of the University of Houston CCDS and his team's superconductivity research was funded in part by CCDS money and by discretionary funding provided by NASA's Marshall Space Flight Center, in addition to grants from NSF and the University of Houston. The work by Dr. Wu and others at the University of Alabama-Huntsville was partially supported by NASA funding (CCDS and Marshall Space Flight Center).

The Centers for the Commercial Development of Space program is a NASA endeavor launched in 1985 to stimulate interest and expand private investment in commercial space activities, because such activities offer high potential for benefit to the U.S. economy. The CCDS effort seeks to encourage space-related research in such areas as microgravity processing of materials toward development of new products and processes; land and ocean remote sensing; advanced space-based communications systems; and terrestrial processes that might be enhanced through orbital research or whose advancement—as is the case in superconductivity—might in turn advance the U.S. space capability.

The Centers are not-for-profit joint undertakings composed of academic institutions, industrial firms and government organizations. NASA provides initial funding for the Centers; after approximately five years they are expected to be self-sustaining. Each Center concentrates on particular areas of research, although there are inevitably areas of overlap; each works closely with NASA field centers in developing and executing research programs. In the summer of 1987, there were nine Centers operating and NASA was evaluating proposals for establishment of additional Centers. The operating Centers, and their areas of focus, are:

- Batelle Columbus (Ohio) Laboratories, materials processing research in metals and alloys, glass and ceramics, polymers, electronic and optical materials.
- The Institute for Technology Development, Jackson, Mississippi, remote sensing technology.
- Consortium for Materials Development in Space, University of Alabama-Huntsville, commercial materials, including experiments in orbit; commercial applications of physical chemistry and material transport.
- Center for Macromolecular Crystallography, University of Alabama-Birmingham, space grown crystals for pharmaceutical, biotechnology and chemical applications.
- Center for Space Processing of Engineering Materials, Vanderbilt (Tennessee) University, space processing of metals, alloys, and composite materials.



- Center for Development of Crystal Growth in Space, Clarkson (New York) University, broad spectrum of crystal growth techniques.
- Center for Space Vacuum Expitaxy, University of Houston-University Park, semiconductor materials and devices, metallic materials and devices.
- Center for Space Automation & Robotics, University of Wisconsin-Madison, robotic systems to replace many astronaut functions, development of an automated greenhouse for space food supply
- Center for Real-time Satellite Mapping, Ohio State University, collection, conversion and distribution of remotely sensed geographic data.

The CCDS program is part of a broader NASA effort to encourage and facilitate commercial use of space. NASA provides technical assistance to companies interested in pursuing commercial space ventures and offers reduced rate space transportation for some high technology endeavors. NASA also conducts workshops and seminars that bring together government, industry and academic researchers and other interests, such as the investment banking and insurance communities. NASA's aim is to expand private sector involvement in space activities, the key to exploiting space for Earth benefit. ▲

Representative of a group of top level scientists who are providing research support for NASA's effort to expand private investment in space is Dr. Paul C. W. Chu of the University of Houston. An internationally-acclaimed leader in the field of superconductivity research, Dr. Chu is director of Houston's Center for Space Vacuum Epitaxy, one of a number of facilities in the NASA-sponsored Centers for the Commercial Development of Space program. The program is a joint academic/industry/government effort to encourage research toward realization of the commercial potential of space.

Launch Systems

In April 1987, NASA and General Dynamics Corporation signed the first U.S. government agreement transferring operation of a government-developed expendable launch vehicle (ELV) to the private sector, in line with a government policy of supporting efforts by U.S. companies to develop commercial launch capabilities competitive to those of Europe, Japan, China and the Soviet Union.

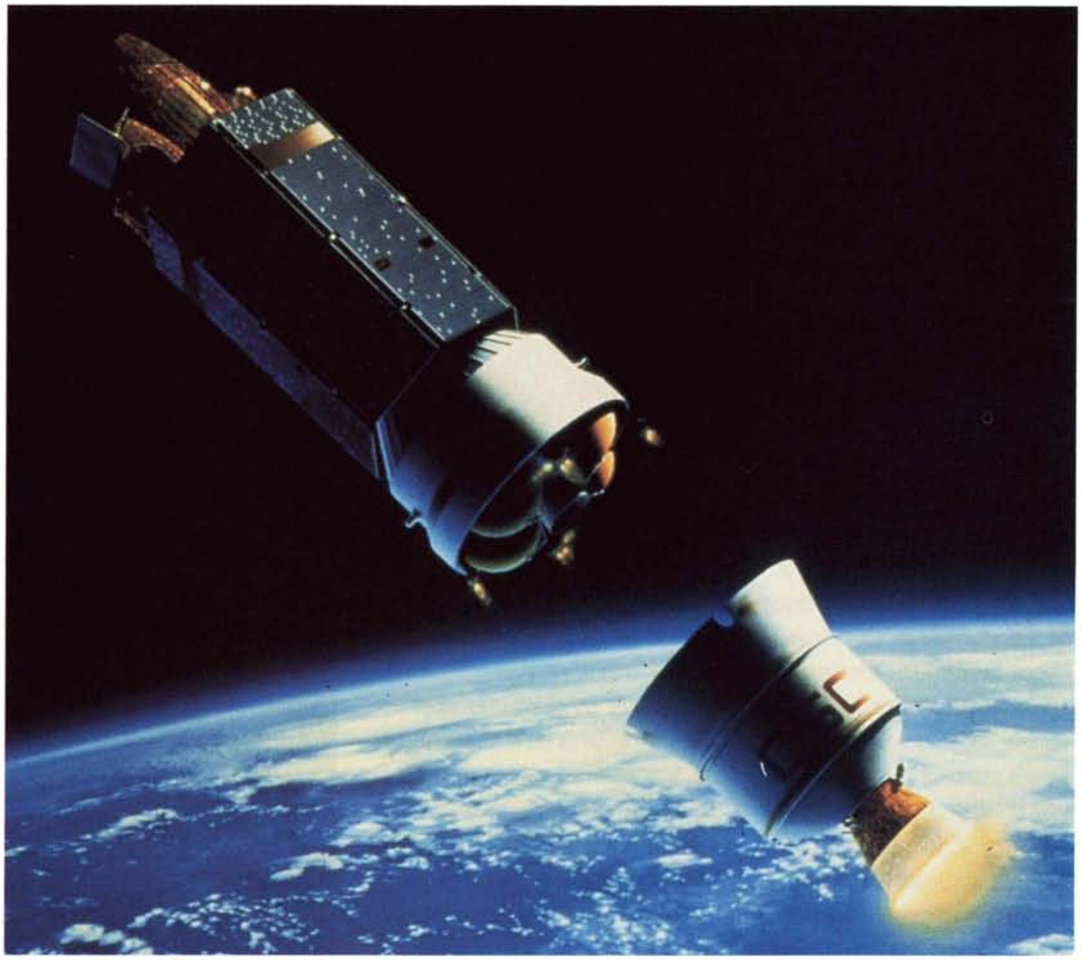
The agreement is with General Dynamics Corporation for the Atlas/Centaur vehicle (right), which has launched 65 payloads since 1962 with a success rate of approximately 95 percent; it transfers to General Dynamics authority to use NASA-controlled facilities and capabilities for commercial manufacture and launch of Atlas/Centaur.

Subsequently, General Dynamics announced plans to start construction in 1987 of 18 commercial Atlas G/Centaurs and to introduce the vehicle to flight service in 1989; it can deliver a 5,200 pound payload to geostationary orbit, the 22,300-mile-high orbit where most commercial satellites operate. The company is planning development of an advanced version that can send 6,650 pounds to geostationary orbit.

NASA has also signed an agreement with Space Services, Inc. (SSI) whereby the company will conduct commercial launch operations of its privately-developed Conestoga ELV from Wallops Flight Facility, NASA's Virginia research rocket launching site. Under the agreement, SSI will be responsible for preparation and launching of the vehicles, and NASA will participate in an observer capacity and be responsible for control, safety and operation of the test range. SSI will reimburse the government for NASA-provided support services.

SSI conducted a successful suborbital flight test of the solid fuel Conestoga in 1982 and has since developed a more advanced ELV called Conestoga II, which can send a 500-pound payload to geostationary orbit or up to 3,000 pounds into low Earth orbit.

In May 1987, SSI announced receipt of its first contract for launch services. The company will use Conestoga II to orbit a series of five navigation satellites intended for use by commercial customers. The satellites are being privately developed by Star Find Inc., Laguna Niguel, California. Target for the initial launch is late 1988.



Another NASA/industry cooperative agreement involves development of an upper stage propulsion system known as TOS®, for Transfer Orbit Stage (right). Capable of being used as a space transfer vehicle in conjunction with the Space Shuttle or the Titan III/IV family of ELVs, TOS is being developed—with private capital—by Orbital Sciences Corporation (OSC), a relatively new (1982) entrepreneurial company engaged in commercial development of space systems. TOS was selected by NASA as the upper stage vehicle to boost the Mars Observer spacecraft into interplanetary trajectory after its deployment from the Space Shuttle in 1992.

In development since 1983, TOS is being built by Martin Marietta Denver Aerospace, prime contractor to OSC. Powered by a solid propellant motor, TOS is being developed under a design philosophy that combines extensive use of space-qualified hardware with selective application of new technologies. OSC completed the TOS research and development phase in the summer of 1987 and began hardware fabrication. ▲

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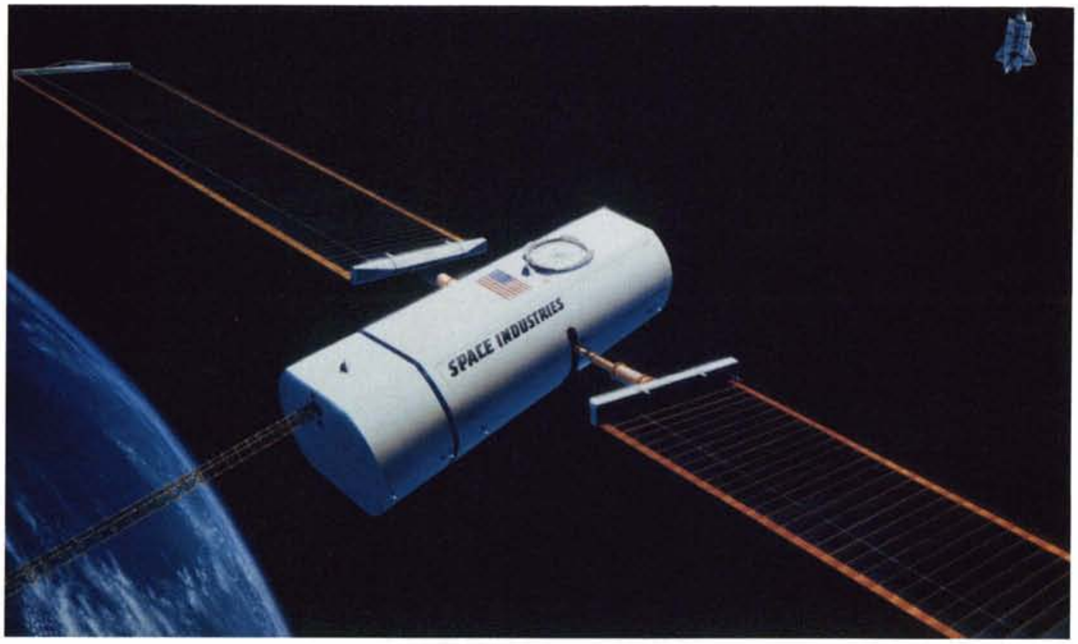
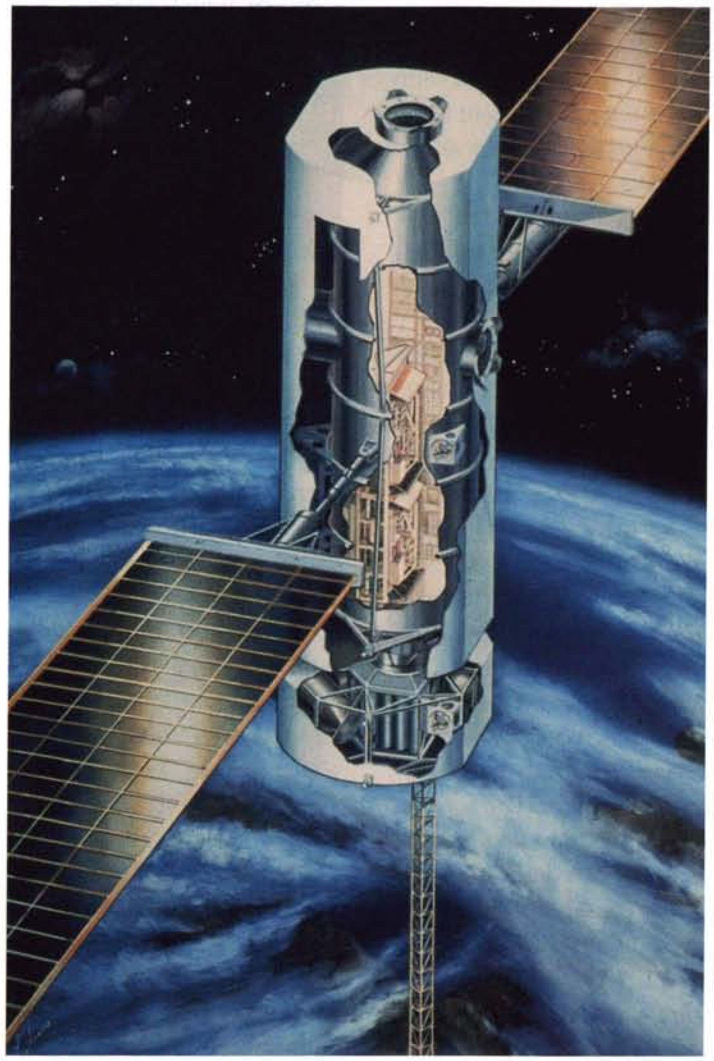
Orbital Systems



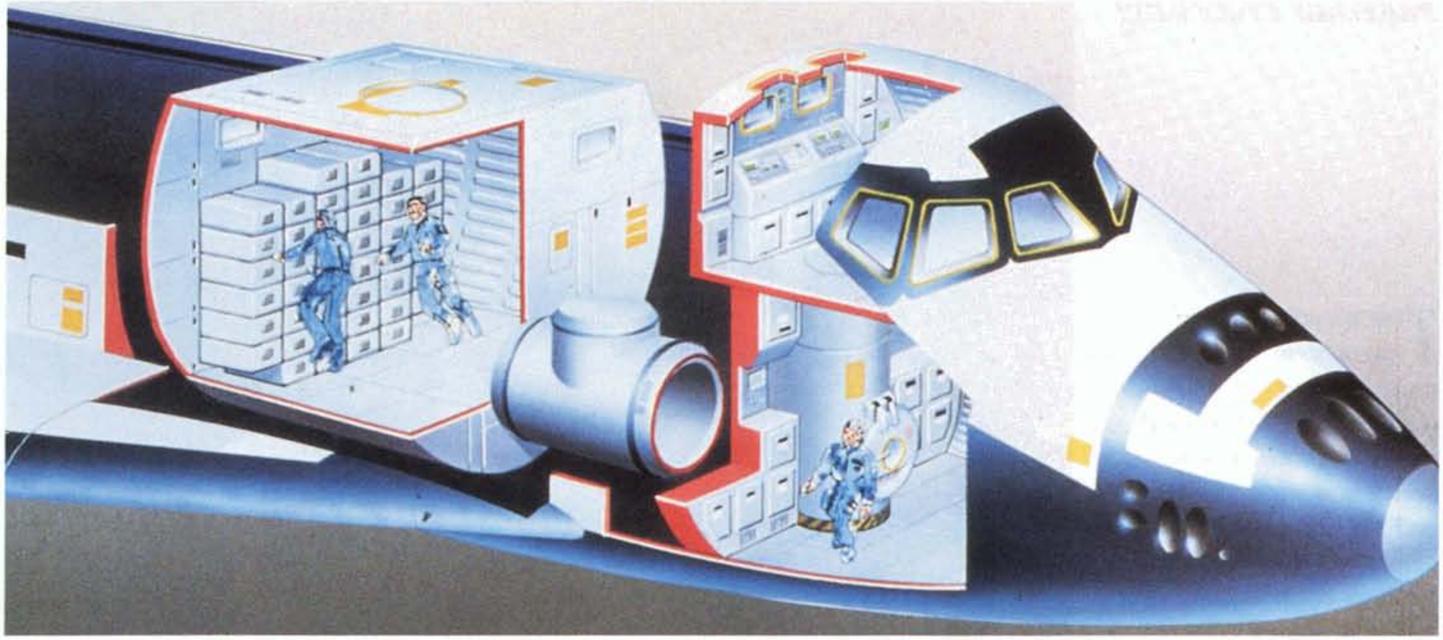
At right is an artist's conception of a Space Shuttle-serviced, free-flying, man-tended Industrial Space Facility (ISF), an orbital station for materials processing experiments or space manufacturing, alternatively for use as a scientific laboratory, as a technology development facility for testing new space equipment and procedures, or as a warehouse/ headquarters for orbital construction projects.

The ISF is a privately-funded venture of the Space Industries Partnership which includes Space Industries, Inc., program manager, and WESPACE Inc., a subsidiary of Westinghouse Electric Corporation, prime contractor. Lockheed Missiles & Space Company is a subcontractor for the 28 kilowatt power system, composed of two flexible solar array wings, each 105 feet long, covered with almost 30,000 solar cells. The Boeing Company is subcontractor for the ISF module.

Shown in cutaway view (center right), the ISF consists of a main Facility Module and a smaller, separable Supply Module. The Facility Module is 35 feet long and 14½ feet in diameter and has a pressurized volume of 2,500 cubic feet. Capable of accommodating 12,000 pounds of payload, the module is being designed to operate for long periods on an unmanned automated basis, with periodic resupply and servicing visits by Space Shuttle crews.



The Supply Modules contain oxygen for pressurization, raw materials for experiments or manufacturing, other consumables and replacement hardware when needed; the same diameter as the Facility Module but only six to 11 feet long, they will be exchanged at intervals by Shuttle astronauts. The servicing crews will be able to work in shirtsleeves in the pressurized area for the two or three days it might take for repairs or adjustments, equipment changeouts, cleaning/restocking production hardware and product harvesting. The ISF's ample power system can supply electricity to the Shuttle Orbiter for

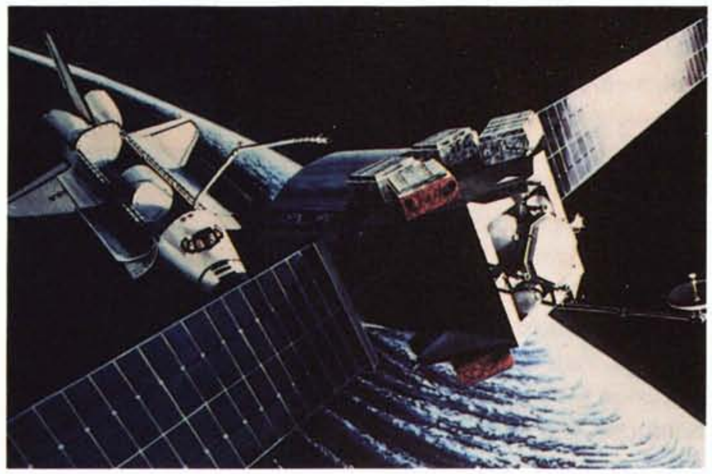


the period it is docked to the ISF. Intended for service in the early 1990s, the ISF will operate in the same orbit as the NASA/international Space Station and may be modified to dock with the station.

Another type of commercial system designed to work in conjunction with the Space Shuttle is Spacehab (above), a human-habitable module intended to provide additional pressurized living, working and storage space aboard the Shuttle Orbiter. Being developed by Spacehab, Inc., Spacehab is a 10 by 13 foot cylindrical module with 1,000 cubic feet of pressurized volume. It is designed to serve as an augmentation to the Orbiter's middeck; it fits into the Orbiter's payload bay and connects to the crew compartment. The modules are intended for use by government or commercial customers engaged in research and technology development that requires human-directed experimentation in orbit.

A concept under consideration for development by General Electric Company is a spacecraft designed to allow commercial customers to conduct materials processing or other types of orbital research/manufacturing operations and bring the payload back to Earth without need for Shuttle retrieval. Called SERVICE (Space Entry Recovery Vehicle in Commercial Environments), it is a reusable, free-flying, unmanned spacecraft capable of controlled reentry and accurate soft landing on Earth. The design draws upon GE reentry technology demonstrated in more than 500 successful recoveries of space payloads.

Fairchild Space Operations Company has designed an unmanned platform called Leasecraft (above),

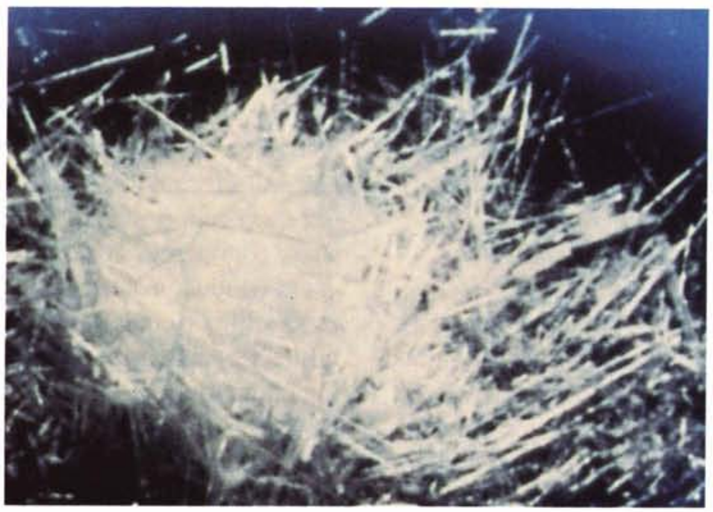


but development is on hold pending further definition of the market. Intended for lease to scientific, commercial and government users the platform would be Shuttle-delivered to low Earth orbit and periodically serviced by Shuttle crews. ▲

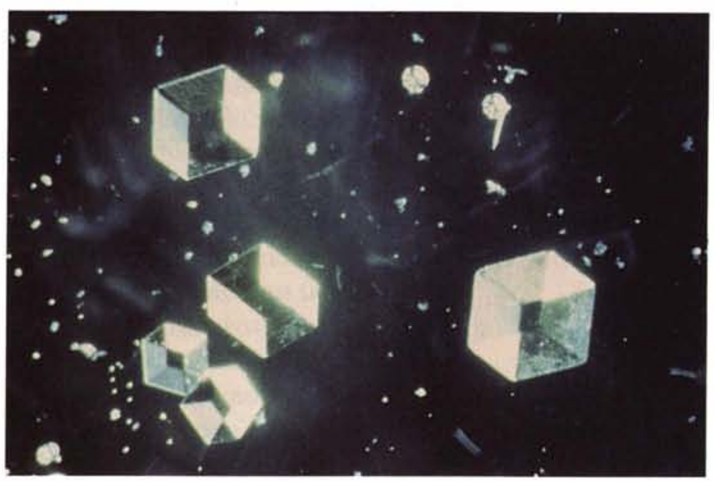
Materials Processing

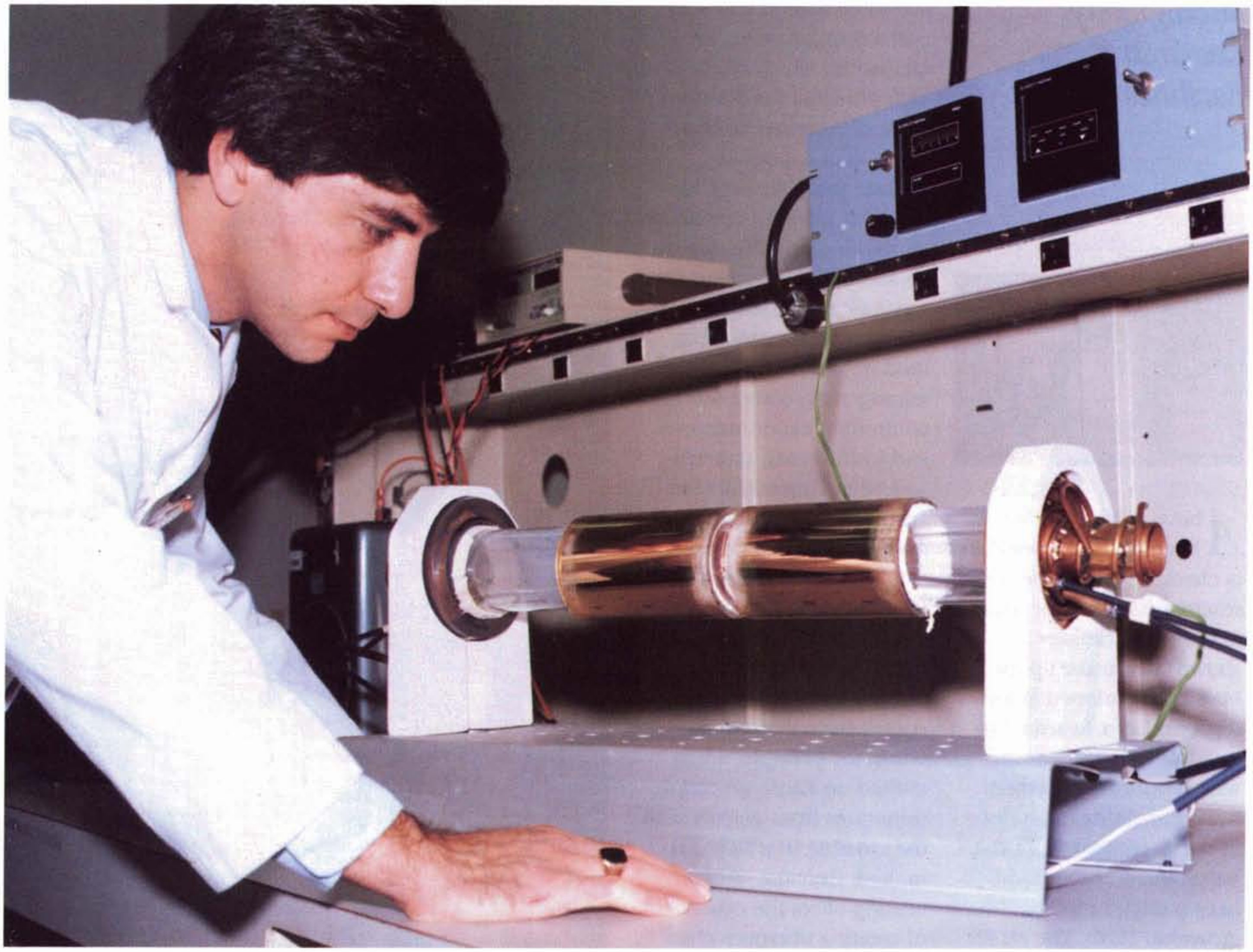
The broadest government/industry agreement yet concluded for cooperative Shuttle-based materials processing research was signed by NASA and 3M Company in December 1986. It provides for 62 flight opportunities, over a 10-year span, for 3M experiments in organic and polymer science, areas in which 3M specializes and which constitute the basis for much of the company's product line.

3M Company is already a veteran of microgravity materials processing, having flown experiments on three Shuttle flights in 1984-85. The first, called DMOS, for Diffusion Mixing of Organic Solutions, was a study of space grown organic crystals such as those shown pictured on this page; crystals like these can be grown larger and more nearly flawless in microgravity than they can be grown on Earth, hence have potential for many important applications. In 1985, 3M conducted a second DMOS experiment and another called PVTOS, for Physical Vapor Transport of Organic Solids. As part of an earlier 3M/NASA agreement, a second PVTOS experiment will be flown when the Space Shuttle resumes operations.



Under the new agreement, the 62 flight experiment opportunities will be divided into two categories: Level I investigations, which will involve basic research in organic and polymer science, and Level II experiments building on Level I experience and oriented toward commercial applications. The 62 experiments are to be carried as secondary payloads, some in Shuttle Orbiter middeck lockers, most in cylindrical canisters in the Orbiter's payload bay.





The 3M/NASA program is one of a score of cooperative NASA/industry agreements for ground-based and space-based experiments in materials processing. A representative example is Boeing Aerospace Company's program for growing large, defect-free crystals that could provide significant advancements in semiconductor and optical system technology. Boeing's experiments to be flown aboard the Shuttle involve manned operation of a chemical vapor transport furnace for forming superior crystals by vaporizing a material, combining it with a second vapor and cooling/solidifying the compound.

Boeing expects to fly three separate furnaces on each of three Shuttle flights. In the photo above, a Boeing scientist is working with a ground laboratory version of a chemical vapor transport furnace. The flight versions will be somewhat different; they will be encased and will have a water cooling system and a mounted camera. Under the agreement with NASA, Boeing will provide the furnaces and other equipment, fund the experiments and process some NASA samples on each flight; NASA will integrate the experiment packages into the Space Shuttle Orbiter, provide some equipment and make available space for the furnaces and crew support for operating them. ▲

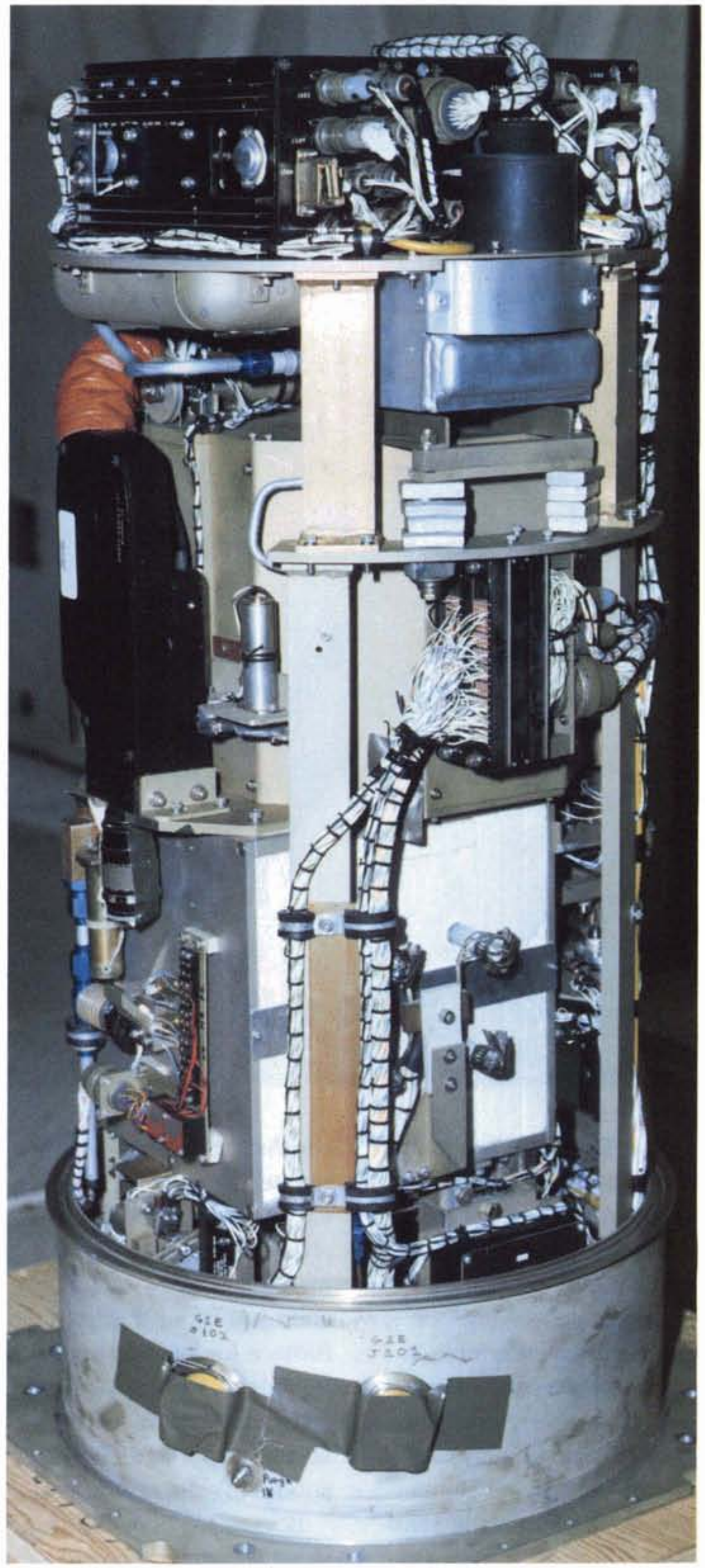
Microgravity Research Facilities

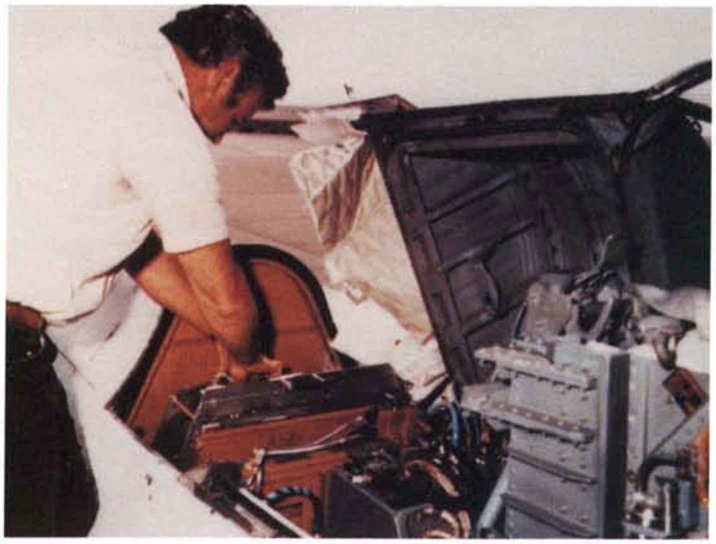
*A*bove, a Marshall Space Flight Center researcher is checking one of the four reactors (encased for flight in the white canister shown) that make up the Marshall-developed Monodisperse Latex Reactor System (MLRS). The system was developed to demonstrate the ability to produce in the microgravity of orbit larger and more uniform latex particles than can be grown on Earth. The MLRS operated successfully on five Space Shuttle flights and produced the first commercial products made in space: millions of tiny plastic beads, called microspheres, each a perfect sphere and all identically sized. They filled an important need of research and industrial laboratories, serving as a reference standard for calibrating instruments with extreme accuracy.

