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NASA's Space Shuttle: Perspectives on Technology Transfer

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Since NASA first started recording its technology transfer successes in 1976 with publication of the annual *Spinoff* journal, over 1,650 documented NASA technologies have benefited U.S. industry, improved quality of life, and created jobs. These benefits have been seen in the fields of engineering, medicine, communications, transportation, environmental remediation, public safety, and even consumer goods. The space shuttle program alone has generated more than 120 of these recorded technology spinoffs. Given the imminent retirement of this program, this paper seeks to examine ways in which the development and servicing of this fleet of space vehicles, designed to ferry astronauts and cargo between Earth and space, has brought about numerous tangential benefits throughout its decades of service. This examination highlights the role of spinoffs as secondary but very real benefits of the original aerospace research and development by juxtaposing the original intent of the program—the numerous successful science missions, deployment and repair of the Hubble Space Telescope, and construction of the International Space Station—with the ancillary outcomes. Examples of these spinoffs include an implantable heart pump—based on shuttle fuel pump technology—that has been credited with saving hundreds of lives; home insulation using the same lightweight flexible aerogel NASA developed to insulate the shuttle launch systems; a high-performance, biodegradable lubricant developed for the enormous crawlers that transport the shuttles to and from their launch pads, now used for cars and sporting goods; and video stabilization software, originally created to clarify space shuttle launch video, now helping clean up crime scene video for law enforcement.

Nomenclature

CASI	=	Center for AeroSpace Information
NASA	=	National Aeronautics and Space Agency
SBIR	=	Small Business Innovation Research
SSME	=	Space Shuttle Main Engine
STTR	=	Small Business Technology Transfer

I. Introduction

NASA's charter requires the Agency to disseminate its technologies to the public. When Congress created the civilian space agency, it mandated that the time and money being invested in space needed to also come back down to Earth in the form of practical benefits. Thus, throughout its history, NASA has worked to transfer its newly-developed technologies to the public sector, partnering with businesses and academia to find secondary uses for its aeronautics and space technologies. One of the most successful programs for technology transfer has been the space shuttle program. Credited with the most recorded NASA spinoff technologies to date, this program is nonetheless often overshadowed by the Apollo program, and is one which many might not readily associate with technological spinoffs. This disconnect is evidenced by the perspective of the general public—and from within the space community—about NASA spinoffs technologies.

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II. Spinoffs and Public Perception

Recently, upon the 40th anniversary of the first manned lunar landing, considerable attention was paid to the spinoff benefits of the Apollo program. Media outlets worldwide reported on the many technologies we have today that trace their roots back to the lunar program.

In his address to the National Academy of Sciences in April 2009, President Barack Obama, speaking of the advances brought about by the investment in the Apollo program, noted:

> The scientific community rallied behind this goal and set about achieving it. And it would lead not just to those first steps on the moon, but also to giant leaps in our understanding here at home. The Apollo program itself produced technologies that have improved kidney dialysis and water purification systems; sensors to test for hazardous gasses; energy-saving building materials; and fire-resistant fabrics used by firefighters and soldiers. And, more broadly, the enormous investment of that era—in science and technology, in education and research funding—produced a great outpouring of curiosity and creativity, the benefits of which have been incalculable.

This type of praise and outpouring of accolades for the new technologies developed during the Apollo program resonated throughout much of the media at this time, with articles appearing in newspapers and on Web sites around the world. Yet while the Apollo program is widely considered the heyday of NASA technology, the program from which NASA has recorded the largest number of spinoff benefits is actually the space shuttle program. With over 120 recorded spinoffs, it is, in terms of technology transfer, the most prolific of any NASA project.

The disparity between popular opinions and the recorded data can be explained by a series of factors, including public perception of new space technologies during the budding "space age," a gradually evolving infrastructure for formally moving NASA technologies into the public sector, and NASA's development of a method for recording its technology transfer successes. Also, while the Apollo program lasted just under a decade, from 1963-1972, the shuttle program lived a considerably longer life—over three decades—beginning in 1972 with President Richard Nixon's announcement that NASA would develop a reusable space shuttle system and continuing to the present day.

Prior to the success of the Apollo program, for many, travel to other celestial bodies and the associated space technologies were dreams of the future, but with the successful Moon landings, there came the realization that these cutting-edge technologies were things of the present. This generated a keen interest in the public and an expectation that, since we were now living in a "space age," that these technologies developed for space should reach homes and factories across the country.

