Aerospace Spinoffs

Twenty-Five Years of Technology Transfer

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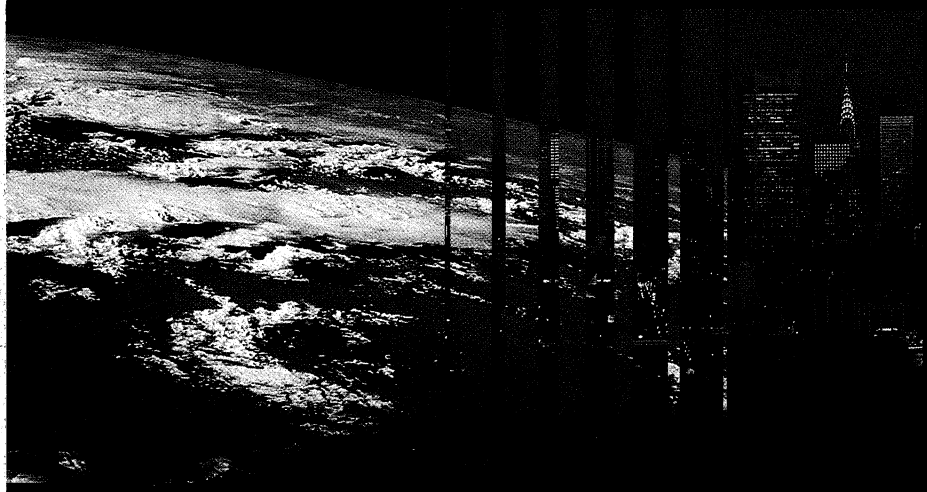

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NASA

Foreword

By their challenging nature, NASA programs are particularly demanding of technological input. Meeting the aeronautical and space goals of the past three decades has necessitated advancements across a broad spectrum that embraces virtually every scientific and technological discipline.

This technology is simply knowledge, or "know-how," and like other forms of knowledge it is transferable; once the technology is developed, it can be reapplied to uses different—often remotely so—from the original application. Thus, the great storehouse of technology NASA has acquired constitutes a valuable national resource, a bank of knowledge available for reapplication to new products and processes of benefit to the national economy, industrial efficiency and human welfare.

By Congressional mandate, it is NASA's responsibility to promote expansion of technology transfer in the public interest. The instrument of that purpose is the Technology Utilization Program, through which NASA seeks to encourage greater use of its knowledge bank by providing a link between the technology and those who might be able to put it to advantageous use.

This year marks the 25th anniversary of the Technology Utilization Program. During the quarter century span, NASA's own efforts to reapply the technology and those of imaginative entrepreneurs have generated tens of thousands of secondary applications, or "spinoffs."

This publication describes a few of the many. It is a random sampling that illustrates the breadth and diversity of aerospace spinoff and underlines the scope of the benefits that have accrued. Some spinoffs offer only moderate increments of economic gain or lifestyle improvement; many others, however, have economic values running to millions of dollars. Collectively, they represent a substantial return on the national investment in aerospace research in terms of contribution to the U.S. economy, job production, industrial productivity, lifestyle innovations and solutions to problems of public concern.

James T. Rose

James T. Rose
Assistant Administrator for Commercial Programs
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Health and Medicine

ORIGINAL CONTAINS
COLOR ILLUSTRATIONS

In aerospace design, every subsystem must be super-efficient and ultrareliable, yet as small and light as technology permits—requirements that are shared by many types of medical devices. That's one reason why the field of health and medicine has been a particular beneficiary of aerospace spinoff.

The United States leads the world in the technology of building complete, reliable aerospace systems in incredibly tiny packages and that technology has spawned a line of life-saving medical adaptations. An outstanding example is the cooperative/development of human-implantable systems by a group of research organizations and medical equipment manufacturers who applied such space technologies as advanced long-life batteries, microminiaturized components, electronic sensors and telemetry, the wireless relay of coded signals for high-volume two-way communication between Earth and orbit. Some examples of the results:

▲ A rechargeable cardiac pacemaker that eliminates the recurring need for surgery to replace batteries.

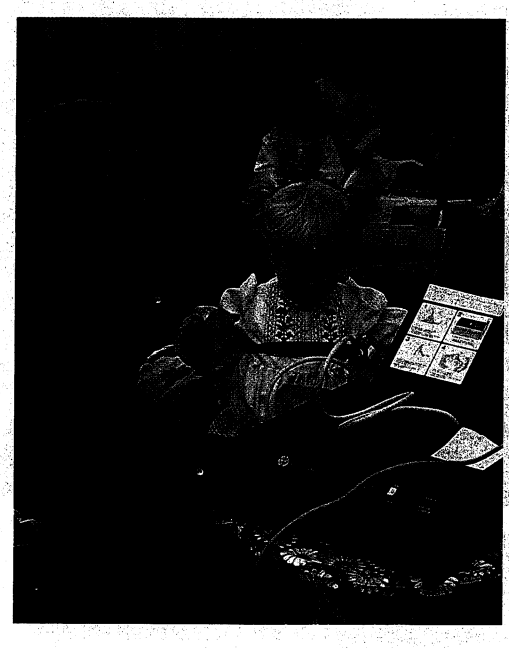
▲ An advanced heart pacer that may be reprogrammed without surgery—via biotelemetry—as a patient's condition changes.

▲ A human tissue stimulator that provides relief from chronic pain by sending electrical impulses to targeted nerve centers.

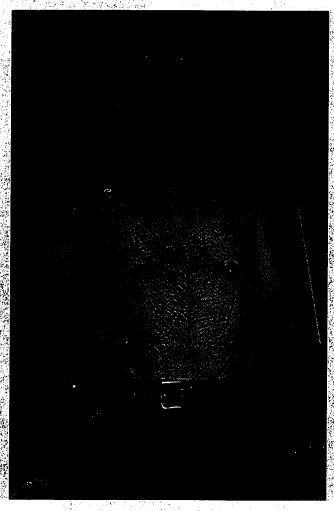
▲ An automatic implantable "defibrillator" that senses the start of fibrillation—in which the heart loses its ability to pump blood—and corrects it by sending an electrical impulse to the heart.

▲ A programmable implantable system that automatically dispenses precisely-measured medication—such as insulin for diabetics—to target organs.

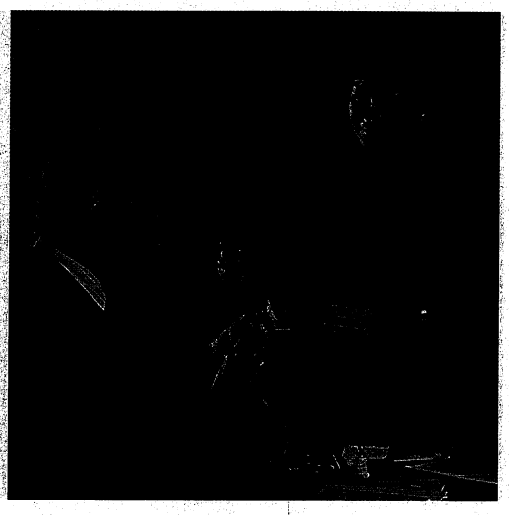
Described on these pages are a few of thousands of applications of aerospace technology that have provided extraordinary benefit to the field of health and medicine.▲



Wearer of a rechargeable cardiac pacemaker, the child is shown with the companion unit that sends an electrical charge to the pacer's battery without surgery.



A wearable computerized system that allows physicians to monitor ambulatory patients with coronary artery disease incorporates technology originally developed to observe the heart action of Space Shuttle astronauts. It continuously evaluates and records heart signals, alerts to danger and allows physicians to determine the efficacy of treatment.