The MLRS is representative of a broad variety of equipment and facilities that had to be invented to support microgravity experimentation, which offers high potential for development of commercial products. Other examples include many types of furnaces for growing crystals or for melting/solidifying metals and alloys; apparatus for separating biological materials; systems for observing fluid processes in microgravity; computers for controlling experiments; and instruments, cameras and other data acquisition systems for recording the results of the experiments.

Of particular interest are several types of "levitators," systems that enable processing of materials without use of containers that might contaminate the sample. Glass, for example, when melted on Earth, develops impurities from contact with the crucible in which it is melted. Containerless processing offers the possibility of creating ultrapure glass for advanced optical and electronic applications. At right is an acoustic levitator that allows containerless study of glass formation processes on Shuttle flights; the glass is melted and resolidified while suspended in the levitator by acoustic energy. The system was developed at Marshall Space Flight Center.

Not all of the experiment support equipment is intended for orbital flight. In many cases, experiments can generate valuable data in brief periods of microgravity ranging from one second to one minute. Special equipment—furnaces,





levitators, etc.—has been developed for use in microgravity research aircraft and Earth-based drop facilities.

Microgravity conditions can be created in aircraft by flying precise parabolic curves during which near-zero gravity is attained for 20-60 seconds. Above, an engineer is checking an experiment package in an F-104 research plane operated by Ames Research Center; the supersonic F-104 is capable of providing a full minute of low gravity experiment time. A Johnson Space Center KC-135 transport can attain microgravity for 25 seconds at a time and make up to 40 parabolas per mission; at right, industrial researchers, strapped to the floor of the KC-135 to prevent floating, are preparing a furnace for an investigation of molten iron characteristics in microgravity. NASA also has a smaller Learjet, operated by Lewis Research Center, that can provide microgravity for 20 seconds at a time on multiple parabolas.

Additionally, NASA operates a number of ground-based drop tubes and drop towers in which orbital microgravity conditions can be simulated for short periods. Drop tubes accommodate small, uncontained material samples, which are heated to the melting point, then allowed to resolidify during free fall in the tube, which is usually airless, sometimes gas-filled. Marshall Space Flight Center has two such tubes, of 100 meters and 30 meters; Jet Propulsion Laboratory has two smaller, special purpose drop tubes. Microgravity time in these facilities ranges from 1.7 to 4.6 seconds.

Drop towers are intended to handle larger experimental packages than can be accommodated in the drop tubes. An example is the Zero Gravity Research Facility at Lewis Research Center, a 145-meter tower with an integral vacuum chamber that allows zero gravity durations up to 10 seconds. Lewis has a second, 30-meter tower and Marshall has a 100-meter facility.

A special facility is Lewis Research Center's Microgravity Materials Science Laboratory (MMSL). Equipped with a variety of furnaces and an instrumented drop tube, the MMSL demonstrates functional duplicates of materials processing systems flown on the Space Shuttle, allowing industrial, academic and government scientists to explore the potential of microgravity experimentation before establishing their own formal research programs. The initial focus of the facility is on metal and alloy solidification and crystal growth research; capabilities are being expanded for low gravity research on polymers, ceramics and glasses. ▲

Technology Twice Used

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 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

Ranger's Legacy

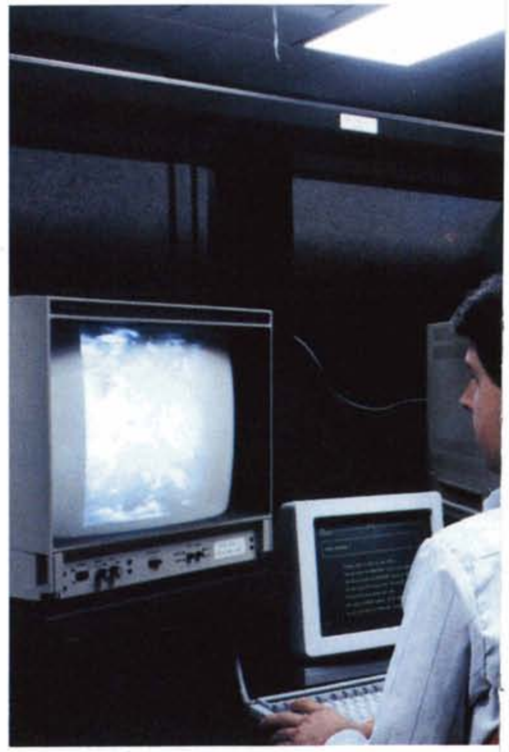
The benefit potential of aerospace spinoff is exemplified by the lengthening list of Earth uses for the space-developed art of image processing

You've seen the fascinating pictures of Jupiter, Saturn and Uranus, sent to Earth from distances up to two billion miles. No doubt you've also seen colorized versions of old black-and-white films, or *Titanic* at the bottom of the sea, or interior views of the human body taken by advanced diagnostic equipment, or images of Earth scenes showing details that could not be seen by the human eye nor captured by ordinary cameras.

They are all products of a common technology known as digital image processing, which involves the use of computers to convert sensor data into informative images. The term "processing" embraces not only the basic image creation but also a variety of computer techniques to correct sensor errors, change contrast, emphasize certain features, make measurements, clarify a point of particular interest, generally to improve and amplify the information that can be extracted from the image.

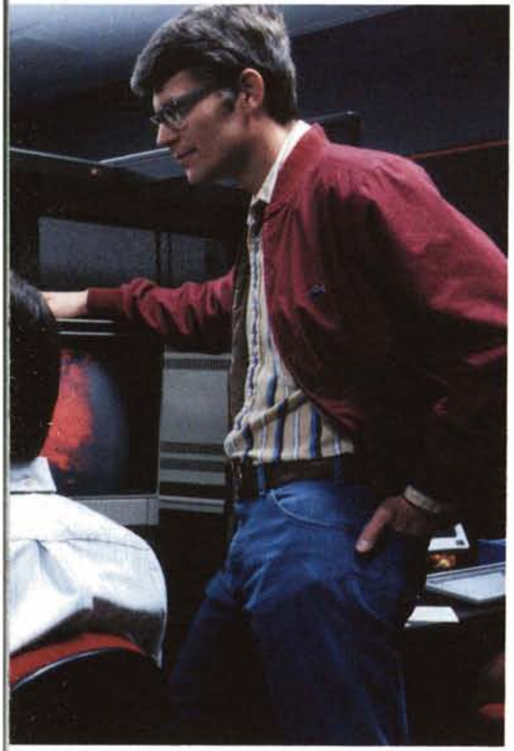
Although experimental work in computerized picture processing predated the start of the U.S. space program, it was a space requirement that propelled image processing from a collection of undeveloped ideas to a burgeoning technology in the early 1960s. Since then, NASA centers—in particular Jet Propulsion Laboratory—have led the way in developing the art of digital imaging processing and the companion technology of image enhancement.

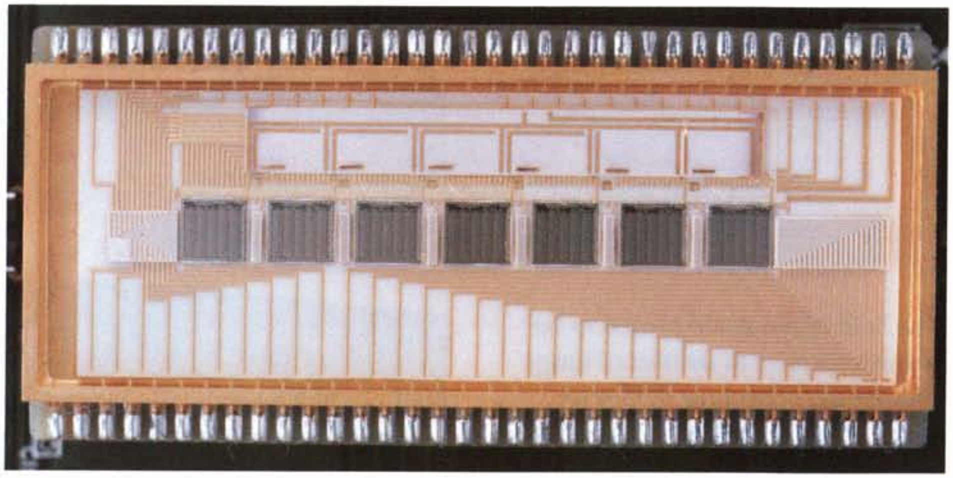
It started with the Ranger program, a preliminary to the Apollo lunar landing missions. Ranger was an unmanned spacecraft designed to make a comprehensive photographic reconnaissance of the moon. Although the first six spacecraft were not successful, Rangers 7, 8 and 9, flown in 1964-65, achieved their objectives and re-



turned some 17,000 high resolution images. Composed of six TV cameras, the Ranger imaging system worked this way: Behind each shutter was a coated vidicon tube not unlike those of the commercial TV cameras of that day. When the shutter clicked, a moon image formed on the tube's face plate. The image was then rapidly scanned by a beam of electrons and converted to FM signals, then telemetered to JPL, where the picture was reassembled.

Ranger's camera systems, though the best available at the time, were subject to a variety of distortions—lopsided, stretched, too light, too dark images—and to contamination by the noise of the spacecraft's electronic equipment. Distortion correction and noise removal could have been accomplished—as the Soviets had done—by conventional photographic techniques, but JPL image data engineer Dr. Robert Nathan had a better idea: convert the Ranger analog signals to digital signals and use a computer for enhancing the images. Accordingly, he began developing what became the first operational digital image processing software.





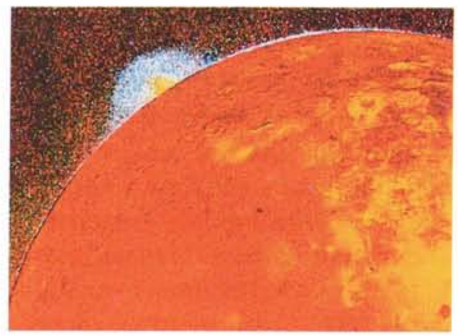
At Jet Propulsion Laboratory (JPL), analysts are employing advanced computer techniques to enhance images sent to Earth in digital form by distant spacecraft. JPL's pioneering work in digital image processing laid the cornerstone for what is now an expanding industry.

This is a hybrid "pipeline filter," composed of seven VLSI (Very Large Scale Integration) chips, for digital image processing. A new JPL development, the filter enhances images up to 200 times faster than earlier-used systems.

There was also a hardware need, a means of recording both analog video and digital images on film. No suitable commercial hardware existed, so JPL's Fred Billingsley designed a system called the Video Film Converter (VFC). Built under NASA contract by Link General Precision, the VFC was installed at JPL in 1963; much modified, updated and otherwise improved, it was used into the 1970s for digital image playback of the striking pictures returned by the unmanned planetary missions of the Mariner spacecraft. Thus, in terms of both hardware and software, JPL's work on the Ranger program was the cornerstone of what has become the sophisticated technology of digital image processing.

Over the years, there has been a steady stream of advances in digital image processing, necessitated by the advent of ever more sophisticated spacecraft sending immense volumes of image data from distances farther and farther form Earth. When the sheer mass of incoming data threatened to overwhelm computer capacity, JPL developed a method of performing simultaneous—rather than step-by-step—image processing operations through application of VLSI (Very Large Scale Integration) circuitry. This "pipeline filter," first used to process Voyager 2's Uranus images in 1986, enhances images 50 to 200 times faster. Concurrent with the explosive growth of commercial computer capacity in the 1970s and 1980s, there were many parallel advancements in spaceborne imaging systems and in processing software, all combining to effect enormous gains in speed, efficiency and enhancement capability.

Inevitably, and with substantial assistance from JPL and other NASA centers, digital imaging technology began to spin off in new directions: to the field of medicine, which has been particularly receptive to space technology transfer; to the new art of Earth resources survey by remote sensing; to enhancement of motion pictures; to quality control systems in industrial plants; and to a variety of other applications, some demonstrably practicable, some purely experimental, some promising but none yet fully commercialized.



When the Voyager spacecraft passed near Jupiter, its thermal mapping data revealed a heat source on the surface of the moon Io. Advanced image processing techniques developed by 3M Comtal enabled analysts to assemble this picture of the heat source and its "halo," a volcanic eruption spewing matter several miles.

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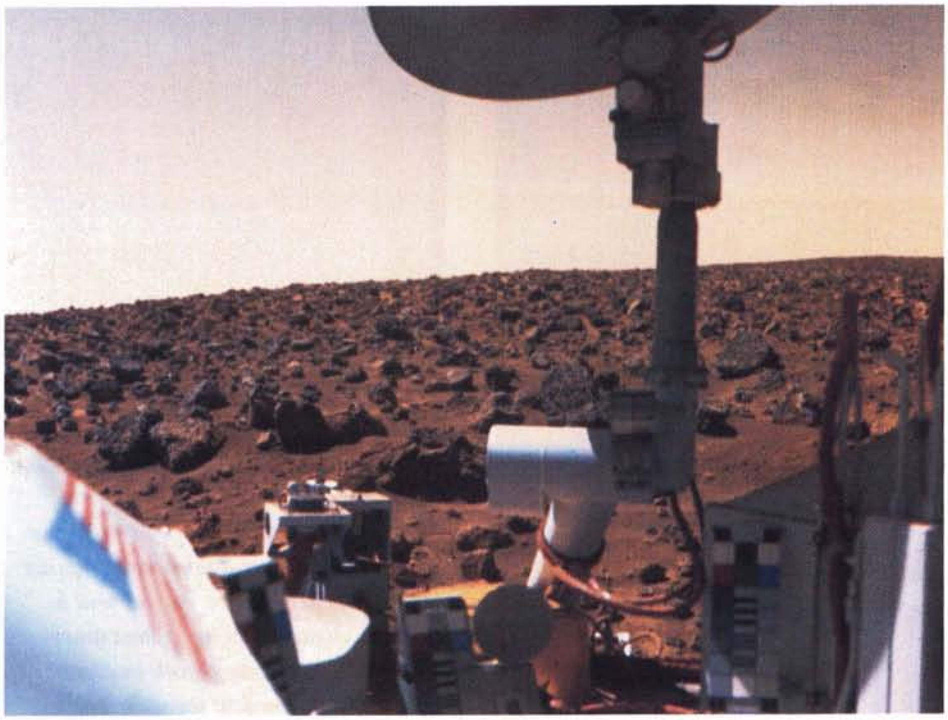


A famous view from space, a Viking Lander's "self portrait" against a backdrop of the bleak Martian surface. Note the color samples at center and right of the spacecraft; 3M Comtal image processing computers were able to balance the colors in the images they produced with the true values of the sample colors, thus providing an accurate coloration of Mars' surface.

The field of medicine proved to be highly receptive to transfer of image processing technology. And once again, it was Jet Propulsion Laboratory that pointed the way.

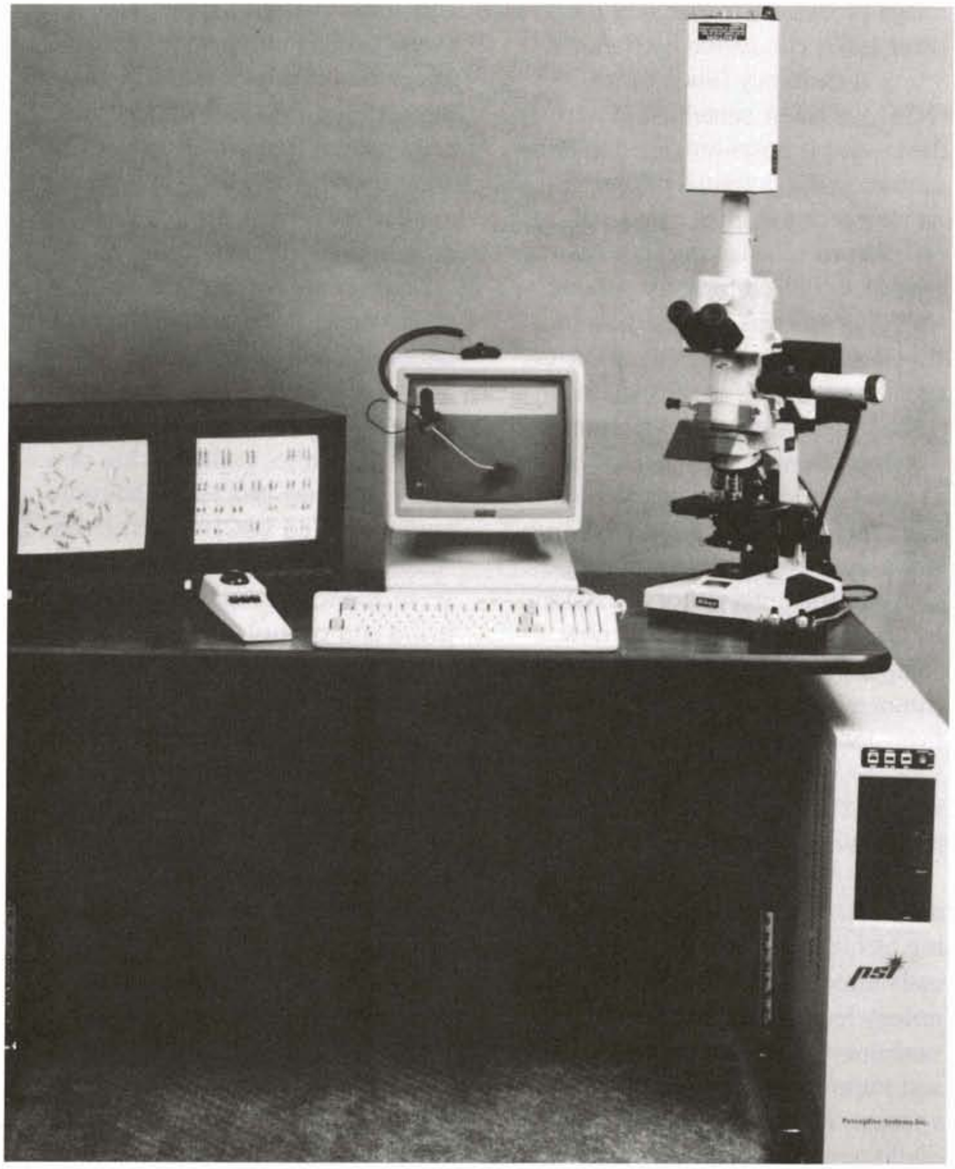
In the 1960s, JPL's Drs. Robert Nathan, Robert Selzer and Kenneth Castleman pioneered use of space-derived digital image processing techniques to enhance electron microscope, x-ray and light microscope images. This work sparked experimental medical applications by other organizations and emergence of a growing industry providing hardware, software and services for non-aerospace uses of image processing technology. Some of the companies were old-line firms that had worked with NASA from the earliest days. Others were new firms specially formed to commercialize the technology, many of them founded by former employees of NASA or space image processing contractors.

An example is Perceptive Systems Inc. (PSI), Houston, Texas, which was founded by Dr. Kenneth Castleman, who had worked on image processing at JPL for 15 years, and Don Winkler, who had served the same length of time at Johnson Space Center's Cell Image Laboratory. Many of the other PSI employees are former NASA image processing specialists.

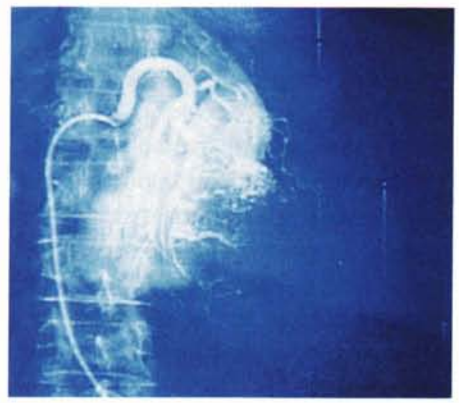
The company's initial technology development was an extension of work in computerized chromosome analysis Castleman and others had started at JPL. The product of that technology is PSI's Genetiscan digital karyotyping system, a valuable aid to the cytogenetics laboratory. Cytogenetics is the science that deals with the relation of human cells—and the constitutents of cells—to heredity. Such laboratories face a time-consuming bottleneck in the process called karyotyping, which involves analysis and classification of a set of chromosomes, the bodies within a cell which carry the genes that determine heredity. While the amount of information that can be interpreted from a karyotype has increased dramatically in the past 20 years, the method of preparing the karyotype has not. It consists of photographing the chromosomes through a microscope, then manually cutting and pasting the images to put together the karyotype classification.

The Genetiscan system eliminates the need for photography, including the hours of darkroom time, and the tedious manual assembly of karyotypes. It employs a video camera mounted on a microscope to capture chromosome images, which are then converted to digital form for processing. Genetiscan offers the ability to improve image quality; it can enhance the contrast of chromosomes, correct for shading in the microscope, and perform several proprietary PSI image enhancement operations. According to PSI, an experienced operator can produce a finished karyotype in less than 10 minutes. A big advancement that helps lower costs and increase productivity in the cytogenetics lab, Genetiscan is sold as a complete package that includes hardware, software and operator training. PSI also produces the PSICOM line of quantitative digital imaging systems *(see photo)* for industrial, scientific and clinical applications.

PSI is one of a growing number of companies producing image processing systems for an expanding range of medical uses. Among medical applications are computerized tomography



Perceptive Systems Inc. employed NASA technology in developing the Genetiscan system (left), a laboratory aid for study of heredity-related chromosomes. Genetiscan automatically processes a microphoto view of the chromosomes into a finished classification by size, shape, arrangement or other characteristics, providing big time savings. Shown above is the same company's PSICOM 327, a general purpose image processing system for medical, scientific and industrial uses.



This is a view of a human kidney made clearer by an image processing technique known as digital subtraction, in which surrounding body tissues are removed form the image. The image can be further processed to isolate or highlight a region of special interest.

(CAT) scanning, diagnostic radiography, brain or cardiac angiography, sonar body imaging, monitoring surgery and diagnostic nuclear magnetic resonance, a relatively new body scanning technique.

A special application of interest is the mobile diagnostic laboratory built by Remote Imaging Systems, a division of Portable X-Ray Labs Inc., Anaheim, California. Contained in a van equipped with a variety of processing equipment, the remote imaging lab is dispatched to a site where an x-ray, ultrasound, electrocardiographic or other type of examination is required. The information acquired on film or hardcopy is digitized and sent over standard telephone lines to a diagnostic center, where a physician interprets the data, provides a written diagnosis and transmits it back to a computer printer in the lab—all within minutes. The system can transfer images between hospitals, clinics or other physician locations and it can be used to communicate with specialists for a second opinion.

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™ SDCIPS is a trademark of Unisys Defense Systems.

Ranger's Legacy
(Continued)

With its Landsat satellites, development of sensors and advancement of processing techniques, NASA provided the initial technology base for another Earth-benefit application of image processing: Earth resources survey by means of remote sensing. The exceptional utility of this technology stems from the ability of sensitive detectors aboard satellites and aircraft to pick up radiations—light and heat waves—emanating from Earth objects. Since each object has its own unique "signature," it is possible to distinguish among surface features and to generate computer-processed imagery identifying specific features of importance to resource managers. This capability offers practical application in such areas as agricultural crop forecasting, rangeland and forest management, land use planning, mineral and petroleum exploration, mapmaking, water quality evaluation and disaster assessment.

The major users of the technology have been federal, state and local governments, but it is making its way into commercial operations—for example, resource exploration companies looking for oil, gas and mineral sources and timber production firms seeking more efficient treeland management. Supporting both government and private users is a small industry composed of companies offering image analysis services and companies producing the processing hardware software. As is the case in the medical application, many of these companies are direct offspring of NASA's work.

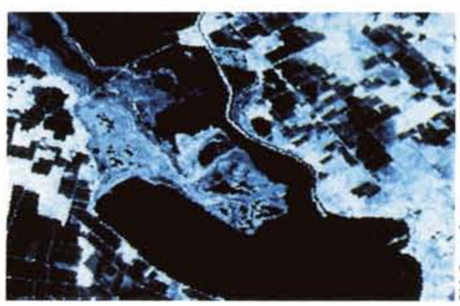
An example is 3M Comtal, Pasadena, California, a subsidiary of 3M Company, which traces its lineage to image processing research of the latter 1960s conducted by National Space Technology Laboratories (NSTL), a NASA center. NSTL was then—and is now—engaged in demonstrating the potential of remote sensing technology in a national interest effort to broaden the user base of space-acquired imagery. Among NSTL's needs was a processing system for an imaging spectrometer; such a system was developed for NSTL by Aerojet General Corporation.

Aerojet, however, later decided not to put the system into production. John Tahl, who had worked for Aerojet on the development project, believed in the potential of the system and he left Aerojet to form a new company for further development and commercialization of the technology. Ever since. Comtal has had a strong supplier/codeveloper relationship with NSTL and, since 1975, a similar relationship with JPL.

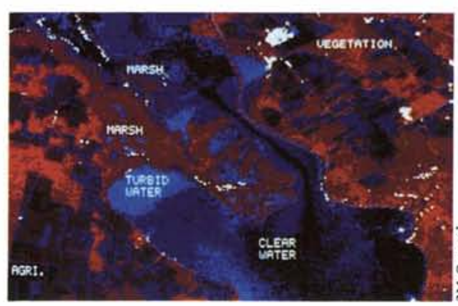
These NASA relationships during the formative years of image processing technology gave 3M Comtal an early opportunity to establish a technology foundation, analyze the advancements that would be needed, and improve the capabilities of its systems. Today, 3M Comtal, whose equipment processed the exciting views of Viking on Mars and the Voyager transmissions from Jupiter, is one of the leading companies in digital image processing. It is still serving the NASA centers and additionally producing image processing equipment used by customers in military, medical, resources management and meteorological applications.

Among other spinoff examples are cases where individual products, rather than whole companies, derived from NASA technology. System Development Group of Unisys Defense Systems, Camarillo, California has developed an image processing software package called SDCIPS™. The software has been applied in such diverse applications as military command and control, document image processing, geographic information systems and U.S. Postal Service video encoding research. SDCIPS consists of some 150 modules capable of performing digital filtering, contrast enhancement, surface illumination and contouring, image-to-image combining, color-space transformations and a variety of other operations. It is a direct spinoff of techniques developed by JPL for medical image processing.

The few companies mentioned are representative of a broader industry that bids to become significantly larger as new computer uses emerge and new applications of



3M Comtal



3M Comtal

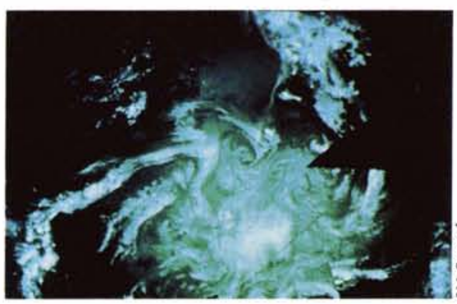
The unprocessed image of Matagorda Bay, Texas (left) shows little except where the land ends and the sea begins. But image processing through several stages produced the classification map above, identifying, in different false colors, the various types of land cover and water characterization.

digital image processing become cost-effective. In addition to the uses described, image processing has applications in defense equipment, chemistry, cartography, manufacture of printed circuitry, metallurgy, ultrasonics and seismography.

The image processing story is an excellent example of the aerospace spinoff process. NASA development of the technology in two different but parallel directions—for planetary and Earth resources imaging—resulted in establishment of a new industry of impressive growth and exceptional potential, with attendant benefit to the Gross National Product and to job creation. Spinoffs like this one, whose benefits are valued in the millions, are not uncommon. In other cases, spinoffs generate only moderate economic gain but provide significant public benefit in other ways, ranging from simple conveniences to important advances in medical and industrial technology.

For more than a quarter century, under its Technology Utilization Program, NASA has been actively engaged in encouraging the secondary application of aerospace technology. During that time, literally tens of thousands of aerospace originated innovations have found their way into everyday use. Collectively, these spinoffs represent a substantial return on the aerospace research investment in terms of economic gain, improved industrial efficiency and productivity, lifestyle enhancement and solutions to problems of public concern. ▲

One of the latest advances in image processing technology is 3M Comtal's Visionlab II, for use with personal computers. Its advanced design provides capabilities and speed once available only on larger, costlier systems.



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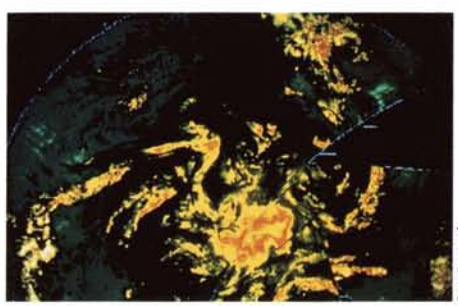

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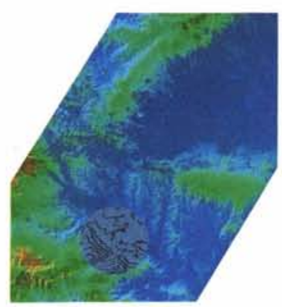


The satellite view of a hurricane at top gave meterorologists information as to the storm's size, strength and direction. But temperatures within the storm, obtained by processing infrared photography data to create the color-coded image in the lower photo, provided a clearer understanding of the storm.

A spinoff software package called SDCIPS combined satellite radar data with digital terrain data through a color-space transformation to produce this composite image in which the circular area highlights topographic contours.

The Stirling Project

An advanced automotive propulsion system heads technology transfers in the field of transportation

A NASA/Department of Energy project involving development of Stirling engine technology represents an unusual kind of technology transfer. It is not an aerospace spinoff, nor is the technology even American. The Stirling engine was initially developed in The Netherlands during World War II, later improved in Sweden. Now NASA and DoE are attempting to transfer the European technology to the United States, advance it several steps and pave the way for its commercialization, because its widespread adoption could bring a number of national benefits.

The Stirling engine is a different breed of automotive propulsion system. Like standard auto engines, it burns a mixture of air and fuel to drive pistons and thus transmit power to the auto's wheels. The Stirling differs from conventional internal combustion engines in that it employs an *external* heater head, where continuous combustion takes place, located outside the cylinders.

This design concept offers many important advantages, among them lower fuel consumption, low exhaust emissions, low noise levels, minimal lubrication requirements, and potential for high reliability, long service life and reduced maintenance costs. Perhaps its most important advantage is its "multifuel capability," meaning its ability to operate on a variety of fuels, such as gasoline, kerosene, alcohol, methanol, diesel fuel, butane and others; this capability will become increasingly important with wider availability of synthetic fuels.

Since 1978, Lewis Research Center has been conducting the Automotive Stirling Engine program as project manager for DoE. The goals established at that time included improvement of at least 30 percent in fuel economy in comparison with comparable internal combustion engines in modern autos; emission levels that meet or exceed the most stringent federal requirements; multifuel capability, including both oil-derived and synthetic fuels; and development of the engine to the point where it is suitable for cost-competitive mass production. The initial base of Stirling technology was provided under subcontract by United Stirling AB, Malmö, Sweden. The American prime contractor responsible for development of engine, component and subsystem technology is Mechanical Technology, Inc. (MTI), Latham, New York.

A basic objective of the program is "to place a manufacturer and end users on the path to commercialization." A potential manufacturer is Deere & Company, Moline, Illinois. The possible end users include such fleet operators as Purolator Courier, Basking Ridge, New Jersey, which has more than 5,000 vehicles and the American Trucking Associations, Alexandria, Virginia, representing 51 associations in each state and the District of Columbia. Also participating are several government agencies. Among the latter, the major program participant is the Air Force Logistics Command's MEEP (Management and Equipment Evaluation Program) organization.

