Technology Development and Infusion from NASA's Innovative Partnerships Program

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Abstract—NASA's Innovative Partnerships Program (IPP) develops many technologies for NASA's programs and projects through a portfolio of technology investments and partnerships. The investment portfolio includes Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR), the IPP Seed Fund, and NASA's Centennial Challenges prize program. In the process of technology development and infusion, the transition of technologies from laboratories or testbeds to their application in flight programs is often one of the most challenging steps. Newly developed technologies achieve full success when they are infused into programs and projects, although there are numerous obstacles to achieving infusion.

This paper[1,2] addresses the IPP portfolio for providing technology, the challenges and obstacles to technology infusion, and some of the methods currently being employed by NASA to help address those challenges and obstacles. The paper also presents some examples of IPP technologies infused into high profile programs and projects and draws lessons learned and best practices from those successful examples.

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1. INTRODUCTION

NASA's Innovative Partnerships Program (IPP) provides needed technology and capabilities for NASA's Mission Directorates, Programs, and Projects through investments and partnerships with Industry, Academia, Government Agencies, and National Laboratories. As one of NASA's Mission Support Offices, IPP supports all four Mission Directorates and has Program Offices at each of the NASA Centers. In addition to leveraged technology investments, dual-use technology-related partnerships, and technology solutions for NASA, IPP enables cost avoidance, and accelerates technology maturation [1].

IPP consists of the following program elements, as summarized in Figure 1: Technology Infusion which includes the Small Business Innovative Research (SBIR)/Small Business Technology Transfer (STTR) Programs and the IPP Seed Fund; Innovation Incubator which includes Centennial Challenges and new efforts such as facilitating the purchase of services from the emerging commercial space sector; and Partnership Development which includes Intellectual Property Management and Technology Transfer, and new innovative partnerships.

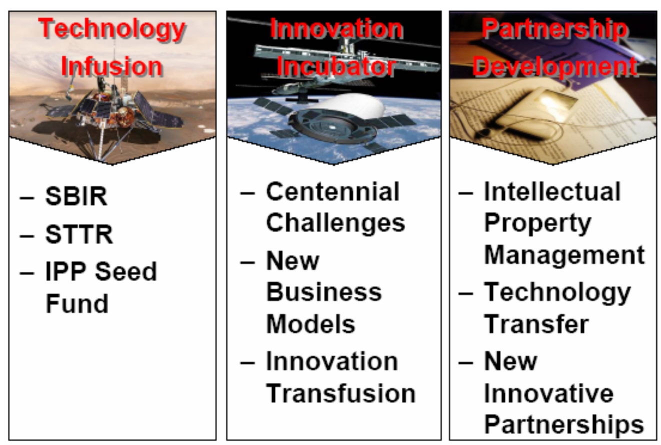

Figure 1 – Elements of NASA's Innovative Partnerships Program.

Together these program elements increase NASA's connection to emerging technologies in external communities, enable targeted positioning of NASA's technology portfolio in selected areas, and secure NASA's intellectual property to provide fair access and to support NASA's strategic goals. Technology transfer through dual-use partnerships and licensing also creates many important socio-economic benefits within the broader community [2].

[2] IEEEAC paper #1538, Version 3, Updated January 3, 2008

During FY 2006, IPP facilitated many partnerships and agreements, including over 200 partnerships with the private sector, Federal and state government, academia, and other entities for dual use technology development and reimbursable use of NASA facilities, over 50 license agreements with private entities for commercial and quality of life applications of NASA-developed technology, reporting of more than 750 new technologies developed by NASA civil servants and contractors and evaluation of those technologies for patent protection, and more than 400 agreements for commercial application of software developed by NASA.

The general process by which IPP develops and provides technology to meet the needs of NASA's Mission Directorates is provided in Figure 2. IPP investments are intended to complement other Mission Directorate and Field Center efforts, filling important gaps in NASA's technology portfolio. In order to understand ongoing and planned technology investments within NASA and needed technologies, IPP pursues many avenues of communication.

