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The Growing Legacy of Spinoffs from the International Space Station and Prospects for Future Benefits

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Abstract

A multinational effort involving NASA employees and contractors across the United States and space agencies in 15 countries, the International Space Station (ISS) is humanity's home in space and has captured the world's imagination since its first component launched into orbit in 1998. While the ISS provides invaluable information about living in space—essential for future long-duration missions and colonies on the Moon and Mars—everything from the station's construction to biological experiments conducted onboard have led to spinoffs that are improving life on Earth. As the ISS nears completion, this paper highlights ISS-influenced technologies that are advancing fitness and medicine, purifying air and water, enhancing safety, and improving daily life in many other ways. This paper also examines several other promising future benefits derived from the ISS.

I. Introduction

When NASA was founded with the passage of the National Aeronautics and Space Act of 1958, the U.S. Congress determined that the innovative new technologies being created to explore space should also find applications here on Earth, benefitting the public and spurring the economy. While this transfer of technology has never been the primary focus of the space program, it is nonetheless a vital part of NASA's mission; and over the course of its history, NASA has nurtured partnerships with the private sector to move its technologies from the laboratory and launch pad into factories, offices, markets and our homes. The benefits of these partnerships have reached throughout the economy and around the globe, helping businesses to create jobs, generate revenue, and save money; while also saving and improving lives, making travel safer, and providing better quality of life to people all around the globe.

The current National Space Policy of the United States[i] notes that:

> The utilization of space has created new markets; helped save lives by warning us of natural disasters, expediting search and rescue operations, and making recovery efforts faster and more effective; made agriculture and natural resource management more efficient and sustainable; expanded our frontiers; and provided global access to advanced

> medicine, weather forecasting, geospatial information, financial operations, broadband and other communications, and scores of other activities worldwide. Space systems allow people and governments around the world to see with clarity, communicate with certainty, navigate with accuracy, and operate with assurance.

Building on this dynamic history, partnerships with the private sector continue to bring NASA technology down to Earth. In 2010, NASA created the Office of the Chief Technologist (OCT), which will lead the Agency's space technology initiatives as it transitions from the retiring space shuttle to next-generation space systems. Coupled with NASA's important mission of exploration and discovery, the OCT is charged with continuing the legacy of transferring NASA technologies to the private sector.

With this task comes the responsibility of demonstrating and communicating these successes to the public and other stakeholders. To accomplish this, NASA has been documenting these benefits in its *Spinoff* publication, a compendium of the most prominent technology transfer successes that annually highlights ways NASA technologies have been "spun" into new applications. The publication, which began in 1976, has since documented over 1,700 of the most prominent commercialized NASA technologies[ii]. This is by no means the total number of NASA spinoff technologies; rather it is a sampling of the 40 or 50 most compelling stories to emerge each year. Spinoff technologies have emerged from all aspects of NASA's research and development activities, from food preservation systems originally designed for NASA's first human space fight missions to composite test systems for the new Orion crew capsules.

A particularly prolific NASA program has been International Space Station (ISS). Through its design, construction, maintenance, and implementation, the ISS has resulted in many secondary benefits. These technologies generally fall into one of seven categories according to the types of societal benefits they provide: health and medicine, transportation, public safety, consumer goods, environmental resources, information technology, and industrial productivity.

In addition, hundreds of additional new and exciting technologies have been or are being developed for—or even on—the ISS, many of which are ripe for transfer to the private sector. With sophisticated systems to generate solar electricity, recycle much of its own water (nearly 85 percent), and supply oxygen, the ISS is a floating model of sustainability. With over 400 experiments completed and approximately 150 underway, the station provides researchers from around the world access to the unique environment of microgravity. These experiments are seeking to answer some of the primary challenges here on Earth and cover a wide variety of disciplines: human life sciences, biological science, human physiology, physical and material science, and Earth and space science. Through this work, researchers are finding new ways to fight disease, advancing our understanding of food-borne illnesses, growing crops for alternative energy usage, and developing superior materials for use in both space and on Earth.