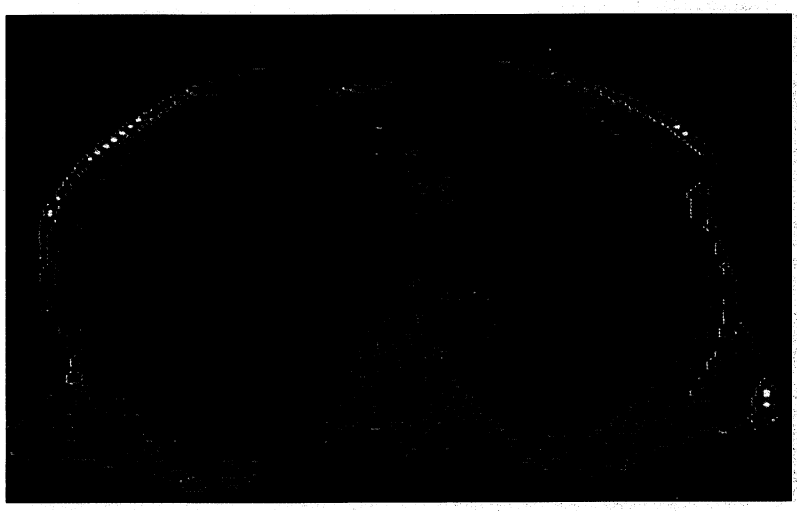
A patient (seated) is briefed on the operation of a wearable system that continuously delivers insulin—through a needle under the skin—for treatment of diabetes, a life-extending invention derived from space microminiaturization techniques.

ORIGINAL PAGE
COLOR PHOTOGRAPH

Body imaging is the art of creating pictures of human interiors to aid physicians in diagnosis, treatment and surgery. The X-ray is a familiar example. But where the X-ray shows only bone structure, medicine now has available a broad range of body scanning equipment and techniques to penetrate bone and produce highly informative images of body tissue and organs.

Much of this technology stemmed from the space technique known as digital image processing, developed as a means of assembling a picture of a planet or moon from bits of sensor data sent to Earth in digital form by a distant spacecraft. Later advances brought ways to correct sensor errors, change picture contrast, emphasize certain features, make measurements, generally to amplify the information that can be extracted from the computerized image.

This explosively-proliferating new technology has spun off to such varied fields as defense equipment, non-destructive testing, archeology, chemistry, cartography, manufacture of printed circuitry, metallurgy, ultrasonics and seismography. Nowhere has image processing technology been more importantly or more effectively employed than in medicine, where it has enabled advancements in CAT scanning, diagnostic radiography, brain and cardiac angiography, sonar body scanning and monitoring surgery. The illustrations show a representative few of the scores of image processing spinoffs in medicine. ▲



NMR—nuclear magnetic resonance—is a promising new technique for diagnostic body scanning, but NMR imagery is complex and difficult to interpret. Space image enhancement technology offers a means of simplifying interpretation for better diagnosis. Three black and white NMR images were computer-enhanced to create this chest scan "theme map," in which each color represents a different type of tissue and a tumor mass (top center) is precisely outlined.

The medical technician is using the system pictured to get a computerized analysis of a microscope specimen that will provide far more information than visual interpretation and do it far more rapidly. This system, several related systems and the whole company that produces them are all spinoffs from NASA digital image processing technology.

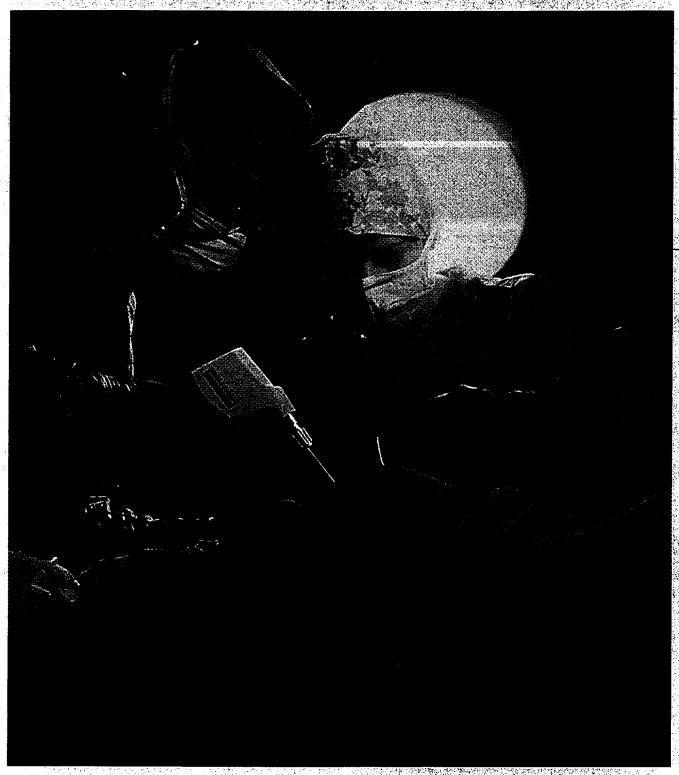
Now in use in more than 20 states and a number of foreign countries, slow scan TV—a technology that originated in the U.S. space program—makes possible instant consultation between medical centers and specialists at home or in their offices. The specialist views the patient's body imagery inexpensively transmitted over a standard telephone line, allowing accelerated diagnosis that could be vitally important to an emergency patient.

For lunar exploration, astronauts needed a compact, lightweight, battery-powered long-use drill to extract core samples from beneath the lunar surface. Under NASA contract a company developed one, then used the technology to produce a line of cordless tools for consumer, industrial and medical use. That's one example of how a space requirement generates new technology for everyday products; here are a few others in the field of health and medicine:

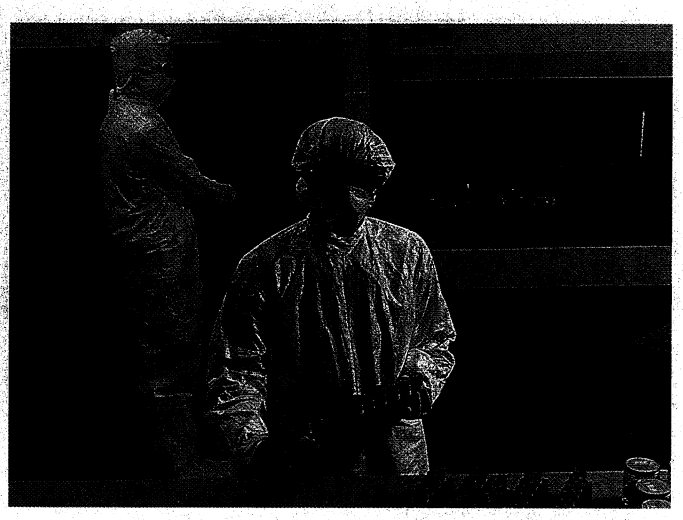
▲ A contractor developed an automatic gas analyzer to monitor Apollo astronauts' respiratory gases; it is now used in hospitals for analysis of anesthetics.

▲ A life-search experiment on a Mars-landing spacecraft required development of miniaturized valving technology, which became the foundation of a family of civil-use fluid control devices, such as a filtering system that removes impurities from blood.

▲ Newborn premature babies are warmed—without noise or burn hazard—in cradles whose electricity-conducting canopies provide controlled radiant heat, an offshoot of NASA technology developed for heated cockpit canopies and astronaut helmet faceplates. ▲



The surgeon is using a self-contained instrument that needs no power source, lines or hoses, thus offers optimum freedom in the operating room. It is one of a line of cordless surgical instruments that stemmed from the developing company's work on a moon drill.



The technicians at left are preparing body fluid samples for analysis by an automatic system that detects and identifies disease-producing mechanisms in the human body. Handling as many as 240 samples at a time, it provides faster analysis—thus earlier treatment—and minimizes human error. Successful transfer of this technology, originally developed to detect bacterial contamination aboard an unmanned planetary spacecraft, resulted in formation of a new company.

A tiny mote of dust could trigger malfunction in a sensitive spacecraft system, so NASA developed contamination control technology for assembly of sensitive flight equipment in hospital-like "clean rooms." One of several offshoots of that technology base is a line of advanced, disposable, inexpensive anticontamination garments for hospitals and pharmaceutical clean rooms.

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COLOR PHOTOGRAPH

Public Safety

The field of public safety has been especially susceptible to transfer of aerospace technology: Some examples:

▲ Developed to minimize Space Shuttle fire hazard, a polyimide foam material with exceptional flame resistance is used on interior furnishings of public-use aircraft, trains and buses.