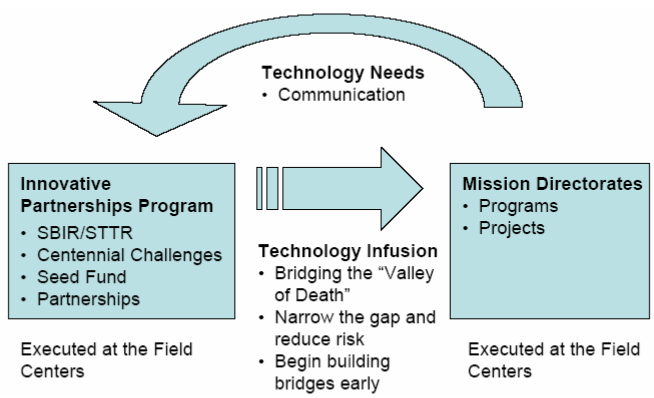

Figure 2 – IPP's technology portfolio is intended to address the needs of NASA's Mission Directorates.

IPP has established the position of Chief Technologist , that focuses on agency-wide technology needs and infusion programs. The IPP Director and Mission Directorate (MD) Associate Administrators (AAs) meet on a quarterly basis to discuss Mission Directorate needs and how well they are being addressed by the IPP portfolio. With the restructuring of NASA's SBIR/STTR organization, there are now four dedicated Level III offices, each one assigned specifically to work closely with a Mission Directorate to understand their needs and ensure that SBIR/STTR projects are addressing those needs.

There is active MD participation in the conduct of all IPP technology activities, from key roles in the solicitation development and selection processes for Seed Fund and SBIR/STTR, to determining future Centennial Challenge competitions and revising rules to best address technology needs. IPP has an office at every Field Center, working with local projects to understand their technology needs and communicate to them what IPP can provide. The Field Center offices each include an SBIR Technology Infusion Manager, and all offices provide local infusion, seed fund and partnership support.

There are several sources of technology in the IPP portfolio that have potential for addressing the needs of the Mission Directorates. These include SBIR/STTR, Centennial Challenges, and the IPP Seed Fund, which will each be addressed in the following sections of this paper. IPP strives to keep abreast of the changes in emphasis within the Agency's technology landscape as they occur. This helps IPP to be more responsive to the needs of the MDs and provide more value through the IPP technology portfolio. As an example, IPP recently aligned its SBIR and Seed Fund topics and sub-topics to reflect the newly reformulated Program and Project Goals of the Aeronautics Research Mission Directorate. This has led to recent IPP investments supporting advances in technologies related to alternative jet fuels and turbine blade superalloys for improved engine performance and reduced emissions.

There are many challenges associated with infusing technologies into programs and projects. IPP is working to implement best practices and is also developing some new projects to help address those challenges, as discussed in later sections of this paper.

2. SBIR/STTR

The purposes of the SBIR/STTR programs, as established by law, are to stimulate technological innovation in the private sector; to strengthen the role of small businesses in meeting Federal research and development needs; to increase the commercial application of these research results; and to encourage participation of socially and economically disadvantaged persons and women-owned small businesses [3].

Technological innovation is vital to the performance of the NASA mission and to the Nation's prosperity and security. To be eligible for selection, a proposal must present an innovation that meets the technology needs of NASA programs and projects and has significant potential for successful commercialization. In this context, commercialization encompasses the transition of technology into products and services for NASA mission programs, other Government agencies and non-Government markets.

The largest portion of IPP's technology portfolio comes from small businesses that are funded by NASA's SBIR/STTR programs. SBIR and STTR are competitive programs that provide technology to address NASA's needs. SBIR is for small businesses (less than 500 employees), and STTR requires that small businesses partner with a research institution (e.g. a University or Federal laboratory) with the objective of transferring research from the laboratory to the small business where it can be further developed and put to commercial use. Each year NASA awards several hundred contracts to small businesses and their partners, as summarized in Figure 3.

NASA considers every technology development investment dollar critical to the ultimate success of NASA's mission and strives to ensure that the research topic areas described in this solicitation are in alignment with its Mission Directorate high priorities technology needs. In addition, the solicitation is structured such that SBIR/STTR investments are complementary to other NASA technology investments. NASA'S ultimate objective is to achieve infusion of the technological innovations developed in the SBIR/STTR program into its programs and projects.