II. International Space Station Spinoffs

What follows are examples of the ways that NASA-developed technologies from the ISS program have been transferred to the private sector for development of commercial products and services. This transfer can be done through a variety or mechanisms, including patent licensing, collaborative development of technologies through formalized agreements, Small Business Innovation Research (SBIR) funding, facility usage agreements, contributions by NASA laboratory personnel, commercial endeavors by former NASA employees who gained specific technical expertise working on the ISS, or from entrepreneurs taking advantage of the wide variety of public data and research findings. The following examples are illustrative—but not an exhaustive listing—of the types of spinoffs coming from the International Space Station.

A. Health and Medicine

Onboard the ISS, diagnosing an injury or medical issue can be problematic, as there is limited access to trained medical personnel, and medical diagnostic equipment is similarly limited. The Advanced Diagnostic Ultrasound in Microgravity (ADUM) experiment resulted in new ultrasound technology for remote use by crewmembers with limited medical training. As part of this experiment, Johnson Space Center, Henry Ford Hospital in Detroit, and Houston-based Wyle Laboratories collaborated to develop medical ultrasound diagnostic techniques for long-distance use. ADUM participants Dr. Scott Dulchavsky, Henry Ford Hospital, and Wyle Laboratories cooperated with Epiphan Systems Inc. to form Mediphan, a Canadian company with U.S. operations in Springfield, New Jersey. Mediphan developed frame-grabber and data archiving technology that enables ultrasound users with minimal training to send diagnostic-quality ultrasound images and video to medical professionals via the Internet in near-real time—allowing patients as varied as professional athletes, Olympians, and mountain climbers to receive medical attention as soon as it is needed. Individuals with limited medical experience can consult with distant doctors to diagnose medical issues such as broken bones or collapsed lungs when and where they occur—whether it is on Earth or in space.

Living in space presents many challenges for the human body, including loss of bone density, exposure to high levels of radiation, and muscle loss caused by the lack of resistance normally afforded by gravity. One NASA researcher, Robert Whalen, was working on a partial solution to the problem of muscle deterioration, developing a method using air pressure to add force to an astronaut's body during treadmill exercise in space. Whalen patented the gravity differential technology and licensed it to Menlo Park, California-based Alter-G Inc. who adapted it for use in its specialized treadmill, the G-Trainer. The G-Trainer applies pressure to a person's lower body to unload weight, lift the body, and reduce strain and impact during treadmill exercise. It has been cleared for medical use by the U.S. Food and Drug Administration, and markets currently include military hospitals, professional athletic teams, university athletic departments, and physical therapists. It primarily used for athletic and other joint stress injuries, recovery from surgeries, and physical therapy for brain injury and other neurological disorders.

While these examples of technologies developed to keep astronauts safe and healthy have found direct corollaries here on Earth, it is not only concerns over the health of the crew that has resulted in medical benefits for people on Earth. A study into remote-controlled robots that could potentially assist humans working in space helped in the development of a weight-control and nutrition program that has helped thousands of clients learn healthier eating habits. Engineer Joseph Graves helped design the Ranger Neutral Bouyancy Vehicle (NBV), an underwater robot for testing space applications. He used the same style of algorithm he developed for the NBV to launch his online nutritional company, Vitabot in Beltsville, Maryland. The company uses intelligent software to allow users to set health goals and then plan balanced meals using a food database, helping users achieve balanced nutrition and weight loss. The company's nearly 1,000 company clients include corporate wellness programs for HBO, Warner Brothers, health clubs like Gold's Gym, and the U.S. Air Force.

B. Transportation

The ISS orbits the Earth approximately once every 90 minutes, at a speed of about 27,700 kilometers per hour. Technologies developed for the orbiting laboratory have also been applied by much slower methods of transportation, like those used by everyday people here on Earth. Just a sampling of these ISS transportation benefits shows technologies increasing airport efficiency, saving fuel, reducing noise pollution, improving aircraft safety, and enabling new generations of vehicles.

