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NASA's Legacy of Technology Transfer and Prospects for Future Benefits

Douglas A. Comstock[1]
National Aeronautics and Space Administration (NASA) Headquarters, Washington DC, 20546

and

Daniel Lockney[2]
NASA Center for AeroSpace Information (CASI), Hanover, MD, 21076

Over the course of its history, NASA has nurtured partnerships with the private sector to facilitate the transfer of NASA-developed technologies. The benefits of these partnerships have reached throughout the economy and around the globe, as the resulting commercial products contributed to the development of services and technologies in the fields of health and medicine, transportation, public safety, consumer goods, environmental resources, computer technology, and industry. The National Aeronautics and Space Act of 1958 that created NASA called for the new agency to disseminate its technology for public benefit. More than 1,500 of the most compelling partnerships and innovations have been documented in NASA's *Spinoff* publication since 1976. Building on this dynamic history, NASA partnerships with the private sector continue to seek avenues by which technological achievements and innovations gleaned among the stars can be brought down to benefit our lives on Earth.

Nomenclature

AESOP	=	*Automated Endoscopic System for Optimal Positioning*
CASI	=	*Center for AeroSpace Information*
CPR	=	*Cardio-Pulmonary Resuscitation*
CRADA	=	*Cooperative Research and Development Agreements*
ICB	=	*Inventions and Contributions Board*
IGDG	=	*Internet-Based Global Differential GPS*
IPP	=	*Innovative Partnerships Program*
LIDAR	=	*Light Detection and Ranging*
LLC	=	*Limited Liability Corporation*
LVAD	=	*Left Ventricular Assist Device*
MFC	=	*Macro-fiber Composite*
NASA	=	*National Aeronautics and Space Administration*
R&D	=	*research and development*
SBIR	=	*Small Business Innovation Research*
STTR	=	*Small Business Technology Transfer*

I. Introduction

As NASA approaches its 50th anniversary, we reflect on a proud history of achievements that have pushed back boundaries and opened new frontiers for all humanity in the exploration of our solar system and our understanding of the universe and our place in it. New technologies have arisen during this journey, developed of necessity and spurred by the innovative spirit that answers the call of doing the impossible. In the wake of a half-century of advancement, myriad technologies—without which the limits of aeronautics and space could not have been challenged—have found other uses. From the mundane to the sublime, these technologies have become part of the fabric

[1] Director, Innovative Partnerships Program; Senior Member, AIAA
[2] Spinoff Editor, Spinoff Project Office

of our everyday life, driving innovation, helping the economy, and adding to the quality of life not only in the United States, but around the world.

Space exploration acts as a lens that sharply focuses the development of key technologies through the rigorous scientific demands that arise from pursuit of the near-impossible. When seeking to do things that have never been done before, especially in the unique and harsh environment of space, NASA creates new capabilities and makes new discoveries that may have been unlikely otherwise. As NASA's Administrator, Mike Griffin, told the World Economic Forum on January 26, 2007[1], "necessity is the mother of invention, and I believe that we are at our most creative when we embark on bold ventures like the space program." Fundamentally, NASA creates new technologies to meet challenging aeronautics and space program goals, and once proven, these technologies often have a multitude of productive uses in society. Making these sometimes surprising connections and transferring NASA's technologies to the public is an important focus of NASA's Innovative Partnerships Program (IPP).

IPP also seeks solutions to some of NASA's pressing technical challenges by funding Small Business Innovation Research and Small Business Technology Transfer projects; seeking cost-shared, technology development partnerships through the IPP Seed Fund; and tapping into new sources of innovation through NASA's Centennial Challenges prize program. IPP seeks to facilitate and catalyze innovative partnerships in two directions: technology infusion to provide technical solutions to some of the challenges being faced by NASA's programs and projects; and technology transfer—or spinoffs—to provide solutions to technical challenges in the private sector or other Government agencies with NASA-developed technology. In short, IPP is seeking to match technology needs with technology capabilities[2], as illustrated in Figure 1. IPP achieves these objectives through a nationwide network of offices across NASA's 10 field centers.

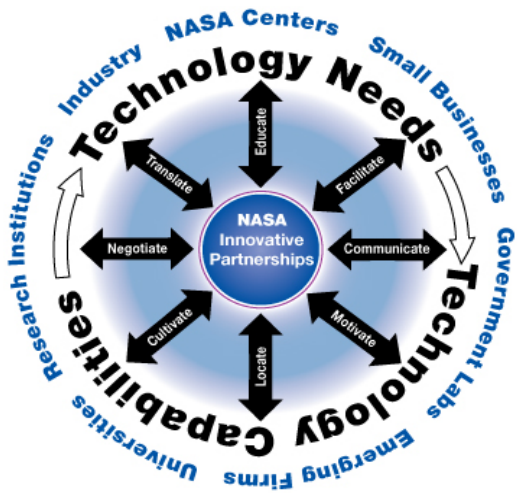

Figure 1. NASA's Innovative Partnerships Program is engaged in a dynamic process to match technology needs with capabilities.