SBIR	FY03	FY04	FY05	FY06	FY07
Millions of $	107.3	107.5	110.0	105.6	106.6
Phase 1 Awards	267	312	291	267	259
Phase 2 Awards	155	139	142	186	130

STTR	FY03	FY04	FY05	FY06	FY07
Millions of $	6.4	12.9	13.2	12.3	12.8
Phase 1 Awards	45	40	35	27	25
Phase 2 Awards	18	26	17	22	18

Figure 3 – NASA's SBIR funding is 2.5% of extramural R&D, and STTR is 0.3% of extramural R&D.

Phase 1 awards for both SBIR and STTR are feasibility studies for $100k that last 6 months for SBIR and 12 months for STTR. Phase 2 awards are for technology development and last two years with funding of up to $750k for both SBIR and STTR. SBIR/STTR investments can support about three years of technology development, including Phase 1 and 2 funding. Often, technology development requires more time and much larger investments than can be made by SBIR funds alone. This is where infusion is so important, in that the SBIR portion of a technology development is one of the critical links in the overall chain of events necessary for developing a technology.

Phase 3 awards for both SBIR are for the technology infusion and commercialization stage, and involve the use of non-SBIR funds from other government or commercial sources. To encourage further development of SBIR-funded technologies, government agencies and their prime contractors have the ability to award sole-source Phase 3 SBIR contracts without need for a justification for other than full and open competition (JOFOC) based on the competitive process for Phase 1&2 awards, and specific SBIR authority.

The Innovative Partnerships Program Office provides overall policy direction for implementation of the NASA SBIR/STTR programs. The NASA SBIR/STTR Program Management Office, which operates the programs in conjunction with NASA Mission Directorates and Centers, is hosted at the NASA Ames Research Center. NASA Shared Services Center provides the overall procurement management for the programs. All of the NASA Centers actively participate in the SBIR/STTR program. To reinforce NASA's objective of infusion of SBIR/STTR developed technologies into its programs and projects, each Center has personnel focused on that activity.

NASA research and technology areas to be solicited are identified annually by Mission Directorates. The Directorates identify high priority research and technology needs for their respective programs and projects. The needs are explicitly described in the topics and subtopics descriptions developed by technical experts at NASA's Centers. The range of technologies is broad, and the list of topics and subtopics may vary in content from year to year. See Table 1 for a high-level summary of the technology taxonomy for research topics, from which more detailed descriptions of specific technology needs are based. The details can be found online at the SBIR/STTR Program website http://www.sbir.nasa.gov [4].

Table 1. Technology taxonomy for NASA's SBIR and STTR Programs.

NASA SBIR/STTR Technology Taxonomy

- **Avionics and Astrionics**
- **Biotechnology**
- **Communications**
- **Cryogenics**
- **Education**
- **Electronics**
- **Extravehicular Activity**
- **Information**
- **Manufacturing**
- **Materials**
- **Microgravity**
- **Power and Energy**
- **Propulsion**
- **Robotics**
- **Sensors and Sources**
- **Structures**
- **Thermal**
- **Verification and Validation**

There have been notable successes from this program, with technologies being infused into some of NASA's highest profile missions and directly contributing to their success. A few examples will be provided here, to illustrate how SBIR technologies are making important contributions. The twin Mars Exploration Rovers, still amazingly conducting science long after their planned mission life, are using 3 specific SBIR-developed technologies as shown in Figure 4.

Maxwell Technologies of San Diego, California, fabricated and tested an ASCII chip with single event latch up protection technology. Their innovation enables the use of commercial chip technology in space missions, providing higher performance at a lower cost. For the Mars rovers, the application was high-performance memory modules and analog-to-digital converters in the power systems and communications electronics. Yardney Technical Products of Pawtucket, Connecticut, developed lithium-ion batteries with specific energy density of >100Wh/kg, volumetric energy density of 240 Wh/l, and long cycle life. Subsequently, they won a large Air Force/NASA contract to develop batteries for space applications, and supplied the lithium-ion battery packs for the rovers. Starsys Research of Boulder, Colorado, developed paraffin based heat switches that function autonomously and are used to control the radiator for the electronics package on the rovers [5].