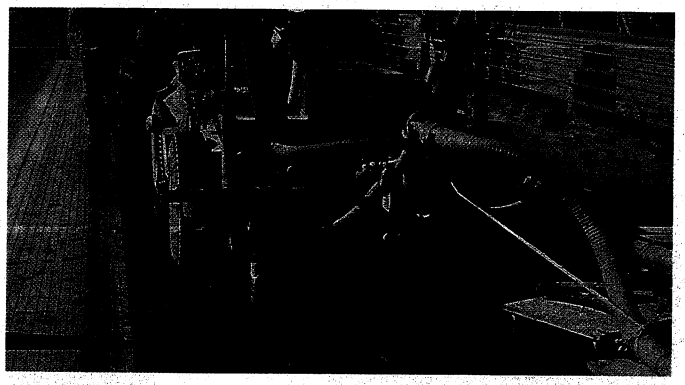
▲ Available to airport, municipal and industrial firefighters is a "bayonet-type" spray nozzle, developed for Shuttle landing emergencies, that can be thrust through the skin of a transportation vehicle or certain building materials to deliver extinguishants to the interior.

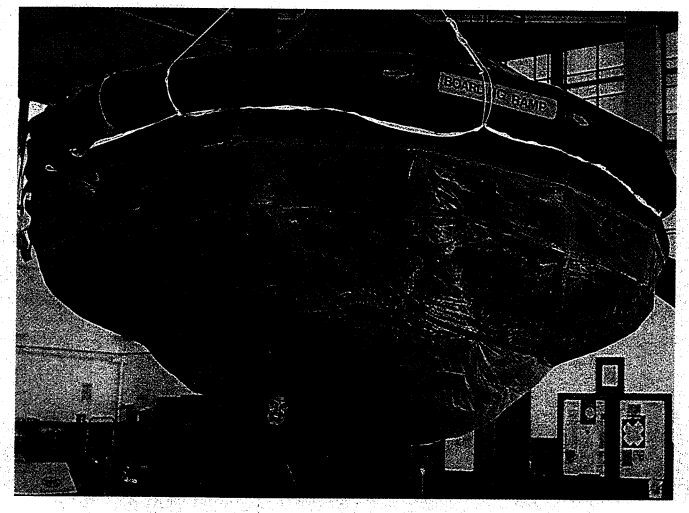
▲ A NASA-developed device for detection of invisible flames in liquid hydrogen propellant tanks has become a commercial product for use in hydrogen generating plants and pipelines.

▲ The sophisticated smoke/fire detecton system used in the Skylab manned spacecraft provided the technology for a home use detection/warning device.

▲ A special type of electronic circuitry developed for space telemetry provided technology for a supersensitive industrial gas leak detector; the same technology was later applied to a post-fire arson detection device and a visual alert system for the hearing impaired.

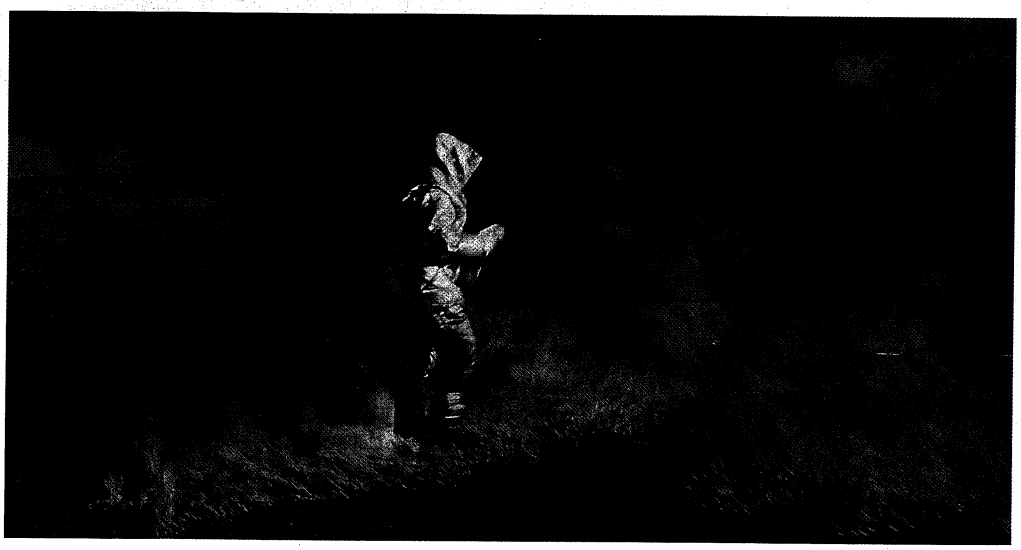
▲ An underwater device that signals the location of a downed





Ocean-landed Apollo astronauts waited for helicopter pickup in inflatable rafts specially stabilized to prevent overturn by the helicopter's downwash. The NASA-patented water ballast stabilization system was employed in a widely used commercial raft that does not capsize in heavy seas.

The workmen are cutting grooves in a highway surface to improve wet weather tracton. Developed by NASA to curb skids of landing aircraft, the grooving technique has been applied to hundreds of airport runways worldwide and to many highways in North America, Europe and Asia.



A thin, lightweight, flexible fire-resistant fabric developed for Apollo astronauts' space suits found application in a fire-entry suit for fire-fighters and industrial workers exposed to high heat, steam or hot liquids.

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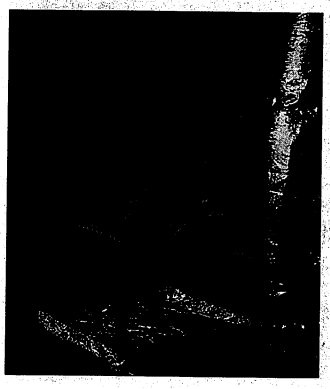
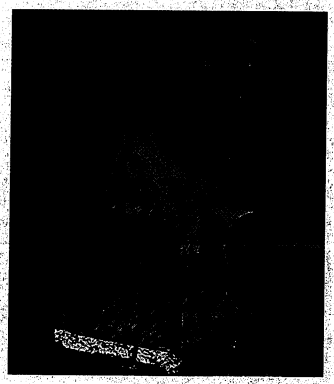
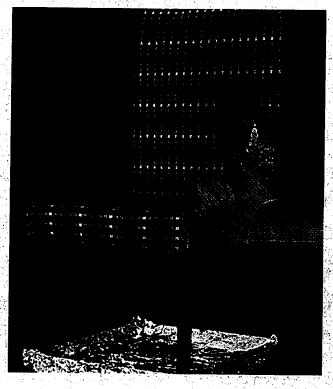
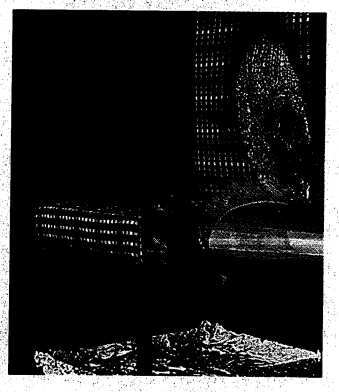
airliner's flight recorder borrowed technology from a NASA/Navy-developed sonar search/locator system. ▲





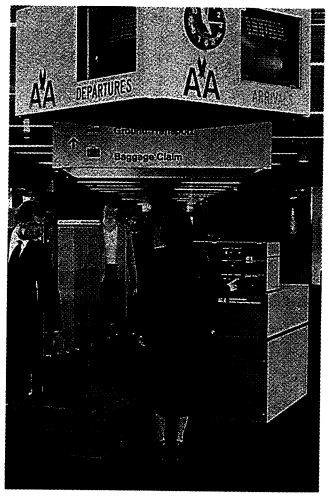




The first two photos above show a conventionally covered chair after 30 and 90 seconds exposure to high temperature. The latter two photos show the effect of the same exposure on a chair covered by a fabric containing fireblocking fibers of a formula originally developed for astronaut flight suits. As is evident, the fibers curb flame spread, hence offer increased safety in a wide range of civil applications from airline seat cushions to auto racing driving suits to foundry workers protective apparel.

These firefighters are wearing a breathing apparatus for protection against smoke inhalation, the result of a multiorganizational development project that adapted aerospace materials and technology to a national need for lighter, less bulky firefighting equipment.