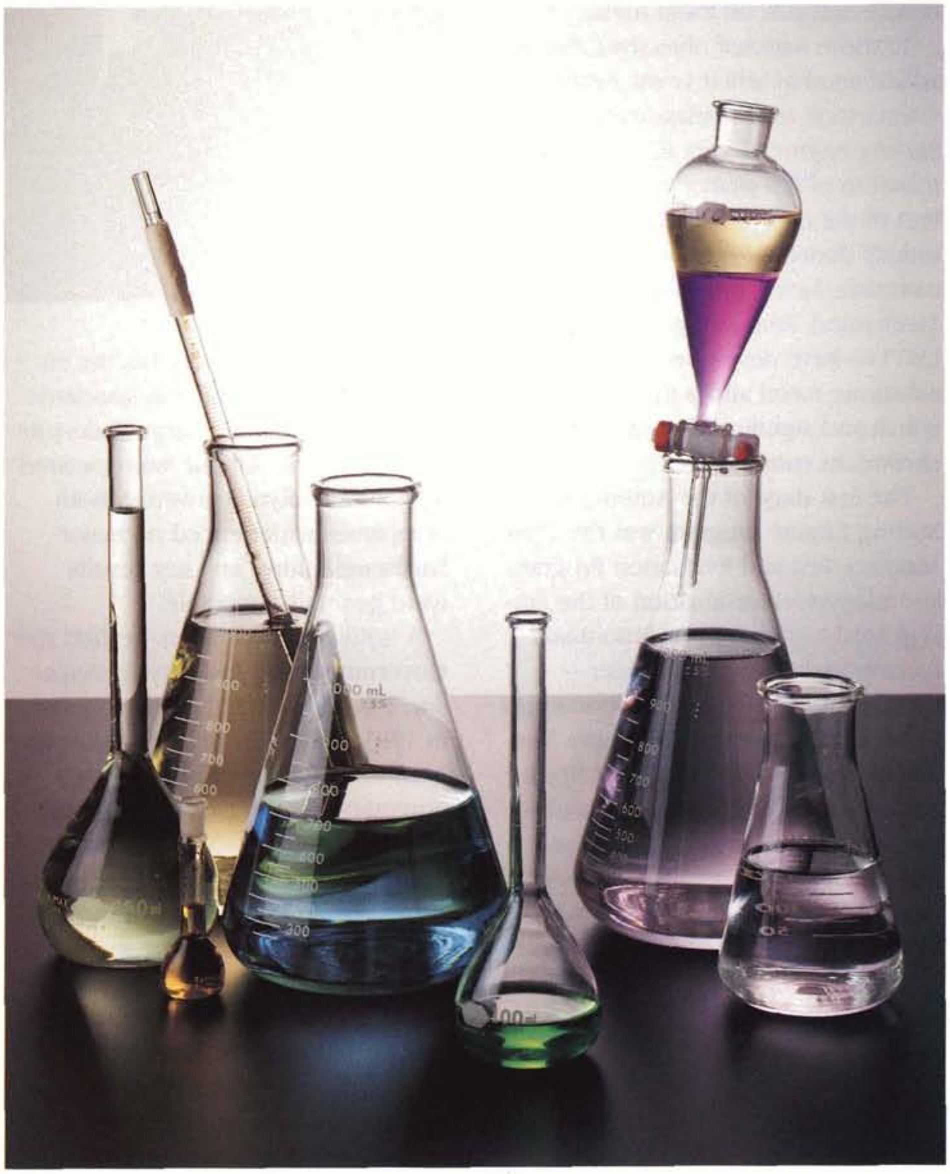
A big milestone was the September 1986 start of the program's Phase I, in which a Mod I Stirling engine is undergoing test—at Langley Air Force Base, Virginia—in a "multistop" Air Force van, a vehicle that transports people and light cargo in a stop-and-go duty cycle on the Langley flight line, providing a realistic test of the engine's capability. Throughout the planned 1,000 hours of testing, MEEP personnel are regularly evaluating the engine's fuel usage, overall performance, exhaust emissions and lubricating efficiency; they are analyzing reliability, maintenance and repair history and operational schedules, generally trying to determine whether the Stirling can in fact achieve the lower life cycle costs claimed for it.

Seven experimental Mod I engines have operated in test cells and vehicles for more than 16,000 hours. They are being used to develop and demonstrate new technologies for incorporation in a second generation Mod II engine, which is now in development. In tests thus far, the Stirling has exhibited engine performance close to predicted levels, good fuel consumption characteristics and low emissions; there has been parallel progress in advancing key technologies needed for a commercialized engine. Lewis Research Center reports that there are no technology barriers to the Stirling's eventual commercialization.

The ultimate success envisioned by the project team is mass production of Stirlings for automobile use. But before that can happen, auto manufacturers say, the Stirling engine must first be commercialized in a "starter market" application, to reduce the financial risk by providing a solid base of commercial experience and to establish a credible guideline for estimating mass production costs. Among possible starter market applications wherein the Stirling offers significant advantages are engine generators, heat pumps, irrigation pumps, trucks and power sources for submarine, solar terrestrial and space electricity generation. Development is already under way for some of these applications.

(Continued)

An Air Force van (above) is being used at Langley Air Force Base, Virginia as a service test vehicle for a new type of automotive propulsion system with broad promise, the Stirling external combustion engine (right). The Stirling engine is a European technology being developed for American use in a NASA/ Department of Energy program.



An advanced technology Stirling engine offers multiple advantages, principal among them reduced fuel consumption and lower exhaust emissions than comparable internal combustion auto engines, plus multifuel capability. This photo illustrates the wide variety of fuels the Stirling can use: gasoline, kerosene, diesel fuel, jet fuel, alcohol, methanol and butane—and that's not the whole list.

The Stirling Project

(Continued)

U.S. interest in the Stirling external combustion engine concept began in the mid-1970s, when the Environmental Protection Agency was looking for an alternative automotive engine with significantly lower exhaust emissions than other engines of that vintage, and additionally was seeking improved automotive fuel economy as a national energy conservation measure, along with multifuel capability to reduce reliance on fossil fuels.

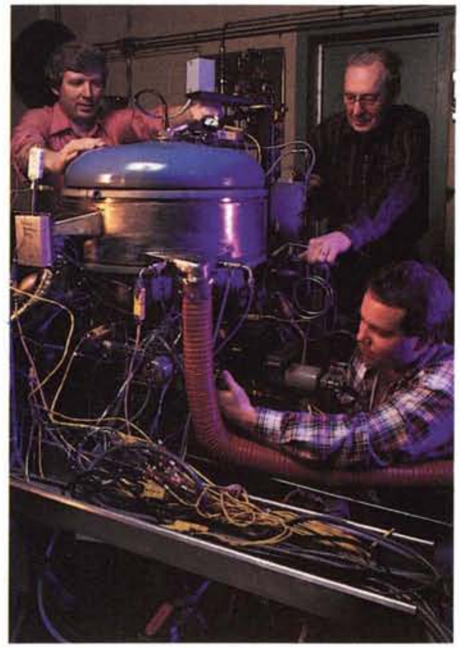
To those national objectives, NASA added another when Lewis Research Center took over management of the Stirling engine project in 1978; minimization of the strategic element content of the engine's metal alloys, to reduce demand for scarce strategic materials. Lewis and its contractor—Mechanical Technology, Inc. (MTI)—have developed low cost substitute metal alloys that eliminated cobalt and significantly reduced the chromium content.

The first stage of the Automotive Stirling Engine program was the 1984 Industry Test and Evaluation Program, an independent evaluation of the Stirling Mod I engine by an auto manufacturer and an engine builder—General Motors Research Laboratories (GMRL) and Deere & Company. The engine was installed in a 1981 Spirit auto and conducted emission, mileage, cooling and driver evaluations. Deere ran the engine for 37 hours in a test cell on gasoline, diesel and jet fuel under a variety of operating conditions. GMRL reported that the engine met federal emission standards with a "comfortable margin," despite the fact that the engine was operated without a catalytic converter. Both companies experienced no major hardware failures and test results were generally favorable.

A follow-on evaluation—called the Government and Industry Participation Program (GIPP)—was initiated in 1985. One GIPP activity under way is an investigation of the Stirling's potential as an electricity generator. The Army's Fort Belvoir (Virginia) has tested a standard Army engine-generator set in which a Stirling Mod 1 is taking the place of the regular diesel engine.

The primary GIPP activity is the Stirling-powered Air Force van project. This is a three-phase program in which Phase I covers routine service testing of a four-cylinder,

The configuration of the Mod II Stirling automotive engine is shown clearly in the upper photo, an uncluttered, wood-sculpted model built for checking precise dimensions prior to machine tooling of parts. The inverted dishpan at top (colored blue) houses the engine's external heat system, including the heater head where combustion takes place. In the lower photo is a closeup of the heater head with its cover removed.



Engineers and technicians of the Stirling Automotive Engine project hook up an engine to a dynamometer prior to a test cell run at various speeds and loads; the extensive wiring is for data recording, not part of the engine.

Lewis Research Center invented a special high-temperature lubricant coating for the Stirling engine; here a Lewis technician is flame-spraying it onto parts of an experimental engine.

78-horsepower Mod 1 engine—400 hours operating on unleaded gasoline and 400 more on kerosene-based jet fuel—in the moderate climate of Langley Air Force Base, located in southern Virginia. By mid-1987, Phase I was nearing completion, after which the engine was to undergo additional testing with diesel fuel.

If Phase I proves successful, Phase II will involve further in-service evaluations of van-mounted engines operating at a higher temperature—820 degrees Centigrade, compared with Phase I's 720 degrees—under a variety of climates and user conditions. Plans for Phase III have yet to be detailed, but generally it will consist of extensive testing of a lighter yet more powerful (85 horsepower) Mod II engine incorporating many of the advanced technologies developed in the course of the program. The projected fuel economy for the Mod II engine, installed in a mid-size car, is 63 miles per gallon on the highway and 33 miles per gallon in city traffic, for an overall average of 42 miles per gallon—approximately 30 percent better than the fuel consumption of a comparable conventional engine. ▲

The Stirling engine has a number of potentially advantageous applications other than automotive use, among them irrigation pumping, heat pumps, and electricity generation for submarine, Earth and space systems. Here project engineers are examining a model of a Stirling "free piston" variant that could be used in the NASA/international Space Station to generate 25 kilowatts of electricity.

Advanced Lightplane Wing

At upper right is the Lancair, a recently-introduced two-place private airplane of the "homebuilt" variety, one assembled by the owner from a parts/components kit supplied by a manufacturer. At lower right is another homebuilt, the four-place Prescott Pusher. In addition to the fact that both are kit planes, they share another common feature: each has a NASA-developed high efficiency natural laminar flow (NFL) wing.

Lancair airframe kits are manufactured by Neico Aviation, Santa Paula, California; the airframe is designed to accommodate any of three basic engines in the 100-125 horsepower range. Capable of cruising at more than 200 miles per hour, the Lancair is built of premolded parts made of advanced composite materials. The airplane has a gross weight of only 1,400 pounds.

Prescott Pusher airframe kits are produced by Prescott Aeronautical Corporation, Wichita, Kansas. The company employed Computer-aided Design (CAD) techniques to assure extreme accuracy in shaping the configuration; at right, a design engineer is studying the NASA NLF airfoil on a CAD terminal. Prescott also employs Computer-aided Manufacturing (CAM) techniques to build the hard tooling that produces the kit parts to extremely precise tolerances.

The tubular fuselage frame of the Prescott Pusher is heliarc welded at the factory and wings, tail and control surfaces are of traditional aluminum. At top right a Prescott employee is "clecoing" a wing—joining wing parts with temporary cleco fasteners, which are removed after the wing is riveted. A rear-mounted 180-horsepower engine with a four-bladed pusher propeller allows speeds up to 200 miles per hour; an advanced rotary engine and other powerplants being tested are expected to boost cruise speed above 200 miles per hour.

Both airplanes were in the conceptual stage in the early 1980s when NASA's Langley Research Center was developing the NLF airfoil. "In fact," says Neico Aviation president Lance A. Neibauer, "it was really the airfoil which provided the final stimulation to charge ahead with the Lancair project."

Prescott Aeronautical had this comment on the wing design:

"NASA's June 1983 release of the natural laminar flow airfoil fit right into the plans of Tom Prescott, who was designing an affordable high performance general aviation aircraft. The new (wing) section was designed by Dan Somers, a research aerodynamicist at Langley Research Center. Somers's objective was to develop a wing that would offer outstanding lift-to-drag ratio with a minimal amount of pitching moment. He succeeded."

Langley has long been active in developing technology for general aviation, meaning all planes other than commercial airliners and military aircraft. Langley's work focuses on improved safety and greater airplane efficiency through development of new wings, auxiliary airfoils and other components. In the 1970s, Langley developed a GAW series of general aviation airfoils with high lift characteristics and better safety through benign stalling qualities. At about the same time, Langley was also working on natural laminar flow airfoils, principally for military aircraft. As a follow-on to the GAW series, Langley began work in the latter 1970s on an advanced technology NLF airfoil for general aviation aircraft.

Laminar means "smooth." The intent of the NLF design is to overcome the tendency of the air flowing over the wing to become turbulent as airplane speed increases. Maintaining smooth airflow in cruise flight reduces air drag and that translates into reduced fuel consumption or greater speed, possibly both. The Langley-designed NLF airfoil can reduce induced drag by as much as 30 percent while also providing improved lift. In addition, it is more tolerant of airflow disturbances than earlier laminar flow airfoil. Says Neico Aviation: "Losing tremendous amounts of lift when laminar flow is lost does not occur with this new NLF series. If laminar flow is lost—due to rain or bugs, etc. on the leading edge of the wing—induced drag will increase somewhat but lift

will remain essentially the same and flight characteristics of the plane will not change noticeably."

The first Lancair prototype flew in 1984 and in 1985 the airplane was a best seller among general aviation aircraft. The Prescott Pusher was first flown in 1985 and kit sales began in 1986. A "frozen-design" Prototype II, shown being assembled above, is in test status. ▲

Riblets for Stars & Stripes

A racing yacht adaptation of NASA drag reduction technology heads a selection of spinoff applications for consumer, home or recreational use

On February 4, 1987, Skipper Dennis Conner and his 10-man crew guided the blue-hulled racing yacht *Stars & Stripes* past the finish line at Fremantle, Western Australia and brought the America's Cup back to the United States.

Representing the San Diego (California) Yacht Club, Conner and *Stars & Stripes* scored a 4-0 clean sweep in the best-of-seven finals over Australia's *Kookaburra III*, after a lopsided 4-1 semifinal victory over *New Zealand*. Rarely headed in those last nine races, *Stars & Stripes* performed magnificently in a variety of wind and wave conditions. There were many contributing factors to *Stars & Stripes'* convincing superiority, such as overall boat design, tactics, sail selection and, most importantly, the impressive seamanship of the 11-man team. An additional factor was NASA technology.

In a Fremantle press conference, *Stars & Stripes* design coordinator John Marshall disclosed the boat's "secret weapon": the hull's underside was coated with "riblets," a technology developed by Langley Research Center as part of NASA's continuing investigation of ways to improve aircraft fuel efficiency. Marshall said his group had selected riblets to improve boat speed after testing more than 40 hull coatings "from gops to goops and paints."

In aeronautical research, riblets are small, barely visible grooves on the surface of an airplane intended to reduce skin friction by smoothing the turbulent airflow next to the skin. The grooves are v-shaped with the angle pointing in the direction of the airflow; no deeper than a scratch, they have a pronounced beneficial influence on air turbulence.

At Langley, the first riblets were machined on flat aluminum sheets

and wind tunnel tested. When engineers of 3M Company, St. Paul, Minnesota learned of the experiments they advanced a suggestion: why not mold riblets into a lightweight plastic film with adhesive backing and press it into place on an airplane? This would be simpler than grooving metal and would offer the extra advantage that the riblet film could be applied to existing aircraft as a relatively inexpensive retrofit measure. Langley accepted the company's offer to produce riblet tapes for research and used them in 1986 tests on a Learjet aircraft. The film riblets demonstrated in flight a drag reduction capability similar to that found in wind tunnel tests—about eight percent.

The technology offers a means to reduce hull friction for vessels moving through water. A collaboration among 3M, The Boeing Company and the Flight Research Institute of Seattle, Washington resulted in the first water tests of riblet film in 1984.

Courtesy Nils Salvesen, Science Applications International Corporation

Stars & Stripes *(US 55), with Dennis Conner at the helm, rounds a buoy in America's Cup competition off Fremantle, Australia. The American boat's hull incorporated a NASA drag-reducing technology called "riblets."*

Among several boats fitted with riblet tapes, one was a U.S. rowing shell that competed in the 1984 Summer Olympics at Los Angeles in the four-oar-with-coxswain category. It won a silver medal in an event where no U.S. team had triumphed for several years. Boeing, the world's largest producer of commercial airliners, has initiated its own research program investigating the application of riblets to jetliners.

Riblet film was not the only aerospace technology employed by the 1986-87 America's Cup teams; in fact, it would have been fairly safe to predict in advance that the eventual winner would feature some type of aerospace technology. Virtually all of the competing syndicates used some form

Photo by Richard Sands.

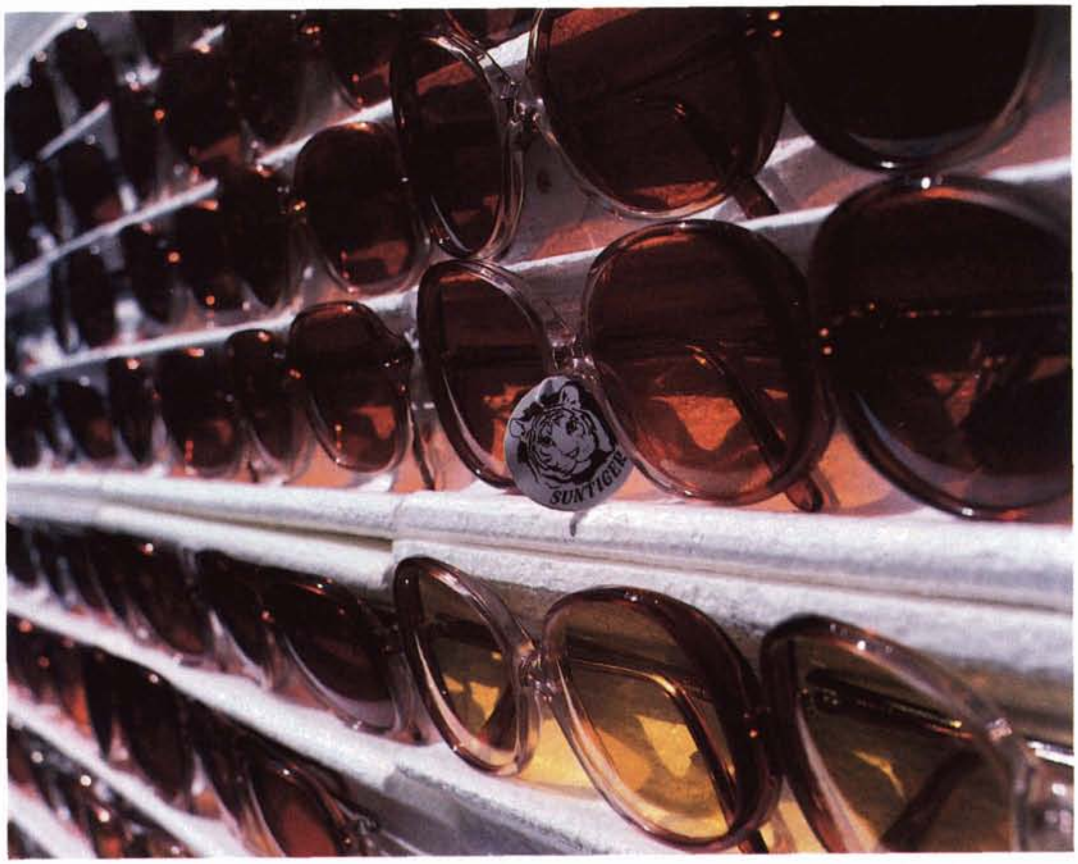
Members of the Stars & Stripes *syndicate examine the riblets on their boat's hull. Riblets are tiny grooves, visible only by very close inspection, molded into a plastic film with adhesive backing; they smooth waterflow over the hull and thus reduce drag.*

of computerized design technique, offshoots of the aerospace-originated practice of creating a mathematical model of a design and "flying" it by computer simulation to study the performance and structural behavior of many different designs before settling on a final configuration. Aided by a number of aerospace companies, who developed special "flow codes" for computerized measurement of water forces on a hull design, and in some cases by NASA-developed computer programs, the 12-meter yacht developers employed advanced fluid dynamics techniques to optimize their designs.

In addition, most America's Cup yachts—including *Stars & Stripes*—had "winged keels," adaptations of aircraft winglets, another technology developed by Langley Research Center to reduce air drag. On the 12-meter craft, the winglets were fins extending horizontally on either side of the keel to provide greater stability through balanced lift when the yachts heeled sharply to one side.

Langley's winglets are already in service on a number of operational aircraft; riblets may soon follow. They are still in an early stage of development, but Langley researchers feel that they can double the demonstrated drag reduction of eight percent. A reduction of 15-16 percent would translate into five percent less fuel expenditure; for the U.S. commercial airlines alone that could mean cost savings in the hundreds of millions annually. ▲

Eyeglass Filters

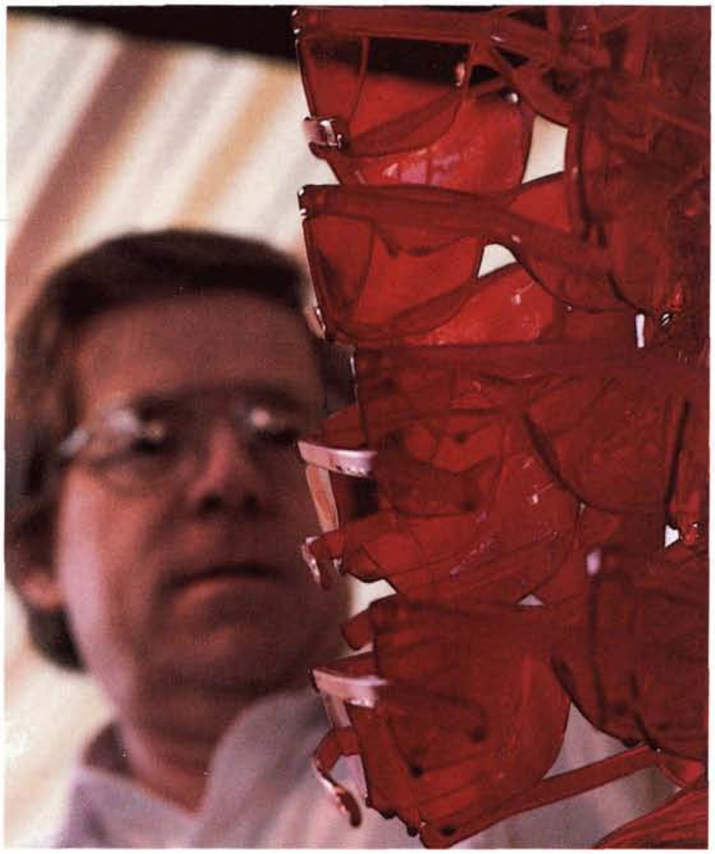


Eagles, hawks and other day birds of prey have excellent visual acuity. One reason is that they have built-in eye filters that absorb near ultraviolet and blue light. Humans do not have such filters and experiments have shown that exposure to ultraviolet radiation and blue light can cause a variety of eye disorders, in particular cataracts and age-related macular degeneration.

"Cataract and senile macular degeneration are the two principal causes of vision loss in Western nations," says Dr. Richard Young of the Department of Anatomy of the University of California at Los Angeles. "A simple, safe and inexpensive way to delay the onset or progression of these diseases is known: wear protective filters that absorb the blue, violet and ultraviolet when exposure to bright light is necessary." Other vision experts go further and suggest that both the retina and the lens of the eye should be protected throughout life from both blue light and ultraviolet radiation. Those most subject to hazard are those who work or play continuously in bright light environments—sunbathers, skiers, hikers, mountain climbers, welders, surgeons and nurses in operating rooms, seamen, farmers, lifeguards and aircraft pilots.

Spinoff products that provide the requisite protection recently appeared on the commercial market. They are amber/orange/brown lens filters that work in similar fashion to the retinal filters of eagle and hawks, selectively blocking blue and ultraviolet light. Marketed as Avian Orange™ and PST™ (Polarized Selective Transmission) lenses by Suntiger™, La Crescenta, California, they are available as sunglasses, visors, ski goggles and prescription eyeglasses. A display of Suntiger glasses of various tints is shown in the top photo. Above, Suntiger officials Lori Paul, Laurie Johansen and Paul Diffendaffer model their product.

The Suntiger lens is a "spinoff from a spinoff," a secondary product that




emerged from research toward development of welding curtains designed to protect persons exposed to welding arcs from blue and ultraviolet radiation. James B. Stephens, a systems engineer at Jet Propulsion Laboratory (JPL) shown above, and the late Charles G. Miller, a JPL physicist, spent three years on their own time applying JPL problem-solving methodology to development of a dye formula for a curtain capable of filtering out harmful ultraviolet and blue rays produced by welding operations. The curtain is now being marketed commercially.

Upon completion of the welding project those who had worked on it with Stephens—Laurie Johansen, a NASA scientist, Paul Diffendaffer and Charles Youngberg, NASA engineers, and Dr. Michael Hyson, a JPL contractor—turned their attention to the related matter of protective glasses. Using the biomedical knowledge acquired during the curtain project, they used a computer to analyze hazards and aid in design of sunglasses for various light environments—mountain or desert light, for example, or that experienced in offices with fluorescent lighting. They eventually developed Suntiger lenses for every natural environment and activity.

Suntiger lenses eliminate more than 99 percent of the harmful light wavelengths. The lenses make scenes more vivid in color, as illustrated in the top right photo, which shows a morning glory in natural view and as viewed through a Suntiger lens. The lenses also increase the wearer's visual acuity: distant objects, even on hazy days, appear crisp and clear; mountains seem closer; glare is greatly reduced; clouds stand out in bold relief; and daytime use protects the retina from bleaching in bright light, thus improving night vision. ▲

™ Suntiger, Avian Orange and PST are trademarks of Suntiger Corporation.

Error Prevention Aid

A life insurance company handles large volumes of constantly changing data: policies are bought or sold, customers change addresses or beneficiaries, mortality tables are revised, interest rates vary. And not only are the databases continually changing, but reports generated from those databases are similarly changing; for example, new laws require new reports for the government, new insurance products demand current status reports, and management needs new types of information for strategic planning.

This continuous evolution of the database keeps a team of computer programmers busy writing new code to implement the changes or to integrate a new software package into the company's system. Thus, the software that runs the computers for a life insurance company is usually composed of many pieces—major programs to manage the customer information base or billing/payment cycles, smaller programs to generate a specific report or enter a new mortality table. All these software packages are meshed into each other and a change in one place can result in a change in another.

In this complex computer environment, there is ample opportunity for error—a mistake by a programmer or a software-induced undesirable side effect. And in insurance, errors can cost a company heavily, so protection against inadvertent change is a must for the efficient firm.

The data processing center at Transport Life Insurance Company, Carrolton, Texas, has taken a step to guard against accidental changes by adopting, as part of its computer system, a software package called EQNINT, for Equations Interpreter Program; above, two center employees are using EQNINT as an error prevention measure. Originally developed by Johnson Space Center, EQNINT cross checks the basic formulas in a program against the formulas that make up the major production system. In other words, EQNINT assures Transport Life that formulas are coded correctly and helps catch errors before they affect the company's customer service or its profitability.

EQNINT was supplied to Transport Life 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 (see page 122). ▲

® COSMIC is a registered trademark of the National Aeronautics and Space Administration.

Solar Water Heater

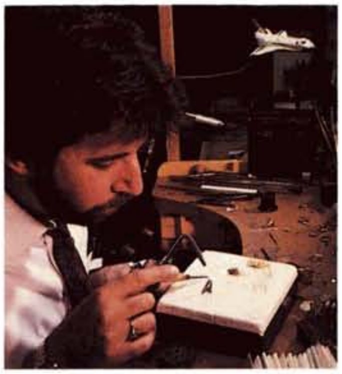
The accompanying photos show a novel solar hot water heating system with a high efficiency heat storage segment that derives from technology developed for the NASA Skylab orbiting laboratory of the early 1970s. Called Energy Garden™ and manufactured by Exemplar, Inc., Hickory, North Carolina, the system offers computerized control with an innovative voice synthesizer that literally allows the control unit to talk to the system user; it reports time of day, outside temperature and system temperature, and asks questions as to how the user wants the system programmed.

At top right is a ground installation of the Energy Garden Master Module, which measures four by eight feet and can also be roof mounted. The Master Module collects energy from the Sun and either transfers it directly to the home water heater or stores it until needed. The computerized control regulates all internal operational functions of the appliance and allows pushbutton reprogramming—after consulting with the Energy Garden voice—on an hourly, daily, weekly or indefinite basis for maximum efficiency. The programmer draws on conventional energy only when solar radiation is inadequate for hot water demands.

With a single Master Module, says Exemplar, the Energy Garden will deliver 40-70 percent of the hot water needed for a typical family of four. With an optional Amplifier unit added to the Master Module (below right), Energy Garden can supply 69-90 percent of the same family's needs. A higher efficiency, second generation unit called FRESOURCE™ was introduced in March 1987.

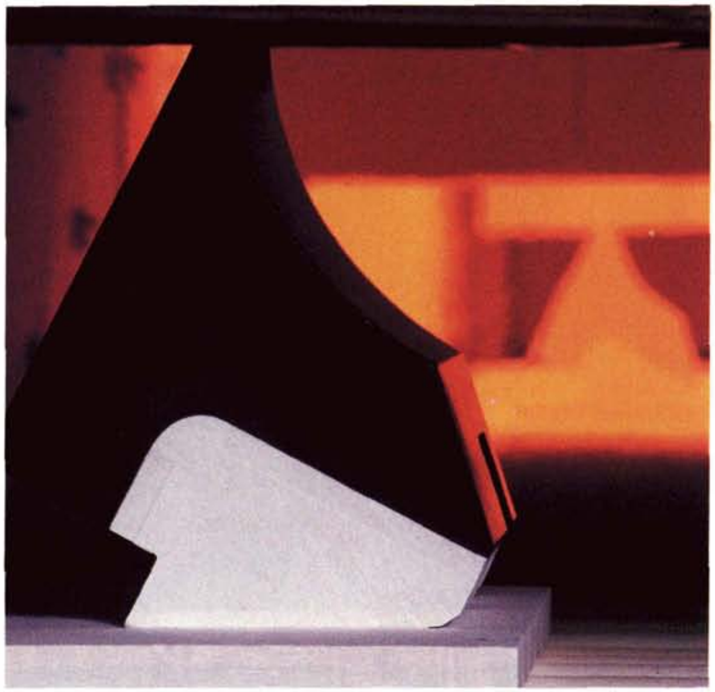
A key part of the Energy Garden/FRESOURCE systems is a patented three-way heat exchanger coupled with a latent heat storage technique in which the system alternately "freezes" and "melts"—releases and absorbs heat—indefinitely; this concept was developed for the Skylab spacecraft to provide efficient, maintenance free heat storage in a compact package. Energy Garden's voice synthesis microprocessor also draws upon space technology, as do the unbreakable covers on the Master Module and Amplifier. The latter units are coated with a glazing material that offers high solar radiation transmission characteristics; the material was originally developed by DuPont and used on the Apollo Lunar Module to protect it from meteorite damage. ▲

™ Energy Garden and FRESOURCE are trademarks of Exemplar, Inc.



Above, Alan Kasson of Kasson Jewelers, Bridgeport, Connecticut is soldering a piece of gold jewelry. In the background is a model of the Space Shuttle Orbiter, a reminder to Kasson's customers that he is using a unique soldering base—a segment of an Orbiter heat shield tile.

Kasson's unusual application of Shuttle thermal protection technology was inspired by an article in *National Geographic* that described the tile shield that protects the Orbiter and its occupants from the searing heat of re-entry. Developed for NASA by Lockheed Missiles & Space Company, the tiles are made of silica fiber insulating material (see page 106) and they can withstand temperatures up to 2,300 degrees Fahrenheit



without melting. It takes some 34,000 tiles, each differently shaped to fit the Orbiter's complex contours, to protect the spacecraft's underbelly, nose and tail.

At left, a Lockheed technician is monitoring a numerically-controlled machine that is shaping an individual "T-bone" tile. After shaping, the tile's boron-coated outer surface must be cured in a kiln; the above photo shows one T-bone in the oven while another (foreground) has just emerged. At upper right are two cubes of tile material freshly removed from the oven; the glowing interiors remain hot but the darkened edges show that the surface has already cooled, illustrating the basic principle of Orbiter protection: the tiles cause heat on their surfaces to dissipate rapidly while slowing heat transfer to their interiors.

The tile story sounded to Alan Kasson like the answer to a problem. A jewelry designer, repairman and stonesetter, Kasson heats and solders precious metals with a jeweler's torch that generates temperatures of 1400-1800 degrees. He was using charcoal or asbestos blocks as soldering bases, but they were disintegrating at high temperatures. The Shuttle tiles offered a base with temperature resistance far beyond his requirements.

Kasson wrote NASA requesting a supply of tiles, stating the size he wanted and explaining how he intended to use them. NASA, which encourages secondary applications of aerospace technology, agreed to furnish the tiles at no cost in exchange for Kasson's pledge to report his experience with the tiles. Not long thereafter he received in the mail from Johnson Space Center four tiles, each six-by-six-by-two inches, rejects designed for the Orbiter's fuselage but never used. Kasson cut them into smaller sizes to better fit his needs.

In the closeup below, Kasson is soldering a piece of gold jewelry; the torch has heated the gold to "yellow hot," but the photo shows no indication of heat transfer to other areas of the tile.

"The tiles are like firebricks," says Kasson, "but much softer, similar to styrofoam, while most fireproof soldering material is very hard. The way in which I find the tiles most useful is to simply push the items to be soldered into the tile, which secures them in place while I solder." Also, the surface of the tile can be shaped and used as a mold for making *objets d'art.* Although the tiles crumble with wear, his technology utilization experiment has been successful, Kasson feels. ▲

Insulation Material

Spacecraft, manned or unmanned, are subjected to temperature extremes that may range several hundred degrees above or below zero Fahrenheit. Thus, they need superior insulation to protect their onboard equipment and instrumentation. On-orbit thermal control requirements are not the same for all types of equipment, so there is considerable variance among the types of insulation NASA has developed over a quarter century.