II. Statutory Authority and Guidance

Technology transfer has been a mandate for NASA since it was established in 1958 by the National Aeronautics and Space Act[3]. National leaders at that time recognized that NASA would play an important role in driving technology development to achieve its goals in space and aeronautics, and that those technologies could provide important benefits for the Nation. The Act requires that NASA provide the widest practicable and appropriate dissemination of results of its activities and results, and also provided NASA with the authority to patent inventions to which it has title. The Act also provides for NASA to retain title to all NASA inventions and intellectual property created using government funds, unless specifically waived by the NASA Administrator.

NASA recognized the need for a structured, organized approach to the often serendipitous process of technology transfer. Accordingly, in June of 1962, NASA created the Industrial Applications Program. This program later evolved into the present day IPP to carry out the responsibilities of sharing NASA's research with the public. In the following decade, requests for NASA technology dissemination skyrocketed from several thousand customers in the early 1960s to over 70 thousand non-aerospace customers by the early 1970s. This office transformed the transfer of NASA technologies from being the casual byproduct of aeronautics and space research to being a structured and intentional system of adaptation and application of NASA technology to a broad spectrum of industrial, medical, and social needs.

Since 1980, Congress has enacted a series of laws to promote technology transfer and allow commercial use of government-funded inventions. These laws encourage the sharing of technology and resources between federal laboratories and private industry, including personnel, facilities, methods, expertise, and technical information in general. Highlights of major technology transfer legislation and other guidance, and how they affect NASA are summarized in Figure 2 and in the following discussion.

Stevenson-Wydler Technology Innovation Act of 1980: This Act is the first of a continuing series of laws to define and promote technology transfer. It made it easier for NASA to transfer technology to nonfederal parties and provided outside organizations with a means to access NASA developments. The primary focus of the Stevenson-

Wydler Act concerned the dissemination of information from the federal government and getting NASA and other federal laboratories more involved in the technology transfer process. The law requires NASA to take an active role in technical cooperation and to set apart a percentage of the laboratory budget specifically for technology transfer activities. The law also established an early form of the Innovative Partnerships Program Office to coordinate and promote technology transfer.

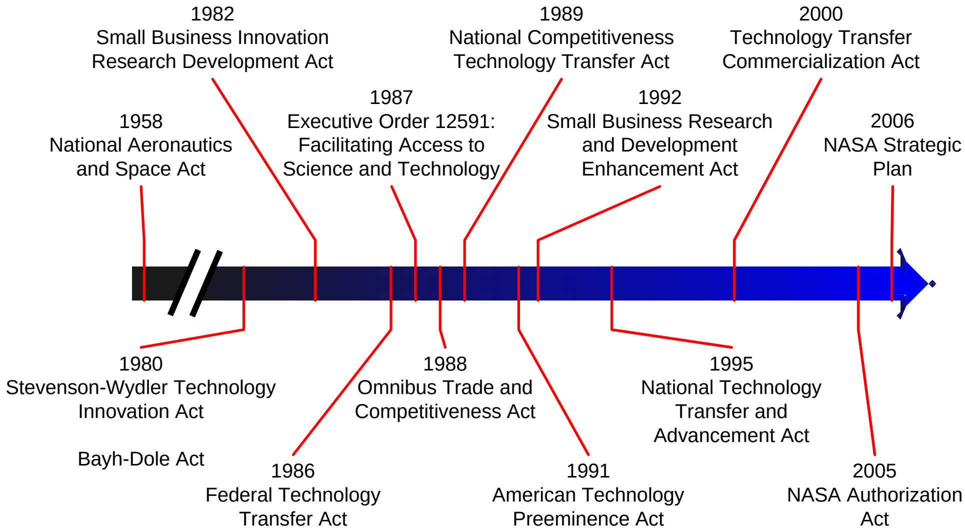

Figure 2. Beginning with the National Aeronautics and Space Act that created NASA in 1958, there has been a series of legislation and executive orders addressing technology transfer.

Bayh-Dole Act of 1980: Together with the *Patent and Trademark Clarification Act of 1984*: This Act established more boundaries regarding patents and licenses for federally-funded research and development. Small businesses, universities, and not-for-profit organizations were allowed to obtain titles to inventions developed by the Space Agency. NASA-owned and -operated laboratories were permitted to grant exclusive patent licenses to commercial organizations.