NASA design technology for "hard shell" pressure suits—intended to protect future lunar colonists against micrometeorites—was incorporated in this advanced deepwater diving system, which has fluidic joints to permit 75 percent normal human mobility.



At left is one of several products that spun off from NASA research in x-ray telescope instrumentation, an x-ray inspection system for examining luggage at airports and other security areas; it produces high quality images at extremely low radiation dosages.

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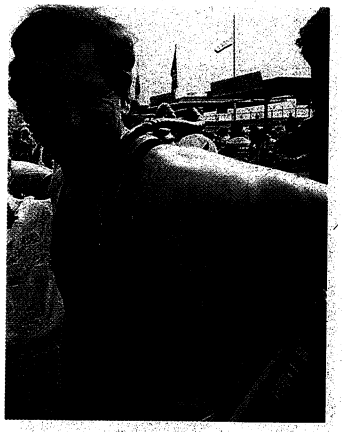
Spinoffs in

Consumer/Home/ Recreation

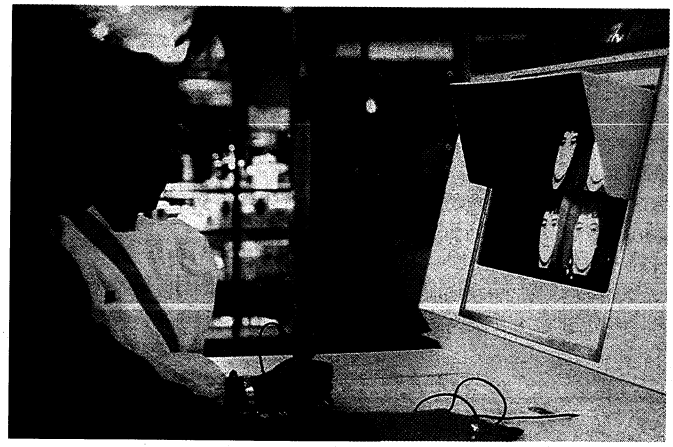
Echo 1, NASA's first experiment in satellite communications, was a 10-story-size balloon used as a giant reflector for "bouncing" radio signals from one point on Earth to another. For its skin, NASA needed a material that was exceptionally thin and light yet highly reflective. A NASA contractor came up with a metal-coated plastic film so fine that the balloon's skin was half the thickness of the cellophane on a cigarette package. That development triggered the growth of a whole new industry making metallized products with extraordinary heat reflection or heat retention characteristics. The technology transfer process went through a second circuit when NASA found that metallized materials were ideal for protection of spacecraft crews and components from solar radiation and extensive space use, plus additional R&D, spawned another round of spinoffs. The list of applications for consumer/home/recreational use alone is uncommonly broad—stadium blankets, tents, suntanning pads, wall coverings, drapery liners, window shades, bedwarmers, windbreakers, candy wrappings, food packaging, to mention only a few among scores—and there are many additional applications in other fields.▲



Auto racing champion Dale Earnhardt displays a "cool vest," part of a personal cooling system many drivers use to combat cockpit temperatures that often get above 130 degrees Fahrenheit. The cool suit, which includes a helmet liner, is a derivative of space suit technology.

For moonwalking safety and comfort, astronauts' lunar boots featured a three-dimensional "spacer" material for cushioning and ventilation. That material, in modified form, has turned up in a popular line of athletic shoes designed for improved shock absorption and reduced foot fatigue.

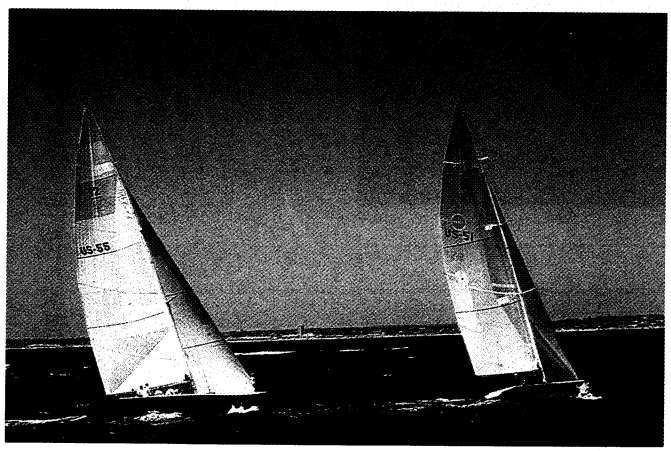
A highly reflective insulating material developed to protect spacecraft and crews from intense solar radiation became an energy-saving window insulator. A thin metallized film bonded to windows of homes, schools, office buildings and other facilities, it reflects the Sun's heat and glare outward, cutting down on energy costs for cooling.



A computerized beauty makeover system incorporates NASA image analysis technology originally developed to construct and analyze pictures of distant planets. Directed by a makeup expert, the system analyzes the client's skin color, considers thousands of makeup color combinations and offers a selection of "new looks."

This ice show troupe is performing on an "instant rink" built atop a theater stage in *one* day by means of a spinoff portable icemaking system. The key is an innovative flexible tube circulation system for the refrigerated coolant, an adaptation of a solar collector heat distribution network developed under NASA sponsorship.

To protect plastic surfaces of aerospace equipment from harsh environments, NASA developed an abrasion-resistant coating that found commercial application in a popular line of sunglasses. The NASA technology was combined with the company's own research to produce a long-wearing lens with scratch resistance better than glass.



Winner of the 1987 America's Cup, the racing yacht *Stars and Stripes* got an assist from NASA-developed "riblets," tiny grooves in the yacht's hull that contributed to increased boat speed. The world's largest jetliner producer is now planning to incorporate riblets in its transports to reduce air drag and improve fuel efficiency.

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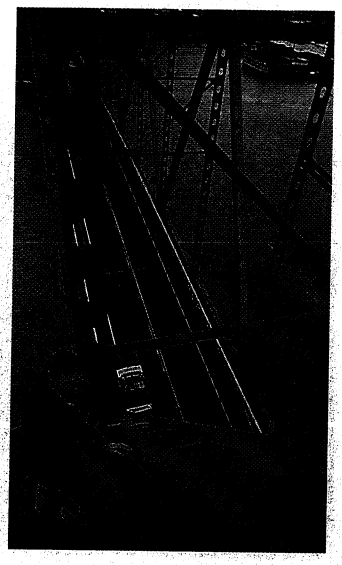
COLOR PHOTOGRAPH