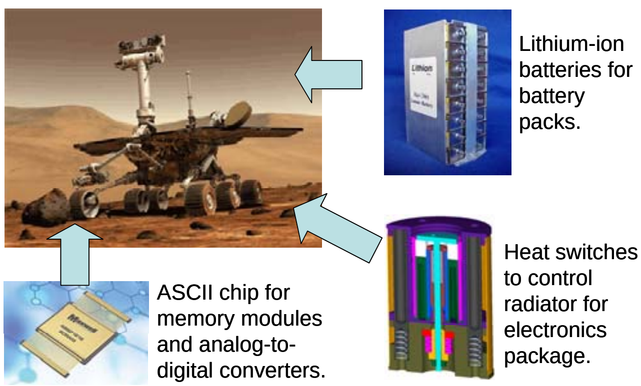

Figure 4. SBIR Technologies on the Spirit and Opportunity Mars Exploration Rovers.

SBIR technologies are also making important contributions to the next Mars rover mission – Mars Science Laboratory, as shown in Figure 5. Microwave Power Technology of Campbell, California, developed a small-format carbon nanotube field emission cathode (CNTFE) X-ray tube for the CheMin instrument on MSL. While a tungsten cathode was ultimately baselined for the flight tube, the form, fit, and function of the flight tube was derived from this SBIR. InXitu, Inc., of Mountain View, California, developed a powder handling device for X-ray Diffraction Analysis based on piezoelectrically-induced sample motion, and a miniature X-ray tube having a grounded cathode configuration is being developed to enable a further 2-fold reduction in the size of CheMin prototype instruments.

Wireless sensors developed with SBIR funding are now placed in the leading edge of the Space Shuttle wings to detect possible damage from foam, ice, ablator, and metallic objects during ascent, as shown in Figure 6. The Enhanced Wide-Band Micro-Miniature Tri-Axial Accelerometer Unit (EWB MicroTAU) system is a wireless, high-speed, synchronized data acquisition network for dynamic acceleration sensing, recording, and processing applications [6].

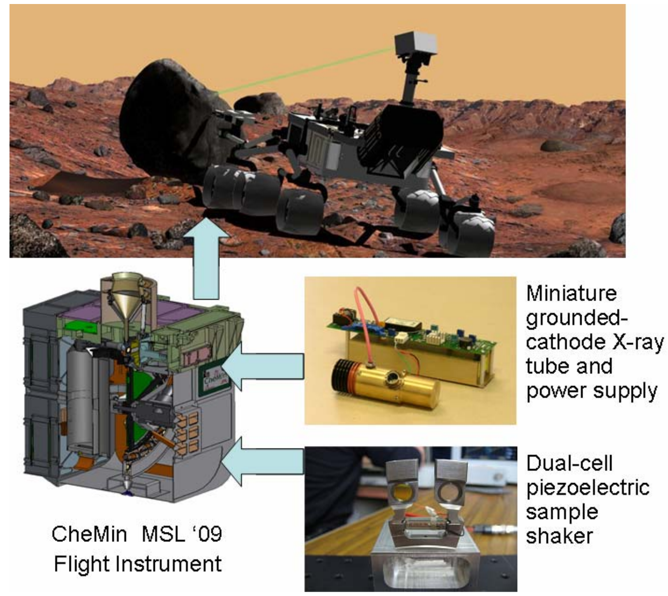

Figure 5. SBIR technology contributions to the Mars Science Laboratory (MSL) /CheMin instrument.

Use of this system as a wing leading edge impact monitoring system was first flown in NASA's Return to Flight mission, STS-114 in July 2005. The general term for this SBIR wireless technology is Sensor Control and Acquisition Telecommunications (SCAT) wireless instrumentation systems. SCAT systems have also been used for multiple applications on the International Space Station (ISS) such as wireless vehicle health monitoring, wireless instrumentation and data recording, and for instrumentation of flight tests for developmental vehicles.