Small Business Innovation Development Act of 1982: This Act established the Small Business Innovation Research (SBIR) program, requiring NASA to provide special funds for small business R&D connected to the Agency's mission and for the purpose of commercialization.

Federal Technology Transfer Act of 1986: This Act was the second major piece of legislation to focus directly on technology transfer. It enabled NASA-owned and -operated laboratories to enter into Cooperative Research and Development Agreements (CRADAs) and to negotiate licensing arrangements for patented inventions made at its laboratories. It also required that NASA-employed inventors share in royalties from patent licenses. Further, the law provided for the exchange of personnel, services, and equipment between NASA and other government laboratories and non-federal partners.

Executive Order 12591, Facilitating Access to Science and Technology (1987): This Executive Order ensures that NASA laboratories assist universities and the private sector by transferring technical knowledge. The Order required NASA heads to identify and encourage individuals who would act as conduits of information among NASA laboratories, other federal laboratories, universities, and the private sector. It also underscored the government's commitment to technology transfer and urged NASA to enter into cooperative agreements to the limits permitted by law. The Order also promoted commercialization of federally-funded inventions by requiring that, to the extent permitted by law, NASA laboratories grant to contractors the title of patents developed in whole or in part with federal funds, as long as the government is given a royalty-free license of use.

Omnibus Trade and Competitiveness Act of 1988: This Act emphasized the need for public/private cooperation in realizing the benefits of R&D, and extended royalty payment requirements to non-government employees.

National Competitiveness Technology Transfer Act of 1989: This Act provided additional guidelines and coverage for the use of CRADAs, extending to government owned and contractor operated laboratories (i.e. Jet Propulsion Laboratory) essentially the same ability to enter into CRADAs that previously had been granted to NASA owned and operated laboratories by the *Federal Technology Transfer Act of 1986*. To protect the commercial nature of the agreements, the Act allowed information and innovations that were created through a CRADA, or brought into a CRADA, to be protected from disclosure to third parties.

American Technology Preeminence Act of 1991: This Act contained several provisions covering the use of CRADAs, including intellectual property as potential contributions under CRADAs. The exchange of intellectual property among parties to an agreement was allowed, and it also allowed laboratory directors to give excess equipment to educational institutions and nonprofit organizations as a gift.

Small Business Research and Development Enhancement Act of 1992: This Act extended the SBIR program to the year 2000, increased the funding level for SBIR and similar programs, and increased the amounts of the awards. The Act also established the Small Business Technology Transfer (STTR) program.

National Technology Transfer and Advancement Act of 1995: This law amended the *Stevenson-Wydler Technology Innovation Act of 1980* to make CRADAs more attractive to both NASA laboratories and scientists and to private industry. The law provides assurances to U.S. companies that they will be granted sufficient intellectual property rights to justify prompt commercialization of inventions arising form a CRADA with NASA, and gives the collaborating party in a CRADA the right to choose an exclusive or nonexclusive license for a prenegotiated field of use for an invention resulting from joint research under a CRADA. The CRADA partner may also retain title to an invention made solely by its employees in exchange for granting NASA a worldwide license to use the invention. The law also increased the financial rewards for scientists who develop marketable technology under a CRADA.

Technology Transfer Commercialization Act of 2000: This Act recognized the success of CRADAs for technology transfer and broadens CRADA licensing authority to include preexisting inventions to make CRADAs more attractive to private industry and increase the transfer of technology. The Act permits NASA laboratories to grant a license for a federally-owned NASA invention that was created prior to the signing of a CRADA. In addition, the Act requires an agency to provide a 15-day public notice before granting an exclusive or partially exclusive license, and requires licensees to provide a plan for development and/or marketing of the invention and to make a commitment to achieve a practical application of the invention within a reasonable period of time; however, the Act exempts from these requirements the licensing of any inventions under a CRADA.

NASA Authorization Act of 2005: This Act called for NASA to develop a commercialization plan that outlines technology transfer activities stemming from human missions to the Moon and Mars, including commercial R&D partnerships between NASA, universities, and the private sector; and translating space research to Earth benefits to advance United States economic interests. The Act also authorized the agency to conduct NASA-funded prize competitions to encourage private sector involvement in meeting NASA technology needs.

2006 NASA Strategic Plan: The 2006 NASA Strategic Plan emphasized the engagement of the private sector in the NASA mission. The Plan encouraged prize competitions to advance needed technologies, and encouraged partnerships with the emerging commercial space sector.