One specific example of a technology born on the ISS and finding application here on Earth is a portable cabin pressure sensor originally designed as a backup device for crews onboard the ISS. It monitors cabin pressure and, in the event of a change in pressure, emits simultaneous audio, vibratory, and visual warnings. NASA licensed the technology to the Kelly Manufacturing Company of Grenola, Kansas, which modified the device for use on aircraft, incorporated several new features, and then commercialized it as the Personal Cabin Pressure Altitude Monitor and Warning System.

A hand-held, personal safety device capable of warning pilots of potentially dangerous or deteriorating cabin pressure altitude conditions, it is a valuable tool in lowering the significant numbers of hypoxia- and cabin pressure-related incidents experienced each year.

C. Public Safety

One of the problems faced by long duration space flight is providing astronauts access to fresh foods, especially fruits and vegetables. A solution to this problem could be to grow crops in space, which is also potentially the answer to another dilemma facing astronauts on long expeditions—the necessity of carrying all of the needed supplies. Growing plants in the restrictive environment of the ISS, though, presents a problem: ethylene. Ethylene—a naturally occurring, odorless gas given of by plants—hastens their ripening, encouraging decay. To address this problem, NASA developed an ethylene reduction device for a plant growth unit that converts ethylene ($C_{22}H_4$) into trace amounts of water and carbon dioxide.

The device was licensed to Aikida Holdings of Jacksonville, Florida, and is now marketed as AiroCide. It is a small unit capable of destroying bacteria, mold, fungi, myotoxins, viruses, volatile organic compounds (like ethylene), and odors. It has been used in supermarkets, produce distribution facilities, food processing plants, wineries, distilleries, restaurants, large floral shops, hospitals, doctor's offices, and operating rooms. It has also found application in remote regions of the world, where harsh environments and underdeveloped infrastructure complicate food storage and distribution as well as needed sterility in hospitals and operating rooms.

Remote regions have also benefitted from a water treatment technology created for the ISS. The Regenerative Environmental Control Life Support System is a complex system of devices intended to sustain astronauts living on the ISS. Part of this system, the Water Recovery System (WRS) launched to the station in November 2008 as part of STS-126 and now provides clean water through the reclamation of wastewater, including condensation, urine, and perspiration.

NASA contractor Hamilton Sundstrand, working with the Umpqua Research Company, helped develop the Water Processor Assembly for the WRS, a component of which is the microbial check valve (MCV), a unique device designed to ensure the potability of the water. The MCV was licensed to the Water Security Corporation of Sparks, Nevada, who has used it to develop several lightweight portable devices for water reclamation. The company has been working with NASA's Marshall Space Flight Center and a nonprofit organization called Concern for Kids to provide drinking water to developing areas of the planet and disaster sites around the world. Several high profile projects have included providing villagers in Sabana San Juan, Dominican Republic and Kendala, Iraq with their first sources of local clean drinking water. Units were also deployed to provide clean drinking water to survivors of the 2005 earthquake in Bakalot, Pakistan.

For its benefit to humanity, the MCV technology, along with its developers and The Water Security Corporation, were inducted into the Space Foundation's Space Technology Hall of Fame.

D. Consumer Goods

NASA developed remote command and control software to run experiments onboard the ISS. The technology marries embedded systems (hardware or software that forms a component of a larger system and is expected to operate without human intervention) and the Internet to let a user monitor and/or control a remote device. Using Embedded Web Technology, NASA can now operate experiments without installing user-interface software on all computers and for every space-bound instrument. This R&D Award-winning technology is estimated to have saved NASA over $150 million. TMIO Inc, of Houston, Texas, worked with NASA to incorporate the concepts into a line of home ovens. These ovens can be programmed to switch from refrigeration to a cooking cycle and can be adjusted remotely with a web-based application. The ovens were recognized as one of *TIME* magazine's "coolest inventions" of 2003.