This era, the middle portion of the 20th century, was also a period when many new technologies were already reaching the public, spurred by advances in manufacturing and electronics. And while this influx of new consumer electronics and gadgets happened during a time when people were discovering the possibilities of space flight, many of the new goods were not directly related to any space or NASA mission. As a result, to this day, people (sometimes employees of NASA included) often mistake common household goods like microwave ovens, quartz wristwatches, smoke detectors, and barcodes for NASA technologies.

While the Apollo program did bring about many significant spinoff technologies—like some of the first practical uses of the integrated circuit, the predecessor of the modern microchip—the difference between recorded spinoff technologies and public perception is pronounced.

The greater number of space shuttle spinoffs recorded by NASA versus the number of Apollo technologies recorded could also be partially attributed to the formalization of the technology transfer program. During the life of the shuttle program, there has been a more organized system in place to effectively move technologies from the laboratory and the launch pad into the commercial sector. The National Aeronautics and Space Act of 1958, which formed NASA, called for the newly-authorized agency to disseminate its new technology for public benefit. The Act requires NASA to 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. Accordingly, in June of 1962, NASA created the Industrial Applications Program, which provided a structured, organized approach to the often serendipitous process of technology transfer.

While this program was in place, with offices at each of NASA's field centers, the relatively new program was not widely known by the public. The success of the Apollo program spurred the business and academic communities to develop these space technologies for terrestrial purposes. This is evidenced in the increased number of requests for NASA technology dissemination, which grew from several thousand customers in the early 1960s to over 70 thousand non-aerospace customers by the early 1970s. This transformed the spinoff of NASA technologies from the casual byproduct of aeronautics and space research into a structured and intentional system.

Additional legislation in the 1980s, including the Stevenson-Wydler Technology Innovation Act of 1980; the Bayh-Dole Act of 1980; the Small Business Innovation Development Act of 1982; the Federal Technology Transfer Act of 1986; Executive Order 12591, Facilitating Access to Science and Technology (1987); the Omnibus Trade and Competitiveness Act of 1988; and the National Competitiveness Technology Transfer Act of 1989, further emphasized and formalized the purposes and methods for transfer of technologies from the Federal laboratory to the public sector.

With the formalization of the technology transfer program also came an institutionalized method for recording these advances. In 1973 and 1974, NASA submitted to the Congress its first two *Technology Utilization Report* documents, highlighting NASA's technology transfer successes. Legislators, realizing that these stories of direct benefits of the Space Program could be useful in convincing constituents of the importance of additional NASA funding, asked NASA to continue producing these reports. In 1976, NASA published its first issue of the annual *Spinoff* journal, which to this day has recorded over 1,650 NASA spinoffs, at the rate of roughly 40 to 50 per year. The articles featured over the past three decades of *Spinoff* represent technologies developed from nearly every NASA mission to date and represent partnerships in a wide variety of industries and in every state in the union.

Although the *Spinoff* publication began in 1976, that does not mean necessarily that it excluded Apollo technologies. New technologies often take several years to reach the market, and many of the technologies featured in the *Spinoff* journal represent NASA work that was done, on average, 5 to 10 years earlier. Several methods exist for commercializing NASA-derived technology, and each one takes a different amount of time, depending on a variety of factors. For a licensed NASA technology to reach commercialization, for example, there first needs to have been a patent filed within NASA. This is followed by a public disclosure of the availability for licensing, which often involves marketing through *NASA Tech Briefs*, a monthly publication developed by NASA to make industry aware of available NASA technologies. An interested company must then negotiate the terms of the license. The company then conducts tests, creates prototypes, and develops a product and manufacturing methods, all while gathering investors. Next, the product needs to be marketed and sold. This process can take years to complete.

Therefore, at the time *Spinoff* was first published, many of the technologies described dated back to the Mercury (1959–1963) and Gemini (1962–1966) programs. Additionally, efforts were made to retroactively attribute Apollo-derived technologies to the program. Nevertheless, to this day, NASA has identified fewer than 80 new technologies that directly trace back to the Apollo program, compared to the over 120 attributed to the space shuttle.

III. Industry Perception of NASA Spinoff

NASA's technology transfer program is sometimes disregarded by those who work within the space community because "space purists" do not believe that the resulting spinoff technologies justify the Space Program.

While the terrestrial use of NASA-derived technologies has been one of the basic tenets of the U.S. Space Agency, it was never intended to be the primary end result of the investment and research. Rather, these are the secondary, even tertiary byproducts of NASA's aeronautics and space research, and the commercialized technological advances often pale in comparison to the primary—yet often intangible—goals of the space program: exploring the universe and our place in it, and expanding the reach of humanity and the breadth of human knowledge.