III. Spinoff

When technology spinoffs began to emerge, NASA considered the possibility of an annual report to present at congressional budget hearings. The result was a black and white "Technology Utilization Program Report," published in 1973, followed by another one in 1974. The technologies in these reports created interest in the technology transfer concept and its successes, and as a result, the reports were considered for use as public awareness tools. The reports generated such keen interest in the public that NASA decided to make them into a glossy publication. The first four-color edition of *Spinoff* was published in 1976. This same year, the Space Agency began publishing *Tech Briefs*, which lists licensing opportunities available through NASA. *Tech Briefs*[4], widely considered by R&D designers and practitioners worldwide as one of the best sources of new technology ideas, is a monthly magazine written specifically for the scientific and technical community; *Spinoff*[5], is an annual publication targeting the general public,

Each year since 1976, a new issue of *Spinoff* has highlighted the transfer of NASA technology to the private sector. The Agency distributes copies to government officials, economic decision makers, company CEOs, academics, professionals in technology transfer, the news media, and the general public. It is now available in its original print form, online through a dedicated Web site, and as an interactive CD-ROM. The Spinoff Project Office also maintains a benefits database[6], where all *Spinoff* stories are now available online in a searchable format. Stories can be retrieved by publication date, key words, NASA field center involvement, originating technology, general benefit category, state, or the article's title.

Spinoff (spin´ ôf´) -*noun*.

1. A commercialized product incorporating NASA technology or "know how" which benefits the public. Qualifying technologies include:
   - Products or processes designed for NASA use, to NASA specifications, and then commercialized.
   - Components or processes involving NASA technology incorporated into a commercial product, employed in the manufacturing of a product, or used to modify the design of an existing product.
   - Products or processes to which NASA laboratory personnel made significant contributions, including the use of NASA facilities for testing purposes.
   - Successful entrepreneurial endeavors by ex-NASA employees whose technical expertise was developed while employed by NASA.
   - Products or processes commercialized as the result of a NASA patent license or waiver.
   - Commercial products or processes developed as a result of the Small Business Innovation Research or Small Business Technology Transfer programs.
2. NASA's premier annual publication, featuring successfully commercialized NASA technologies.

NASA's *Spinoff* publication accomplishes several goals. First, it communicates some of the benefits being derived from the continued expenditure of NASA funds. It serves as a tool to educate the media and the general public by informing them about the benefits of the Nation's investment in NASA. It reinforces interest in space exploration. It demonstrates the possibility to apply aerospace technology in different environments. It highlights the ingenuity of American inventors, entrepreneurs, and application engineers, and the willingness of a government agency to assist them. And finally, it continues to help ensure global competitiveness and technological leadership by the United States. The total number of stories published since 1976 is over 1,500, which does not include approximately 100 stories featured in the 1973 and 1974 reports, nor is it entirely representative of the total number of technology transfer successes that have come out of NASA. Each year, NASA features approximately 50 of the best commercialized technology stories, based on factors such as improvements to the quality of life, remarkable technological advances, economic impact, market penetration, and human interest. The total number technologies NASA has contributed to the world is much larger—according to a recent NASA Inventions and Contributions Board report[7], NASA has received over 6,500 patents since it was founded (about one in every thousand patents issued by the U.S. Patent and Trademark Office since its creation in 1802).

IV. Benefits to Society

NASA's technologies have been transferred to many different areas that contribute to quality of life and safety of the public, as well as to economic growth. These areas include: Health and Medicine; Transportation; Public Safety; Consumer Goods; Environmental and Agricultural Resources; Computer Technology; and Industrial Productivity. A sampling of some well known historic examples, all of which can be accessed through the Spinoff database, include:

1978: Teflon-coated fiberglass developed in the 1970s as a new fabric for astronaut spacesuits has been used as a permanent roofing material for buildings and stadiums worldwide.

1982: Astronauts working on the surface of the Moon wore liquid-cooled garments under their space suits to protect them from lunar temperatures that often reached 250°F. Developed by NASA's Ames Research Center, the technology is one of the most widely used spinoffs in NASA history. The technology has been adapted to portable cooling systems for treatment of medical ailments such as burning limb syndrome, multiple sclerosis, spinal injuries, and sports injuries.

1986: A joint National Bureau of Standards/NASA project directed by Johnson Space Center resulted in a lightweight breathing system including face mask, frame, harness, and air bottle for fire fighters. To this day, every major manufacturer of breathing apparatuses incorporates NASA technology in some form, and inhalation injuries have been significantly reduced.