To help develop technologies for growing edible biomass (food crops) in space, Kennedy Space Center partnered with Orbital Technologies Corporation (ORBITEC), of Madison,

Wisconsin, through the Small Business Innovation Research (SBIR) program. One result of this research was the High Efficiency Lighting with Integrated Adaptive Control (HELIAC) system, components of which have been incorporated into a variety of agricultural greenhouse and consumer aquarium lighting features. The new lighting systems can be adapted to a specific plant species during a specific growth stage, allowing maximum efficiency in light absorption by all available photosynthetic tissues.

Lack of resources and potentially dangerous conditions mean repairs on the ISS must be done quickly and as efficiently as possible. Toward that end, NASA funded design of a simple, reusable patch repair system for use in space. Cornerstone Research Group Inc., of Dayton, Ohio, has been the recipient of numerous Small Business Innovation Research (SBIR) contracts with NASA with a variety of different focuses, including projects like creating inflatable structures for radio frequency antennas and, most recently, healable polymer matrix composites for future space vehicles. One of its earlier SBIR contracts, with Kennedy Space Center, led to the development of a new type of structural patch for a variety of consumer uses: Rubbn'Repair, for automotive uses; and Rec'Repair for the outdoors and adventure market. Both are flexible, heat activated structural patches.

E. Environmental Resources

Growing plants in space presents unique challenges, including water limitations and soil particles floating in microgravity. Many ISS research projects have, therefore, focused on developing and improving hydroponic methods of plant cultivation for use in space. A water analyzer developed under Small Business Innovation Research (SBIR) contracts with Kennedy Space Center now monitors treatment processes at water and wastewater facilities around the world. Originally designed to provide real-time detection of nutrient levels in hydroponic solutions for growing plants in space, the ChemScan analyzer, produced by ASA Analytics Inc., of Waukesha, Wisconsin, utilizes spectrometry and chemometric algorithms to automatically analyze multiple parameters in the water treatment process with little need for maintenance, calibration, or operator intervention. The company has experienced a compound annual growth rate of 40 percent over its 15-year history as a direct result of the technology's success.

Through Small Business Innovation Research (SBIR) contracts with Marshall Space Flight Center, Micro-Bac International Inc., of Round Rock, Texas, developed a phototrophic cell for water purification in space. Inside the cell: millions of photosynthetic bacteria. Micro-Bac proceeded to commercialize the bacterial formulation it developed for the SBIR project. The formulation is now used for the remediation of wastewater systems and waste from livestock farms and food manufacturers. Strains of the SBIR-derived bacteria also feature in microbial solutions that treat environmentally damaging oil spills, such as that resulting from the catastrophic 2010 Deepwater Horizon oil rig explosion in the Gulf of Mexico.

F. Information Technology

Onboard the ISS NASA employs systems health management processes to understand various programs, assess their relative health, pinpoint problems, and support maintenance or repair. Qualtech Systems Inc. (QSI), of Wethersfield, Connecticut, adapted its Testability, Engineering, and Maintenance System (TEAMS) toolset under Small Business Innovation Research (SBIR) contracts from Ames Research Center to strengthen NASA's systems health management approach for its large, complex, and interconnected systems, like those used in support of the ISS. Today, six NASA field centers utilize the TEAMS toolset, including TEAMS-Designer, TEAMS-RT, TEAMATE, and TEAMS-RDS. TEAMS is also being used on industrial systems that generate power, carry data, refine chemicals, perform medical functions, and produce semiconductor wafers. The conditions that cause the equipment to fail can be modeled and analyzed, then linked to test procedures, finally resulting in a trouble-shooting solution. QSI finds TEAMS can lower costs by decreasing problems requiring service by 30 to 50 percent.