An example of a high efficiency superinsulator, used to protect experiments and pressurized modules in the open cargo bay of the Space Shuttle Orbiter, is multilayer insulation, or MLI. Developed in the mid-1970s by Marshall Space Flight Center, the MLI "blanket" employs multiple radiation barriers to retard the flow of energy. This is accomplished by metallizing the surfaces of the barrier material, causing them to reflect radiant energy—retaining wanted heat and blocking unwanted heat or cold. The radiation barriers consist of a plastic film coated on both sides with vapor-deposited layers of metal, such as gold or aluminum. A typical MLI blanket, one that covers the Shuttleborne Spacelab manned laboratory, is composed of 19 layers of "goldized" plastic film separated by layers of dacron netting. The layers of netting reduce loss of energy by convection and serve to hold the blanket together.

Apex Mills Corporation, Lynbrook, New York, a manufacturer of nettings, meshes, scrims and fabrics for industrial use, is a NASA vendor which has been supplying space insulation materials, including netting for MLI, since the late 1960s. The company put this experience to work by adapting the MLI insulation theory to an advanced insulation system—called Texolite®—for consumer and commercial use.

The basic Texolite product is a five-layer insulator, with three layers of netting and two layers of metallized film (aluminized polyethylene). A heavier version for extra insulation is Texolite Plus®, a sandwich containing outer layers of netting covering vacuum-plated film and a core of fiberfill. In the top photo, a sample of the basic Texolite, pulled apart to show the netting, is at upper right; a Texolite Plus sample is at lower left in the photo.

The two products are used in window energy applications as liners for curtains that reduce heat transfer to the insides of buildings and block escape of cool conditioned air, or retain warm air in the heating season. They are also used by makers of cold weather apparel—parkas, jackets, boots—and outdoor gear, such as sleeping bags; their attraction in such applications is that radiant barrier insulation offers excellent warmth retention at minimal weight and bulk. ▲

® Texolite and Texolite Plus are registered trademarks of Apex Mills Corporation.

Water Filters

In the accompanying photo are a Bon Del™ kitchen counter top water filter (white) and a portable water treatment unit, the latter a second generation product of a line that originated in Space Shuttle technology. The Bon Del filter development represents an instance wherein NASA technology spawned formation of a whole new company. This particular company—Water Filter Company of America (WFCA), a subsidiary of Dubarry, Inc., National City, California—was started with an investment of $27 and is now a multimillion dollar a year business.

It began when Ray Ward, now board chairman of Dubarry, moved from Utah to Arizona and didn't like the taste of the water in his new locale. He decided to develop his own water filter and conducted extensive exploratory research on various types of filtering systems. From this research, he learned of a NASA unit developed to purify the water aboard the Space Shuttle Orbiter. A compact, lightweight electrolytic water filter, it generates silver ions—in concentrations of 50 to 100 parts per billion—in the water flow system. The silver ions serve as effective bactericide/deodorizers. Ray Ward requested and received from NASA a technical information package on the Shuttle filter and used it as the basis for his own initial development, a home use filter.

Ward had originally not planned to manufacture filters, only to build one for his own home. But friends and neighbors wanted one, and that launched a booming business. In 1977, Ward formed the Bon Del Manufacturing Company of Mesa, Arizona and began producing the first generation filters. About the size of a thermos bottle, the basic kitchen model attaches to a faucet. Tap water passes through a filtering element of silver that has been chemically plated onto activated carbon. The silver inhibits bacterial growth while the activated carbon removes objectionable tastes and odors caused by addition of chlorine and other chemicals to the municipal water supply. A filter will treat up to 10,000 gallons of water.

Ward originally offered three models, including the counter top unit, portable system and a refrigerator unit. Subsequently, the product line was expanded and improved, and the growing company, which by the early 1980s was supplying filtered water to more than a million people, was moved to California. In 1987, WFCA introduced a new inline unit featuring more modern design and more bacteriostatic media for greater efficiency. ▲

™ Bon Del is a trademark of Water Filter Company of America.

A Boon for the Diabetic

Among a representative selection of spinoffs to medicine is a space-derived pump that offers new freedom to people dependent on insulin

Diabetes mellitus is a disease wherein a malfunctioning pancreas fails to manufacture enough of the hormone insulin to keep the amount of sugar in the blood at a normal level. Poor control of blood sugar levels can cause such serious complications as blindness, kidney disease, nerve damage, loss of extremities, even death. To maintain blood sugar control, many diabetics—more than a million in the United States—need daily, twice daily or multiple injections of insulin. This generally provides the requisite control, but at a price: the insulin dependent diabetic is tied to a rigid schedule in which mealtimes, sleep time and exercise must be matched to insulin injections and "peaking."

Some 12,000 diabetics have freed themselves of such lifestyle restrictions through pump therapy. A development of recent years, pump therapy involves use of an external pump to deliver insulin continuously at a preprogrammed, individually adjusted rate. No longer concerned with scheduling activities around peaking insulin levels, the pump wearer can lead a more normal existence, even participate in sports or travel. And there is an even greater benefit: research indicates that infusion of "short-acting" insulin in tiny amounts over a long period—instead of multiple daily injections of "long-acting" insulin—has helped many diabetics achieve better control of blood sugar levels, thereby minimizing the possibility of complications and in some cases even halting the progression of complications.

An example of a pump system is the MiniMed® 504 Insulin Infusion Pump, a space spinoff manufactured by MiniMed Technologies, Sylmar, California. MiniMed 504 is designed to replicate, to the extent possible, the action of the pancreas in a normal person. Dimensionally no larger than a credit card, it weighs only 3.8 ounces, which is important to someone who must wear it 24 hours a day. Within that compact package, it houses a microprocessor, a long-life battery, and a syringe reservoir filled with insulin. The syringe is connected to an infusion set, which consists of a thin, flexible plastic tube about 30 inches long with a needle at its end. The patient inserts the needle subcutaneously, usually in the abdomen.

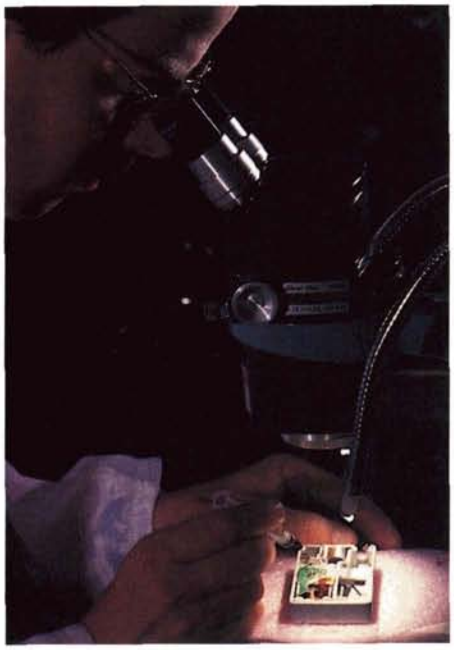
Clipped to a belt or just about any part of the wearer's clothing, the minipump infuses insulin in two ways: the "basal rate," a preprogrammed continuous delivery at the precise rate of one microliter per stroke; and the "bolus," a larger amount of insulin administered prior to meals or when blood sugar levels are elevated. The pump is not automatic; it must be told how much insulin to give and when to give it. The proper amount is determined by careful monitoring of the patient's blood sugar levels, taking into consideration the effects of stress, exercise, different kinds of food and other factors that influence blood sugar levels. The amount is communicated to MiniMed 504's microprocessor by tapping pushbuttons. The system can be programmed with up to four basal rates; this is important to patients whose insulin requirements change during the course of a day.

MiniMed 504 traces its ancestry to NASA-funded research in the 1970s which sought to transfer to the field of medical instrumentation space-derived microminiaturization techniques. A key player in the program was the Applied Physics Laboratory (APL) of Johns Hopkins University, whose extensive and innovative work in design of small satellites had provided a technology base for developing medical systems in which electronic and other components were reduced to incredibly tiny dimensions.

One such system was the Programmable Implantable Medication System (PIMS), developed by APL in cooperation with Goddard Space Flight Center and Pacesetter Systems, a manufacturer of cardiac pacemakers located in Sylmar, California. In 1981, Pacesetter formed an Infusion Division, incorporating its research and development personnel who had worked on the NASA/APL program; the division continued work on an advanced version of PIMS and also initiated work on external insulin pumps, of which MiniMed 504 is a third generation product. In May 1985, when Pacesetter Systems was acquired by Siemens Corporation, the Infusion Division became a separate, privately-held company named MiniMed Technologies.

MiniMed continues to refine external pump technology and has developed the implantable insulin pump to the point where it is undergoing human clinical trials, initiated last year. The company's long-range goal is a commercially available artificial pancreas with a sensor that will continually measure blood sugar level and automatically regulate insulin delivery through an implanted pump. The "when" is uncertain, due to the extensive development and testing required to achieve the requisite reliability but the goal, says MiniMed, "appears more and more attainable." ▲

® MiniMed is a registered trademark of MiniMed Technologies.



At left, a MiniMed Technologies technician uses magnifying glasses to assemble the tiny parts of a MiniMed 504 Insulin Infusion Pump, an aid to diabetics shown in closeup above.

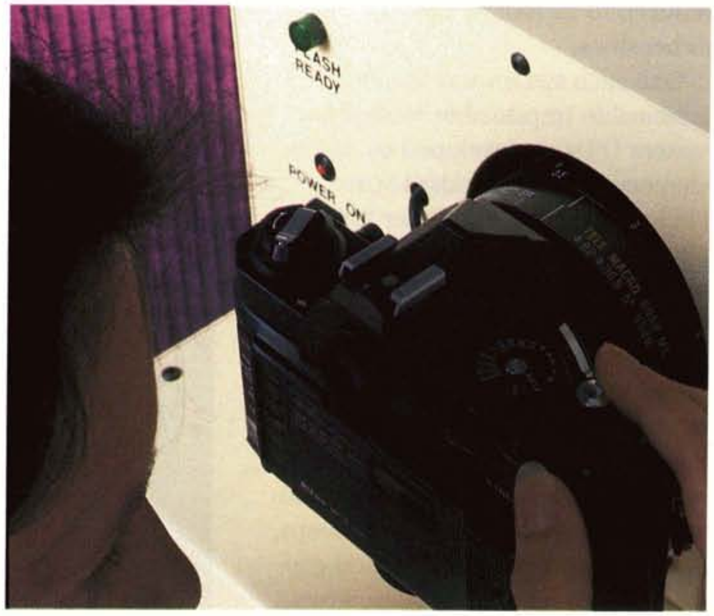
Above, a MiniMed 504 user (seated) is briefed on the operation of the system. Clipped to a patient's clothing (left), the minipump delivers insulin continuously at a preprogrammed rate adjusted to the individual, allowing the insulin-dependent diabetic to lead a more normal life.

Ocular Screening System

Above, a patient is undergoing a vision screening test by means of an economical, highly reliable VISISCREEN-100 Photorefractor Ocular Screening System, a portable device designed especially to detect eye problems in children through analysis of retinal reflexes. The system, which incorporates NASA image processing technology (see page 54), is manufactured by Medical Sciences Corporation, Wedowee, Alabama. Initiated as a NASA sponsored applications engineering project, it was developed jointly by Marshall Space Flight Center and Joe Kerr, now president of MSC and chief engineer of the company's research and development department.

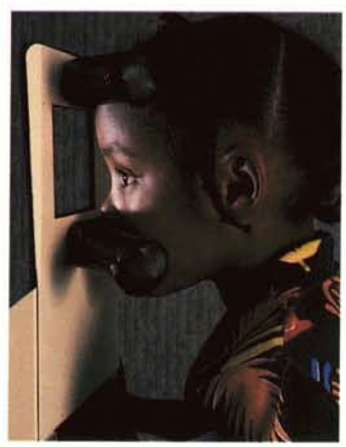
Although children should be screened regularly for amblyopia—potentially progressive dimness of vision—and other eye defects, screening programs have not been widely instituted in the United States for want of a simple, reliable, fast and relatively inexpensive method. VISISCREEN-100 fills that need. It is additionally important in that it can be used to test infants and preschool children, who otherwise might not be tested until school age. This capability allows much earlier diagnosis of "lazy eye," potentially a cause of later blindness. Dr. Keith Morgan, pediatric ophthalmologist at Louisiana State University and medical director of MSC, states that 20 percent of blindness that develops after birth is caused by too late detection of lazy eye combined with loss of vision in the healthy eye, most often from injury or diabetes.

VISISCREEN-100 was evaluated in field tests on thousands of subjects before becoming fully registered with the U.S. Food and Drug Administration. During the past two years, more than 10,000 additional persons have been screened and the system's use is expanding rapidly. Last year, MSC entered into an agreement with KinderCare Corporation for vision screening at 1,025 KinderCare Learning Centers in the U.S. and Canada. MSC has also established programs in conjunction with the Illinois Department of Health and the CIGNA Healthplan of Georgia. The company has opened district offices in Illinois, Georgia and Tennessee and has plans for regional offices across the U.S. by 1991. In addition, MSC has an ongoing research program—in which Dr. Morgan and Joe Kerr are co-investigators—with the Eye Research Center of Louisiana State University.



VISISCREEN's photorefractor is basically a 35 millimeter camera with a telephoto lens and an electronic flash (for camera buffs, it's a 500 millimeter f.8 telemacro catadioptric lens). By making a color photograph, the system can test the human eye for refractive error and obstruction in the cornea or lens. Ocular alignment problems are detected by imaging both eyes simultaneously.

At top is the business end of the VISISCREEN-100 system, the camera and controls. At right is a young subject at the head positioning hood eight feet from the camera. The electronic flash sends light into the youngster's eyes and the light is reflected from her retina back to the camera lens. The photorefractor analyzes the retinal reflexes generated by the subject's response to the flash and produces an image of the subject's eyes in which the pupils are variously colored; the nature of a defect, where such exists, is identifiable by a trained observer's visual examination of the pupils in the image. Such analyses are performed by MSC staff members at the company's Wedowee headquarters. When defects are noted,



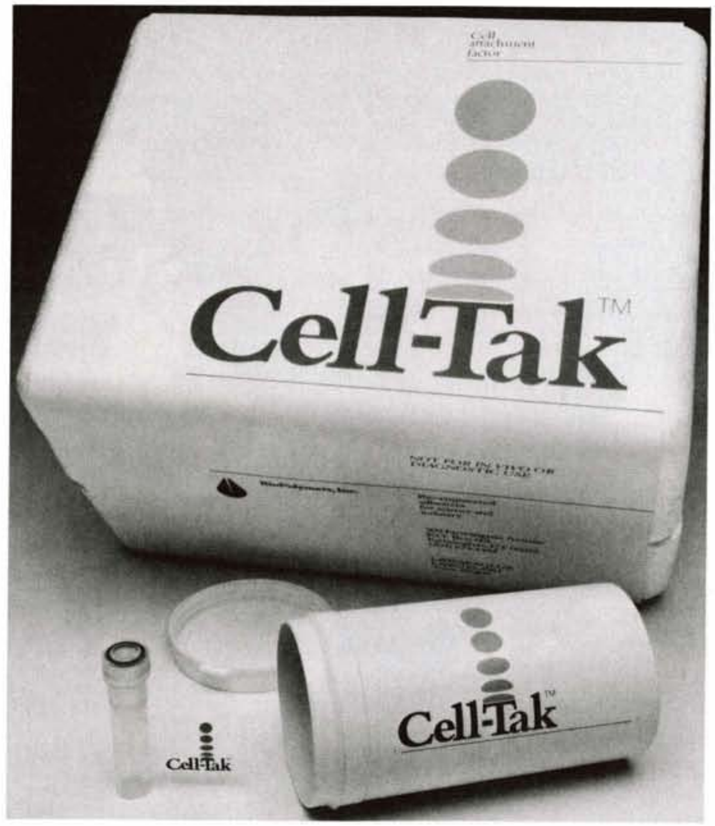
they are verified by ophthalmological follow-up. Above, Dr. Morgan displays an example of a defect detected by VISISCREEN-100. Note the difference in the child's pupils, as captured by the image. The right eye shows a red disc characteristic of a normal retinal reflex; the dark coloration of the left eye's retinal bed indicated a defect, which analysis showed to be cataract.

At upper right is a VISISCREEN photo of a child's eyes found to be normal (two red discs). In the next lower photo, the child is farsighted; the indicator is the yellow crescent at the top of the right eye. Strabismus of the right eye—squint or cross-eye—is shown in the next lower photo. The child in the bottom right photo has a moderate degree of farsightedness in both eyes, or hyperopia, as indicated by the yellow crescents at the tops of both eyes. Independent tests by Smith-Kettlewell Eye Research Foundation, San Francisco, California rated the accuracy of an early prototype of the photorefractor at 88 percent and MSC has since improved the system. ▲

Mussel Glue

Above, a *mytilus edilus*—a common blue ocean mussel—is attaching itself to the underside of a wet glass in a laboratory. It does so by secreting a glue-like substance in the form of multiple threads, which attach to surfaces such as shells, rocks, piers and ships. This natural "superglue" hardens within minutes and keeps the mussel tightly affixed to its selected platform, even in the roughest seas. Its superior adhesive properties suggest many practical applications and one company—Bio-Polymers, Inc., Farmington, Connecticut—has developed a synthetic mussel glue for the commercial market.

A potential early application, says Bio-Polymers president Thomas M. Benedict, is in dentistry as an adhesive between filling material and teeth. Current dental adhesives require etching of the tooth or an almost perfectly dry surface, very difficult to achieve in the moist human mouth—but the synthetic superglue, like its natural counterpart, bonds in moisture. Other possible medical applications include glueing fractured bones together; coating sutures for preventing infection after surgery; closing corneal puncture wounds to prevent astigmatism after ophthalmological surgery; and general tissue culture in research laboratories.



The superglue is not derived from aerospace technology, but the formation of Bio-Polymers and its program for commercializing the product represent an example of how small businesses can benefit from the services of NASA's industrial applications centers. The story begins in 1981 when Dr. J. Herbert Waite, Assistant Professor of Orthopaedics at the University of Connecticut Health Center, successfully isolated the protein the mussel uses to make its adhesive bond and characterized the protein's structure, a breakthrough—after a decade of effort—that ultimately led to development of the synthetic substance. Publication of Waite's findings aroused wide interest among drug companies seeking quantities of the material for further research in their own laboratories. This led to a decision in 1984 to form a company, with Benedict as president and Waite as a consultant, to produce the basic protein for sale as a research chemical and to develop formulations for medical/industrial use.

The company's efforts were aided by NERAC, Inc., Storrs, Connecticut, one of nine NASA-sponsored technology transfer service centers that provide customized search and retrieval services for industrial clients. NERAC was engaged by Bio-Polymers to provide information that would help the company secure federal grants for further research and to identify commercial applications for the product. NERAC conducted searches of several data banks, including NASA's, and was able to supply the requisite information. Says Benedict: "While NERAC helped us meet the Small Business Innovation Research Criteria for companies seeking research grants, even more important were the numerous applications its searches uncovered." Late in 1985, Bio-Polymers succeeded in synthesizing the glue and in October 1986 introduced the first of many planned products: Cell-Tak™ (above), an adhesive anchoring product for cell and tissue research. ▲

™ Cell-Tak is a trademark of Bio-Polymers, Inc.

Relaxation System

At right is the Environ behavior and stress management system, a "get-away-from-it-all" refuge from the pressures and tensions of modern fast-paced lifestyles whose users can simultaneously take accelerated learning courses in a variety of self-improvement subjects.

Marketed by Medical Behavioral Technology (MBT), Inc./Frank Italiane, Laguna Beach, California, the system is built around a "body lounge," a kind of super easy chair that incorporates sensory devices. The computer controlled enclosure provides filtered, ionized air to create a feeling of invigoration, enhanced by mood-changing aromas. Environ's occupant is surrounded by multi-dimensional audio and the lighting is programmed to change colors, patterns and intensity periodically. These and other "sensory stimulators" are designed to provide an environment in which, according to MBT, the learning process is accelerated because "research has proven that while an individual is in a deep state of relaxation, the mind is more receptive to new information. When information is combined with programmed sensory stimulation, acquisition of new knowledge takes place at an accelerated rate and retention is increased."

To activate the educational narrations, the user selects the desired program from a lengthy list and pushes a button. Examples of programs in the Environ catalog are Stress Management; Personal Motivation; Career Development; Sales Management; Physical Health and Longevity; Weight Reduction; Stop Smoking Now; and Foreign Languages.

The enclosure was designed for MBT by Powers Design Intra, Newport Beach, California and the design incorporates NASA anthropometric technology. Anthropometry is the study of the size, shape and motion characteristics of the human body; it is fundamental to successful design of clothing, equipment and workplaces in flight vehicles.

In planning for the Space Shuttle, Johnson Space Center (JSC) felt a need to expand the anthropometric data base. Accordingly, JSC undertook—with the assistance of Webb Associates, Yellow Springs, Ohio—to assemble the information available worldwide and produce a centralized collection of anthropometric knowledge. The result was a three-volume *Anthropometric Source Book*, a complete survey of data and a guide to its application; it has been

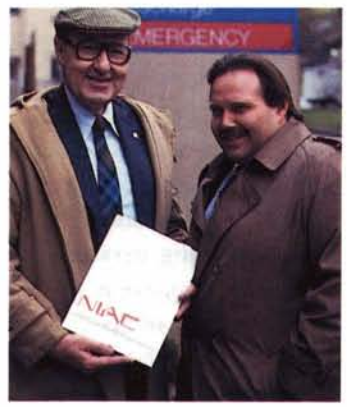
used in a number of spinoff applications involving design of workplaces and equipment of a non-aerospace nature. In addition to the NASA anthropometric data utilized in the design of the chamber itself and the body lounge, Environ also employs a NASA-designed pulse-monitoring electrode that is supplied by Heart Rate, Inc., Costa Mesa, California. ▲

Speech Aids

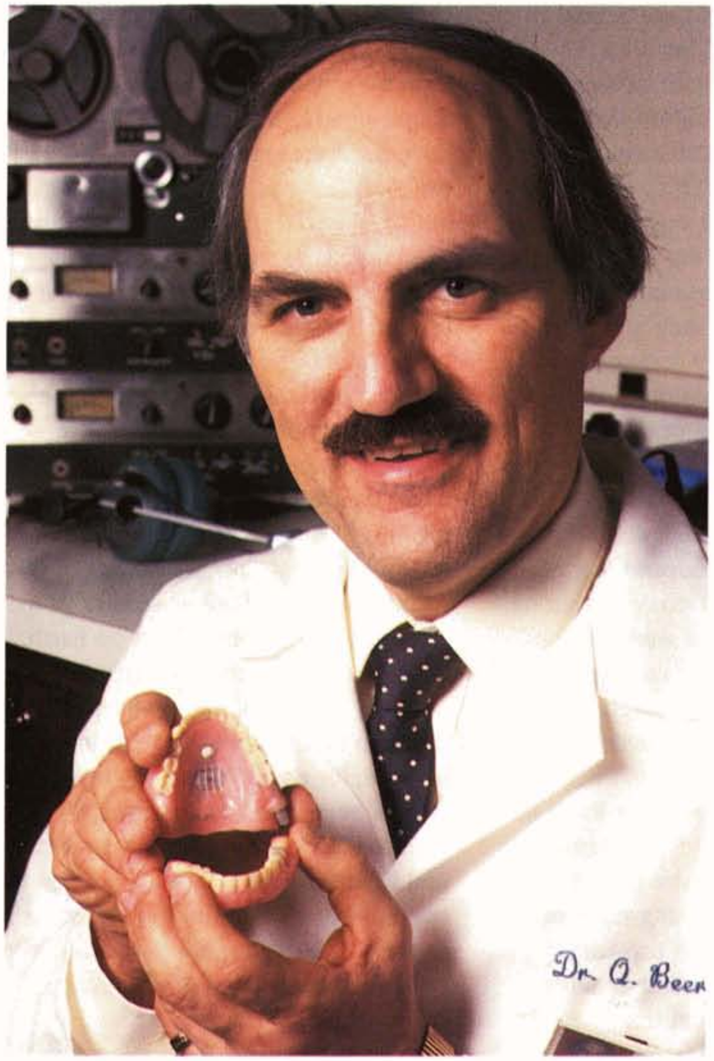
At right, Joseph A. Resnick, president of Dynamed Audio Inc., Natrona Heights, Pennsylvania is describing the operation of the Resnick Speech Teacher™ he invented. Designed to assist deaf and hearing-impaired persons in achieving better speech, the device provides a visual means of "cueing" the deaf as a speech improvement measure. This is done by electronically processing the subject's speech sounds and comparing them with optimum values, which are displayed for comparison.

For example, many deaf people tend to speak in high-pitched amplitude ranges. Indicator lights on the Speech Teacher's panel responding to the subject's speech are compared with a display representing the desired speech tone and amplitude level. The subject then tries to adjust his speech to match the model. In addition to the desk model, intended for use by clinicians, the Resnick Speech Teacher is also available in a wrist-mounted model (shown in woman's hand), which works in the same fashion but can be worn by the deaf person in everyday social situations.

The Speech Teacher is one of several medical related devices invented by Resnick in which a NASA information service played a part. Resnick's "research partner," to use his term, is the NASA Industrial Applications Center (NIAC) at the University of Pittsburgh, one of nine NASA-sponsored dissemination centers that perform computer search and retrieval services for industrial clients. "Before I commit any funds to developing an idea," says Resnick, "I commission a complete technical and field search through NASA at Pitt. On the basis of the information extracted by NIAC, I then determine whether or not my idea is feasible, and if feasible I commit and put the rest of the gears into play." At right Resnick is shown with his NIAC contact, project manager Robert W. Baird (wearing cap).



Among other Resnick inventions for which NIAC provided assistance is the Resnick Tone Emitter I™, a miniature electronic device intended for persons who have lost the natural larynx as a result of injury, cancer or other diseases. Built into a denture, the device—like a human voice box—produces a tone which is shaped into words by the tongue, teeth, lips and palates. Some components are so miniaturized they fit like fillings into three or more artificial teeth within a partial or full denture; the emitter is implanted in the den-



ture displayed above by Dr. Quinter Beery, Speech Pathologist and Associate Professor, Department of Otolaryngology at Pittsburgh's Eye and Ear Hospital Center for Audiology and Speech Pathology. Included in the miniaturized system are a microchip, microcircuitry, a power switch, a speaker covered with impervious membrane, an articulator switch and a rechargeable/replaceable battery. Development of the Tone Emitter was aided by a NIAC literature search of several databases that produced a number of pertinent reports relative to other voice prosthesis devices and research.

At right above is a new Resnick invention, introduced to the commercial market early in 1987: an in-home audible water pollution detection and alert system. Designed to fit most standard water lines, the "filter minder" shown monitors purity levels in water filters and sounds an alarm—a squealing tone and a flashing light—when foreign substances are detected. It does not analyze the substance, simply alerts the homeowner, who can take a sample to a laboratory. The system is produced under license by Polu-Med Technologies, Inc., a Resnick affiliate company located in Minneapolis, Minnesota. Polu-Med has an agreement with Pro-Bac International, Sarasota, Florida, whereby the latter company will have an exclusive manufacturing/distribution license for the monitor.

NIAC's search prior to development of the filter minder turned up nine "citations" of technical reports in such areas as water/wastewater evaluation, detection of bacteria in water, audio alarms and monitoring systems, including two NASA reports on Langley Research Center's development of a portable water quality monitoring system.

"I have developed a number of technologies," says Resnick, "but had it not been for the accuracy of the information systems of NASA, I doubt seriously whether the devices would have come to fruition." ▲

TM Resnick Speech Teacher and Resnick Tone Emitter I are trademarks of Joseph A. Resnick, licensed to Dynamed Audio, Inc.

Hi-Tech for Archeology

Application of remote sensing to archeological reconnaissance exemplifies technology transfers in the related fields of resources management and environmental control

On the shores of Lake Arenal in northeastern Costa Rica, University of Colorado scientists are uncovering a wealth of information about an Indian culture that began there about 2000 B.C. and flourished for some 3,500 years before the Spanish conquest of the 16th century. The discoveries represent an archeological triumph, but they are the more exciting because they constitute an impressive demonstration of the tremendous potential of remote sensing technology in archeological reconnaissance.

Blanketed by thick tropical vegetation and covered by several feet of volcanic ash from 10 major eruptions of Arenal Volcano, the area is difficult to explore on foot. But remote sensing offers a means of accelerating the ground-based effort by steering field investigators to the potentially most productive areas. Looking at Earth in wavelengths of the electromagnetic spectrum invisible to the human eye, electronic remote sensing equipment in satellites and aircraft provides images that reveal hidden detail of immense archeological importance.

NASA's Thomas L. Sever, who conducted the Arenal remote sensing operations, has an analogy to explain the great difference between what can be seen by the naked human eye and by advanced remote sensing equipment. "If," he says, "the electromagnetic spectrum were a line 25,000 miles long—roughly the circumference of the Earth—the unaided eye could see only a piece of that line as wide as a pencil."

Sever is an archeologist and a remote sensing specialist with the Earth Resources Laboratory of NASA's National Space Technology Laboratories (NSTL); his job is to assist scientific groups, not only in archeology but in such other areas as land resources inventory and land development. Remote sensing is the process of acquiring physical information from a distance, for example, obtaining data on Earth features from a satellite or an airplane. Aerial photography is a form of remote sensing, but it is usually limited to the extremely narrow visible light portion of the spectrum. Advanced remote sensing instruments detect radiations—not visible to the ordinary camera or the human eye—in several bands of the spectrum; these data are computer processed to produce "multispectral" images that can provide enormous amounts of information about Earth objects or phenomena. Since every object on Earth emits or reflects radiation in its own unique "signature," remote sensing data can be interpreted to tell the difference, for example, between one type of vegetation and another, between densely populated urban areas and lightly populated farmland, between clear and polluted water or—in the archeological application—between rain forest and hidden man-made structures.

More than a decade ago, local inhabitants of the Lake Arenal area began finding ancient artifacts and that led to the University of Colorado's research project, financially supported by the National Geographic Society and the National Science Foundation. However, it was not until remote sensing was employed that the researchers began to comprehend the scope of the Arenal find.

Beginning in 1984 and continuing into 1986, Tom Sever applied satellite data together with infrared imagery he acquired on several flights over the area in a NASA remote sensing aircraft. This input enabled the University of Colorado's Payson D. Sheets, project director, to plan field investigations that led to excavation of 62 sites, such as villages, cemeteries, buildings and tombs. The most impressive contribution of remote sensing was discovery of many footpaths buried under the volcanic ash; tracing the footpaths, which seemed to connect villages with cemeteries, springs and stone quarries, provided a great deal of information about movement patterns and lifestyle of the ancient Indians, and also suggested sites for excavation. Director Sheets became an enthusiast of remote sensing in archeology. "It really is a new window on the past," he says.

Seeking to acquaint the archeological community with the potential of remote sensing, NASA has for several years been conducting demonstrations. For example, at Poverty Point, Louisiana, processing of remotely sensed data provided detailed imagery of a prehistoric site that may represent the oldest civilization in the United States. In New Mexico's Chaco Canyon, satellite images showed prehistoric roads invisible to the naked eye, built by the Anasazi culture about 900 A.D. In Kenya, remote sensing assisted noted researcher Richard Leakey in his search for early hominid remains, and in the desert of Sudan, remote sensing instruments penetrated deep into the Earth to find subterranean evidence of a culture that existed some 200,000 years ago.

Archeologists have been slow to accept remote sensing techniques, but recent successes have made a strong impression. Use of the technology is beginning to expand and some universities have already established Centers for Remote Sensing. Tom Sever stresses that remote sensing is not intended to locate individual arrowheads or pottery shards, nor to replace the archeologist's skills and the need for painstaking excavation; rather it offers a time-saving, low-cost way of prioritizing the archeologist's work and pinpointing sites for excavation. Remote sensing technology is itself advancing rapidly and, says Sever with respect to the archeological application, "What we will be able to do within a few years is literally unbelievable." ▲

At left is a remotely sensed image of an archeological site at Poverty Point, Louisiana that may represent the oldest civilization in North America. The image, which shows a large central plaza surrounded by six concentric ridges, contains many features of importance to archeologists.

In the center photo is a topographic image of Costa Rica's Lake Arenal area prepared from data acquired by a Landsat satellite. Enhancement of satellite data, coupled with infrared imagery from a remote sensing aircraft, led to discovery of the otherwise invisible footpaths (white lines) shown at left. Tracing and excavating the footpaths provided a wealth of information about an Indian culture that existed in the area some 4,000 years ago.

Wetlands Survey

Two hundred years ago, when the United States was an infant nation, there were more than 200 million acres of wetlands in what would later become the contiguous U.S. By 1980, less than 100 million acres remained—and losses are now estimated at 450,000 acres a year.

To Ducks Unlimited, Inc., Long Grove, Illinois, an organization dedicated to preservation of the world's waterfowl, current inventories of wetland resources are crucial to effective waterfowl management. To get continually updated information on the changing conditions of waterfowl habitats, Ducks Unlimited contracted with NASA to use data from the Landsat satellites' Thematic Mapper (TM), an advanced Earth-scanning instrument that collects data in seven bands of the spectrum.