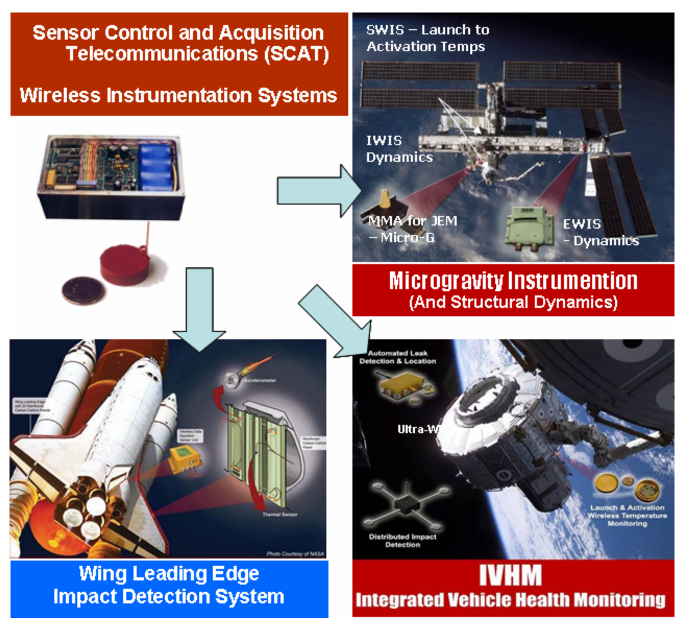

Figure 6. SBIR contributions to wireless technology.

Another example of how SBIR has played a critical role in technology development is the maturation of Phenolic Impregnated Carbon Ablator (PICA) heatshield material, invented at NASA Ames in 1993, as shown in Figure 7. PICA was a very promising material but only small specimens (~ 0.1 m) of PICA had been produced at the time of its invention. It was being considered as an enabling technology for the Stardust mission, but required the production of a much larger piece (~ 1.0 m). Available flight proven heatshield materials (e.g. carbon-phenolic) were too heavy to use for the Stardust sample return capsule, which needed to be very mass efficient. In 1994, PICA was selected by Lockheed Martin for the re-entry heatshield on Stardust.

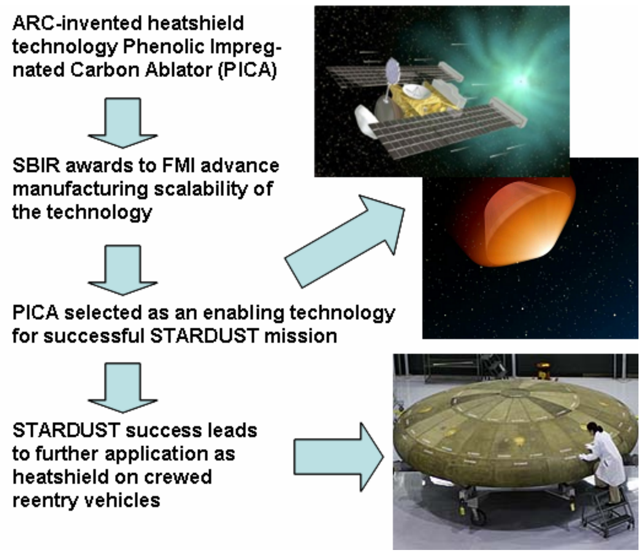

Figure 7. SBIR contributions to heatshield technology.

A Phase I SBIR with Fiber Materials, Inc. (FMI) of Biddeford, Maine, was further developing PICA technology at the time of the PICA selection for Stardust. A Phase II SBIR with FMI proved critical for scaling up fabrication of PICA from ~0.1 to ~1.0 m as required. Successful scale-up led to selection of Stardust as the fourth Discovery Class mission for NASA, and FMI provided the flight heatshield for Stardust under contract to Lockheed Martin.

The Stardust sample return capsule entered the Earth's atmosphere in January 15, 2006 at 12.9 Km/sec, the fastest Earth entry ever of a man-made object. With its exceptional performance proven by the Stardust sample return capsule entry, PICA is the leading candidate for the heatshield on NASA's Orion crew capsule. The Orion heatshield is being developed by Boeing, with FMI as their primary sub-contractor. PICA is also being used as the heatshield for the commercially developed SpaceX Dragon capsule.

These are just a few examples of how SBIR technologies have made important contributions to some of NASA's highest-profile missions. Other examples can be found by searching the 'success story' database on the SBIR/STTR website [7]. Technologies which are currently being funded are searchable on the SBIR/STTR website [8], and the interface for this searchable database is shown in Figure 8.