G. Industrial Productivity

To reduce the risk and cost associated with human-operated tasks in space, NASA develops complex robotics to work solely or in tandem with astronauts. Control and simulation software developed under Small Business Innovation Research (SBIR) contracts with Johnson Space Center is now providing user-friendly, optimized design and control of innovative robots used for military, agriculture, health care, and industrial applications. Created by Energid Technologies Corporation, of Cambridge, Massachusetts, the Actin toolkit provides for fluid robot motion, enhancing strength and accuracy while avoiding collisions and joint limits. Actin provides control capabilities for virtually any kind of robot, any joint type or tool type, and for any number of joints, degrees of freedom, and branches. In addition, the software provides powerful simulation capabilities, allowing developers to rapidly devise and test robot designs before the robot is built.

III. Future Benefits

Current research onboard the ISS is steadily progressing, including development of humanoid robots for space and industrial applications; experiments to understand the muscular deterioration of astronauts' hearts in the reduced gravity environment, which will add to the understanding of heart function here on Earth; experiments into accelerated cell growth in microgravity that are showing promise for the development of new vaccines and therapies; and experiments to grow and harvest new crops in space that show potential for producing biofuels that can be used as energy sources for future space missions or here on Earth.

A. Humanoid Robots for Space and Industrial Applications

Under a cooperative Space Act Agreement to design a humanoid robot for use in both the automotive and aerospace industries, NASA's Dexterous Robotics Laboratory at Johnson Space Center teamed up with General Motors (GM). The Robonaut2 (R2) will be used to improve auto manufacturing on Earth and to define a new era of exploration in space. Two R2 units have been constructed; one of the constructed Robonauts will be tested on board the International Space Station.

Through the Space Act Agreement, GM engineers have been working closely with NASA personnel during the design, development, assembly, construction, evaluation, and demonstration process of the R2 units. Thirty-six patents have been filed based on the R2 design.

This state-of-the-art robotics technology will enhance space exploration and automobile manufacturing. Working side by side with humans, or going where the risks are too hazardous for people, R2 will broaden the competitive advantage in U.S. industry and open up new areas of scientific discovery.

NASA expects to use R2 in several capacities: for human and robotic teamwork on construction, maintenance, and scientific work at the International Space Station; as a spacewalk assistant, to save time and reduce risks to spacewalking astronauts; as a scout on the moon or a planet where humans might land; and as a stand-in on routine maintenance tasks or hazardous missions. GM, one of the world's largest automakers, plans to use the humanoid robot to test advanced vehicle safety systems and to create safer, more competitive manufacturing operations. R2 will provide a test bed for sensors, controls, and vision technologies that could be incorporated into future automobiles. It can also automate tasks that are repetitious, dull, or ergonomically challenging. GM expects the humanoid robot will eventually be used on the factory floor, alongside workers, to build better, higher quality vehicles.

B. Astronaut Health Studies with Direct Medical Applications on Earth

Microgravity poses unique challenges for the human body; in particular, without the force of gravity, muscles begin to weaken and atrophy. This is true of all muscles, including the heart. Studies into cardiac atrophy onboard the ISS are helping researchers understand both how to keep astronauts healthy in space as well as develop understandings of how to treat patients

whose conditions do not allow their hearts adequate exercise, like wheelchair-bound individuals and those on long-term bed rest.

The experiments began in space in 2009, during Expedition 20, and involved MRI scans of crewmembers' hearts before and after flight. While in space, they wore heart monitors that recorded heart rates over extended periods; a device to measure blood pressure with each heartbeat; and a device on one ankle and one wrist to measure activity.

Three international partners contributed to this research, and results are still under analysis.

C. Cell Growth Experiments for Discovery of New Vaccines and Therapies

The ISS is an ideal environment for biotechnology research, where new drugs and vaccines can be discovered to treat many common problems here on Earth.

As NASA has discovered during previous space flight studies, the unique environment of microgravity often encourages exceptional developments in cellular growth. In the case of Salmonella, this exhibits as increased virulence. This allows researchers onboard the ISS to conduct experiments on the effects of promising drug candidates. Quicker testing allows drugs to get to market faster—sometimes years faster than they would on Earth. Unsuccessful tests can be terminated early, and successful tests can be fast tracked.