1991: Employing three separate NASA-developed technologies in the design and testing of its school bus chassis, a Chicago-based company was able to mathematically analyze a design and predict how it will hold up under stress, monitor structural changes during fatigue testing, and develop a measurement of ride vibration and sound level. This testing contributed to the company's creating of a safer, more reliable, advanced chassis and allowed the company to gain nearly half of the school bus chassis market within its first year of production.

1994: Using technologies created for servicing spacecraft, a Santa Barbara-based company developed a mechanical arm that enables surgeons performing laparoscopic surgery to operate three instruments simultaneously. The robot, AESOP (Automated Endoscopic System for Optimal Positioning), holds the laparoscope and moves it in response to a controller operated by the surgeon. In August of 2001, the first complete robotic surgical operation was performed, when a team of doctors in New York removed the gallbladder of a woman in France using the Computer Motion equipment.

1995: The Left Ventricular Assist Device (LVAD) is used to supplement the heart's pumping capacity in the left ventricle. David Saucier of NASA's Johnson Space Center teamed with Dr. Michael DeBakey of the Baylor College of Medicine to develop the device with tools and techniques used by NASA in spacecraft propulsion system component design. The device can maintain the heart in a stable condition in patients requiring a transplant until a donor is found, which can range from one month to one year. In some cases, the need for a transplant may be negated by permanent implantation of the LVAD.

2000: Internet-based Global Differential GPS (IGDG) was developed at Jet Propulsion Laboratory and won its inventors the "2000 NASA Software of the Year" award. The C-language package provides an end-to-end system capability for GPS-based real-time positioning and orbit determination. The software is being used to operate and control real-time GPS data streaming from NASA's Global GPS Network. The Federal Aviation Administration (FAA) adopted its use into the Wide Area Augmentation System program that provides pilots in U.S. airspace with meter-level accurate knowledge of their positions in real-time.

2002: Three SBIR contracts with NASA's Langley Research Center to research and develop a new, low cost, lightweight recovery system for aircraft in both civilian and military markets resulted in a unique ballistic parachute system that lowers an entire aircraft to the ground in the event of an emergency. These parachutes are designed to provide a safe landing for pilots and passengers while keeping them in their aircraft, and a uniquely effective safety technology in the event of engine failure, mid-air collision, pilot disorientation or incapacitation, unrecovered spin, extreme icing, and fuel exhaustion. To date, over 200 lives have been saved as a result of this parachute system.

The uniqueness of living and working in space teaches us to think in new ways. The weightless environment can be very counter-intuitive, as things don't fall when you drop them, and liquid doesn't pour. A key example of this is what was learned from a sintering experiment on Shuttle, which led to improved manufacturing here on earth. Liquid-phase sintering is an industrial process of heating and compacting materials used to manufacture many products such as cutting tools and automotive turbochargers. Experiments conducted in space showed exactly the opposite behavior relative to what was predicted: the sintered samples distorted more in microgravity. After analyzing the surprising behavior with NASA researchers, Kennametal, Inc., the North American market leader in the metal-cutting tool industry and second worldwide, with annual sales of $1.8 billion, changed their sintering process. Before, grinding was required to bring the part into specification after sintering because the sintering process produced an imperfect shape. The cost of this extra production step was about 40% of the total manufacturing cost. Using the insight obtained from space research, it was possible to nearly eliminate the grinding step, and make parts more simply and at less cost. The importance of this Shuttle-based research was verified by independent experts of the National Research Council[8].

NASA technologies have been saving lives and improving the quality of life all over the globe. Advances recently featured in *Spinoff* include the use of a portable water filtration device that is a direct descendant of a technology developed for use on the ISS and space shuttle to provide clean drinking water to people in Pakistan, the Dominican Republic, and Northern Iraq. Space suit technologies have been adapted to create a type of weather balloon that have been used as an affordable "satellite" for cell phone coverage in remote parts of Africa. A technique for diffusing landmines with surplus NASA rocket fuel is saving lives in Kosovo and Jordan. A device originally developed for monitoring astronaut health is now being used in networks of sensors for monitoring environmental changes, including monitoring water quality in Vietnam and tracking public health information in Ethiopia. The radiant barrier material popularized as the "space blanket" was shipped in mass quantities to Pakistan after the earthquakes in 2005. Techniques developed for groundwater remediation at Kennedy Space Center's launch sites have been used to reclaim areas heavily contaminated with solvents and industrial byproducts.

These are just a few of the many historic examples of how NASA technologies are helping people around the world, and exemplify the type of public benefits NASA seeks to document each year in *Spinoff*. While historic examples are interesting, what has NASA done lately? To provide a sense of the current benefits NASA technology is providing, a few brief examples – that are fully documented in the soon-to-be-released 2007 edition of *Spinoff* – are summarized below. They are presented in seven major benefits categories.