The value of space research is often felt in immeasurable ways: the shift in global understanding of the Earth as a fragile ecosystem that came about after the widespread distribution of Apollo 8 astronauts Bill Anders' and Frank Borman's historic Earthrise photographs, oft cited as integral to the birth of the environmental movement in the 1970s; the feeling of National pride and world wonderment when the Apollo 11 astronauts first set foot on the Moon and the subsequent inspiration of generations to achieve the unattainable; the amazement felt when seeing images sent back to Earth from the Hubble Space Telescope, or the sports fan-like rooting for the tenacious Mars Rovers Spirit and Opportunity.

This is the material that fills science textbooks and informs our collective conscience, and it should be ample justification for the investment in continued aerospace research. Because of the ethereal nature of these benefits, though, often times when people discuss the reasons for embarking on this research, they cite the spinoff benefits as an answer to the age-old question of "What's in it for me?" This was evidenced by congressional support for development of the legislation to support technology transfer and the subsequent reliance on the annual *Spinoff* journal.

As demonstrated in NASA-funded research conducted in 2007 by the Office of Communications Planning and published in the Strategic Communications Framework Implementation Plan, people's impression of NASA tended to improve when they were informed that NASA had created or helped in the development of various everyday items. While NASA generally had a favorable rating among respondents, the Agency's relevance increased when people saw how it affected their daily lives. In one poll conducted as part of the research, approximately 1,000 people were asked to rate the relevance of NASA to their everyday lives. Prior to being told that NASA had helped develop a series of specific technologies, the majority (53 percent) of respondents reported favorably, saying that NASA was either extremely (16 percent) or somewhat (37 percent) relevant to them. After being told that NASA had helped develop key everyday items, the numbers shifted dramatically, with a 94 percent favorability rating—65 percent who now reported that space research was extremely important, and 29 percent saying it was somewhat relevant. Given this type of trend, spinoff technologies often take on the role of justifying the Space Program.

Interestingly, it is often the Space Program spinoff advocates who tell the stories inaccurately, assigning more credit to NASA than rightfully due. Rarely, if ever, is NASA the sole inventor of anything that we use in our daily lives. Rather, NASA develops key, sometimes enabling, technologies and then partners with industry to transfer the technologies out of the government laboratories. Commercial companies are the ones who then design, manufacture, market, and sell the products.

Yet, to hear the typical space spinoff enthusiast speak—and this comes even from within the Space Agency itself—one would think that NASA had invented smoke detectors, quartz clocks, Velcro, Teflon, barcodes, and cordless power tools. Each of these items existed before any NASA involvement. In some instances, for example with Velcro, NASA simply popularized its use. In other cases, NASA provided technology that allowed an industry partner to advance the features of an already existing model or product line.

Confusion about NASA's technological contributions to daily life exists even at the highest levels of government. In his speech at NASA Headquarters in January 2004 in support of the Vision for Space Exploration, President George W. Bush said, "Medical technologies that help prolong life—such as the imaging processing used in CAT scanners and MRI machines—trace their origins to technology engineered for the use in space." This, like the previous examples, is incorrect. NASA has contributed in recent years to the advancement of several specific forms of medical imaging devices, and in the past the Jet Propulsion Laboratory has done groundbreaking research in the field of digital imaging. The CAT scan and MRI technologies, however, are specific applications for which NASA can take no direct credit.

Further, in the same market research in which NASA determined that exposure to NASA-derived technologies has a tremendous impact on a person's perception of NASA's relevance to their daily lives, the researchers used many examples that were not actually NASA spinoffs. For example, the 85 percent of poll respondents who said NASA research was extremely important after being told that the Agency had developed the smoke detector may be a skewed statistic; NASA did not invent the smoke detector.

It is this advocacy, sometimes based on misinformation, combined with the attempts to overshadow the primary goals of the Space Program, that contribute to giving NASA's technology transfer program a bad reputation with space purists. Spinoff technologies do, however, have a place in the discussion, for to not mention them would neglect both a congressional mandate as well as deny the very real outcropping of innovative technologies that result from research.

Examining the space shuttle program from a technology transfer perspective, then, can help to clarify the role of spinoff technologies within the context of the larger Space Program.

First, the space shuttle is a vehicle with a set purpose of carrying astronauts into Low Earth Orbit and bringing them safely back to Earth. The designers and engineers who created it and its support infrastructure were clearly involved in a specific, goal-oriented task: that of making a spacecraft. The goal of making this spacecraft was obviously to transport crew and cargo, not to advance medical technologies or protect the environment.

Second, since the shuttle program evolved in relatively recent memory, in an age when we already had at least simple versions of many of the technologies and products that we use every day, there is not as much of a tendency to credit NASA's space shuttle with products that clearly already existed. And since these products have evolved in the public marketplace, it is easier for the average person to see that many, even most, of the technological advances we see in the consumer realm are prompted by market competitiveness, not necessarily by space travel.