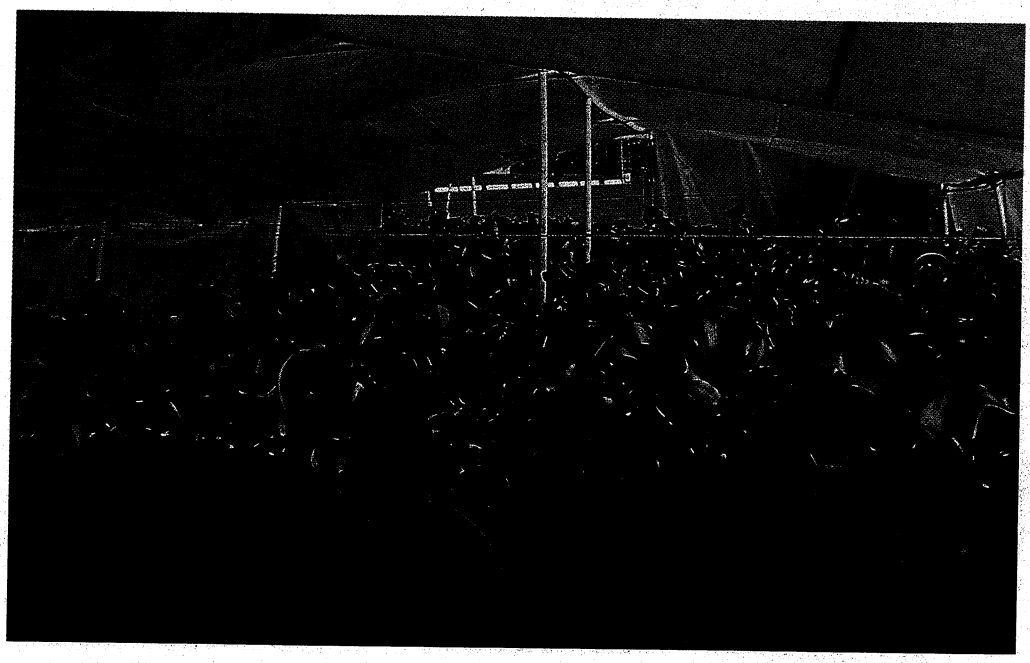
Spinoffs in

Environment and Resources Management

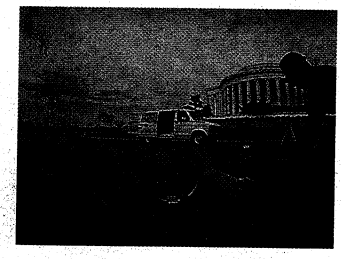
Several aerospace technologies have found spinoff utility in environmental and resources management applications. NASA-pioneered satellite survey of Earth resources, provided a technology base for commercial remote sensing networks. Space image processing is being used in geology, archeology and pipeline monitoring. And many types of aerospace instruments and materials are being employed in such areas as air quality monitoring and noise abatement. ▲



NASA's need to protect ground and flight equipment from corrosion—in particular coastal area erosion induced by salt spray—led to development of many types of coatings that have spun off to commercial use. In the photo, a bridge maintenance inspector is checking a girder covered by an inorganic coating—produced under NASA license—with superior corrosion resistance. The Statue of Liberty wears a NASA-developed interior coating and a variety of other coatings are protecting office buildings, tank farms, ships, oil rigs and other structures.



For future space colonists and long-duration space flights, NASA has extensively explored the use of aquatic plants—which absorb impurities from sewage—as a means of treating and recycling wastewater. This research has found broad civil application; dozens of small towns are using water hyacinths as their primary wastewater treatment system and one major city uses them in a secondary treatment technique. In the photo, a hyacinth aquaculture filtration tank in San Diego, California.

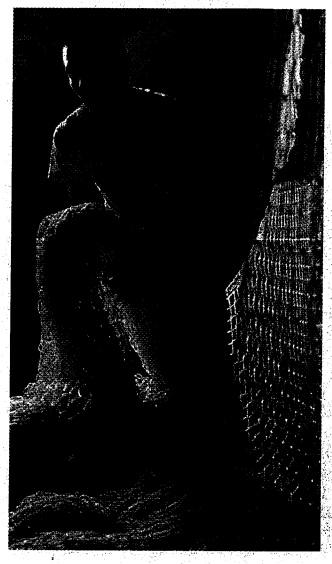


In Washington, D.C., a crew is installing a sewer monitor that tracks wastewater processing, warns of potential overload and reports how the system is functioning generally. In use in hundreds of cities, it employs multiple aerospace technologies, in particular sensors, microcomputers and redundant subsystems.

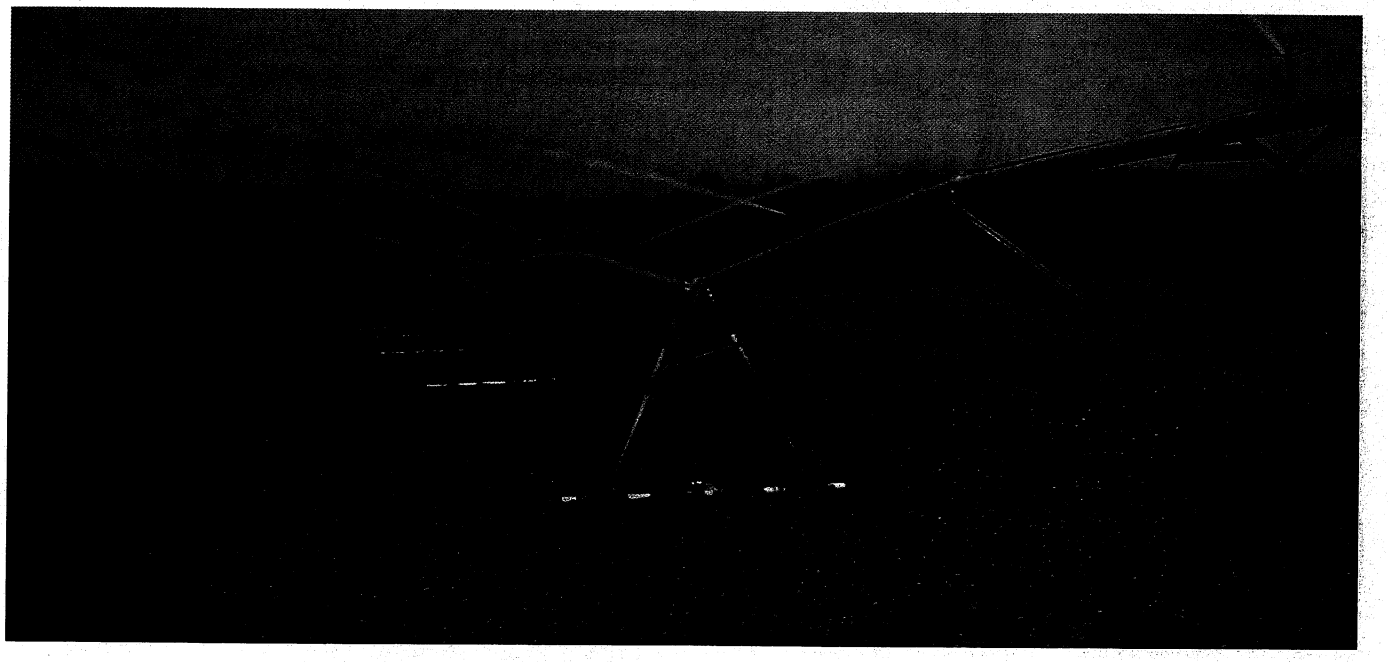
Spinoffs in

Food and Agriculture

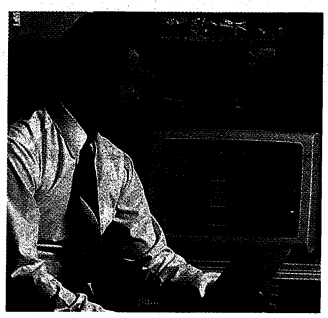
A microwave system dries agricultural crops with less chance of quality loss and a lower energy requirement than hot-air blowers; it is a spinoff from space-simulating vacuum chamber technology. For increased hog production, some farmers are using a robotic sow—an artificial nursing machine for piglets—whose key element is a miniature heat pump developed for satellites. These are examples of many widely varied aerospace spinoffs in food and agriculture; a few more are illustrated.▲



Not your ordinary fishing net is the one pictured; it is a spinoff seine that sinks faster and arrives at its fishing depth quicker than conventional nets, thus traps extra tons of fish that would otherwise dart away. The key is a superstrong twine and a twisting process first used in a safety net for personnel working on the Space Shuttle.



This irrigation system rotates around a center pivot, watering multi-acre areas in a single revolution. Each three-ton wheeled "tower" has its own electric motor; power is transmitted to the wheels by individual gear boxes that incorporate NASA technology to protect them from wear and heat stress.



More than a decade of research by NASA and the Department of Agriculture brought a solution to a major crop dusting problem: wasteful and environmentally unacceptable drift of chemicals beyond target areas. The answer: a complex computer program that considers all variables and provides information on how to adjust spray height, nozzle position or other factors to get the desired coverage with minimal drift.