A. Health and Medicine

NASA advances in health care have resulted in advanced telemedicine capabilities and unique applications of imaging techniques to the first bedside arrhythmia-monitoring system, allowing physicians to view real-time arrhythmia data. Recently documented cases of NASA technology transferred from research related to astronaut life support, satellites and imaging technology, the International Space Station, the space shuttle, and space telescopes and deep space exploration have yielded health care innovations that improve CPR, detect cardiovascular disease, assist patients with cognitive disorders, evaluate nerve function, fight acne, broaden cellular analysis, and enhance diagnostic imaging. Two examples are briefly summarized below:

Circulation-Enhancing Device Improves CPR: NASA studies on cardiovascular responses and fluid shifts in the body for astronaut life support led to collaboration with Advanced Circulatory Systems Inc., to develop the ResQPOD Circulatory Enhancer. This impedance threshold device improves the standard of care provided to patients with a variety of clinical conditions due to low blood flow.

Noninvasive Test Detects Cardiovascular Disease: NASA-developed Video Imaging Communication and Retrieval software for analysis of images from Mars laid the groundwork for a project seeking to use imaging technology to analyze X-ray images of soft tissue. The same methodology applied to ultrasound imagery resulted in a non-invasive diagnostic system with the ability to accurately predict heart health.

B. Transportation

It is safe to say that a vast majority of aircraft today have benefited in some way from NASA's advanced aeronautics research, dating back to the agency's origination as the National Advisory Committee for Aeronautics in

1915. Recently documented cases of NASA technology transfer from aeronautics research have yielded benefits that ease air traffic management, advance rotorcraft design, launch personal air vehicles, improve flight safety, boost helicopter performance, and protect general aviation aircraft. Two examples are briefly summarized below:

Comprehensive Software Eases Air Traffic Management: NASA's Future Air Traffic Management Concepts Evaluation Tool, developed for air traffic control centers to improve the safety and efficiency of the National Airspace System software, was licensed by Flight Explorer Inc. The software now offers automatic alerts of events such as weather conditions and potential airport delays, and real-time flight coverage over Canada, the United Kingdom, New Zealand, and sections of the Atlantic and Pacific Oceans. Flight Explorer Inc. recently formed several partnerships to expand coverage worldwide.

Deicing System Protects General Aviation Aircraft: Kelly Aerospace Thermal Systems LLC collaborated with NASA scientists on deicing technology with assistance from the SBIR program. New and previous work combined in the development of a lightweight, easy-to-install, and reliable wing and tail deicing system called Thermawing, a DC-powered air conditioner for single-engine aircraft called Thermacool, and high-output alternators to run them both.

C. Public Safety

NASA's strict emphasis on creating a culture of safety has benefited us all, whether it be in creating cleaner drinking water, threat detection technologies, rescue equipment, or bolt stress monitors for mine shafts. Recently documented cases of NASA technology transfer from research in aeronautics and the International Space Station have yielded benefits that detect potential threats, sharpen views in critical situations, and clean air and water for indoor environments. Two examples are briefly summarized below:

Chemical-Sensing Cables Detect Potential Threats: SBIR contracts helped Intelligent Optical Systems Inc. (IOS) develop moisture- and pH-sensitive sensors to detect corrosion or pre-corrosive conditions before significant structural damage occurs. The company subsequently worked with the U.S. Department of Defense to continue development of the sensors for detecting chemical warfare agents. IOS has also sold the technology to major automotive and aerospace companies, who are finding a variety of uses for the devices.

Infrared Imaging Sharpens View in Critical Situations: Innovative Engineering and Consulting Infrared Systems received NASA assistance to develop commercial infrared imaging systems that better differentiate the intensity of heat sources. The research resulted in the NightStalkIR and IntrudIR Alert Systems, now being used abroad to locate personnel stranded in emergency situations and protect high-value operations. The company is also applying its thermal imaging techniques to medical and pharmaceutical products.

D. Consumer Goods

Myths about NASA contributions to everyday consumer goods abound. Common misperceptions persist that NASA invented Tang, which was actually a product created by General Foods in 1957 and popularized during its first and only trip to space in 1962 when astronaut John Glenn performed eating experiments in orbit; Teflon, a material invented for DuPont in 1938 and linked forever to NASA in the public consciousness when the Agency applied it to heat shields, space suits, and cargo hold liners; and Velcro, used during the Apollo missions to anchor equipment for astronauts' convenience in zero gravity situations but properly credited to a Swiss inventor who marveled at how burs were sticking to his wool plants while out walking his dog. Other technologies mistakenly attributed to the Space Agency include barcodes, quartz clocks, smoke detectors, and even MRI. These technologies were borne of different necessities, and like most common goods, were the result of problems met in every day life.