Orbiting the Earth at 438 miles altitude aboard Landsat 5, the TM measures and records six values of light energy reflected from Earth and one value of heat energy as it scans the Earth below. On each orbital sweep, its sensors produce a series of digital "scenes" representing the features of Earth segments measuring about 100 by 110 miles, each scene covering about eight million acres and each containing some 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 designed especially for analysis of Landsat data. Called ELAS—for Earth Resources Laboratory Applications Software—it is supplied by NASA's Computer Software Management and Information Center (COSMIC)®. Located at the University of Georgia, COSMIC routinely makes available to industrial and other customers government-developed computer programs that have secondary applicability (see page 122).

The raw Landsat data con-

tains seven values for each pixel. Each of the seven bands of raw data can be displayed as shades of gray on a monitor or plotter (top right). Any three bands of raw data can be combined to produce color-coded informational images such as the one at left. From these images, displayed on monitors or film, analysts can extract volumes of information about the ability of an area to support waterfowl, and the information can be updated every 16 days.

In its Habitat Inventory and Evaluation Program, Ducks Unlimited is using this information to identify critical wetlands for waterfowl production; to select optimum sites for habitat enhancement projects; monitor habitat losses and habitat changes caused by drought and other conditions; and generally improve waterfowl production estimates by including habitat availability factors. ▲

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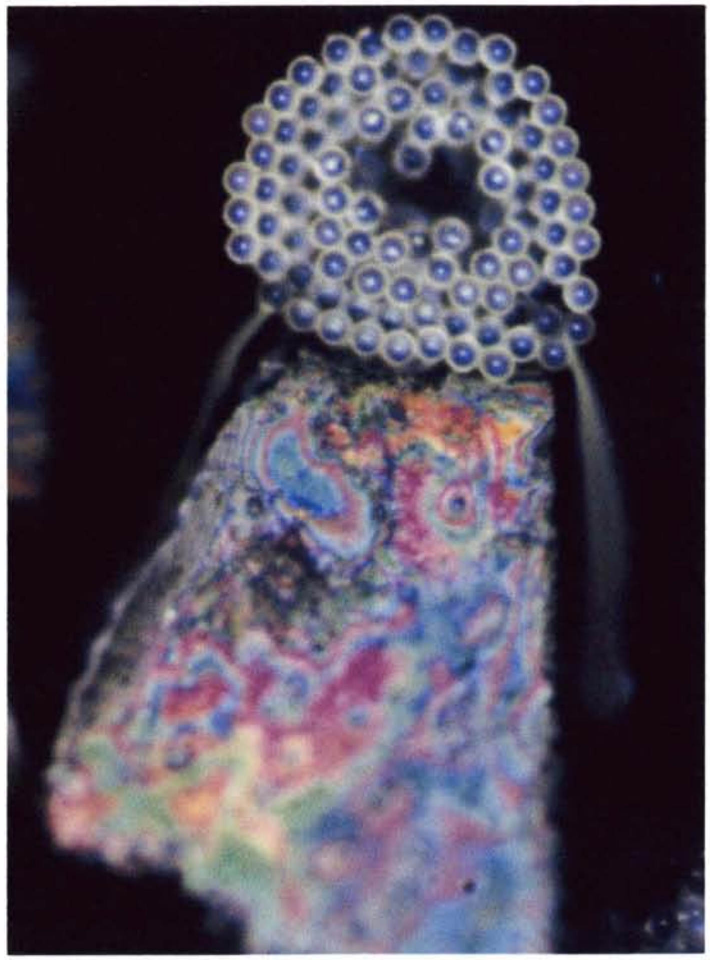
Particle Sizer

At right is a batch of microspheres, tiny plastic beads that represent the first commercial products manufactured in orbit. Part of a production run of millions of spheres made during four 1982-84 Space Shuttle flights, the beads are all perfect spheres and all of identical diameter because they were produced in the absence of gravity. Thus, they serve an important need among research and industrial laboratories as a reference standard for calibrating instruments with extreme accuracy. They are being sold for a number of applications in environmental control, medical research and manufacturing operations where there is a requirement for precise measurement of microscopic particles.

An example of how they are used is a new Aerodynamic Particle Sizer® designated APS 33B, produced by TSI Incorporated, St. Paul, Minnesota, which took the accompanying photo in a laboratory environment. TSI purchased the microspheres from the National Bureau of Standards, which certified their exact size, and the company uses them in calibration of the APS 33B instrument, latest in a line of TSI systems for generating, counting and weighing minute particles of submicron size. Such instruments are used for evaluating air pollution control devices, quantifying environments, meteorological research, testing filters, inhalation toxicology and other areas where generation or analysis of small airborne particles is required.

The APS Sensor operates on the basic principle of physics that if one can measure the speed of an accelerating particle in a known flow field, one can measure the particle's true aerodynamic size. Aerodynamic size is important in all the aforementioned applications because particles of equal aerodynamic diameter share similar characteristics; for example, they have similar probabilities of penetrating a filter, they have similar airborne lifetimes or, in medicine, they tend to deposit in similar locations of the human respiratory system. While there are other ways of sizing particles, TSI claims that the APS 33B instrument offers faster, more precise and more comprehensive measurement.

The instrument draws particles through a flow nozzle, producing a precisely-controlled, accelerating high-speed jet of air. Particle velocity is measured by a laser velocimeter. The velocity within the flow field remains constant—therefore, when particles accelerate at varying rates, it is due to size difference: small particles accelerate more rapidly, large particles more slowly. The system measures the time it takes a particle to pass through two laser beams; computer analysis of the time interval indicates the velocity of the particle under study—hence its aerodynamic size. ▲



® Aerodynamic Particle Sizer is a registered trademark of TSI Incorporated.

Particle Measurement

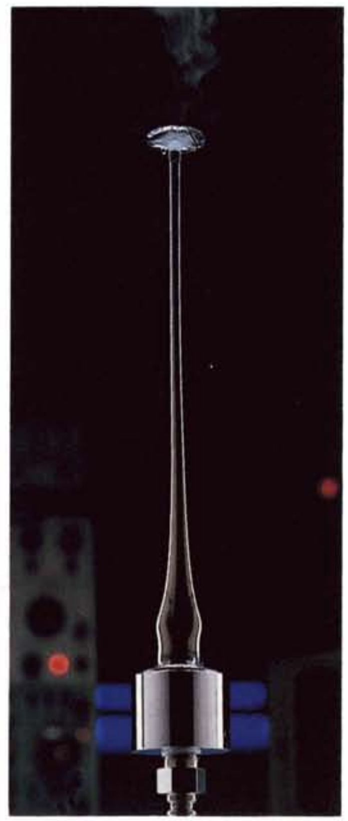
Rupprecht & Patashnick Company, Inc. (R&P), Voorheesville, New York, is a small firm whose origin stems from expertise in particle mass measurement acquired by its founders in aerospace programs. In the mid-1960s, Harvey Patashnick built a foundation for such work when he developed a method for weighing minuscule grains—"space dust"—captured in the upper stratosphere by high altitude balloons. Later, Patashnick received a contract from Martin Marietta Corporation, a NASA contractor on the Skylab orbiting laboratory project; his job was to measure the mass of ice crystals that were forming outside of Skylab and study the behavior of ice under space conditions. His contract monitor on the project was German-born scientist Dr. Georg Rupprecht. That marked the start of a collaboration in which Rupprecht and Patashnick worked together on a number of projects, including several NASA contracts, involving instrumentation for study of condensed gases under space-simulated conditions.

In the late 1970s, the two researchers formed a partnership to explore the possibilities of a supersensitive commercial instrument for direct mass measurement. The result, introduced in 1986, is the TEOM® Series 1100 Particulate Mass Monitor (right), a device that provides measurements of exceptional sensitivity and accuracy. It has applications in such areas as evaluation of diesel exhaust, dust concentration, smoke measurement and other situations wherein particulate matter in gas streams must be detected and weighed.

TEOM stands for Tapered Element Oscillating Microbalance, the most important component of which is a tapered hollow tube mounted in a protective enclosure (lower right). To measure particles in gas streams, the tapered element is set into oscillation and a microprocessor continually monitors the frequency of oscillation. A vacuum pump at the base of the tube draws the gas through a filter atop the tube. When particles become trapped in the filter, the increased mass changes the frequency of the tube's oscillation, and that frequency change enables the microprocessor to compute the mass of the particles. As additional particles collect on the filter, the TEOM measures the incremental change. The TEOM, says R&P, offers direct mass measurements of particulates that were once impossible.

R&P is applying the TEOM technology to other applications, for example, designing instrumentation for determining the coal-burning efficiency of power plants operated by New York State electric utilities. Additionally, the company is working under NASA contract on an instrument capable of weighing particles as light as a trillionth of a gram; it has potential use in comet-rendezvous spacecraft for measuring individual dust particles in a comet's tail. ▲

® TEOM is a registered trademark of Rupprecht & Patashnick Company, Inc.



Sewage Monitors

Under the Clean Water Act of 1972, the Congress mandated that every major U.S. municipality must determine how much wastewater it is processing and, more importantly, how much is going unprocessed into lakes and streams, either because of leaks in the sewer system or because the city's sewage facilities were getting more sewer flow than they were designed to handle. This prompted development, by American Digital Systems (ADS), Huntsville, Alabama, of the Quadrascan Flow Monitoring System, which met the need for an accurate method of data collection. The system consists of a series of monitoring sensors and microcomputers—typically 50 to 100—that continually measure water depth at particular sewer locations and report their findings to a central computer. This provides precise information to city managers on overall flow, flow in any section of the city, location and severity of leaks, and warning of potential overload. The system quickly gained wide acceptance.

The technology that enabled sensors and microcomputers to work reliably in the harsh environment of a sewer, subjected to slime, toxic gases and rank humidity, found a related application. Sewage treatment plant operators suggested that ADS sensors might be the answer to their problems of failed equipment, erroneous readings and clogged metering points due to the sewage environment. ADS responded with the Quadrascan 4000 Instrumentation/Process Control system which, like the sewer monitor, borrows the space technology of multiple redundancy—in this case four sensors at any one location—as a safeguard against failure or inaccuracy of any one sensor. In sewage treatment, the system's sensors measure such factors as the level in a tank, the pressure in a pipe, the temperature in a vat, the amount of contaminant in a solution and report continuously to a central computer. A quadredundant sensor package is shown below being checked out by ADS engineers. The new system has been installed in sewage treatment plants at Orlando, Florida; Houston, Texas; and Lorain, Ohio. Although initially designed for sewage treatment monitoring, it is applicable to a wide variety of industrial processes wherein key operations must be monitored and controlled.

ADS monitors represent an example of the personnel-type technology transfer, in which aerospace personnel move to other industries and apply their aerospace acquired skills to non-aerospace applications. The monitors were invented by Peter Petroff, who worked as an instrumentation designer at NASA's Marshall Space Flight Center and as an electronics specialist with aerospace companies producing missiles, satellites and commercial aircraft. In addition to the technique of quadredundancy, Petroff applied to development of his systems electronic circuitry and data collection expertise he acquired during the Apollo program and data acquisition expertise derived from his work on NASA satellites. Petroff founded ADS as a garage industry in 1975 and since then his innovative products have been installed in more than 2,000 cities. ▲

Robotic Sow

*I*n swine farming, 15 to 25 percent of piglets die before weaning and that poses a serious economic problem for hog producers. Many of the reasons for high piglet mortality center about the mother pig, or sow. Sometimes a sow will accidentally crush her piglets, sometimes she will reject or abuse a piglet. Frequently a litter is oversized and the sow cannot accommodate all her piglets for nursing. In some cases, sows are unable to nurse due to lactation disorders; in others, a sow may die while its litter is very young.

For years, people in the swine industry have tried without success to increase hog production efficiency by developing a machine that can nurse piglets from birth to weaning. In 1986, a Canadian group claimed a breakthrough with the introduction of the Farmatic Robotic Sow, manufactured by Farmatic, London, Ontario. The system incorporates NASA technology.

The Farmatic mechanical mother pig comes in two models, one with eight artificial teats (rubber nipples) and another with 16. Shortly before feeding time, the automated sow releases a prescribed amount of formula from a refrigerated compartment into a warming chamber, where the milk is heated to the desired temperature. At feeding time, a heat lamp simulating a sow's body warmth is automatically turned on and the machine emits rhythmic grunts like a mother pig summoning her piglets. As the piglets scamper to their mechanical mother, a panel across the front of the machine opens to expose the row of nipples.

The Farmatic Robotic Sow is the result of several years research at the University of Guelph, Ontario, by Dr. Frank Hurnik, who built and successfully operated a prototype system (above) with which he raised 58 piglets with only a single loss. Farmatic's research and development team then refined the University of Guelph apparatus, drastically reducing the complexity of the system and incorporating advanced electronics technology to produce a Robotic Sow that would maintain reliability in the harsh hog barn environment and operate on only 12 volts for safety (below).

NASA technology employed by Farmatic played a key role. The piglets' milk had to be cooled until used, then warmed to a precise temperature. With conventional technology, this would have required a refrigeration compressor, a coil and a supply of freon for cooling, plus a heating cable and a thermostat for heating. Use of such equipment would have involved too many mechanical parts and would not have permitted low voltage operation. Instead, Farmatic used miniature heat pumps, originally developed by NASA for satellite cooling, that have no moving parts, measure only one inch square and perform both the heating and cooling functions. ▲

Smart Houses

A sophisticated approach to home energy efficiency highlights technology transfers in energy production and conservation

The environmental control system of the Apollo lunar landing spacecraft was a masterpiece of energy efficiency. It had to be, to protect the crew from outside temperatures that ranged from 400 degrees above to 400 below zero Fahrenheit. Inside the Command Module, the three-man crew worked in a shirtsleeve environment with temperatures approximating those of a business office. This extraordinary degree of temperature control was achieved with a total energy expenditure equivalent to that of 10 150-watt electric light bulbs.

It occurred to a group of engineers who had worked on Apollo that this superefficient technology could effectively be applied to reducing energy consumption in residential and commercial buildings. From that idea, there emerged in the 1970s a new company spawned by Apollo technology—Watt Count Engineering Systems, Inc., Nashville, Tennessee—and an innovative and highly successful energy conservation technique known as the Watt Count System. Today there is a spinoff from that spinoff, another energy efficiency service that employs variations of the same Apollo-derived technology. Called the Smart House™ program, it is a joint venture of Guaranteed Watt Savers, Inc. (GWS), Charlotte, North Carolina and Smart House Consultants, Inc., Oklahoma City, Oklahoma.

Headed by Tracy Bass, GWS originated in the early 1980s as three Watt Count dealerships in North Carolina. Personally trained by Watt Count president Mike Busby, a Doctor of Engineering from Massachusetts Institute of Technology, Tracy Bass drew upon his own extensive experience as a building, heating/air conditioning and insulation contractor to modify the original technique. In 1985, he reorganized his dealerships as Guaranteed Watt Savers and the following year Smart House Consultants joined GWS as Oklahoma representative.

Like its predecessor Watt Count, the GWS design technique combines space technology, advanced building technology and an engineering systems design approach to offer dramatic reductions in home heating and cooling costs—typically, says GWS, about 50 percent or as much as $8,000 for a representative home over a 30-year mortgage span.

GWS takes plans for a new home, subjects them to intensive computerized analysis that takes into account some 10,000 calculations relative to expected heat loss and heat gain, then provides specifications—designed specifically for each structure—as to heating, cooling, ventilation and insulation. As construction on the home progresses, GWS inspects the work of the electrical, plumbing and insulations contractors and installs its own Smart House Radiant Barrier. On completion of the home, GWS technicians use a machine that creates a vacuum in the house and enables computer calculation of the air exchanged, a measure of energy efficiency. Satisfied that the home has been built to its specifications, GWS delivers—a month after owner occupancy—a five-year guarantee that energy consumption will not exceed the kilowatt-hour level determined by the computer in the energy analysis.

A key factor in the company's ability to make such guarantees is the Radiant Barrier, the main feature borrowed from the Apollo program. This is an adaptation of a highly effective aluminized heat shield used in the Apollo Command and Lunar Modules—and on other space systems—as a radiation barrier, holding in or keeping out heat, cold air and water vapor. GWS uses a barrier of aluminized polymer film that serves three purposes: as a vapor barrier; a barrier

Heating and cooling costs for this large new home at Lake Wylie, South Carolina average well under $40 a month. It is a home that has been "treated" by the Guaranteed Watt Savers Program, which employs space technology and other advanced building techniques to effect dramatic reductions in energy consumption.

to air infiltration, reducing the necessary operating time for the heating/air conditioning unit; and as a barrier to radiant heat, the major factor in home energy efficiency. The Radiant Barrier, says Smart House Consultants, will reflect away up to 95 percent of the Sun's energy.

The GWS/Smart House program extends to existing as well as new homes. Using sophisticated computerized test equipment, the company measures and reduces air infiltration and a Radiant Barrier is placed in the attic along the roof line. Smart House Consultants acknowledge that it is not possible to be as thorough on an existing home as on new construction, but no matter how old the home, it can be made more energy efficient.

GWS has applied its energy efficiency program in more than 2,000 new homes and acceptance is growing. There are now eight GWS centers in Maryland, North Carolina, South Carolina, Georgia, Oklahoma and Arizona, and by year-end 1987 the company expects to have 30 centers operating in the U.S. ▲

™ Smart House is a trademark of Smart House Consultants, Inc.

Guaranteed Watt Savers (GWS) energy efficiency measures are applicable to existing as well as new homes. The century-old Cabarrus Academy, Concord, North Carolina, a combined home and private school, had a heating bill of $700 a month; GWS cut it to less than $300 a month while improving occupant comfort.

Guaranteed Watt Savers president Tracy Bass (right) explains to GWS Houston (Texas) dealer Al Clark the function of the company's Radiant Barrier, an adaptation of an aluminized heat shield used on spacecraft.

Energy Recovery

Millions of tons of waste are generated annually in the United States and municipalities face mounting problems of disposing of the waste in an economical, environmentally safe manner. A solution widely applied in Europe and being increasingly adopted by American communities is "Waste-to-Energy," incinerating the refuse and using the steam produced by trash burning to drive an electricity producing generator.

One company specializing in Waste-to-Energy is Blount Energy Resources Corporation, a division of Blount, Inc., Montgomery, Alabama. Blount designs and builds energy recovery facilities using technology developed by Widmer + Ernst, Zurich, Switzerland. Such technology includes an innovative horizontal grate, special boiler configurations and an extra-efficient ash removal system that combine to achieve nearly complete incineration of municipal waste. An example of a Blount/Widmer + Ernest facility design is the Solid Waste Processing Project plant in San Juan, Puerto Rico shown above.

Although the basic technology applies to any facility, construction of a Waste-to-Energy plant requires a customized design for each community that takes into account such variables as the amount of waste available, power requirements, transportation patterns and seasonal fluctuations in trash availability. Blount Engineers, Inc., which handles plant design for Blount, Inc., must know how much electricity can be generated from the refuse under many different conditions of trash composition, full or part load operation, and local climate. This requires detailed computer calculations of power train balance.

For such calculations, Blount Engineers first use a Control Data computer program called Syntha III, Power Plant Design, for making preliminary calculations for the entire plant, including boilers, turbines, heaters and condensers. For the highly detailed heat balance around the turbine heat cycle proper, Blount relies on NASA's PRESTO II, Performance of Regenerative Superheated Steam Turbine Cycles. PRESTO provides the power engineers with the ability to model such features as process steam extraction, induction and feedwater heating by external sources, peaking and high back pressure. Expansion line efficiencies, exhaust loss, leakage, mechanical losses and generator losses are used to calculate the cycle heat rate and the generator output. The program is sufficiently precise that it can be used to verify performance quoted in turbine generator suppliers' proposals.

The PRESTO II software package was supplied to Blount Engineers by NASA's Computer Software Management and Information Center (COSMIC)®. A unit of NASA's technology transfer network, COSMIC collects and stores government-developed computer programs that have secondary applicability and makes them available to industrial firms and other organizations (see page 122). ▲

® COSMIC is a registered trademark of the National Aeronautics and Space Administration.

Chemistry Research

At Philip Morris USA Research Center, Richmond, Virginia (right), scientists are using a NASA-developed computer program in a study of basic chemistry, a relatively new use of computer software.

They are studying the chemical reactions of burning, which is not the fairly simple process it is generally thought to be. Cellulose and other complex polysaccharides, for example, are capable of decomposing into a variety of smaller molecules as they burn, and these smaller molecules can combine with each other in many ways. These different options are called "reaction pathways."

Combustion reaction pathways have been mapped for many small and simple molecules, but larger molecules—like cellulose—are much more complicated; they break down into many different basic compounds when subjected to various burning conditions and thus are more difficult to study. The complex reaction pathways of these larger molecules are the focus of the Philip Morris study.

In order to gain insight into the behavior of atoms as they progress along the reaction pathway, Philip Morris scientists use a computer program called CECTRP, for Chemical Equilibrium Composition and Transport Properties. Originally developed by Lewis Research Center to model rocket fuel combustion, CECTRP was supplied to Philip Morris by NASA's Computer Software Management and Information Center (see page 122).

Use of the program lets the scientists predict accurately the behavior of a given molecule or a group of molecules. The computer-generated data must, of course, be checked by laboratory experiment, but the use of CECTRP saves the researchers hundreds of hours of laboratory time, since experiments must be run only to validate the computer's predictions, not to test each variable condition. Thus, CECTRP provides savings in experiment supplies and manpower while enabling scientists to test more ideas in a shorter period of time. In addition, Philip Morris estimates that, had CECTRP not been available, at least two man-years would have been required to develop a program to perform similar free energy calculations. ▲

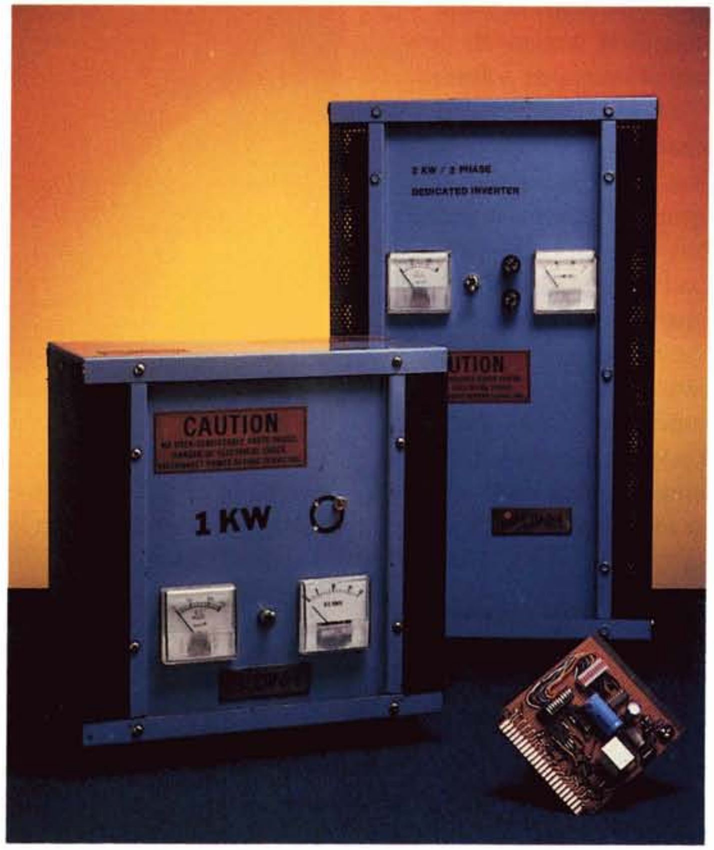
Solar Electric System

At right are three solar photovoltaic (PV) generators, terrestrial cousins to the PV arrays that have supplied electrical power for the great majority of all U.S. spacecraft. These units are part of an advanced, high efficiency, Sun-tracking PV system designed to provide sufficient electricity for all the normal functions of a home in isolated areas where there are no connecting lines to the utility company's power grid.

Developed by Dinh Company, Inc., Alachua, Florida, the system is operating at a lakeside home in Micanopy, Florida, which is remote from any power grid; the property owner elected to try PV power rather than pay the heavy cost of building a link to the utility's grid. The installation is a test system intended to prove a concept developed by Khanh Dinh, president of Dinh Company, under a technology utilization contract with NASA's Kennedy Space Center (KSC).

Photovoltaic conversion, in which arrays of solar cells convert sunlight directly into electricity, has demonstrated its potential as an alternative energy source in more than a thousand specialized Earth-based applications. Years of research by NASA and the Department of Energy have effected substantial reductions in the cost of PV power, but it is still too expensive for widespread Earth applications, except those where no conventional power source exists—for example, remote automated weather stations, sea-based navigational buoys, forest stations and third world villages.

Khanh Dinh undertook to develop a PV system that could bring solar electricity to the individual home at reasonable cost. His system employs high efficiency PV modules plus a set of polished reflectors that concentrate the solar energy and enhance the output of the modules. Dinh incorporated a Sun-tracking system derived from space tracking technology employed at KSC; it automatically follows the Sun throughout the day and turns the modules so that they get maximum exposure to the solar radiation, further enhancing the system's efficiency.



The generator being tested at Micanopy produces an average 20 kilowatthours of electricity daily, an amount sufficient to run a refrigerator, a freezer, a well pump, lights, appliances, TV and partial air conditioning.

Since PV-produced electricity is direct current (DC), it can easily be stored in batteries and used at any time. Some electrical equipment, such as incandescent lamps, can use DC current; other equipment, such as appliances with induction motors, requires use of an inverter to produce AC current from the batteries. Unable to find suitably reliable and efficient inverters in the commercial marketplace, Dinh developed his own, for which he claims efficiencies of more than 95 percent and very low manufacturing costs. At left below are Dinh-developed inverters of one kilowatt and two kilowatt capacity.

Included in the new inverters is another application of NASA technology: heat pipe technology originally developed as a means of cooling space electronic systems. In the PV generator system, heat pipes cool the power transistors; cooling is necessary to assure proper operation and prevent damage to the inverter. The photo at right shows a power transistor connected to one of the heat pipes; the spiral ribbing of the pipe dissipates heat along the entire length of the pipe and into the atmosphere, providing, according to Dinh, a cooling technique of "unsurpassed efficiency."

The whole PV generator system, says Khanh Dinh, "represents a stand alone power plant that can be installed anywhere in the world at a cost that compares favorably with that of small diesel generators."

In addition to the PV system, Dinh Company is associated with NASA on an application engineering project intended to apply space-developed heat pipe technology to the problem of controlling humidity in buildings located in warm, humid climates. In such areas, moisture removal remains a persistent problem, not only for personal comfort but for proper storage and functioning of costly equipment. A one-time specialist in heat pipe research, Khanh Dinh advanced the idea of a heat pipe-based dehumidifier as a promising, cost-effective approach to the problem. Under contract to KSC, he developed an experimental air conditioner/dehumidifier employing heat pipe technology. The system is undergoing test at several Florida sites. Meanwhile, Dinh has developed a second generation unit for general residential applications; he is shown with the new system at right. ▲

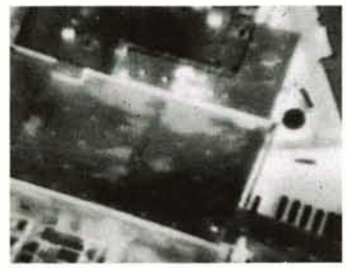
Infrared Scanning

At right is a twin-engine Piper Aztec with an infrared scanning system mounted beneath its nose section; the FLIR 2000A Night Vision System is shown in closeup at right center. The scanner-equipped Aztec is operated by Midwest Infrared Scanning Service (MISS), Galesburg, Illinois, which provides Aeroscan™ infrared thermography services to industrial clients.

Infrared thermograpy, to use the MISS description, "is a relatively new non-contact, non-destructive inspection and testing tool which makes temperatures visible to the human eye." Generally, infrared scanning devices produce images that show—by color or black-and-white shading differences—heat losses through damaged or inadequately insulated walls and roofs. The MISS Aeroscan services are designed to take the guesswork out of industrial roof maintenance and provide companies big savings by identifying the location of moisture damage from roof leaks, effectively targeting maintenance attention. This negates the possibility of missing damaged areas in simple visual inspection, or of needlessly repairing and replacing undamaged roof areas. At far right is an Aeroscan thermogram in which the bright spots identify areas of suspected moisture damage.

Roof-level moisture surveys by thermography experts using hand-held infrared systems are available to industry, but Aeroscan offers a cost advantage, according to MISS; the service is relatively inexpensive because the company can accomplish a number of roof evaluations on a single airplane flight. Says the company: "Typical fees can be one-fourth the cost of a roof-level survey."

Infrared technology dates all the way back to World War II, but accelerated development of infrared imaging systems occurred in the 1960s and 1970s under the combined impetus of military missile guidance requirements and NASA development of space sensory systems. Use of infrared imaging for roof-scanning began in the 1970s, when the Army Corps of Engineers investigated the technique and found it to be a



reliable and cost effective means of locating moisture-damaged roof insulation at Army facilities. At about the same time, with the oil crisis at its peak, Lewis Research Center pioneered infrared roof survey as a national energy conservation measure. Lewis conducted aerial demonstrations, making thermograms that measured heat loss from home and industrial rooftops and pinpointed buildings that were losing excessive heat. The Lewis program heightened awareness of the technology and spurred commercial use of airborne, roof-level and ground-mobile infrared scanning.

In addition to roof evaluations, MISS offers thermographic inspection of underground steam distribution systems and a variety of ground-based infrared inspection services to detect interior heat loss in buildings; indicate maintenance needs for electrical equipment, mechanical systems and piping; and locate deteriorating areas in road beds and bridge decks. ▲

™ Aeroscan is a trademark of Midwest Infrared Scanning Service, Inc.

Image Processing

In the upper photo, GeoSpectra image processing specialists are working on a TOPOIMAGE™, a highly accurate topographical map developed from a new GeoSpectra computer program. At right below is Dr. Robert K. Vincent, founder and president of GeoSpectra Corporation, Ann Arbor, Michigan, a company formed specifically to transfer NASA-developed remote sensing technology to natural resource companies.

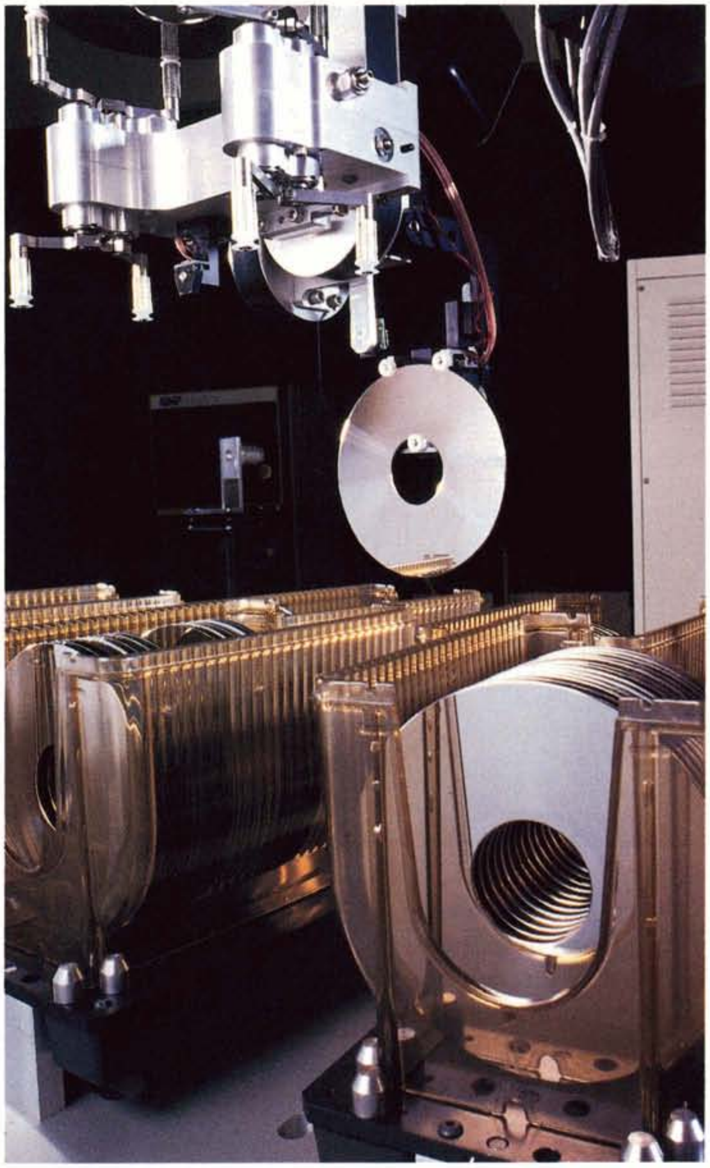
Vincent, once a principal investigator on NASA's Landsat 1 resources survey satellite, wrote his Ph.D. thesis on multispectral scanning and later—in March 1974—founded GeoSpectra with $1,100 borrowed from a credit union. Today, GeoSpectra is a highly successful firm offering many types of image products, usually with interpretive geological exploration studies, to petroleum and mining companies. The company has accomplished a wide range of survey programs for such companies as ARCO, Bendix, Coastal Oil and Gas, Exxon, Getty Oil, Phillips Petroleum, Sun Oil, Texaco and Total Petroleum.