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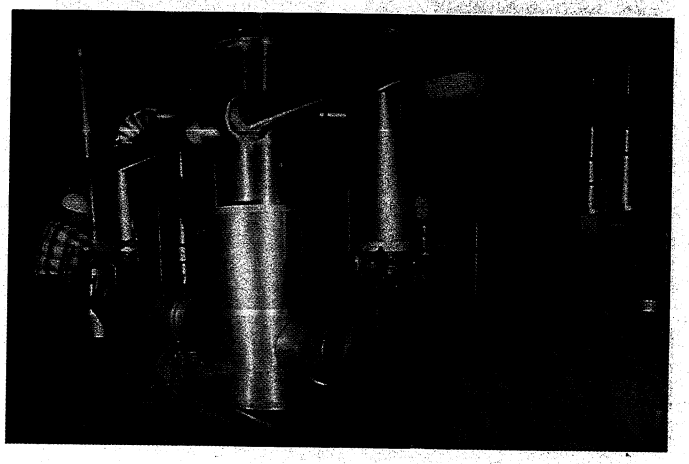
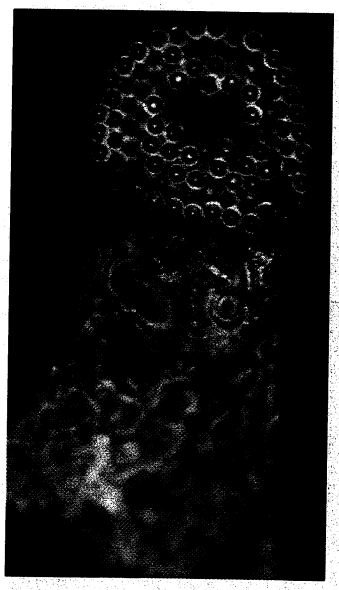
Spinoffs in

Manufacturing Technology and Industrial Productivity

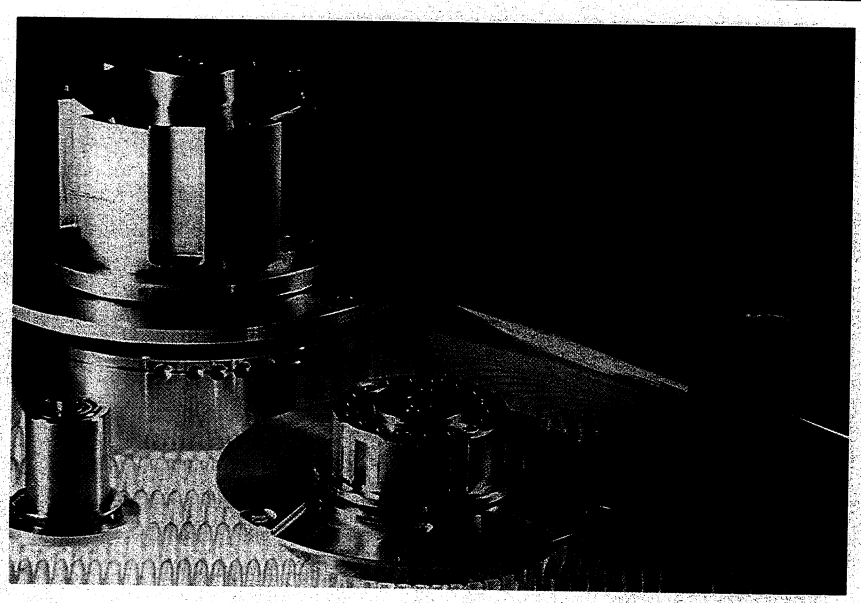
Among examples of aerospace technology being put to productive use in industrial facilities are an air flotation system that allows heavy loads to "float" over the plant on air bearings, an adaptation of the method used by NASA to move multi-ton launch vehicle segments; use of the material in Space Shuttle thermal tiles as an insulator for the heating chambers of a high temperature laboratory system; and a NASA-developed system that facilitates robotic welding by employing closed-circuit TV to guide an arc welding torch without human intervention. Some other examples are pictured. ▲



To increase the thrust of liquid fuel rockets, NASA developed an "inducer" to boost the flow rate of rocket fuel pumps. A pump manufacturer used the NASA technology to increase the speed of special purpose pumps such as the one shown, which is used to recirculate wood molasses.



Pictured above is a batch of microspheres, plastic beads so tiny that a vial as long as an index finger can hold 15 million of them. Perfectly spherical because they were grown in gravity-free space, they serve an important need among industrial laboratories and manufacturing facilities as reference standards for calibrating instruments with extreme accuracy.



In the photo are a variety of ferrofluid bearings. Ferrofluids are liquids provided with magnetic properties. They had their origin in the space program when scientists experimented with drawing weightless fuel into a rocket engine by magnetizing it. NASA licensed the technology to a company formed specifically to commercialize it. Ferrofluids offer unique advantages in manufacture of electronic products, industrial processes, medical equipment, visual displays, automated machine tools and a wide range of other applications.

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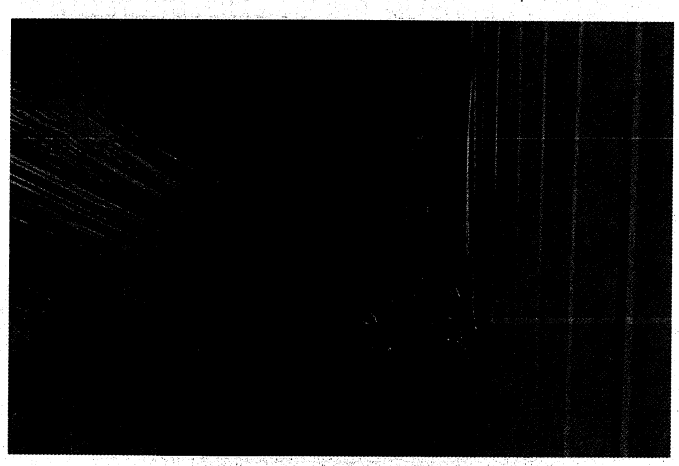
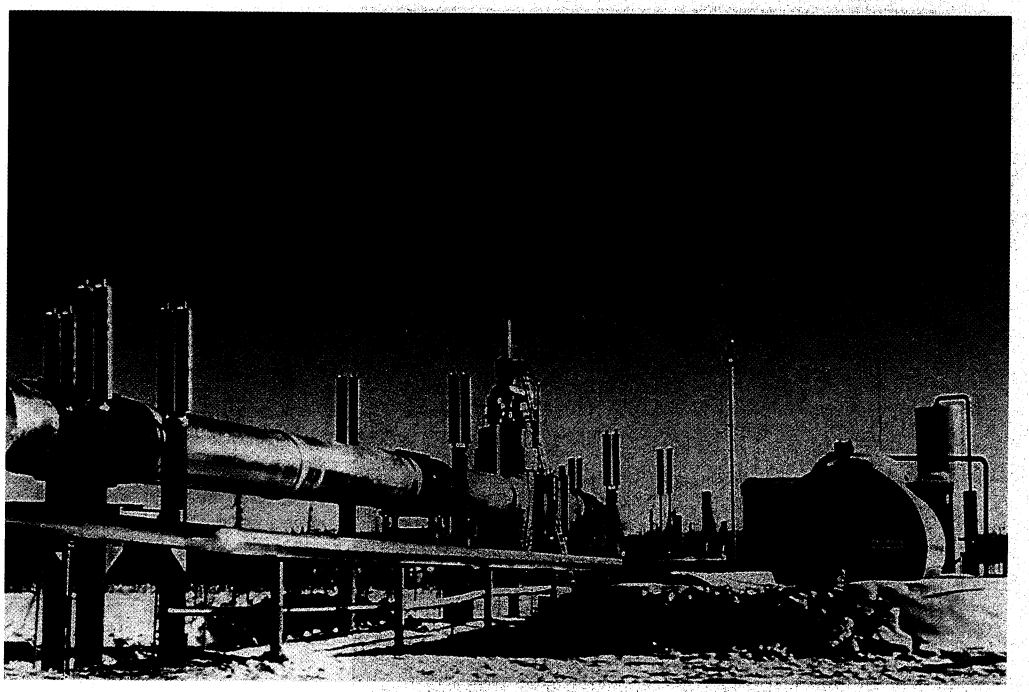
Space-pioneered solar energy technology has found wide usage in Earth heating, cooling and electricity-generating applications. Among other spinoff technologies are heat pipes used to cool spacecraft electronics and a variety of techniques originally designed to minimize energy use in aircraft and spacecraft, now serving the same purpose in Earth applications. Among unusual spinoffs are the employment of space telemetry in an automatic oil well production reporting system, and the use of space-developed power amplifiers to reduce TV stations' transmission costs. ▲



The aluminized "heat shield" being applied holds out or keeps in heat, cold air and water vapors. Once used as a radiant heat barrier in Apollo and other spacecraft, the heat shield insulation is the key element of a sophisticated energy conservation technique for homes and office buildings that offers dramatic energy savings and is finding rapidly increasing acceptance in the U.S.