While each of these owes its origin to another maker, NASA has made significant contributions to the way that we live, and technologies created for the Space Program have been applied to everything from golf clubs to carpet cleaning devices. Recently documented cases of NASA technology transfer from research related to the International Space Station, satellites and imaging technology, astronaut life support, and the space shuttle have yielded benefits that restore artwork, enhance education and recreation, reduce fat while improving flavor, transform paint into insulation, and protect machines and the environment. Two examples are briefly summarized below:

Corrosive Gas Restores Artwork, Promises Myriad Applications: NASA research on corrosion and long-duration coatings led to alternate applications of atomic oxygen. Atomic oxygen was found to remove organic compounds high in carbon (such as soot) from fire-damaged artworks without altering the paint color, and has been tested on oil paintings, acrylics, watercolors, and ink. Atomic oxygen's unique characteristic of oxidizing primarily hydrogen, carbon, and hydrocarbon polymers at surface levels has also been applied to the detection of document forgeries and removal of bacterial contaminants from surgical implants.

Food Supplement Reduces Fat, Improves Flavor: NASA helped Diversified Services Corporation develop a nutritional fat replacement and flavor enhancement product. The now-commercialized substitute, Nutrigras, is primarily intended for use as a partial replacement for animal fat in beef patties and other high-fat meat products, and can also be used in soups, sauces, bakery items, and desserts. Nutrigras costs less than the food it replaces, and helps manufacturers reduce material costs. In precooked products, Nutrigras can increase moisture content and thereby increase product yield.

E. Environmental and Agricultural Resources

NASA's research has not only enhanced our understanding of air and space, but also our understanding of the Earth and how to preserve it. Using remote-sensing data from satellites, NASA scientists are giving us a better understanding of the causes and effects of global climate change, and NASA technologies have advanced irrigation and crop management techniques for farmers around the world. In short, NASA's research helps sustain the Earth and its resources. Recently documented cases of NASA technology transfer related to research on satellites and imaging technology, astronaut life support, and the space shuttle have yielded benefits that map, monitor, and manage Earth's resources, provide environmental data, save energy and prolong motor life, and prevent corrosion in steel and concrete structures. Two examples are briefly summarized below:

Advanced Systems Map, Monitor, and Manage Earth's Resources: A NASA STTR contract developed a hyperspectral cropimaging project to enhance airborne hyperspectral sensing and ground-truthing means for crop inspection. SpecTIR LLC, recognized for innovative sensor design, on-demand hyperspectral data collection, and image-generating products, integrated the hyperspectral data with LIDAR systems and other commercial technologies. Areas of application include precision farming and irrigation; oil, gas, and mineral exploration; pollution and contamination monitoring; wetland and forestry characterization; water quality assessment; and submerged aquatic vegetation mapping.

Treatment Prevents Corrosion in Steel and Concrete Structures: A NASA-developed electromigration technique to prevent corrosion in rebar was combined with Surtreat Holding LLC's chemical anti-corrosive solution. NASA followed this effective match with a liquid galvanic coating for reinforced concrete, applications for which include bridge and building infrastructures, piers and docks, parking garages, cooling towers, and pipelines. Surtreat's Total Performance System, a natural compliment to the coating, provides diagnostic testing and site analysis, manufactures and prescribes site-specific solutions, controls material application, and verifies performance through follow-up testing and analysis.

F. Computer Technology

Modern microchips are direct descendants of the integrated circuits used in the Apollo Guidance Computer, which was onboard for many of the Apollo space missions from 1969 to 1972 and was used during the Apollo 11 mission, which landed on the moon on July 20, 1969. NASA is still on the cutting edge of advanced computing, best evidenced by Columbia supercomputer at Ames Research Center, which is not only the making it possible for NASA to achieve breakthroughs in science and engineering for the Agency's missions and Vision for Space Exploration, but is also available to the general scientific community for projects such as understanding how turbulence starts in high-speed airflow over air vehicles, accelerating the realization of simulation-based design of naval ships, reducing the pollution produced by power generation, and predicting future global climate change through analysis of the world's oceans. Recent NASA technologies transferred from research related to space telescopes and deep space exploration, aeronautics, the space shuttle, the International Space Station, and satellites and imaging technology have yielded benefits that simplify analysis and design, translate 2-D graphics to 3-D surfaces, improve health and performance monitoring, enable smarter content management, and validate system design. Two examples are briefly summarized below:

Design Application Translates 2-D Graphics to 3-D Surfaces: NASA developed a flattening process to translate surface geometry of a model to a 2-D template. Fabric Images Inc., specializing in the printing and manufacturing of fabric tension architecture for the retail, museum, and exhibit/trade show communities, utilizes software derived from NASA's to translate 2-D graphics for 3-D surfaces prior to print production. Benefits of this process include 11.5 percent time savings per project, less material wasted, and the ability to improve upon graphic techniques and offer new design services.