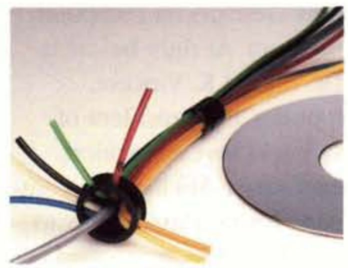
A new spinoff product derived from the company's expertise in processing Landsat data in a software package called ATOM™—for Automatic Topographic Mapping—which is capable of digitally extracting elevation information from stereo photos taken by airborne or spaceborne cameras. ATOM, says the company, offers a new dimension of realism in applications involving terrain simulations; it produces extremely precise maps of an area's elevations in less time and at less cost than traditional methods. ATOM has a number of applications in defense training simulations and also offers utility in architecture, urban planning, forestry, petroleum and mineral exploration. GeoSpectra has concluded an agreement with Litton Industries, one of the

largest aerospace companies, for joint marketing of ATOM and ATOM-related products for non-civil applications. ▲

™ TOPOIMAGE and ATOM are trademarks of GeoSpectra Corporation.

Tangleproof Coupling





For use in a satellite, Marshall Space Flight Center developed a unique rotary coupling capable of connecting a large number of electrical cables to a turntable without stressing the cables or tangling them. The device accommodates 246 cables and allows the turntable to rotate through an arc of 320 degrees. At the extremes of rotation, the cables remain loose enough so that they are not pulled taut and overstressed; at halfway rotation, the cables are not so loose that they tangle. The rotary connector was developed to carry electrical signals to and from a telescope platform on the satellite without employing a complex set of slip rings, which are electrically noisy and could have caused signal interference.

Details of this technology were described in an issue of NASA *Tech Briefs*, a publication intended to let potential users know what NASA-developed technologies are available for transfer (see page 118). Engineer Eugene F. Duval, then with Phase 2 Automation, a Palo Alto, California company manufacturing robotic systems for industry, saw a use for the tangleproof rotary coupling technology; he applied the basic concept in designing connections for multiple hoses and wires in a robot manipulator joint. The joint is part of a proprietary gripper in Phase 2 Automation's CAS-100 Certifier Automation System for handling rigid disc media. The gripper is a high efficiency device for transferring discs to and from cassettes and disc testing machines; it is shown above holding the doughnut-shaped disc. The tangleproof coupling, normally not visible because it is inside the robot arm, is the tiny device between the fingers of the hand in the top right photo, shown in closeup at right above. ▲

Pile Driving

A marine-oriented structural engineering firm, TERA, Inc., Houston, Texas, is engaged in a project to evaluate the reliability of offshore pile driving prediction methods, a step toward an eventual capability for predicting the best pile driving technique for each new offshore oil platform. TERA is conducting the evaluation in behalf of seven offshore oil rig operators: Chevron Corporation, Conoco, Inc., Marathon Oil Company, McDermott International, Inc., Mobil Oil Research and Development Corporation, Pennzoil Company and Shell Oil Company. The upper right photo shows an offshore pile driving operation; at lower right is a working offshore platform.

In Phase I of the project, TERA digitized the pile driving records of 48 offshore platforms, including such information as blow counts, soil composition and pertinent construction details. In Phase II, the pile driving records were statistically compared with current methods of prediction. The result of the work was development of modular software that participating companies can use to evaluate other prediction procedures or other data bases.

TERA, Inc. was aided in its software development by the software package CRISP80, Software Design Analyzer System. Originally developed for Jet Propulsion Laboratory, CRISP80 was supplied to TERA by NASA's Computer Software Management and Information Center (COSMIC), which makes available to industrial clients government-developed computer programs that have secondary applicability (see page 122). Dr. E.A. Verner, principal of the project, reports that CRISP80 was very valuable in construction of TERA's Pile Driving Predictability Program and a real bargain: "A similar program would have cost around $15,000. At $400, CRISP80 was a good buy."

For the first five years, TERA's Pile Driving Predictability Program will be distributed only to project sponsors. The software will help determine an unknown in wave equation methods: soil resistance and behavior as a stress wave travels down the pile. The data base contains information on more pile driving influences than can be accounted for by present theories; eventually, TERA hopes to expand the program to account for more of these influences. ▲

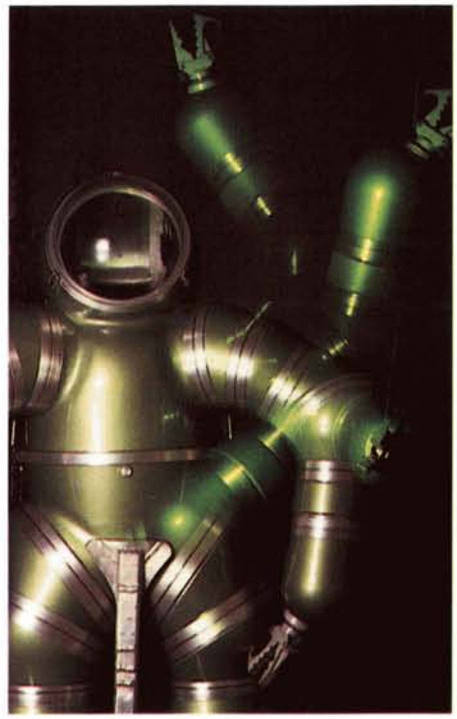
Space Technology for Deepwater Divers

Among a selection of spinoffs that contribute to enhanced public safety is an ocean diving system that promises new underwater efficiency

Many of the tasks involved in underwater inspection and maintenance of offshore oil rigs are complex and must be accomplished by human divers rather than automated systems. But some underwater assignments require divers to reach depths of 1,000 feet. At that depth the diver's mobility is severely limited; he waddles along the ocean floor in a "hard shell" suit that may weigh half a ton or more, his leg and arm motion sharply restricted by mechanical joints sealed against the crushing pressure of the deep. The work is at best arduous, at times dangerous.

Phil Nuytten hopes to change all that with his "Newtsuit." Nuytten is president of Can-Dive Services Ltd., North Vancouver, British Columbia, which is developing the Newtsuit with help from NASA technology that originated in the mid-1960s, when Ames Research Center was conducting design studies of hard shell pressure suits capable of providing protection against meteorites for future lunar colonists. Can-Dive acquired a number of reports on Ames' developments and incorporated in the Newtsuit NASA technology relative to space suit design and human ergonomics, or man/machine relationships.

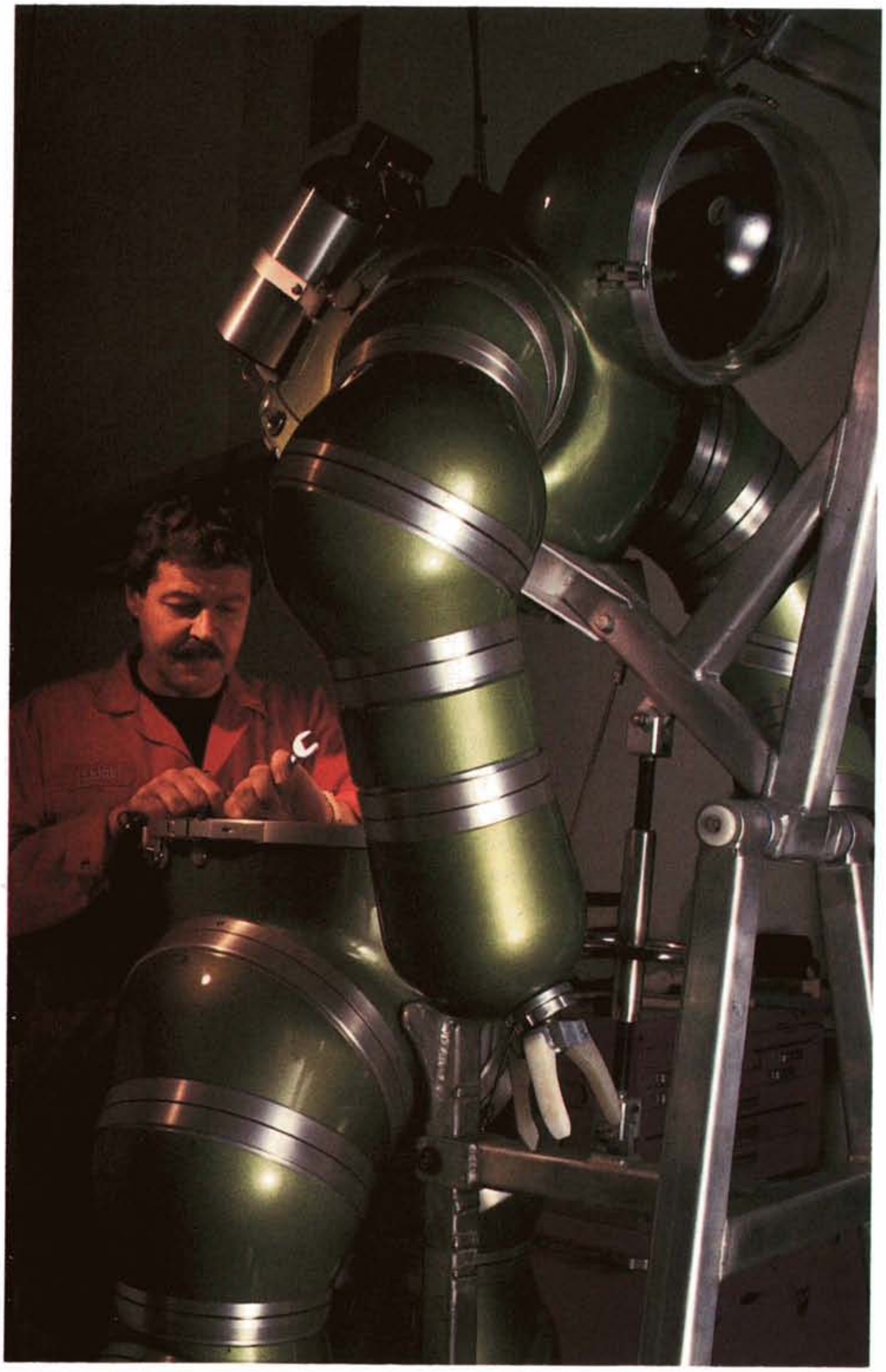
The Newtsuit offers several features that the Canadian company feels will be attractive to both divers and their employers. Although it is a hard shell—armored—suit, it is a relatively light 400 pounds, made of aluminum; future Newtsuits may be made of carbon fiber composite material that is lighter yet stronger than steel. It has a constant pressure of one atmosphere, meaning that the pressure all the way down to the suit's 1,000-feet limit will be the same as on the surface. The Newtsuit, like a space suit, has a self-

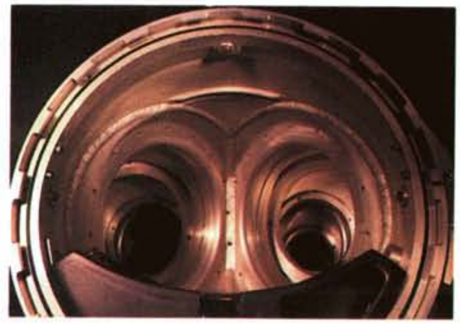


The Newtsuit, a deepwater diving system that incorporates NASA technology developed for "hard shell," meteorite-proof space pressure suits. A major feature is mobility provided by fluidic joints; the multiple exposure photo illustrates the exceptional range of movement the joints allow.

contained backpack breathing system with a duration of 48 hours. And it employs a series of patented low friction fluidic joints designed to make underwater motion easier and permit 75 percent normal human mobility.

The combination of design features promises manifold advantages in safety, efficiency and economics. A dive to 700 feet under ambient pressure would require that the diver spend five days or more in a decompression chamber to avoid the decompression sickness known as "the bends." With a constant one atmosphere pressure, that need is eliminated. That's not only a safety factor, it has economic implications for the oil rig operator; divers are paid not just for underwater time but for total task time, including the time they spend in compression/decompression chambers.



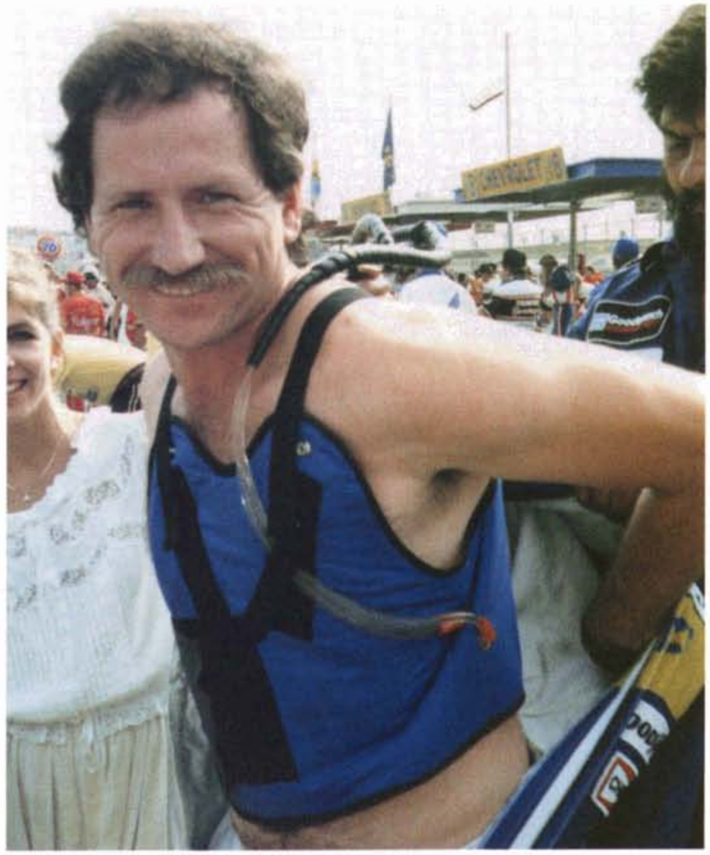


At left, the Newtsuit is shown in open position preparatory to diver's entry. The technician is adjusting a rebreathing device that cleans air for reuse. The above photo is an interior view of the bottom half of the seat, showing the leg wells and the joints that permit knee bending.

The Newtsuit also offers extended "bottom time," limited only by diver fatigue, and compressed mission time; a maintenance task that might otherwise take a week, counting chamber and underwater time, can be accomplished in a day.

Can-Dive has been working on the Newtsuit for three years and it is still in research and development status but scheduled for advanced operational trials this year. This development could eventually prove to be a full-circle spinoff, one that transfers *from* aerospace technology and eventually generates technological advances transferrable *to* aerospace systems. NASA is studying space suit designs for extravehicular activity associated with the Space Station, for astronaut servicing of high orbit platforms and for 21st century establishment of colonies on the moon and elsewhere in the solar system. Phil Nuytten feels that much of the technology he is developing and some other ideas still in the conceptual stage might prove useful in the development of advanced space suits. ▲

Cool Suit



It gets pretty hot in a racing car. The powerful engine is, of course, the big heat contributor but there are other factors, such as aerodynamic design measures that detour cooling air away from the cockpit. Temperatures in the cockpit of 130-140 degrees Fahrenheit are not unusual and an actual thermometer reading at one race last year showed an astonishing 215 degrees. At such temperatures, driver's elevated body temperatures can cause fatigue, dehydration and even collapse.

So more and more drivers are taking to "cool suits"—helmet liners and/or body vests through which a fluid circulates, cooled by a refrigeration unit and pumped through tubes to the garments. At lower right, Ayrton Senna, winner of the 1986 Detroit Grand Prix is tightening a helmet liner while a member of the pit crew attaches the connection to the cooling unit. In the upper photo, Dale Earnhardt, 1986 NASCAR Winston Cup champion, shows off his cool vest. Their Carlson Personal Cooling Systems, which are based on aerospace technology, are supplied by Carlson Technology Inc., Livonia, Michigan, a company that specializes in customized cooling systems for auto, boat and airplane racing teams.

Motor racers tried for years to find an effective method of body cooling but early systems were unreliable and too heavy and bulky for race car use. Dennis Carlson, president of Carlson Technology, sought to develop an effective system after a driver blacked out in the 1978 Brazilian Grand Prix. He learned of cool suit research performed by Ames Research Center and a contractor, Acurex Corporation. Under contract to Ames, Acurex developed a heat-stress alleviating liquid-cooled helmet liner for military pilots after a series of accidents in Vietnam had suggested heat exhaustion as the cause. The system, which pumped a cooled fluid through channels in the helmet liner, proved effective in eliminating 40-60 percent of stored body heat.

In 1980, William Elkins, a key developer of the cooling system as an Acurex employee, left the company to form Life Support Systems, Inc., Mountain View, California. LSSI supplies helmet liners and vests to Carlson Technology. The latter company customizes a complete interior cooling system, including hardware, controls and other components tailored specially to the requirements of the user. Acceptance of the Personal Cooling System is growing, says Dennis Carlson, as is the number of success stories. Last year the winners of 12 major racing championships used Carlson cooling systems; in one race alone—the 1986 Talladega 500—there were 24 Carlson systems in use, compared with five in the prior year. ▲

™ Cool Head is a trademark of Life Support Systems, Inc.

Structural Diagnosis

All over the world, officials charged with preservation of historical structures are faced with a growing problem: environmental contamination of building materials that causes structural deterioration. A first requisite to preserving the structures is identification of the nature of the contaminants, such as salt or moisture. The conventional method of doing that is laboratory analysis of core samples of materials suspected of contamination. That method is used sparingly, however, because core sampling can damage the structures.

A "non-invasive" technique, based on space technology and capable of being carried out with commercially available equipment, has been developed and tested by a group of Maryland scientists: Dr. Jacob I. Trombka of Goddard Space Flight Center; Dr. Larry G. Evans of Computer Sciences Corporation (CSC), Silver Spring, Maryland; and Richard A. Livingston of the University of Maryland's Geology Department.

First used to analyze lunar soil, the procedure stems from NASA technology developed for on-site planetary exploration by unmanned spacecraft. It employs a neutron source and a gamma ray detector. Placed on one side of the wall to be examined, the source fires neutrons created by the decay of a radioactive isotope. As they pass through the wall, the neutrons collide with atoms and the atoms—depending on their type—emit various kinds of gamma rays. These rays are identified by the gamma ray detector on the other side of the wall. The energy of the rays shows the kind of element present; the intensity level indicates the quantity. The composition of the contaminants within the walls is determined by a multichannel analyzer.

In the upper photo, CSC's Dr. Evans (left) is positioning the neutron source on one side of a demonstration wall while a University of Maryland graduate assistant positions the gamma ray detector on the other side. In the lower photo, the university's Richard Livingston (left) and Dr. Trombka are using the multichannel analyzer to determine the nature of the contaminants within the wall.

The Maryland trio first tested the procedure successfully on an 18th century smokehouse in Colonial Williamsburg, Virginia. Subsequently, at the invitation of a group of Italian conservation scientists, they used it to analyze contaminants at St. Mark's Basilica and Gradenigo Palace in Venice. The technique provided the Italians with their first solid information on conditions inside the Basilica's walls, which contain priceless mosaics.

The structural diagnosis procedure is still in an early stage of development. However, say its developers, "no major research and development is required before it can be used routinely." ▲

Shuttle Technology for Earth Laboratories

An analytical system that incorporates Space Shuttle thermal tiles heads a sampling of spinoff advances in industrial productivity and manufacturing technology

In the first decade of U.S. space flight, protection of manned spacecraft from the searing heat of re-entry was provided by heat shields made of material that literally burned away. The burning dissipated the energy of atmospheric friction as the spacecraft plunged Earthward and thus reduced heat buildup on the spacecraft itself. The heat shields on Mercury, Gemini and Apollo spacecraft performed flawlessly—but they were good for only a single flight.

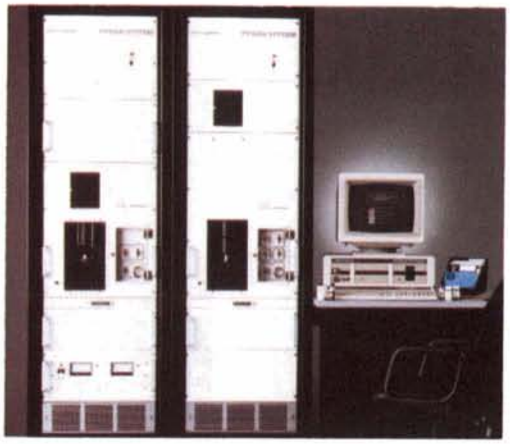
With the advent of the reusable Space Shuttle, there was need for a new system to protect the Orbiter and its occupants from re-entry temperatures as high as 2300 degrees Fahrenheit. NASA sought a material that could withstand heat greater than that of a blast furnace yet survive repeated heating and cooling without need for replacement. Years of research provided an answer: the "thermal tile," developed for NASA by Lockheed Missiles & Space Company. Made of a silica fiber insulating material, the tiles cause heat on their surfaces to dissipate rapidly while heat transfer to the inner areas of the tiles is extremely slow, the key to repeated-use Shuttle shielding. The material is cut and formed in some 34,000 shapes and sizes to fit the Orbiter's contour.

The extraordinary insulating characteristics of the tiles led to their use in a recently introduced spinoff application, the Pyran™ System produced by Ruska Instrument Corporation, Houston, Texas, a company which has been engaged for more than 50 years in the manufacture of precision pressure calibration instruments and petroleum reservoir fluid analyzers. Ruska states that the PYRAN System represents a major advancement in control of pyrolysis, the technology of subjecting organic materials to selected temperatures to break them down into their component parts, and that the system offers capabilities hitherto unavailable.

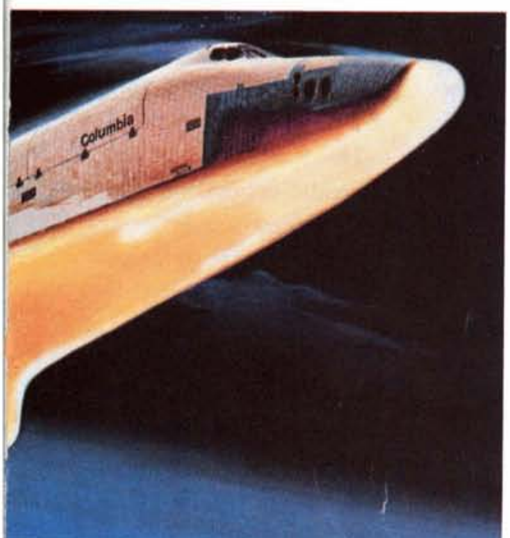
The PYRAN System is designed for rapid, automated analysis of the composition of organic matter. It is capable of heating samples to 1130 degrees Fahrenheit with infrared heat at a precisely controlled rate in a carefully controlled atmosphere. In order to do this with the degree of control and repeatability desired, the developers of the PYRAN System decided they would need a special type of material to insulate the heating chambers. Ruska scientists conferred with Lockheed and Johnson Space Center thermal experts and these consultations resulted in Ruska's adoption of Space Shuttle tiles for the difficult insulating job. Purchased from Lockheed, the tiles provide the superior insulating characteristics needed and they can be readily cut and formed to fit the heating chambers.

Ruska's first PYRAN System sales were to petroleum industry laboratories for analysis of geochemical samples. The company has since found broadening interest among general analytical laboratories for analysis and quality control of such things as forensic evidence, polymers, catalysts, chemical warfare agents, tobacco products, cosmetics, pharmaceuticals and foods.

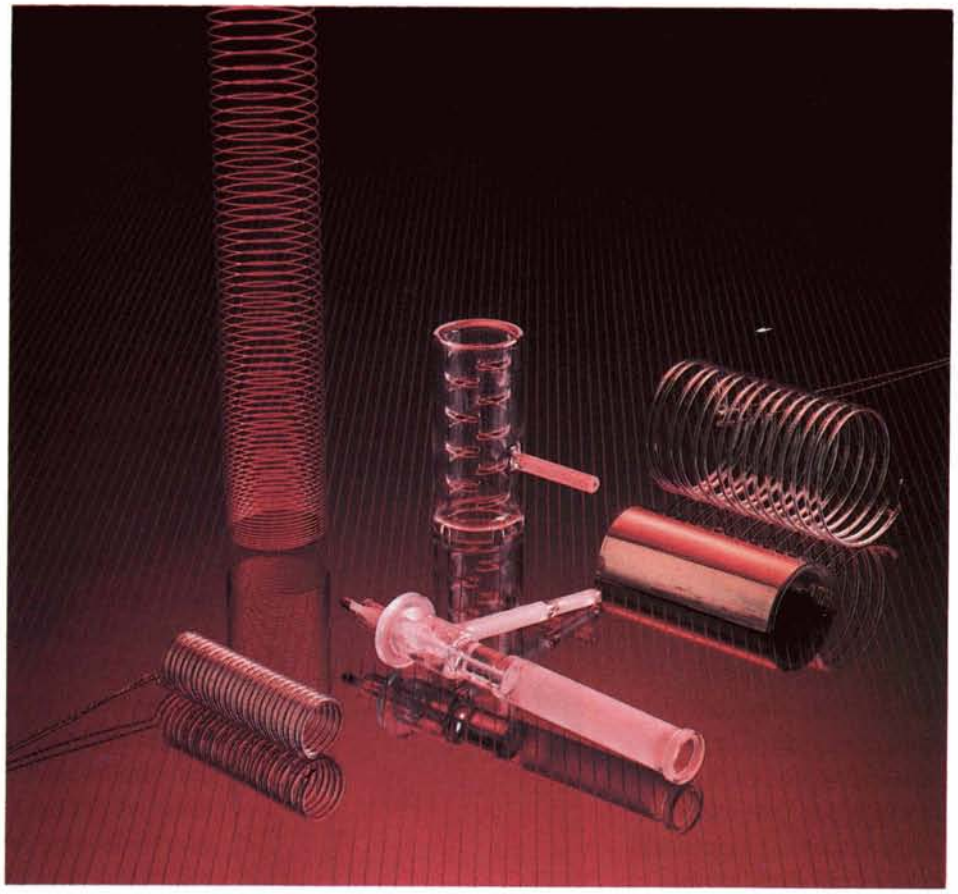
An interesting sidebar: the PYRAN System, which did not exist at the time NASA's Apollo astronauts acquired samples of moon rock and soil, was recently used to check those samples. They are stored in special airtight containers; the PYRAN System was used to ensure that the lunar material was not being contaminated by organic material used in the storage process. ▲



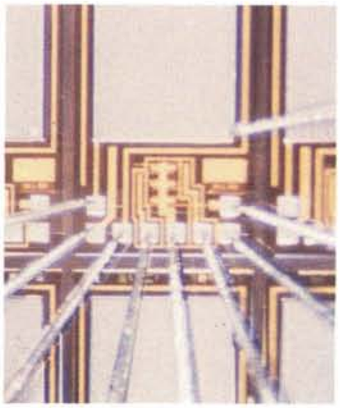
Among spinoff applications of the Shuttle tile material is the Pyran System (above), a high temperature system for laboratory analysis of organic materials. The tile material provides the superior insulation characteristics essential to protection of the system's fused quartz components (below).



An artist's concept shows how the underside of the Space Shuttle Orbiter heats up to more than 2,000 degrees Fahrenheit during re-entry. The temperature of the aluminum airframe however, never exceeds 350 degrees, due to a protective system—a thin glass skin supported by silica fiber tiles—that dissipates more than 90 percent of the heat energy. The rapid dissipation of heat from the tile's surface is illustrated at left, where an engineer is holding barehanded a tile removed only seconds earlier from oven heat of 2400 degrees.



Cure Monitoring

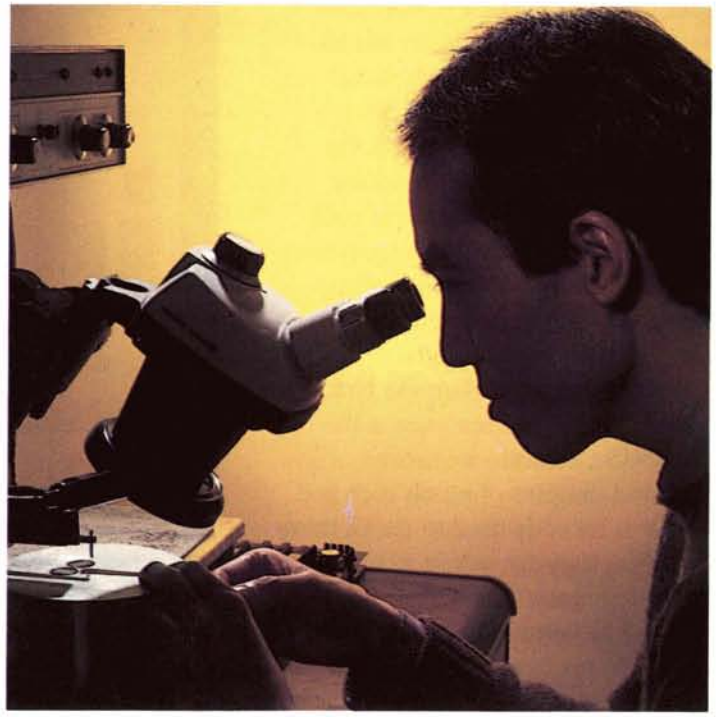


Microdielectrometry is definitely not a household word and few can define it, but it is a technology of growing importance at a time of rapidly increasing use of composite materials in high performance military and commercial products. Composites, invariably lighter and usually stronger than the metals they replace, are sheets of woven fibers impregnated with a matrix of resin or other material. A vital step in their manufacture is the curing process, which is critical to the strength, quality and consistency of the product.

That's where microdielectrometry comes in. Its principal application is monitoring the chemical changes that take place when resins, adhesives and plastics are cured or processed, for example, measuring the behavior of the resins used to bind fiber reinforced composites for aircraft, spacecraft or jet engines—in other words, providing information that enables precise control of the curing process for optimum results.

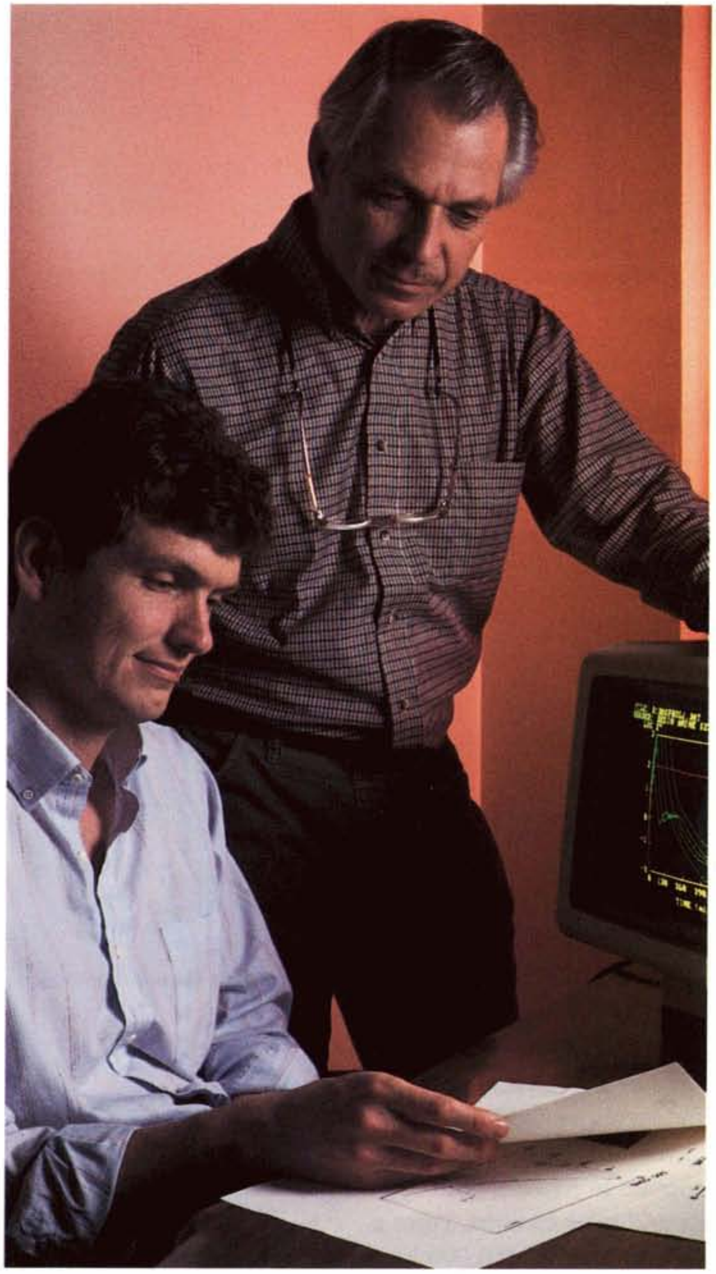
Micromet Instruments, Inc., Cambridge, Massachusetts, manufactures the Eumetric System II Microdielectrometer, key to which is a miniature electronic probe—a silicon microchip—that contains electrodes and circuitry for measuring the electrical properties of whatever material is placed in contact with the electrodes; the microchip, magnified 15 times, is shown at left. The rest of the system consists of additional sensors, electronic components, microcomputer modules and software.

In composite curing, usually carried out in autoclaves, large pressure vessels that can be heated to as much as 800 degrees Fahrenheit, the microdielectrometer is used to probe the resins as they cure in the autoclave. The sensors communicate data to the system's computer about the chemical changes occurring. At left below, Micromet's Dr. Huan Lee is preparing a test of a polymer resin, dipping a ribbon sensor in the resin; the large black box is the Eumetric System II Microdielectrometer. Above, Lee is using a microscope to position the silicon microchip on the ribbon and at center right engineers are studying the results of the test.