The benefits of NASA's technology transfer program, however, are very real, and they have saved, changed, and improved lives.

IV. Spinoff Benefits of the Space Shuttle

Through the course of organizing the technologies featured in the *Spinoff* journal, NASA has found that the technologies span a wide variety of fields and has categorized the spinoffs into seven areas that seem to encompass all the areas in which the developed technologies appear: health and medicine; transportation; public safety; consumer goods; environmental management; computer technology; and industrial productivity. What follows is a brief overview of some of the many space shuttle-derived spinoffs from each of these categories.

A. Health and Medicine

Medical spinoffs from the shuttle are as diverse as an implantable heart resynchronization device, an improved form of LASIK eye surgery, a manufacturing process for contact lenses, and research into light emitting diodes (LEDs) for treating a wide variety of ailments.

Based in part on space shuttle fuel pump technology, a miniature implantable heart pump has successfully been implanted into over 450 patients. The lifesaving heart pump, designed for patients awaiting heart transplants, came about through collaboration between NASA, Dr. Michael DeBakey, Dr. George Noon, and MicroMed Technology, Inc. The MicroMed DeBakey VAD functions as a "bridge to heart transplant" by pumping blood throughout the body to keep critically ill patients alive until a donor heart is available. Weighing less than 4 ounces and measuring 1 inch by 3 inches, the pump is approximately one-tenth the size of other currently marketed pulsatile VADs. This makes it less invasive and ideal for smaller adults and children. Because of the pump's small size, less than 5 percent of the patients implanted developed device-related infections. It can operate up to 8 hours on batteries, giving patients the mobility to do normal, everyday activities.

A NASA-private industry Small Business Innovation Research (SBIR) partnership to develop technology for autonomous rendezvous and docking of the space shuttle to service satellites resulted in a new eye-tracking device for LASIK surgery, called LADARTracker. Eye-tracking devices must be able to sample the eye's position at a rate of at least 1,000 times per second to keep up with saccadic movements, which do not stop during LASIK surgery. LADARTracker measures eye movements at a rate of 4,000 times per second, 4 times the established safety margin. The device is manufactured by Alcon Laboratories, of Fort Worth, Texas, and is used in conjunction with the company's LADARVision 4000 system for LASIK surgery, which is being used by eye surgeons across the country.

In 1993, Paragon Vision Sciences Inc. participated in a research project using the space shuttle to perfect a process for developing contact lenses and advanced materials. The project called for three experiments that would fly onboard the space shuttle over the course of three separate missions. By unleashing contact lens materials to the microgravity settings of space, scientists from NASA and Paragon hoped to better understand how polymers-large molecules that make up plastics-are formed. The resulting contact lenses are based on the unique technological advancements derived from the NASA experiments. They are gas permeable, resistant to deposits, and are less likely than soft contact lenses to harbor bacteria. The rigidity of the gas permeable contact lenses also makes them easier to handle than soft lenses, plus they retain their shape over time. Paragon additionally leveraged what it learned from the space shuttle experiments to invent a contact lens made from the same materials that non-surgically reshapes the cornea during sleep.

Tiny LED chips used to grow plants on the space shuttle and the International Space Station are lighting the way for wound healing and chronic pain alleviation on Earth. Developed with Small Business Innovation Research (SBIR) support from Marshall Space Flight Center, the LED chips have made their way into a non-invasive, handheld, portable medical device called WARP-10. This device is intended for the temporary relief of minor muscle and joint pain, arthritis, stiffness, and muscle spasms, and it was initially designed to provide armed forces personnel with immediate first aid care for minor injuries and pain. A consumer version sharing the same power and properties of the military model is also available, from Quantum Devices Inc., of Barneveld, Wisconsin.

B. Transportation

In the field of transportation, space shuttle spinoffs have been as varied as a profound change to the way semi trucks are designed, environmentally friendly lubricants, and advanced fireproof insulations for a variety of vehicles.

During the 1970s, researchers at Dryden Flight Research Center studying the aerodynamics of the space shuttle conducted numerous tests to refine the shape of trucks to reduce aerodynamic drag and improved efficiency. The researchers used expertise gleaned from designing the space shuttle to alter the shape of large vehicles—rounding corners and edges, and adding fixtures known as "fairings" to improve aerodynamic efficiency, which led to markedly improved gas mileage. Virtually all tractor-trailer big rigs and recreational vehicles on the highway today bear physical evidence of the project.