Within the upright supports of the Alaska pipeline are some 76,000 heat pumps, compact, no-moving-parts devices that, in space use, alternately heat or cool spacecraft components subjected to varying temperatures. In Alaska, the permafrost soil alternately freezes and thaws. That could weaken the pipeline's support structure—except for the heat pipes; they keep the ground near the pipeline permanently frozen, protecting against pipeline ruptures that could cause economic loss or environmental disaster.

To conserve energy in aerospace systems, NASA developed a controller for electric motors that senses a motor's load and feeds it only the minimum voltage it needs to do its job—hence sharply cuts power wastage. Installed in manufacturing facilities—such as the home products conveyor line pictured—it can save big companies millions a year in power costs.

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Construction

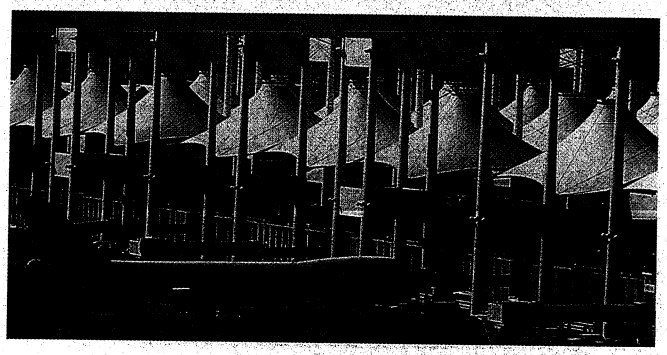
Fabric structures and flat conductor cable for building electrification are examples of extraordinary spinoff benefit to the field of construction, but there are many others that offer important gains in economy, safety and construction simplification.

A random selection:

▲ NASA's long experience in fracture toughness testing for aerospace hardware contributed to safety-enhancing test procedures and requirements for all U.S. federal-aid highway bridges.

▲ An aluminum color finish that improves the weather resistance and attractiveness of commercial buildings is based in part on an anodizing process developed to produce a hard protective finish for spacecraft exterior surfaces.

▲ Developed for measurement of bolt stress in wind tunnels, a NASA bolt monitor provides extremely precise information on bolt tensioning in construction jobs and reduces chance of serious accidents caused by overtightened or undertightened bolts. ▲



In the 1960s, two contractors teamed to produce a special fabric for space suits that was thin, light, flexible, yet durable and noncombustible. The material provided the basis for later development of heavier, construction-use fabrics with similarly advantageous properties. The first adaptation was Michigan's Silverdome (left). Their relatively low cost has inspired widespread acceptance of fabric-roofed structures in shopping malls, stadiums, field houses, schools, theaters, exhibit halls and industrial facilities. American companies are also taking the technology abroad; in the upper photo is the Haj Terminal at King Abdulaziz International Airport in Saudi Arabia.

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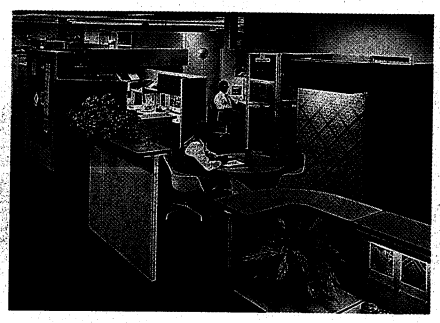

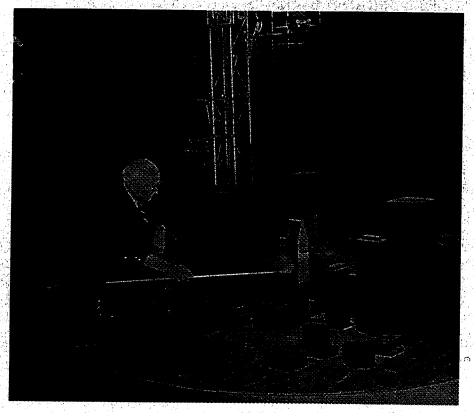

Use of flat conductor cable (FCC)—rather than round cable—to reduce the size and weight of aircraft and spacecraft systems sounds like a simple switch but it took years of research. NASA subsequently applied that know-how in a multiyear, multi-organizational effort to adapt the technology to design of electrification systems for commercial buildings and obtain approval from fire protection and insurance authorities. Offering speedy installation, reduced cost of rewiring and simplified building construction, use of FCC has expanded rapidly since the first commercial installation in 1979. Above left, an undercarpet installation. With wiring out of sight and no vertical wiring enclosures needed, interior designers have new latitude in planning attractive "open landscape" office layouts such as that in top center.

Strong winds can cause a lot of problems for buildings, particularly tall buildings, so architects are increasingly employing "wind engineering," a relatively new discipline that involves testing models of new buildings in wind tunnels. In the photo, a leading wind engineer is setting up a test in a university wind tunnel; his special technique incorporates NASA predictive technology for comparing simulated with actual wind flows at levels below 2,000 feet.

A line of cordless tools and instruments based on technology developed for a lunar subsurface drill includes self-contained construction tools for use where a power source is not readily available.

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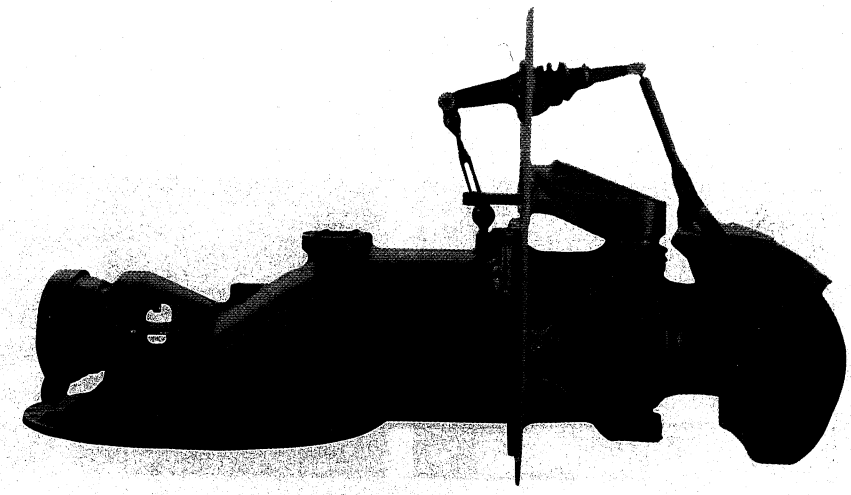
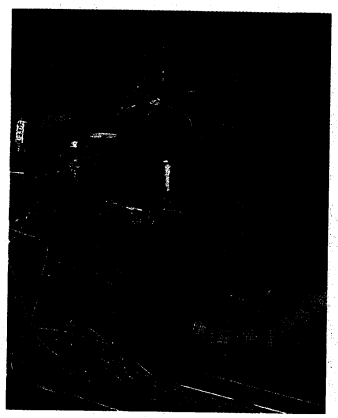
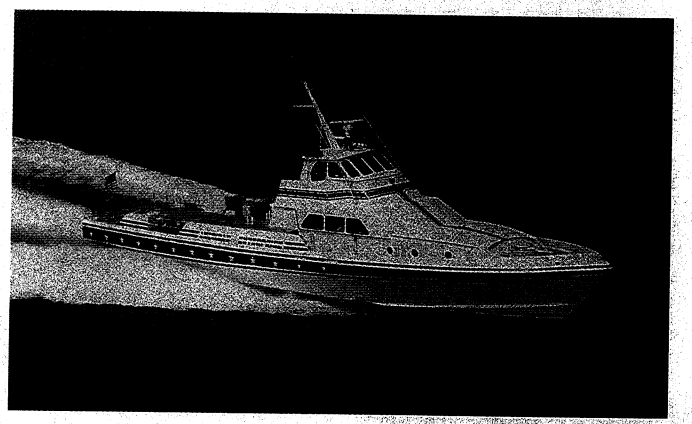
Many of the aerodynamic, propulsion and other advances that have made American-built airliners the most widely operated in the world originated in NASA aeronautical research. NASA also applies aviation-acquired propulsion expertise to automotive research. And many other aerospace technologies have found adaptation, via the spinoff route, in surface transportation applications.▲