A NASA partner, Astrogenetix of Austin, Texas, who has sent more than 1,500 experiments into space, has had recent success with experiments as part of the ISS National Laboratory Pathfinder Vaccine (NLP-V) missions. It has been conducting experiments onboard the ISS to discover vaccines and treatments for Salmonella-related illnesses and methicillin-resistant *Staphylococcus aureus* (MRSA).

According to numbers from the U.S. Center for Disease Control, Salmonella, a deadly food-borne bacteria, sickens approximately 7,000,000 people in the U.S. each year and is credited with killing about 500 of these victims. Expedited by experiments on the ISS, Astrogenetics is moving toward commercializing what it hopes will be a vaccine for Salmonella poisoning.

MRSA bacteria do not typically respond to common antibiotics and is credited annually with over 19,000 deaths in the U.S and 100,000 cases of severe infection. Through its research on the ISS, Astrogenetix believes that it can drastically shorten the amount of time it will take to develop a viable medicine to combat the infection.

Astrogenetix has a Space Act Agreement with NASA for continued use of the ISS to conduct biomedical research.

D. Plant Growth Experiments for New Biofuels

A recent NASA experiment onboard the ISS aimed to discover whether the microgravity environment would encourage certain plant cells to grow faster. The experiment, the National Lab Pathfinder-Cells 3, focused on *Jatropha curcas* plant cells, which, if encouraged to grow faster, could potentially be a promising source for biofuels. The plant is known to produce high quality oils that can be converted into alternative energy fuel, and acceleration of its cultivation could increase commercial viability. The first experiment to study the effects of microgravity on a biofuel plant, the goal was to accelerate cultivation potential by improving cell structure, growth, and development.

The experiment launched onboard STS-130 in special flasks containing both nutrients and vitamins that were then exposed to microgravity before being returned to Earth during STS-131. For comparison, a control group was maintained at the University of Florida's Tropical Research and Education Center.

While the final results of this experiment have yet to be released, it is the hope of the researchers that the results will add to the development of new cultivars of an alternative energy crop that can be readily available to farmers while also contributing towards energy independence from fossil fuel sources.

IV. Conclusion

Current research onboard the International Space Station is steadily progressing, and NASA and its partners are actively pursuing new tests and experiments to conduct on this orbiting laboratory. Some outcomes can be expected, such as an increased understanding of the long-term effects of living in space on the human body and the benefit that physiological information can have on Earth; the continued advancement of telemedicine procedures that allow astronauts in space to stay healthy as well as provide needed medical support and expertise to people in remote regions of the globe; and the development of new methods to recycle water and conserve energy, needed both in the orbiting laboratories of the ISS and on Earth as we learn to be better stewards of our home planet. Other outcomes are less known, less predictable or less tangible. Of these benefits, perhaps one of the most profound is the strong spirit of international collaboration. The ISS is the largest and most complex spacecraft ever built, and unlike the space race of the 1960s that culminated with American astronauts landing on the Moon, this is an international partnership, a team effort. In addition to station assembly, the international partner agencies (NASA, the Canadian Space Agency, the European Space Agency, the Japan Aerospace Exploration Agency, and the Russian Federal Space Agency Roscosmos) train and launch crews and provide ground support for the orbiting research facility. This continued level of international commitment to and partnership in space is what will be needed as people continue their exploration of the cosmos, and like many of the technologies created for ISS, the benefits of this international partnership also come back down to Earth.

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[i] National Space Policy of the United States of America, June 28, 2010 is available at http://www.whitehouse.gov/sites/default/files/national_space_policy_6-28-10.pdf.

[ii] The more than 1,700 documented NASA Spinoffs are searchable using the NASA Spinoff database at http://www.sti.nasa.gov/spinoff/database.