In 1994, NASA and Lockheed Martin Space Operations commissioned Sun Coast Chemicals of Daytona Inc to develop a new type of lubricant that would be safe for the environment and help "grease the wheels" of the shuttle-bearing launcher platform. In a matter of weeks, Sun Coast Chemical produced the biodegradable, high-performance X-1R Crawler Track Lube. The company now incorporates the environmentally safe benefits into a full line of standard automotive and specially-formulated racing products. The entire X-1R automotive product line has stood up to rigorous testing by groups such as the American Society of Mechanical Engineers, the Swedish National Testing and Research Institute, the Department of Mechanical Engineering at Oakland University (Rochester, Michigan), and Morgan-McClure Motorsports (Abingdon, Virginia).

Scientists at Langley Research Center created polyimide foam insulation for reusable cryogenic propellant tanks on the space shuttle. Meanwhile, a small Hialeah, Florida-based business, PolyuMAC Inc., was looking for advanced foams to use in the customized manufacturing of acoustical and thermal insulation. The company contacted NASA, licensed the material, and then the original inventors worked with the company's engineers to make a new material that was better for both parties. The new version, a high performance, flame retardant, flexible polyimide foam, is used for insulating NASA cryogenic propellant tanks and shows promise for use on watercraft, aircraft, spacecraft, electronics and electrical products, automobiles and automotive products, recreation equipment, and building and construction materials.

C. Public Safety

Public safety spinoffs from the shuttle program include video-enhancing software, infrared cameras for detecting fires, a low cost, lightweight alternative to the Jaws of Life, a tool for investigating crime scenes, and landmine destroying devices.

Using techniques and technologies developed for stabilizing the shaky shuttle launch video, NASA scientists developed the Video Image Stabilization and Registration (VISAR) technology to help FBI agents analyze video footage of the deadly 1996 Olympic Summer Games bombing in Atlanta, Georgia. Through a licensing agreement, Intergraph Government Solutions adapted the technology for enhanced video imaging by developing its Video Analyst System. Adaptable to many uses, Intergraph's Video Analyst System meets the demands of the law enforcement industry in the areas of surveillance, crime scene footage, sting operations, and dash-mounted video cameras. Military applications include security, video feed from aircraft, target identification and confirmation, weapons deployment, damage assessment, surveillance and reconnaissance, training, and mission debriefing. The Video Analyst also adds significant value to the sophisticated surveillance systems prevalent in the intelligence field. Since its use in the 1996 bomb scene analysis, it has also been used in additional high-profile cases, such as in capturing kidnappers and in correctly identifying Saddam Hussein in footage sent back from Iraq, when it was unclear whether the dictator had survived an airstrike the previous day or was using a body double.

A sensitive, infrared hand-held camera that observes the blazing plumes from the shuttle is also now used to scan for fires. During wildfires, the camera is used to point out hot spots for firefighters. The hand-held camera uses highly sensitive arrays in infrared photodetectors known as quantum well infrared photo detectors (QWIPS). QWIPS were developed by the Jet Propulsion Laboratory's Center for Space Microelectronics Technology in partnership with Amber, a Raytheon company. Night vision, early warning systems, navigation, flight control systems, weather monitoring, security and surveillance are among the additional duties for which the camera is suited.

As a result of space shuttle technologies, rescue squads have a new extrication tool to help remove accident victims from wrecked vehicles. The hand-held device requires no auxiliary power systems or cumbersome hoses and is 70 percent cheaper than previous rescue equipment.

The Lifeshear cutter, a rescue tool for freeing accident victims from wreckage, was developed under the Clinton Administration's Technology Reinvestment Program. The cutter is pyrotechnically-actuated, using a miniature version of the power cartridges used for separation devices on the space shuttle. Hi-Shear Technology Corporation developed the cutter with the Jet Propulsion Laboratory and input from the City of Torrance (California) Fire Department.

After a hailstorm damaged the foam insulation covering the external tank on the space shuttle (while on the launch pad), Kennedy Space Center developed a scaling and measurement imaging device to determine the exact scale of the damage incurred. This device, manufactured by Armor Holdings Inc., of Jacksonville, Florida, is now very helpful in law enforcement, as it is being used to shoot scaled photos of blood patterns, graffiti, and other criminal evidence.

The same rocket fuel that helps launch the space shuttle is now being used to save lives—by destroying land mines. A flare device, using leftover fuel donated by NASA, is placed next to the uncovered land mine and is ignited from a safe distance using a battery-triggered electric match. The explosive burns away, disabling the mine and rendering it harmless.

D. Consumer Goods

The space shuttle program even produced some consumer goods, items that the average consumer could acquire, and they range from the brains behind an online dating service, insulation for homes and clothing, simulation devices for exhibits, and lubricants for hunting and fishing equipment.