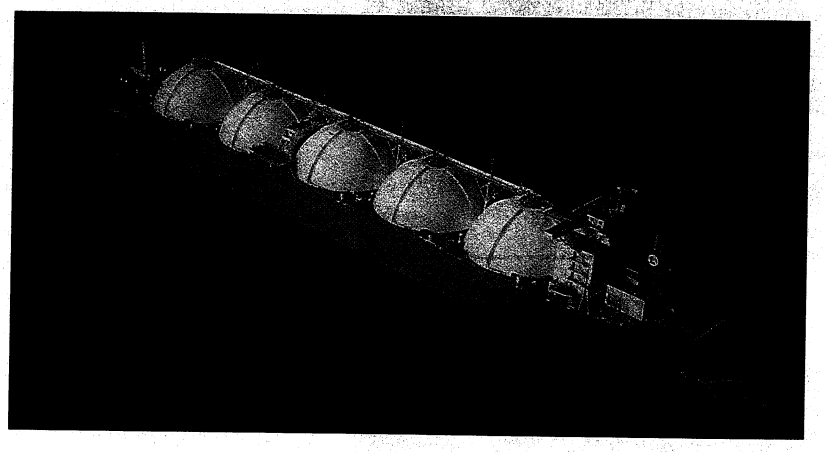






The mighty turbopumps of the Saturn V moonbooster fed fuel to the launch vehicle's engines at the rate of 200,000 gallons a minute. The turbopumps (above) later found commercial utility as primary propulsion systems in a type of high speed crewboat and supply vessel (left) for the offshore oil industry.

In cooperation with truckers, engine manufacturers, and other government agencies, NASA is developing—for cars, buses and trucks—an advanced Stirling external combustion engine that offers dramatically lower fuel consumption and environmental gains in reduced noise and exhaust emissions.



The Space Shuttle's sophisticated, computerized propellant management system, especially designed to monitor the flow of supercold cryogenics, provided the technology for a system that measures precisely the cryogenics loaded and offloaded by liquefied natural gas tankers like the one pictured.

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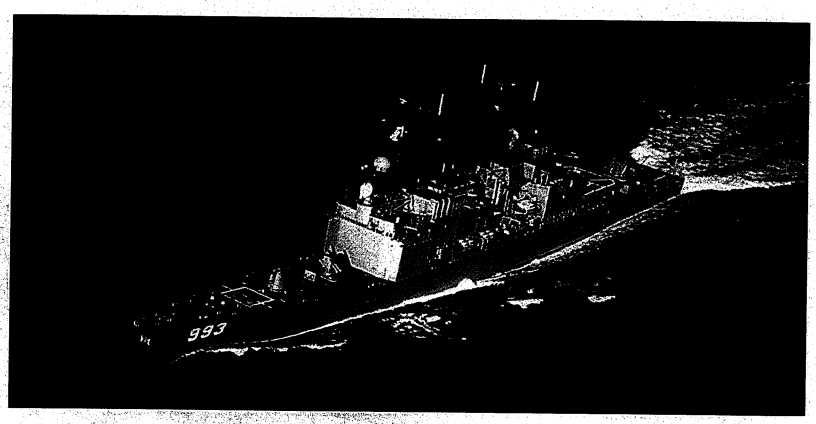
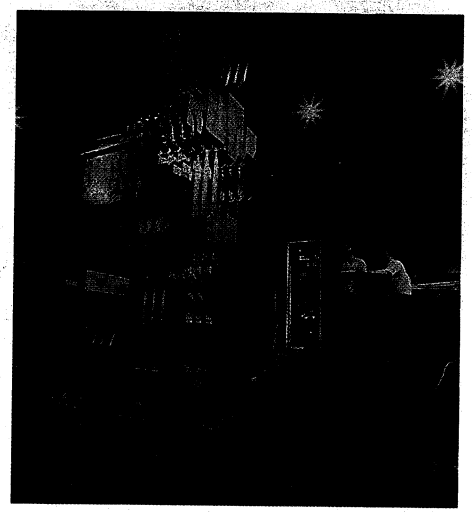
Structural Analysis

For years, aerospace engineers have employed a design technique in which they create mathematical models of an airplane or space vehicle and "fly" it by means of computer simulation; that enables them to study the behavior of a number of different designs before settling on a final configuration. For this technique, NASA developed the NASTRAN program—NASA Structural Analysis—which takes an electronic look at a computerized design and predicts how the structure will perform under service use conditions. Quick and inexpensive, it minimizes trial and error in the design process, this has become one of the most widely employed spinoffs, used to analyze autos, trucks, railroad cars, ships, nuclear reactors, steam turbines, bridges, rollercoasters, office buildings and hundreds of other structures.▲

A decade ago the U.S. auto industry began designing cars with help from the NASA-developed NASTRAN program. Today the NASTRAN program is incorporated in the computer design processes of sevaral major auto companies.

A machinery manufacturer used the NASTRAN program to design these steam turbines. A predictive tool, NASTRAN analyzed the dynamic behavior of turbine components, allowing substantial savings in development costs.





A major shipbuilder used the NASTRAN program in designing the U.S. Navy's *Kidd Class* destroyers, one of which is pictured, and the *CG-47 Class* of guided missile cruisers.

In the photo, a mammoth valve for a nuclear power plant is undergoing shock and vibration testing on a "shake table." In designing a line of valve products, the manufacturer uses the NASTRAN program to identify high stress areas and to establish design adequacy under the most severe conditions the valve might encounter in service use, including earthquakes.

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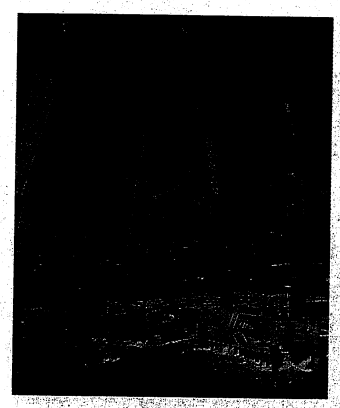
Computer Programs

NASA and other government agencies develop many types of computer programs that frequently can be adapted—with little or no modification—to secondary uses, often remote from their original purpose. In the interest of national productivity, NASA's Computer Software Management and Information Center (COSMIC) offers adaptable programs to industry at a fraction of their originial cost. Since a customer gets a return many times the investment, COSMIC's service has become one of the broadest areas of spinoff applications. COSMIC offers some 1,400 programs and their potential secondary uses would fill a catalog; the illustrations show a few of the many examples.▲

A COSMIC software package helps an insurance company catch data processing errors before they affect the company's customer service or its profitability.



A COSMIC-supplied computer program is used in an offshore oil industry project aimed at developing a capability for predicting the best pile driving technique for each new offshore platform.

How various chemical structures will hold up when used in plastic products—like the containers shown—is analyzed by COSMIC software supplied to a manufacturer of chemical compounds for plastics.

Two COSMIC computer programs that predict noise levels of machinery were employed in a noise analysis performed for a tobacco company that sought to reduce noise so its employees would not have to wear ear protection devices.

A waterfowl preservation society uses NASA-developed software to interpret satellite data on the continually changing conditions of waterfowl habitats.

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NASA Technology Transfer System

NASA's system of technology transfer personnel and facilities extends from coast to coast and permits geographical coverage of the primary industrial concentrations in the United States, together with regional coverage of state/local government transfer activities. Main elements of the system include Technology Utilization Officers (TUOs) at nine NASA field centers, who manage their center's participation in technology utilization matters, and 10 Industrial Application Centers (IACs), which provide information retrieval services and assistance in applying technical information to user needs. TUO and IAC contacts are listed below. For information about other NASA technology transfer services, contact the Director, Technology Utilization Division, NASA Scientific and Technical Information Facility, Post Office Box 8757, Baltimore, Maryland 21240.

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