The instrument is also used in quality control laboratories to verify the properties of new batches of materials and in research laboratories to investigate the cure behavior of new materials. At far right, Dr. Brenda Holmes, research scientist at the Naval Research Laboratory in Washington, D.C., is using the microdielectrometer to study the cure characteristics of a polymer network.

The System II Microdielectrometer and the art of microdielectrometry trace their roots to NASA's Technology Utilization Program. Principal inventor of the technology is Stephen D. Senturia, a professor of electrical engineering at Massachusetts Institute of Technology (MIT). During the early 1970s, Senturia served as a consultant to a NASA technology utilization contractor seeking to develop urban applications for NASA technology, in particular a project involving development of an advanced home fire alarm. The consulting group found potential utility in research performed by Dr. Norman Byrd of McDonnell Douglas Corporation who, investigating safety devices for spacecraft, had been working on



polymeric thin films that would change their electrical properties when exposed to hazardous gases.

NASA funded two contracts to explore this potential, one with McDonnell Douglas for additional polymer research and another with MIT under which Senturia was to seek new methods of measuring electrical properties with an eye toward developing low-cost components of a home fire alarm. In the course of this contract, Senturia invented the "charge-flow transistor," a microchip for measuring the electrical properties of thin polymer films. A direct ancestor of the microdielectrometer, the first successful device was built at MIT in 1976.

The NASA contract failed to produce a commercial product but Senturia continued his work under sponsorship of the Office of Naval Research and the National Science Foundation; ultimately, with the aid of others at MIT, he developed the present microdielectrometer. In 1982, Senturia and four colleagues obtained a license from MIT for the technology and founded Micromet Instruments. The technology is finding wide acceptance among government agencies, aerospace firms, chemical and electronic companies. ▲

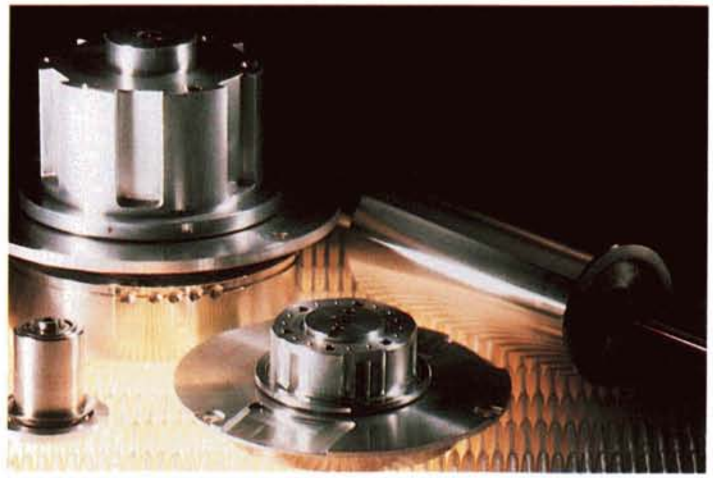
Magnetic Liquids

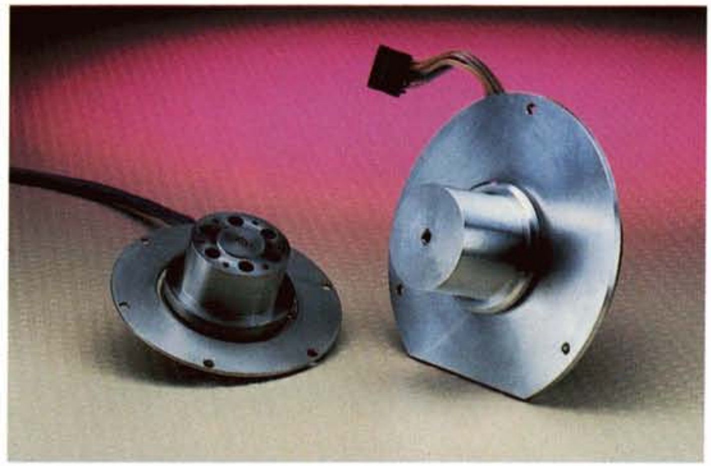
Ferrofluids are magnetic liquids that do not exist in nature; they are man-made substances that originated in space technology, fluids in which tiny particles of iron, nickel, cobalt or their alloys have been suspended. The material thus created can be positioned and controlled by magnetic force—and that offers unique advantages in a growing range of ferrofluid applications.

A recent ferrofluidic innovation is a spindle for rotating computer discs that supports the disc's rotating shaft on a film of magnetic fluid instead of conventional ball bearings. The spindle, according to its developers, offers greatly increased rotational stability, meaning substantially reduced vibration and mechanical noise, and non-repeatable runout, thus allowing disc drives to store two to 10 times more information.

The spindle is produced by SPIN Technology, Nashua, New Hampshire, a subsidiary of Ferrofluidics® Corporation of the same city. The latter company was formed in 1969 to develop and market the ferrofluid concept, which had its genesis at Lewis Research Center in the early days of the space program. Looking for a means of feeding weightless fuel to the engine of an orbiting spacecraft, a Lewis scientist hit upon the idea of magnetizing the fuel by dispersing within it finely ground particles of iron oxide; the fuel could then be drawn into the engine by a magnetic source. NASA never applied the concept to that problem but it surfaced again in the mid-sixties—at Avco Space Systems Division—as a possible means of controlling the temperature of a spacecraft. Again ferrofluids was bypassed in favor of another solution.

However, two of the Avco scientists—Dr. Ronald Moskowitz, now president of Ferrofluidics, and Dr. Ronald Rosensweig—saw great commercial potential in ferrofluids, obtained a NASA license for the technology and formed Ferrofluidics Corporation. They found an initial commercial application in a zero leakage, non-wearing seal for the rotating shaft of a system for making semiconductor "chips." The ferrofluidic seal solved a persistent problem—contamination due to leaking seals—and sparked widespread interest in the new technology. Use of ferrofluids in rotary shaft seals has increased rapidly and the great majority of computer memory disc drives also employ magnetic fluid exclusion seals. In the top photo are fluid film bearings in a variety of sizes and configurations; examples of ferrofluid bearings used in disc drives are shown above. Additionally, ferrofluids are now being applied in robotic, fiber optic and laser systems. From a sales volume of $65,000 in its first year of operation, Ferrofluidics has grown to a $30 million dollar a year company operating in six countries. ▲





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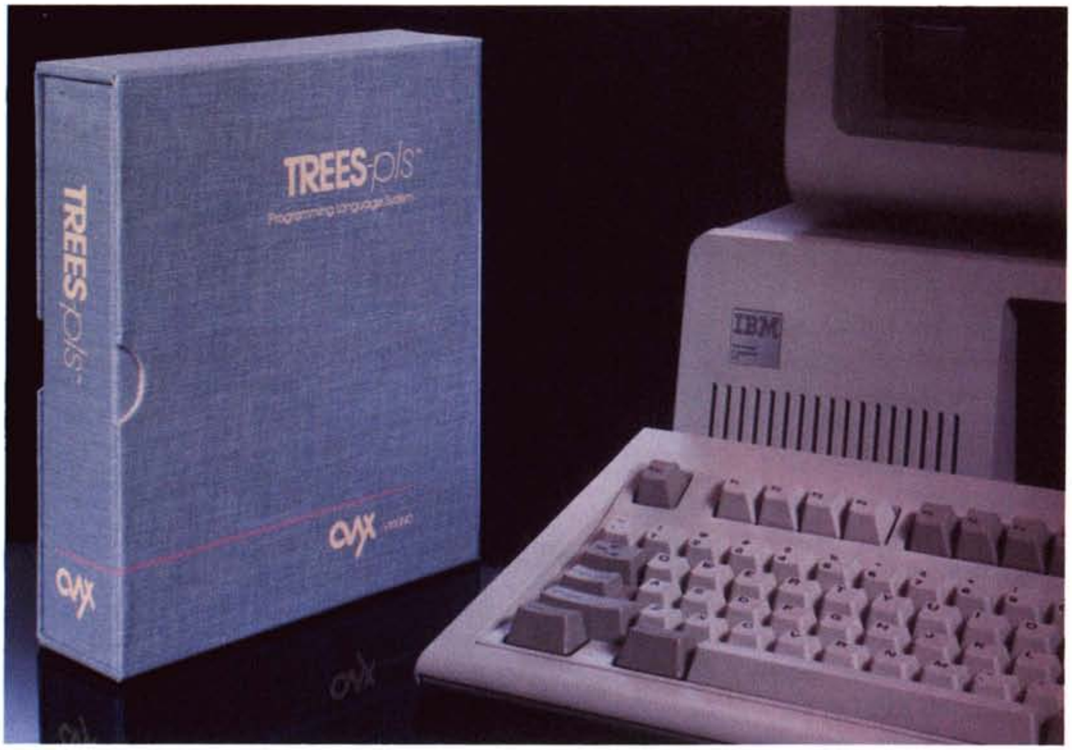
Management Tools



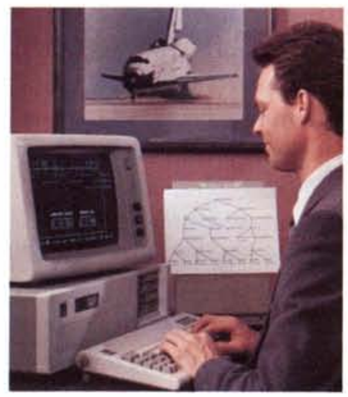
A recently-formed company, AVYX, Inc., Englewood, Colorado has introduced a new programming language for IBM and IBM-compatible computers. Called TREES-pls (right), it is a resource management tool that can be used in such applications as scheduling, resource allocation, project control, information management and artificial intelligence.

TREES-pls is a NASA spinoff and so, in fact, is AVYX, Inc. This is one of many examples wherein not only a product line but the company itself owes its existence to aerospace technology transfer. TREES-pls is a commercially-available microprocessor version of a programming language originally developed for NASA use. AVYX is an offshoot of Information Sciences, Inc. (ISI), formed in 1981 to provide computer-related services to NASA and other government agencies, such as computerized activity scheduling and the application of artificial intelligence to complex resource management problems. ISI technology is currently being used for scheduling Space Shuttle flights, which will resume next year, for deep space tracking network activities, and for designing operational concepts for communications satellites.

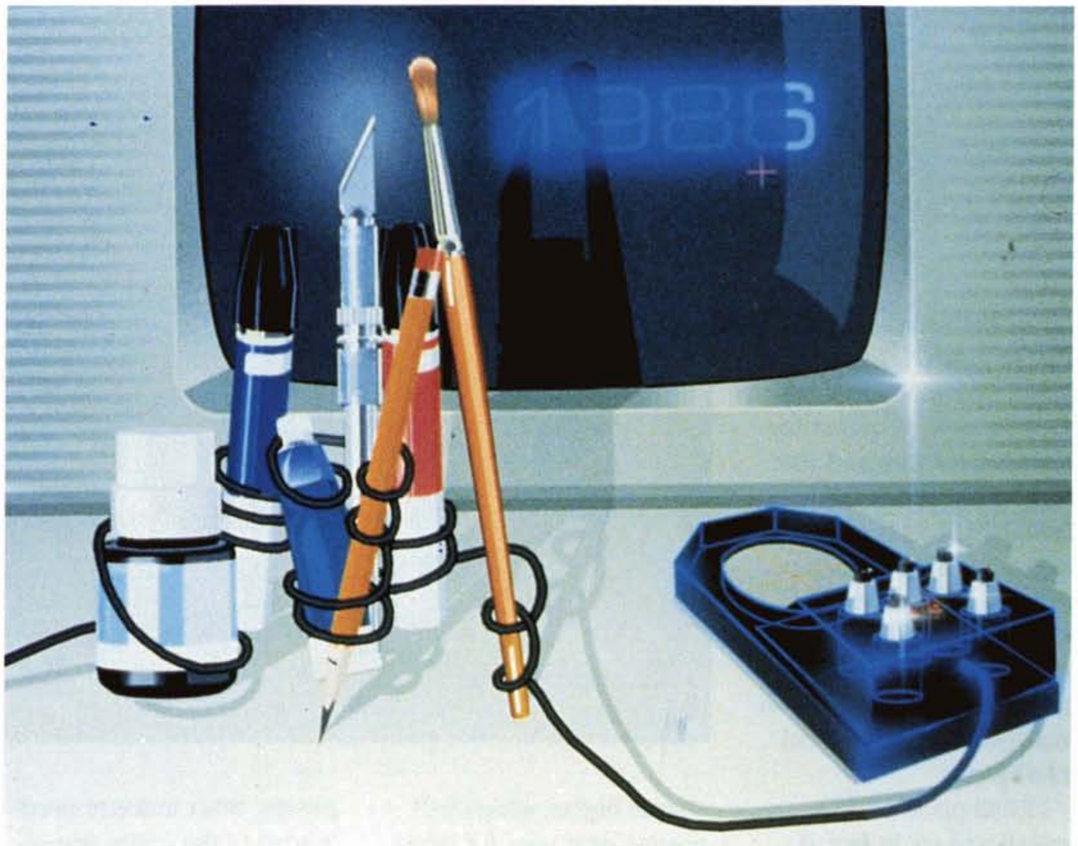
In 1984, co-founders John Willoughby and Jo Anne Gardner saw a commercial market for the technology and services ISI had been providing NASA: developing advanced tools for more efficient management of resources—people, dollars, machines—by industry. They created a common logical architecture that can be applied to solving any type of activity scheduling problem and founded AVYX. ISI has become the research and development arm of AVYX and TREES-pls is the first commercial product of the new firm.

AVYX activity scheduling tools seek to maximize utilization of resources, eliminate industrial bottlenecks and curb idle time expenses. What industry needs instead of the costly one-of-a-kind solutions to activity scheduling problems employed in the past, says AVYX president John Willoughby, is "a flexible tool that can be applied to many problems with minimal adaptation. TREES-pls is a cost-effective answer; it can save up to 80 percent of programming costs."

Willoughby adds that "TREES-pls and future AVYX products are most appropriate for industries and companies that are incurring significant resource management costs." Among the non-government markets AVYX is initially targeting are aerospace, other manufacturing, transportation, health care, food and beverage, and professional services. ▲



Business Graphics



At right is an example of the high quality graphics that can be imaged on the MASTERPIECE 8770 ™ FilmRecorder, an advanced high resolution system designed to improve and expand a company's in-house graphics production. The artwork in the smaller photo exemplifies the type of business graphics that can be generated on personal computers through use of the GRAFTIME ™ software package, designed to allow office personnel with minimal training to produce professional level graphics for business communications and presentations.

Both MASTERPIECE 8770 and GRAFTIME are products of Genigraphics® Corporation, Liverpool, New York, a high technology company whose first commercial products were rooted in technology developed for NASA. Genigraphics serves the international market with an extensive line of business presentation and graphic arts systems, together with high performance digital film recorders. In addition, Genigraphics operates a Network Services Division employing more than 150 artists who translate customer ideas into graphics. Operating from 24 locations in the U.S., the division produces more than 1.5 million visuals a year for some 8,000 clients.

A pioneer in the computer graphics industry, Genigraphics began life—in the late 1960s—as the Genigraphics Product Section of General Electric Company. The division's first product was a computer graphics system developed for NASA for use in space flight simulation. The technologies thus developed provided a foundation for the company's expansion into the commercial market; a refined version of the NASA development became the Genigraphics Series 1000 computer graphics system, introduced commercially in the mid-1970s. In August 1982, Genigraphics was sold to its current management and to two venture capital firms. NASA is still a user of Genigraphics systems but the customer base has expanded enormously and annual revenues now top $60 million. ▲

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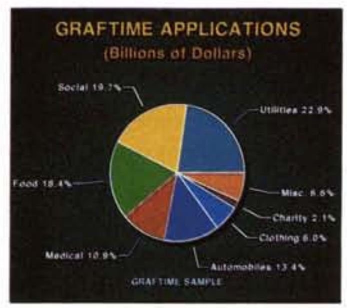
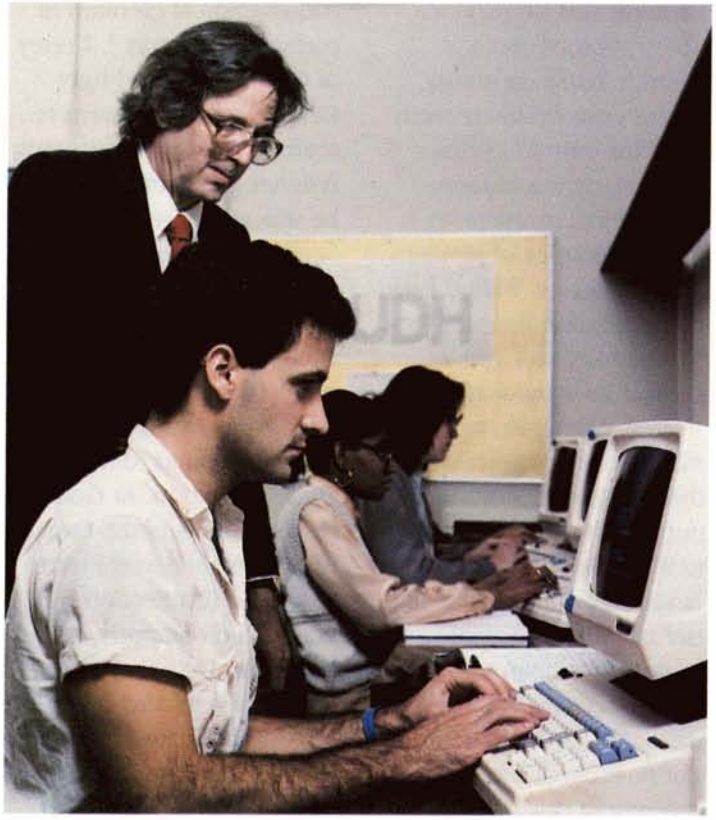


Computer Reliability



Computer programs developed by NASA and other government agencies have many potential applications other than their original purposes. To help computer users reduce automation costs by taking advantage of this resource, NASA's Computer Software Management and Information Center (COSMIC) collects, screens, stores and distributes programs that have secondary applicability. For the most part, COSMIC's customers are industrial firms and the applications are in industrial research and development or manufacturing technology. But often COSMIC finds unusual applications in such fields as medicine, meteorology or education. An example is the use of a NASA-developed program by Dr. J. Walter Bond at California State University, Dominquez Hills, who is creating a course in computer reliability modeling.

The course will examine three different computer programs, one of them NASA's CARE III, the others UCLA's ARIES 78 and ARIES 82. All three programs are designed to help estimate the reliability of complex, redundant, fault-tolerant systems. In computer design, software of this kind can predict—or "model"—the effects of various hardware or software failures, a process called reliability modeling.

The three programs have strong similarities, but they also have many differences. By assigning the same set of problems to each of the programs and analyzing the differences, students will be better able to understand the subtleties of programming. They will then investigate the "dynamic modeling" approach to computer reliability analysis, employing failure simulation techniques to assess the behavior of an entire system. This approach enables diagnosis of the cause of a computer failure by pinpointing the effects of the failure of various components, and it allows students to see where a problem is statistically expected to arise.

Dr. Bond's course is not purely theoretical. Eventually, the students' work will be incorporated into a software package that addresses the redundancy management of a computer system based on VLSI (Very Large Scale Integration) or VHSIC (Very High Speed Integrated Circuits). The underlying aim is development of advanced reliability modeling tools that would help assess future failure rates of sealed chip devices; this can contribute to a new generation of ultrareliable computers by allowing action to be taken during the design phase to provide extra redundancy where needed. ▲

Self-locking Fasteners

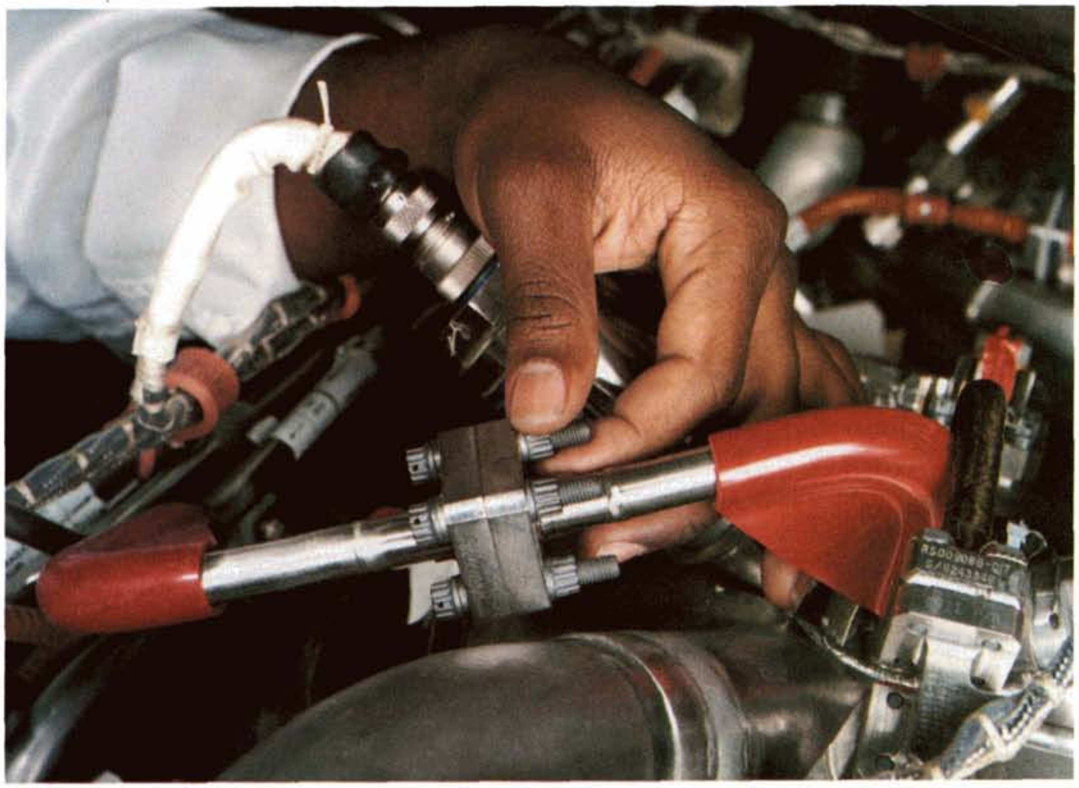
The Space Shuttle Main Engines (SSME) generate some 400,000 pounds of thrust and are subjected to tremendous vibration during the launch phase of a Shuttle flight. It follows that the fasteners—nuts and bolts, for instance—that attach joints, brackets, tube clamps and other parts must be capable of withstanding severe stress and vibration, and they must also be capable of repeated reuse, as is the SSME. Each SSME now uses 757 Spiralock™ fasteners made by Kaynar, a division of Microdot Aerospace Fastener Systems, Fullerton, California. These fasteners offer a number of technical advantages over the fasteners they replaced, in particular improved stress/vibration resistance and a 50-cycle reuse capability, where prior fasteners were good for only 15 cycles.

Spiralock is a fastener thread form invented by Horace Holmes of Holmes Tool Company, Walled Lake Michigan, and licensed to Kaynar Microdot and to Detroit Tool Industries, Warren, Michigan, which manufactures a Spiralock threading tool. Holmes set out to solve a major industrial problem, the matter of fasteners coming loose under vibration. Loosening is caused by vibration-induced lateral movement between the flanks of the bolt and nut threads; this lateral movement releases the locking friction that holds the joint together.

The Spiralock solution is a uniquely-designed female thread form which, used with male fasteners of standard thread form, provides a self-locking action that prevents the lateral movement and thus makes the threaded joint highly resistant to the effects of vibration. Additionally, thread contact runs the entire length of the nut, offering greater stress resistance than earlier fasteners.

Spiralock is not a conventional type of spinoff, because it is not based on NASA technology. It is, however, an example of technology transfer in that NASA's exhaustive testing of Spiralock for Shuttle use, and the resulting analyses and reports, made an important contribution to greater industry understanding of the complexities of fastening mechanical devices. The contribution is credited in particular to James J. Kerley of Goddard Space Flight Center for his extensive research on the self-loosening fastener problem, in which he was aided by Northrop Services test engineer Carol Jones. Kerley served for several years with the American Society of Mechanical Engineers (ASME) Subcommittee on Loosening Mechanisms of Bolted Joints Under Vibration. At Goddard, Kerley and the Structural Dynamics and Electromagnetic Test Section conducted comprehensive tests of Kaynar Microdot Spiralock nuts and several types of bolts under most severe vibration. The tests demonstrated that the fasteners would not "back off," or loosen, even when vibrations were applied 10 times as strong and 10 times as long as Space Shuttle specifications. Kerley's work, which went beyond Spiralock nuts and examined in depth the factors involved in generic fastener failure, was described by P.P. Zemanick, chairman of the ASME subcommittee, as "a valuable block of research into the phenomenon of threaded fastener self-loosening in a vibratory environment."

The Spiralock thread form has found wide acceptance in applications where fasteners are subjected to heavy vibrations and it has proved a problem-solver for many firms. An example is the experience of Chevron U.S.A.'s West Texas Production Division. At upper left is an oil production site beside which J. R. Butter, a Chevron production foreman, is holding a Spiralock rod coupling. On four wells, rod string failures were occurring two to three times a year. Each failure required pulling the rod string up to the surface, at a cost of



$1,000-2,000 per occurrence plus, typically, replacement of three to five couplings and rods.

Butter decided that the fault was in the stress concentration of the threads of the standard type of rod coupling. He substituted Spiralock couplings, mated to the same type of rods previously used, on the four problem wells. After the strings had been down for a year, no failures of any type had been experienced; according to Butter, at least one and probably all four strings would have failed within the year if standard rod couplings had been used.

At left below is a truck-mounted seismic vibrator, manufactured by Litton Resources Systems, Alvin, Texas, used to generate subsurface ground vibrations for oil exploration and other geophysical investigations. Reliability of the vibrators was substantially improved by substitution of Spiralock for standard thread joints and fastener failures in field operations were sharply reduced.

Another application is illustrated at right, an angle-of-attack sensor used in the Boeing 757 and 767 jetliners. The sensor continually measures the angle between the chord—the fore to aft line—of the jetliner's wing and the direction of the airflow; the monitored data provides warning of impending stalls and also helps enhance fuel economy. Produced by Rosemount Inc., a subsidiary of Emerson Electric Company, Minneapolis, Minnesota, the sensor employs about 50 Spiralock fasteners to insure reliability in the severe stress and vibration environment in which the system operates. Additionally, use of Spiralock simplifies maintenance by negating the need to stock special types of fasteners earlier used and by eliminating special assembly procedures.

In addition to these examples, the Spiralock thread form is used in such diverse applications as intercontinental missiles, military fighter aircraft, automobiles and trucks. A closeup of an automotive application is shown in the top photo. ▲

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Technology Utilization

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

Putting Technology to Work

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

The wealth of aerospace technology generated in the course of NASA programs 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. But such secondary applications do not happen automatically; it takes an organized effort to put the technology to work in new ways and to reap thereby a dividend on the national investment in aerospace research.

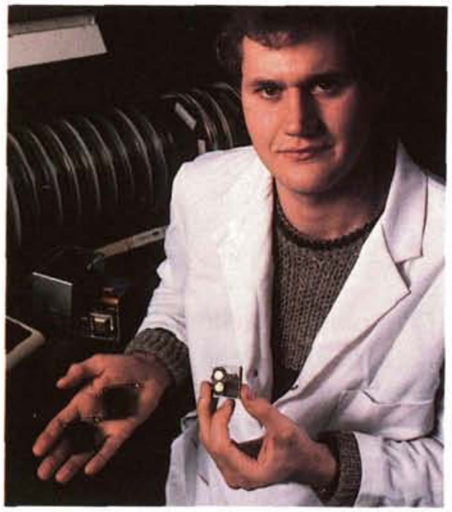
NASA's instrument for accomplishing that objective is the Technology Utilization Program, which employs several types of mechanisms intended to broaden and accelerate the transfer of aerospace technology to other sectors of the economy. An important mechanism is the process of "getting the word out"—letting potential users know what NASA-developed technologies are available for transfer. That job falls principally to *NASA Tech Briefs*.

Published since 1962, *Tech Briefs* is a current awareness medium and problem tool for more than 100,000 government and industry readers. Each of its 10 issues a year 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 100,000 such requests are generated annually.

An example of how *Tech Briefs* spreads the word and inspires secondary uses of NASA technology is a case involving a solar dosimeter, a miniature integrating light meter originally developed by Langley Research Center for measuring accumulated radiation in the ultraviolet and other regions of the spectrum. A group of researchers at the University of Cincinnati Medical Center was conducting a study of the effect of sunlight exposure on maintaining Vitamin D status in infants. Vitamin D is acquired from dietary sources or from skin stimulation by ultraviolet light. The Cincinnati team wanted to learn how much Vitamin D was obtained by exposure to ultraviolet, important in the care of breast-fed infants who are not receiving supplements, because breast milk has little Vitamin D content. To quantify sunshine exposure in study infants, volunteer mothers were to keep a diary recording the time each day the infant was outdoors. For scientific accuracy, the group needed a way of double checking the diaries.

One of the group read an article in *Tech Briefs* describing the solar dosimeter, followed up by requesting a Technical Support Package from Langley Research Center and by conferring with Langley officials. The University of Cincinnati Medical Center then sought and received a NASA license for use of the technology and the Center's engineering group modified the dosimeter for the Vitamin D study; they made it tamper-proof by sealing it, made it more durable and reduced its size for easy wear by infants. Some 70 units were fabricated.

In the ensuing investigations, readings from the solar dosimeter correlated well with the sunshine diary data recorded by participating mothers. The study provided valuable information on the sunshine exposure/Vitamin D relationship, including the fact that Vitamin D concentrations in the blood of infants correlated directly with the degree of sunshine exposure, and that infants were able to maintain Vitamin D concentrations within normal ranges with weekly sunshine exposures of 30 minutes to two hours.



At left, a researcher holds an infant wearing a dosimeter that records accumulated solar radiation, part of a study by the University of Cincinnati Medical Center on the relationship of Vitamin D and solar ultraviolet light. Above, a member of the study team displays the Medical Center's version of the dosimeter, specially modified for the study.

Available to scientists, engineers, business executives and other qualified technology transfer agents in industry or government, *Tech Briefs* is the primary 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 number almost 4,000 (the latter publication can be purchased from the National Technical Information Service, Springfield, Virginia 22101).

NASA's Technology Utilization Program is managed by the Technology Utilization Division, an element of the Office of Commercial Programs. Headquartered in Washington, D.C., the division coordinates the activities of technology transfer specialists located throughout the United States.

In addition to the publications, other mechanisms employed in the program include Technology Utilization Officers, located at each of NASA's nine field centers, who serve as regional program managers; a network of user assistance centers that provide information retrieval services and technical help to government and industry clients; applications engineering projects, efforts to solve public sector problems through the application of pertinent aerospace technology; and a software center that provides, to industry and government clients, computer programs adaptable to secondary use. These mechanisms are amplified on the following pages. ▲

An adult wearer of the dosimeter is given a dosage of ultraviolet in a light chamber in a related University of Cincinnati Medical Center investigation of the Vitamin D/skin pigmentation relationship. The study team learned of the dosimeter through NASA Tech Briefs, *one of several transfer mechanisms employed in NASA's Technology Utilization Program.*

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.

The IAC network is now undergoing expansion, with the 1986-87 initiation of agreements linking the IAC system with technology oriented technical 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, geographically 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.

Through the application centers, clients of the combined network have access to nearly 100 million documents contained in the NASA data bank and more than 400 other computerized data bases. The NASA data bank 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 some 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 data banks to start the process of getting the client the specific help he needs from the best source.

State-sponsored centers in seven Western states have added the RISS capability and have concluded cooperative arrangements with NASA whereby they will work in concert with NASA IACS; they have been designated NASA Industrial Applications Center Affiliates. Similar introduction of RISS capabilities and cooperative linkages between IACs and state-sponsored centers are being developed in the Plain States and the Midwest. By midyear 1987, NASA was cooperating with or discussing linkage agreements with 24 states.

An example of how the industrial assistance network operates is the help provided Chatham Manufacturing Company, Elkin, North Carolina by one of the IACS—the North Carolina Science and Technology Research Center (NC/STRC), Research Triangle Park, North Carolina.

Chatham Manufacturing produces fabrics for blankets (above), furniture, auto interiors, wearing apparel, rugs and carpets, and other products. Chatham R&D, the research and development division of the company, was experiencing a problem with its looms: rapid oscillation of a rocker arm assembly was accelerating metal fatigue and causing fractures in the metal, a significant problem due to the high cost of replacing parts.

Chatham R&D sought problem-solving assistance from NC/STRC. The IAC conducted a computer search of the NASA data base and produced a number of reports on metal fatigue and crack propagation. The NASA-provided literature not only shed light on the basic cause of the metal fatigue, but it also suggested a remedy: improving stress resistance of the metal by "shot peening," a technique in wide aerospace use. Shot peening involves bombarding a part with a high velocity stream of very small shot, which act like thousands of tiny ball peen hammers pounding and compressing the surface of a part (at right, the silvery parts of a loom have been peened by the tiny shot seen on the fingers). Chatham has since peened all moving parts of its machines and failure elimination has resulted in annual savings on the order of about $250,000.