To prevent the highly complex Reaction Control System engines from malfunctioning during space shuttle flights, and to provide a diagnosis if such a mishap were to occur, NASA turned to a method of artificial intelligence that truly defied the traditional laws of computer science. Dr. Michael Georgeff, the inventor of the radical methodology, is among the world’s leading experts in the research and application of artificial intelligence. He assisted NASA by developing the first “intelligent agent” software system to ever go into space. This system had its own goals and beliefs, and could pursue these goals and beliefs and then determine how it wanted to achieve them, in much the same way that humans do. Essentially, a computer equipped with this intelligent agent software could make decisions and deal with problems through a human-like power of reasoning. Should a first attempt at a solution fail, it takes into account alternative solutions, rather than it having to depend on a constrained, preprogrammed set of parameters that only leads to one attempted solution-as most conventional computers do. By furnishing a computer with a human-like power of reasoning, the computer ultimately assumes human-like logic and behavioral traits. This real-time reasoning and control software was first used to monitor Discovery’s Reaction Control System and its engines in 1997. In 1998, the intelligent agent software came down to Earth to improve the operation of a different kind of engine: an online matchmaking search engine. Founded in 1998 and incorporated in 2000, weAttract.com, Inc., combines scientific and mathematical innovations to enhance human relationships. The concepts that Georgeff developed for NASA are at the core of the company’s computerized matchmaking technology.

Aspen Aerogels, of Northborough, Massachusetts, worked with NASA through an SBIR contract with Kennedy Space Center to develop a robust, flexible form of aerogel for cryogenic insulation for space shuttle launch applications. The company has since used the same manufacturing process developed under the SBIR award to expand its product offerings into the more commercial realms, making the naturally fragile aerogel available for the first time as a standard insulation that can be handled and installed just like standard insulation.

MOOG Inc. supplies hydraulic actuators for the space shuttle. When MOOG learned NASA was interested in electric actuators for possible future use, the company designed them with assistance from Marshall Space Flight Center. They also decided to pursue the system’s commercial potential. This led to partnership with InterActive Simulation, Inc. for production of cabin flight simulators for museums, expositions, etc. The resulting products, the Magic Motion Simulator 30 Series, are the first electric powered simulators. Movements are computer-guided, including free fall to heighten the sense of moving through space. A projection system provides visual effects, and the 11 speakers of a digital laser based sound system add to the realism. The electric actuators are easier to install, have lower operating costs, noise, heat and staff requirements. The U.S. Space & Rocket Center and several other organizations have purchased the simulators.

In 1996, Sun Coast Chemical determined there was an additional market for its automotive lubricants (based on the lubricants it had made for the crawlers) and introduced three derivative products: Train Track Lubricant, Penetrating Spray Lubricant, and Biodegradable Hydraulic Fluid, and then quickly followed with a gun lubricant/cleaner and a fishing rod and reel lubricant. The X-1R Corporation also markets small packages for simple jobs around the house, consisting of a multi-purpose, multi-use lubricant and grease. In 2003, the X-1R Corporation teamed up with Philadelphia-based Penn Tackle Manufacturing Co., a leading manufacturer of fishing tackle since 1932, to jointly develop and market a line of advanced lubrication products for saltwater and freshwater anglers.

E. Environmental Conservation

The environmental spinoffs from the shuttle program range from biodegradable pesticides to whale tracking methods to monitoring barometric pressure for weather forecasting.

Microcide Inc. work with personnel from Johnson Space Center to develop safe and non-toxic, biodegradable, microbicidal product to disinfect fresh fruit and vegetables for space shuttle crews. Called PRO-SAN, the technology comprised of safe sanitizing agents that could possibly be used as a disinfectant. A NASA-commissioned study proved the potential of PRO-SAN as a safe, stable, and biodegradable product for use in space; however, at the time, it was only available as a concentrated powder and a ready-to-use liquid. The powder is difficult to handle in zero gravity and the use of liquid presents increased payloads for flights. NASA and Microcide decided that the alternative would be to have the PRO-SAN powder concentrate available as a water-soluble package. Once this package is dropped in water, it can be stirred until it dissolves, creating a ready-to-use sanitizer. Based on this research, Microcide has perfected a food-grade soluble packaging design for use on Earth.

A computer program which was used to store data for analyzing heat shielding tiles on the space shuttle was adapted by the National Marine Mammal Laboratory and the College of the Atlantic to provide and advanced computerized photo matching technique for identification of humpback whales. The program compares photos with stored digitized descriptions, enabling researchers to track and determine distribution and migration patterns.