Hybrid Modeling Improves Health and Performance Monitoring: A NASA SBIR contract helped Scientific Monitoring Inc. create a simplified health monitoring approach for flight vehicles and equipment. I-Trend, the resulting product, compares equipment performance to design predictions, to detect deterioration or impending failure before operation is impacted. I-Trend also characterizes health or performance alarms that result in "no fault found" false alarms. Several commercial aviation programs use I-Trend technology, and the U.S. Air Force tapped Scientific Monitoring to develop next-generation engine health-management software.

G. Industrial Productivity

NASA creates technologies that are often expected to function in high-stress, high-heat, critical environments. These technologies often find their ways into the manufacturing processes here on Earth, where composite materials, stress tests, safety innovations, insulating materials, and advanced lubricants all help maintain the Nation's economic competitiveness.

Recent NASA technologies transferred from research related to the space shuttle, satellites and imaging technology, and astronaut life support have yielded benefits that strengthen structures, boost data transmission, enhance precision fabrication, broaden sensing horizons, resist extreme heat and stress, develop ultra-hard steel, save time and energy, streamline production, control noise and vibration, and advance thermal management. Two examples are briefly summarized below:

Novel Nanotube Manufacturing Streamlines Production: NASA's IPP office promoted a NASA-developed process for creating nanotubes, and Idaho Space Materials Inc. (ISM) applied for a nonexclusive license for the single-walled carbon nanotube manufacturing technology. ISM commercialized its products, and the inexpensive, robust nanotubes are now being used to create the next generation of composite polymers, metals, and ceramics. Researchers are also examining ways to use these materials in myriad technologies, including transistors, fuel cells, televisions, supercapacitors, catalysts, and advanced composite materials.

'NASA Invention of the Year' Controls Noise and Vibration: NASA's Macro-Fiber Composite (MFC) is designed to control vibration, noise, and deflections in composite structural beams and panels. Smart Material Corporation licensed the MFC technology to add it to their line of commercially produced actuators, and to date has sold MFCs to over 120 customers, including Volkswagen, Toyota, Honda, BMW, General Electric, and the tennis company, HEAD. Consumer applications already on the market include audio speakers, phonograph cartridges, microphones, and products requiring vibration control such as sports equipment.

The examples summarized here demonstrate that NASA does, indeed, have a legacy of success at transferring technologies for public benefit. Such a track record, however, does not ensure continued success going forward. NASA will surely have new technologies in the future, but must continue to actively work at transferring those technologies for broader public benefit. A 2004 study done by the National Academy of Public Administration (NAPA)[9] addressed the issue of how NASA could ensure it was positioned to continue the legacy of technology transfer success. Many recommendations from that report have already been implemented, and NASA's Innovative Partnerships Program continues to seek opportunities to be even more effective at adding to NASA's legacy of technology transfer success.

V. Conclusion

As we look forward to NASA's next 50 years, boundaries will be pushed even further. Future achievements will be enabled by new technologies—many perhaps not even imagined today. Fifty years ago, we could not foresee that heart disease would one day be detected early and with no discomfort, using technology developed to analyze images from Mars probes. So today, we cannot predict the technologies of tomorrow or the spinoffs they will leave in their wake. However, NASA is tapping into the imagination of our youth to see what they envision as potential future benefits. NASA will be conducting a contest for middle-school students this year, in which they can enter two essays – one describing how they benefit today from NASA's first fifty years of aerospace technology development and spinoffs, and a second describing how they may benefit from the next 50 years of NASA technology. Only time will tell if the students get it right, but as the 1,500 examples in *Spinoff* attest, we are confident that NASA's future technologies will continue to generate many more spinoffs and public benefits. As NASA's Deputy Administrator, Shana Dale, said at the 2nd AIAA Space Exploration Conference on December 5, 2006[10], "Of course, much of what we gain from exploring and settling the Moon will not be in what we find on it, or in the observations we make from it, but in the scientific and technological progress that will come in the process of doing it. And much of that will have direct economic and health benefits for those of us who remain behind on Earth."

Acknowledgments

The successful transfer of NASA technologies is a result of the hard work and dedication of the scientists, enginееrs and technologists, and the technology transfer professionals at each of NASA's ten field centers.

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