Another example is the help provided Raymond Engineering, Inc., Middletown, Connecticut, by the New England area IAC, NERAC, Inc., Tolland, Connecticut. Raymond's Power-Dyne® Division produces specialized bolting and torquing

equipment. In recent years, Power-Dyne has expanded its bolting capability through development of a line of sophisticated tools and instruments for producing and controlling high torques affecting bolted joints in military, petrochemical, nuclear power, automotive and other applications. Two examples are pictured: at upper right a worker is using an ultrasonic bolt gage for monitoring bolt tension; at lower right, another worker is using a wrench attachment known as a blind flange adapter, used where there is no adjacent structure to provide a torque reaction point.

Raymond Engineering credits NERAC with a supporting role in development of the advanced Power-Dyne bolting tools and in expanding the company's general technology base. NERAC conducted a series of worldwide literature searches of the latest bolting technology, aiding company development of the bolting tools by identifying unfilled technical needs and by providing information that helped define better specifications for Raymond Engineering products. The NERAC effort also contributed to expansion of the company's own computerized bank of information on bolted joints. ▲

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Software Center

Spurred by the need to improve business efficiency in today's highly competitive economic environment, thousands of companies each year are joining the ranks of computer users. In the interests of national productivity, NASA is helping these newcomers to computerization—along with longtime computer users who are expanding their information processing operations—by providing a way to effect significant reduction of automation costs: use of already developed computer programs that have secondary utility.

NASA and other technology generating agencies of the government make extensive use of computers and have of necessity developed many types of computer programs. Although they may long since have served their original purposes, these programs are still a valuable resource because frequently a program developed for one purpose can be adapted to a totally different application with little or no modification. 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 at far less than the cost of developing a new program.

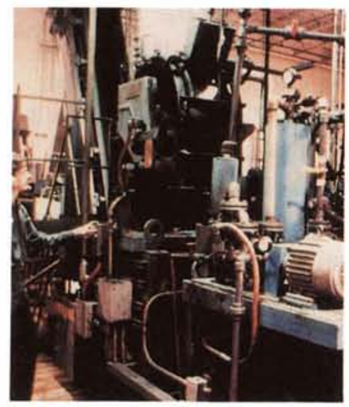
NASA's mechanism for making such programs available to the private sector is the Computer Software Management and Information Center (COSMIC)®. Located at the University of Georgia, COSMIC gets a continual flow of government-developed software and identifies those programs that can be adapted to secondary 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 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 Chrysler Corporation's use of a computer program originally developed by NASA's Lewis Research Center. Chrysler, which has one of the world's largest computer systems, uses computer technology to create vehicle body designs, including panels, steering geometry, suspension and other systems. The imagery pictured at left was part of a seating study for the Chrysler LeBaron GTS, which is shown in its final configuration at lower left. To optimize the design of the outer body panels of cars and trucks, Chrysler uses the Lewis-developed SPAR (Structural Performance and Design) program. SPAR's advantage is that it is interactive, easy to use and fast. It is used to solve relatively small problems when quick response is important; other programs provide the necessary structural analysis for large problems.

Another example is the work of Advanced Fuels Technology (AFT), Cleveland, Ohio, which has developed an economical process for "cleaning" coal, making it environmentally acceptable by removing 85 percent of the mineral sulphur and 75 percent of the ash. Coal thus cleaned provides more energy with less variability in burning characteristics; it also provides better boiler performance and reliability while reducing air pollutant emissions. In the top photo is the control room of AFT's pilot plant at Bridgeport, New Jersey, where coal development work is conducted; at right is a ball mill that grinds the coal in preparation for cleaning.

In the course of its coal-cleaning technology development, AFT-Bridgeport tested unclean slurry against clean slurry to determine the amount of sulphur and ash that would be allowable. To evaluate the products left after combustion—solid, liquid and gaseous materials—AFT employed a COSMIC computer program that provides specific capabilities for determining the products of combustion. AFT reported a saving of four man-months that would have been required to develop similar software had the COSMIC program not been available.



To assist prospective customers in locating potentially useful software, COSMIC publishes an annual indexed catalog of all the programs in the Center's inventory. Available on microfiche, computer magnetic print tape or in hard copy form, the catalog may be purchased directly from COSMIC. The Center also helps customers define their needs and suggests programs that might be applicable. For further information on COSMIC's services, contact the director at the address in the directory that follows. ▲

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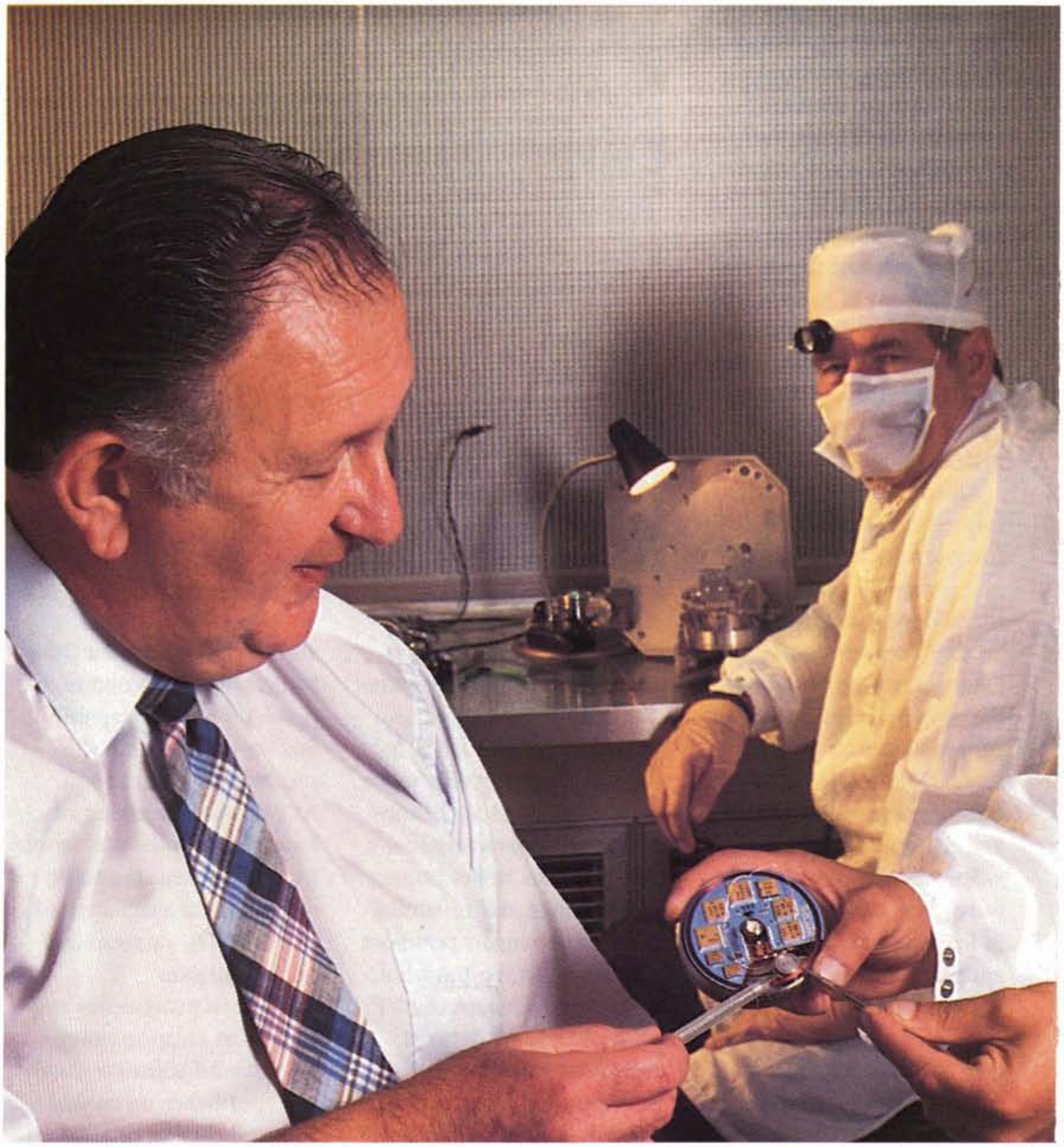
Technology Utilization Officers



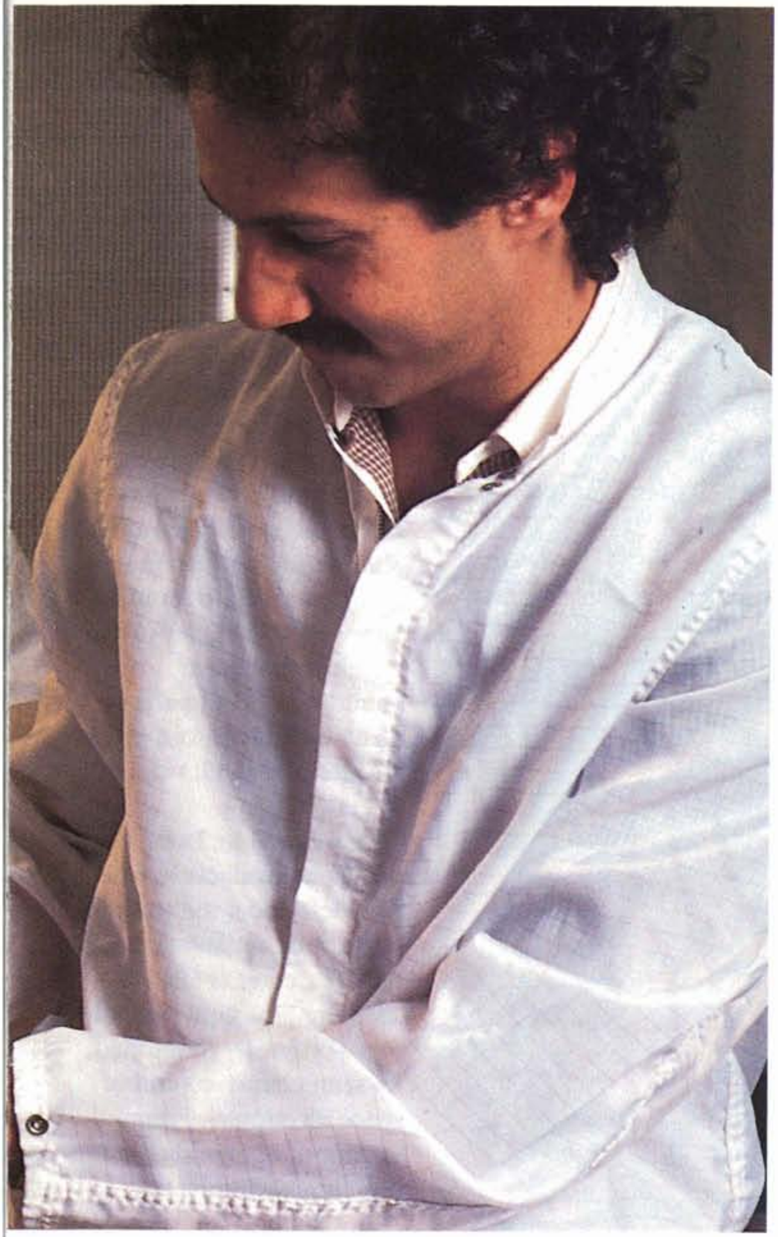
An important element among the NASA mechanisms for accelerating and broadening aerospace technology transfer is the Technology Utilization Officer, or TUO. TUOs are technology transfer experts at each of NASA's nine field centers and at one specialized facility who serve as regional managers for the Technology Utilization Program. At right the TUO at Goddard Space Flight Center (left) is conferring with Goddard technologists about an implantable device for continuous, computer-directed delivery of medication within the human body.

The TUO's basic responsibility is to maintain continuing awareness of research and development activities conducted by 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 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 use.

To advise potential users of the technology's availability, the TUO evaluates and processes selected new technology reports for announcement in NASA publications and other dissemination media. Prospective users are informed that more detailed information is available in the form of a *Technical Support Package.*

The TUO also serves as a point of liaison between industry representatives and personnel of his center, and between center personnel and others involved in applications engineering projects, 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 other federal agencies and industrial firms.

NASA conducts, independently or in cooperation with other organizations, a series of conferences, seminars and workshops de-



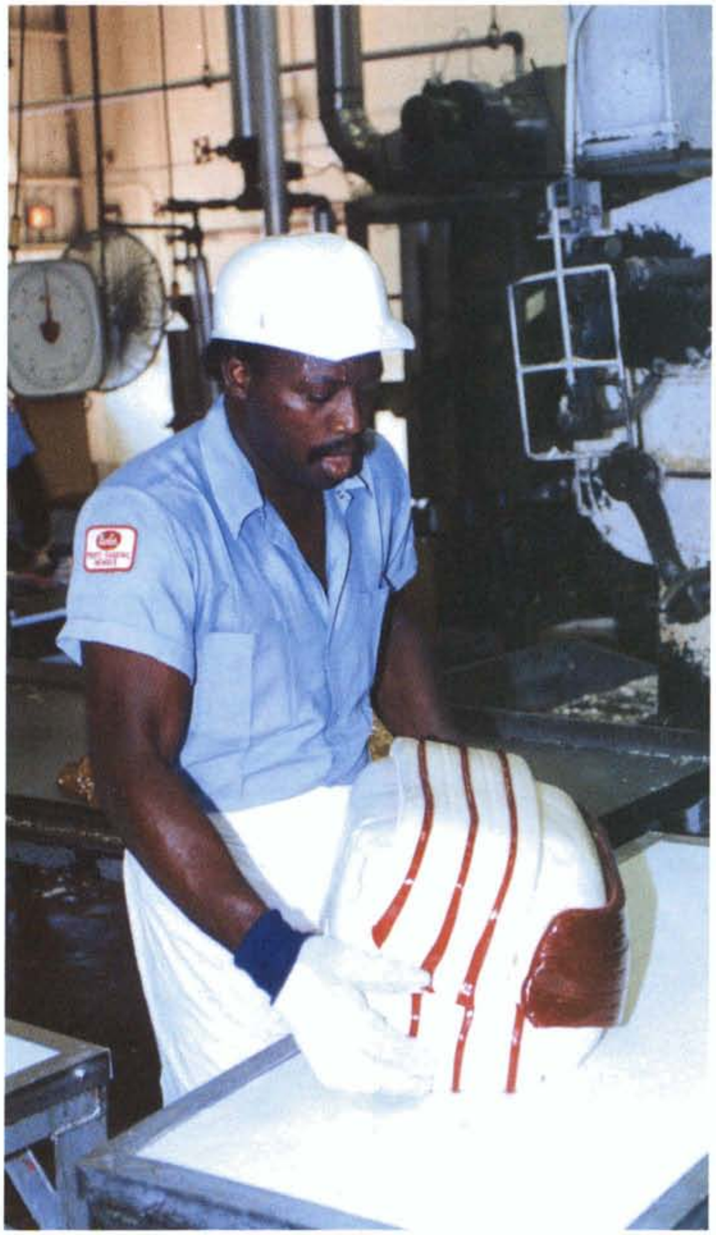
signed to encourage broader private sector participation in the technology transfer process and to make private companies aware of the NASA technologies that hold promise for commercialization. The TUO plays a prominent part in this aspect of the program. He arranges and coordinates his center's activities relative to the meetings and when—as frequently happens—industry participants seek to follow up with visits to the center, he serves as the contact point.

Support for the TUOs—and for all 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 *Tech Briefs* (top), NASA's principal tool in advising potential users of technologies available for transfer; maintenance and mailout of Technical Support Packages (above), which requires a reproduction effort of more than 1.5 million pages annually; and responding to requests for information (above), an activity that entails processing of some 80,000 mail and other inquiries and results in mailout of more than 200,000 informational documents. The TUO/STIF is also responsible for distribution of technology utilization publications, for research and other work associated with this annual *Spinoff* volume, for retrieval of technical information and referral of highly technical requests to appropriate authorities, for developing reference and bibliographic data, and for public relations activities connected with media interest in technology utilization matters. ▲

Technology Applications

One 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.

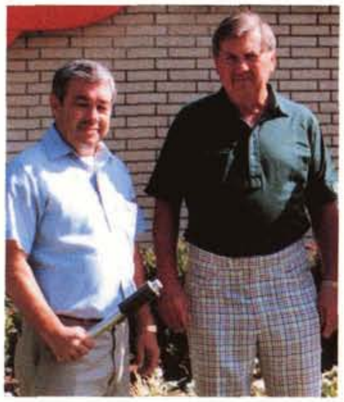
Applications engineering projects originate in various ways. Some stem from requests for assistance from other government agencies, others are generated by NASA technologists who perceive possible solutions to problems by adapting NASA technology to the need. NASA employs an application team composed of several 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 involves use of heat pipe technology to solve a problem experienced by a candy manufacturer—Bobs Candies, Inc., Albany, Georgia. The company produces more than 200 varieties of candy, much of it striped peppermint sticks, canes and balls. Bobs makes 75-80 percent of its sales during the Christmas season, but to meet the demand for millions of sticks and canes the company must produce year-round and store the product until shipping time. At left, a Bobs employee has just added red striping dye to a batch of white candy; the candy next goes into a machine to be stretched, twisted and cut into sticks.

The candy, of course, is temperature sensitive; heat and humidity makes the sticks soft and runny, causing the stripes to bleed into the white as shown in the comparison photo below. To bar that possibility, Bobs' warehouse must be carefully controlled to temperatures of 78-80 degrees Fahrenheit with relative humidity of 38-42 percent. That's expensive; last year's electric power bill was $57,000.

Don Bravaldo, Bobs' vice president-production, read an article about the work of NASA and the Florida Solar Energy Center (FSEC) in adapting heat pipe technology—originally developed for temperature control of space electronic systems—to control of humidity in building environments. FSEC had been engaged for



several years in investigation of ways to curb the high energy losses incurred in extracting excess moisture from superinsulated buildings in very humid climates. In normal operation, an air conditioner only partially reduces humidity; to lower it to acceptable levels, the air conditioner must operate longer, using more energy. In so doing, it overcools room air, which must then be reheated to get the desired temperature—and that takes still more energy. FSEC's experimental approach involves use of heat pipes that 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. This approach affords significant energy savings.

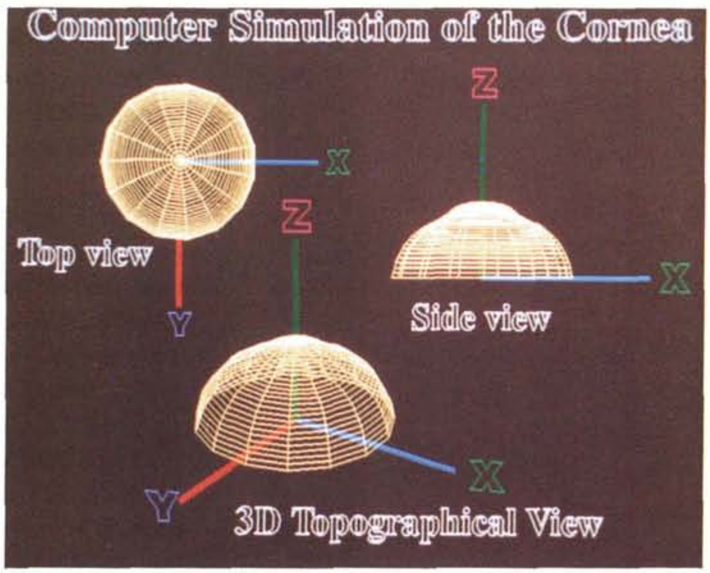
Bravaldo saw a possibility of applying heat pipe technology to his warehouse control problem, so he contacted FSEC systems engineer Mukesh Khattar and advanced the idea. From that contact, there eventually emerged a cooperative test project to install a heat pipe system at Bobs' warehouse, operate it for a period sufficient to determine accurately the cost benefits, and gather field-measured data applicable to development of future heat pipe systems potentially beneficial to a wide range of users. The project is jointly funded by Bobs Candies, Kennedy Space Center, FSEC and Georgia Power Company, which installed meters and other devices to monitor the heat pipes' performance. The test installation was completed in June 1987. Bobs' plant engineer Gene Sharp estimates energy savings of 30 percent; FSEC's Khattar thinks it might go as high as 50 percent. In the photo above, Sharp (left) is holding one of the test system heat pipes; also pictured is company president Bob McCormack Jr.

Another example is a device, under development by Jet Propulsion Laboratory (JPL) with funding from the Office of Technology Utilization, for improving procedures in eye surgery, specifically surgery of the cornea. The most common type of corneal surgery is called radial keratotomy, in which the surgeon makes carefully spaced radial incisions in the cornea to correct extreme myopia.

When preparing a patient for such surgery, it is essential to make accurate measurements of the curvature of the cornea. By comparing this preoperative measurement with one taken postoperatively, the surgeon can identify and evaluate the precise physical changes effected by the surgery. Repeated measurements over a period of years show the long term effects, allowing refinement of procedures for future surgery.

However, existing methods for quick measurement of corneal curvature can only be used on a portion of the central cornea three millimeters wide. A larger area can be investigated by adaptation of these methods, but not quickly, since time consuming data analysis is required. Thus, existing techniques have limited utility for immediate preoperative measurements and for immediate postoperative evaluation.

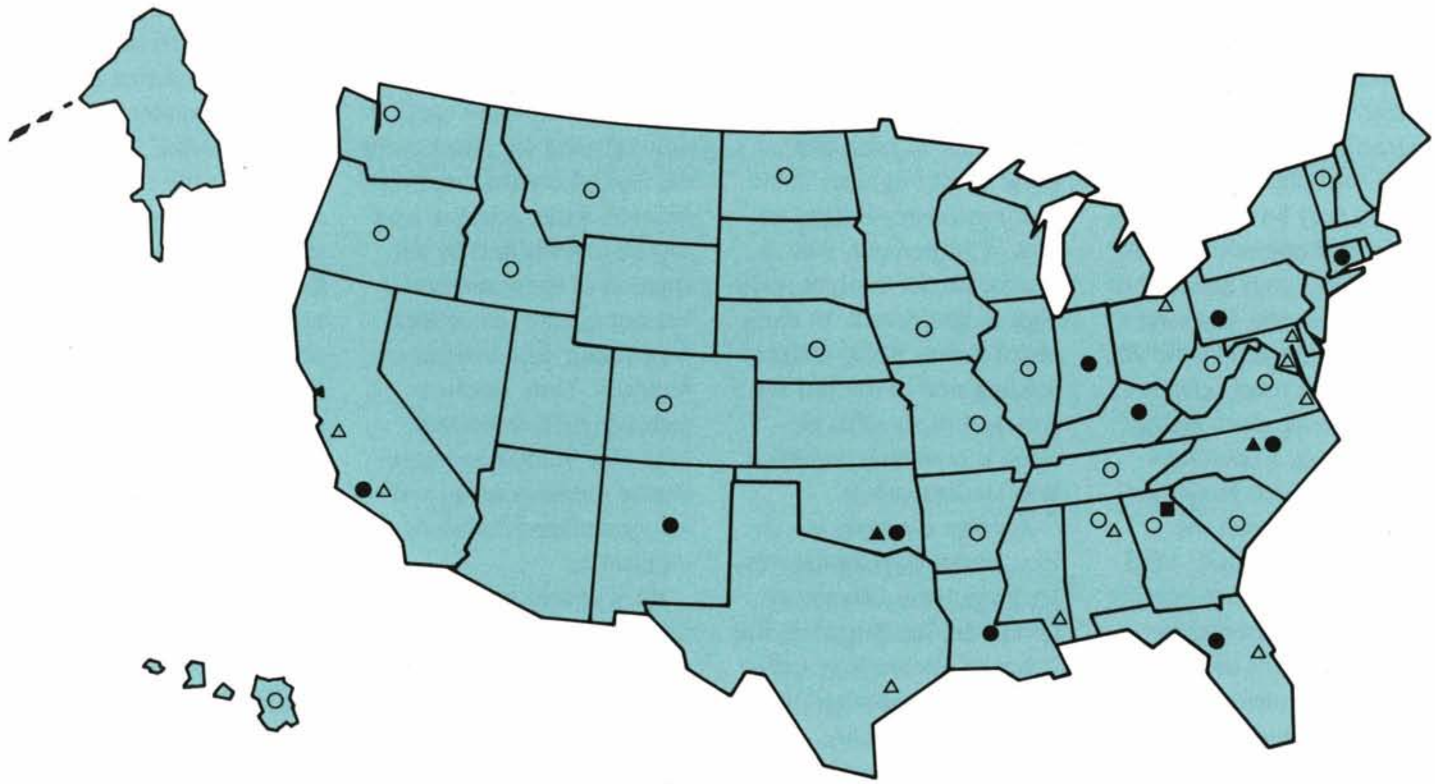
JPL's development is designed to overcome these difficulties. It is an instrument that employs a low powered helium neon laser, in conjunction with a sophisticated optical system, to provide information on corneal curvature over a field 12 millimeters wide—thus covering almost the entire surface affected by surgery. With the incorporation of a small, charge-coupled detector camera and a microcomputer, the instrument can provide near real time information to the surgeon. Below is an example of the type of information the system will be able to generate, an actual map of the cornea under study. In addition, it will be possible to provide the surgeon with a rotating image, so he can study the patient's condition from any perspective he wants. Along with the speed of the device and the wide field of view it will present, the accuracy of the information will be much greater than can be attained by existing techniques. JPL is completing a prototype instrument for final clinical testing and discussions are under way with an industrial firm concerning development of a commercial version for clinical and research use. ▲



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 Director, Technology Utilization Division, 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:* provide 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 Team:* works with public 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) 694-6370

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 Hammond
Phone: (305) 867-3017

Langley Research Center
National Aeronautics and Space Administration
Hampton, Virginia 23665
Technology Utilization and Applications Officer: *John Samos*
Phone: (804) 865-3281

Lewis Research Center
National Aeronautics and Space Administration
21000 Brookpark Road
Cleveland, Ohio 44135
Technology Utilization Officer:
Daniel G. Soltis
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 91009
Technology Utilization Officer:
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: (213) 354-4849

National Space Technology Laboratories
National Aeronautics and Space Administration
NSTL, Mississippi 39529
Technology Utilization Officer:
Robert M. Barlow
Phone: (601) 688-1929

• Industrial Application Centers

Aerospace Research Applications Center
611 N. Capitol Avenue
Indianapolis, Indiana 46204
F. T. Janis, Ph.D., director
Phone: (317) 262-5003

Central Industrial Applications Center
Southeastern Oklahoma State University
Durant, Oklahoma 74701
Tom J. McRorey, Ph.D., director
Phone: (405) 924-6822

NASA Industrial Applications Center
823 William Pitt Union
Pittsburgh, Pennsylvania 15260
Paul A. McWilliams, Ph.D., executive director
Phone: (412) 648-7000

NASA Industrial Applications Center
Research Annex, Room 200
University of Southern California
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Los Angeles, California 90007
Radford G. King, director
Phone: (213) 743-8988
(800) 642-2872 (CA only)
(800) 872-7477 (toll free, US)

NERAC, Inc.
One Technology Drive
Tolland, Connecticut 06084
Daniel Wilde, Ph.D., director
Phone: (203) 872-7000

North Carolina Science and Technology Research Center
Post Office Box 12235
Research Triangle Park,
North Carolina 27709
J. Graves Vann, Jr., director
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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
109 Kinkead Hall
University of Kentucky
Lexington, Kentucky 40506
William R. Strong, manager
Phone: (606) 257-6322

NASA/SU Industrial Applications Center
Southern University
Department of Computer Science
Baton Rouge, Louisiana 70813
John Hubbell, Ph.D., director
Phone: (504) 771-2060

○ Industrial Application Center Affiliates

Alabama
Alabama High Technology Assistance Center
University of Alabama-Huntsville
(205) 895-6303

Arkansas
Industrial Research and Extension Center
University of Arkansas
(501) 371-1971

California
See Industrial Applications Center
University of Southern California •

Colorado
Small Business Assistance Center
University of Colorado-Boulder
(303) 444-5723

Florida
See Southern Technology
Applications Center
University of Florida ●

Georgia
Economic Development Laboratory
Georgia Institute of Technology
Research Center
(404) 894-3863

Hawaii
Pacific Business Center Program
University of Hawaii
(808) 948-6286

Idaho
Idaho Business Development Center
Boise State University
(208) 385-1640

Illinois
Technology Transfer Center (ANL)
Argonne, Illinois
(312) 972-7694

Indiana
See Aerospace Research
Applications Center
Indianapolis Center for Advanced
Research ●

Iowa
Center for Industrial Research and Service
(CIRAS)
Iowa State University
(515) 294-3420

Kentucky
See NASA/UK Technology
Applications Program
University of Kentucky

Louisiana
See NASA/SU Industrial
Applications Center
Southern University ●

Missouri
Technical Search Program
University of Missouri-Rolla
(314) 341-4004

Montana
University Technical Assistance Program
Montana State University
(406) 994-3812

Nebraska
Nebraska Technical Assistance Center
University of Nebraska
(402) 472-5600

New England
See Industrial Applications Center
NERAC, Inc. ●

New Mexico
See Technology Applications Center
University of New Mexico ●

North Carolina
See Industrial Applications Center
North Carolina Science and Technology
Research Center ●

North Dakota
Center for Innovation and Business
Development
University of North Dakota
(701) 777-3796

Oklahoma
See Central Industrial
Applications Center
Southeastern Oklahoma State
University ●

Oregon
Regional Services Institute
Eastern Oregon State College
(503) 963-2171

Pennsylvania
See Industrial Applications Center-
University of Pittsburgh ●

South Carolina
The State Board for Technical and
Comprehensive Education
Columbia, South Carolina
(803) 737-9320

Tennessee
Center for Industrial Services
University of Tennessee
(615) 242-2456

Small Business Development Center
Memphis State University
(901) 454-2500

Vermont
Agency of Development and
Community Affairs
State of Vermont
(802) 828-3221

Virginia
Technical Information Services
Center for Innovative Technology (CIT)
(703) 689-3000

Washington
Small Business Development Center
Washington State University
(509) 335-1576

West Virginia
The Software Valley Association
c/o Department of Statistics and
Computer Science
University of West Virginia
(304) 293-3607

Science and Technology Center
West Virginia Board of Regents
(304) 348-2101

■ *Computer Software Management and Information Center*

COSMIC
Computer Services Annex
University of Georgia
Athens, Georgia 30602
John A. Gibson, director
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▲ *Application Team*

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Commercial Space Programs

Headquarters, National Aronautics and Space Administration
Office of Commercial Programs
Commercial Programs Division
Washington, D.C. 20546
Henry J. Clarks, acting director
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NASA Scientific and Technical Information Facility

Technology Utilization Office
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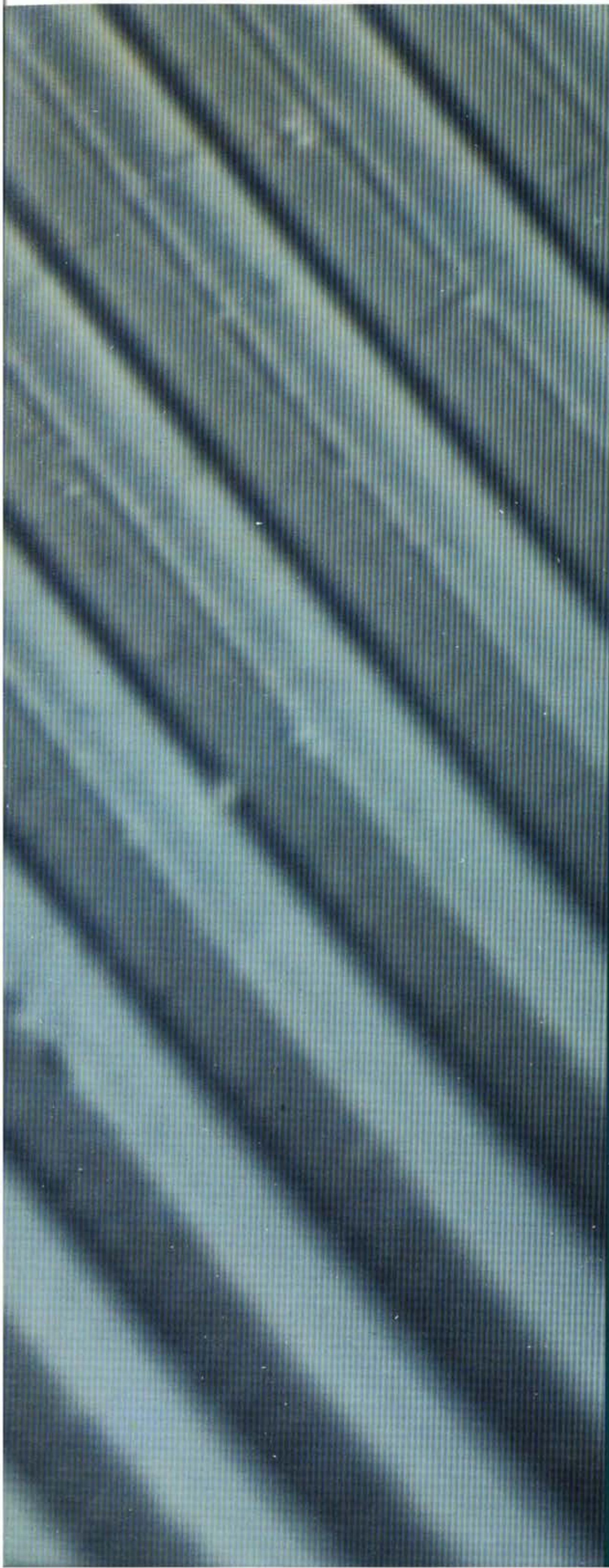

Director, Technology Utilization Division
Office of Commercial Programs
NASA Headquarters
Washington, D.C. 20546

National Aeronautics and
Space Administration