Carlton Controls Corporation incorporated space shuttle technology into the development of the meteorological instrument called a barograph. This instrument traces historical ups and downs of barometric pressure and plots a rising or falling curve. The company’s device provides a reading of barometric rate of change in millibars per hour. Information is provided to meteorologist every 15 minutes on an automatic printout. Tied in with other data, pressure rate of change information adds useful dimension for predicting exactly when a high or low pressure weather system will reach a particular locale. Also useful in tracing high altitude air movements such as jetstreams, it has potential for predicting the onset of severe storms or tornadoes.

F. Computer Technology

NASA attempts to defray costs by using commercially available software and hardware when possible, but because of the specific nature of its work, oftentimes these either need to be built from scratch or heavily modified in order to fit mission needs. As a benefit of this work, though, many of these advances find their way back into the private sector in the form of advanced structural analysis software, data mining tools, and risk assessment software.

In 1984, NASA initiated the Probabilistic Structural Analysis Methods (PSAM) project at Glenn Research Center to develop analysis methods and computer programs for the probabilistic structural analysis of select engine components for current Space Shuttle and future space propulsion systems. NASA envisioned that these methods and computational tools would play a critical role in establishing increased system performance and durability and assist in structural system qualification and certification. As the prime contractor on the PSAM project, Southwest Research Institute developed a sophisticated computer program called NESSUS (numerical evaluation of stochastic structures under stress). Designed specifically for predicting structural response caused by uncertain basic variables such as loads, material properties, geometry, and boundary conditions, NESSUS is used by NASA to assist in the evaluation of existing critical space shuttle components, including the Space Shuttle Main Engines (SSME). Not only was the PSAM project beneficial to aerospace, it paved the way for a commercial risk-probability tool that is evaluating risks in diverse, down-to-Earth applications, in industries such as health and medicine, automotives, biomechanics, nuclear waste packaging, munitions (weapon systems), and offshore pipeline construction. Recently, NESSUS provided the U.S. Naval Biodynamics Laboratory/U.S. Naval Air Warfare Center Aircraft Division with a probabilistic methodology and computational tool for evaluating the risk of cervical spine injury during pilot ejections.

Between 1981 and 2005, SSME faults caused 23 scrubbed launches and 29 percent of total space shuttle downtime, according to a compilation of analysis reports. The most serious cases typically occur in the last few seconds before ignition; a launch scrub that late in the countdown usually means a period of investigation of a month or more. In 2002, NASA's Kennedy Space Center, the Florida Institute of Technology, and Interface & Control Systems Inc., worked together to attack this problem by creating a system that could automate the detection of mechanical failures in the SSME fuel control valves. Indialantic, Florida-based Interface & Control Systems was awarded a Kennedy Space Center Small Business Technology Transfer (STTR) contract to develop a failure-detection system called SensorMiner. SensorMiner is a time-series data-mining tool that uses past performance data to build human-readable models for real-time fault detection. The system "learns" from the past performance data, develops a "signature" for nominal operation, and automatically generates a fault-monitoring system. Conventional technology has made this process both a labor-intensive and error-prone task that is often misunderstood, even by experts, according to Interface & Control Systems. SensorMiner, on the contrary, will automatically correlate seemingly unrelated data and provide rich graphical feedback to the user. The company is introducing the commercially available data-mining tool to existing control system and test set markets that require advanced real-time anomaly detection and analysis systems.

In July 2003, received an exclusive license for the Quantitative Risk Assessment System (QRAS) software, which was jointly developed by NASA's Marshall Space Flight Center, its Office of Safety and Mission Assurance, and researchers at the University of Maryland. QRAS automatically expands the reliability logic models of systems to evaluate the probability of highly detrimental outcomes occurring in complex systems that are subject to potential accident scenarios. It was developed as a probabilistic risk assessment tool to support decisions on the funding of space shuttle upgrades. At the Beth Israel Deaconess Medical Center, Harvard Medical School's major teaching hospital, QRAS is being used to determine the health care risk associated with general surgical processes, pharmaceutical ordering, transfusion services, and organ procurement and transplantation. Other examples of application include determining the probability of: airplane crashes arising from factors such as engine failure, avionics failure, or human failure at the air control tower; and train collisions caused by failures in train-signaling systems.

G. Industrial Productivity

NASA's technical spinoffs often lend themselves well to industrial applications, and the space shuttle spinoffs are no exception, emerging in fields as varied as food production, bar coding for inventory control, strain gauges, and low-cost actuators.

Known as MRO for Maintenance, Repair and Operating supplies, Tropicana Products, Inc.'s automated inventory management system is an adaptation of the Shuttle Inventory Management System (SIMS) developed by NASA to assure adequate supply of every item used in support of the space shuttle. The Tropicana version monitors inventory control, purchasing receiving and departmental costs for eight major areas of the company's operation.

Veritec's VeriSystem is a complete identification and tracking system for component traceability, improved manufacturing and processing, and automated shop floor applications. The system includes the Vericode Symbol, a more accurate and versatile alternative to the traditional bar code, that is scanned by charge coupled device (CCD) cameras. The system was developed by Veritec, Rockwell International, and Marshall Space Flight Center to identify and track space shuttle parts.

To maintain the Aquarius underwater research facility, the International Space Station, and the space shuttle as safe, healthy living/research habitats for its personnel-while keeping costs in mind-NASA, in 1997, recruited the help of Invocon, Inc., to develop wireless sensor technology that monitors and measures various environmental and structural parameters inside these facilities. This project, funded through a Johnson Space Center Small Business Innovation Research (SBIR) contract, focused on developing wireless sensors to help cut back on the integration costs associated with wired sensors. It included the conceptual design, fabrication, and demonstration of a battery-powered, miniature, wireless temperature sensor. NASA and Invocon agreed to take Invocon's existing wireless network communication system and combine it with various microelectromechanical systems (MEMS) sensors. The innovation consisted of a PC interface unit, a graphical user interface, and multiple wireless sensors that are each equivalent in size to a stack of five quarters. The resulting sensor system has flown and operated successfully on numerous space shuttle missions, and further use is being investigated for monitoring carbon dioxide concentrations onboard the ISS, in the crew's sleeping quarters, and in regions of reduced airflow. The commercial offspring is a wireless, remote, low-power, carbon dioxide data-acquisition system for near-static sensing and recording applications. Invocon has also spun off several "next-generation" MicroWIS products that are configured for applications other than carbon dioxide sensing. The latest of these products, the MicroWIS-XG, can be used for sensing environmental, temperature, strain, and pressure parameters, for example. In the area of construction, one of these next-generation systems was used to monitor external grout pressure during the building of three tunnels in the Netherlands.

NASA's Stennis Space Center provides testing of Space Shuttle main engines, rocket propulsion systems, and related components with several test facilities. NASA has been seeking ways to lower the cost of maintaining the facilities, and has aided in the development of an improved linear actuator that arrives onsite quickly and costs less money than other actuators. The actuator was developed as part of a Dual-Use Cooperative Agreement between BAFCO, Inc., and Stennis Space Center. In partnership with BAFCO, the existing commercial product's size and weight were reworked, and cost and delivery time were reduced, while the actuator was made more reliable. The BAFCO Model 773 is a next-generation, high-thrust, high-response actuator designed to meet performance standards in aerospace, industrial, and petrochemical applications. The actuators are adaptable for use in a variety of industrial applications, including steam turbines, process-control valves, dampers, for motion control, and a variety of other mechanical purposes.

V. Conclusion

The space shuttle has served NASA for several decades, conducting over 130 missions. At times, the program has been rocked with tragedies, like the loss of Challenger, Columbia, and their crews. But it has also witnessed successes, carrying crew and payloads both large and small into space; assembling, staffing, and maintaining the International Space Station; carrying large satellites into orbit; and deploying and servicing the Hubble Space Telescope. Together, the five shuttles—Columbia, Challenger, Discovery, Atlantis, and Endeavor— staffed by pilots, scientists, teachers, and various mission specialists, have made over 20,000 orbits around the Earth.

The shuttle is now retiring, and NASA is embarking on a new journey, one that will launch robotic probes into the depths of the solar system as precursors to manned missions. NASA will invest in the development of a heavy lift vehicle research and development program, with the eventual goal of taking humans to near-Earth asteroids, the Moon, and eventually to Mars. In tandem with these initiatives, NASA will continue to ensure an American presence in space aboard the International Space Station and empower a robust and competitive American commercial space program.

Before these new goals are met, though, a plan must be made, and hardware and infrastructure for the new launch vehicles must be designed and developed. The gap between the last shuttle flight and the first launch of the next new system NASA develops—a handful of years when NASA astronauts will have to rely on purchased flights from the Russian Federal Space Agency—is now the focus of attention. This transition has many in the space community concerned that, without the continuation of human spaceflight, NASA will become less exciting and relevant.

As NASA sets off on this bold new journey, though, with a renewed commitment to conducting fundamental research and developing game-changing technologies, we can expect to see new capabilities for the Nation's Space Program. From these advances, new benefits to the American people will emerge. This next wave of spinoff technologies, like those developed from the remarkable efforts of the space shuttle program, will then assume their roles as further evidence of the importance of robust and active space exploration.

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