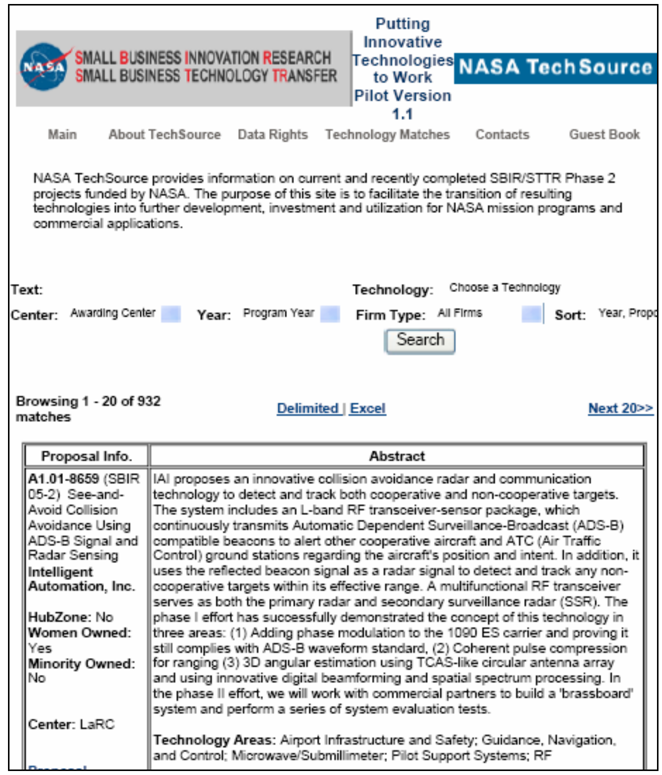

Figure 8. SBIR/STTR technologies can be searched using the NASA TechSource database.

3. SEED FUND

The IPP Seed Fund has been established as a annual process to enhance NASA's ability to meet mission technology goals by providing seed funding to address barriers and initiate cost-shared, joint-development partnerships. The IPP Seed Fund is used to provide 'seed' funding to enable larger partnerships and development efforts to occur and will encourage, to the maximum extent possible, the leveraging of funding, resources, and expertise from non-NASA partners, NASA Programs and Projects and NASA Centers.

The IPP Office at NASA HQ provides an annual Seed Fund Call for Proposals to NASA Centers, soliciting proposals for cost-shared partnerships with industry, academia, research institutions, national laboratories, and other Government agencies for joint development of technology that is of Mission interest to NASA.

The Call is developed in coordination with all Mission Directorates, and distributed to all Field Centers. In order to solicit external interest for partnerships an announcement is also posted to the FedBizOpps website. Responses to the Call must be from NASA personnel participating as a Partnership Manager (PM) in the Center IPP Office; with proposals including both an internal NASA Co-Principal Investigator (Co-PI) and an External Co-PI.

Proposed projects should be one year in duration and must include one or more non-NASA partners who are willing to provide cost-sharing at a level equal to or greater than the IPP funding provided to the project. Acceptable cost-sharing from the partner includes actual dollars applied directly to the project, in-kind considerations such as workforce labor and the use of unique and dedicated facilities and testbeds. Such leveraging of non-NASA resources also helps ensure successful application of the technology, because the partners have 'skin in the game' as stakeholders. The technology landscape covered by the successful proposals embraces the needs of all four Mission Directorates, as summarized in Figure 9 below.

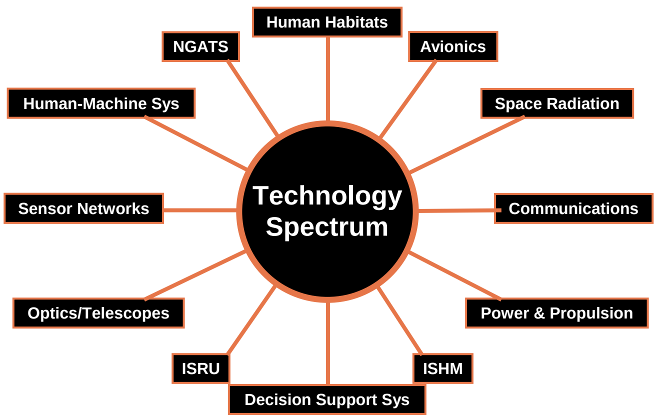

Figure 9. Technology spectrum of technologies sought from the IPP Seed Fund.

Proposals are evaluated against criteria which include: relevance/value to NASA Mission Directorates; scientific/ technical merit and feasibility; and leveraging of resources. The review process begins at each of NASA's 10 Field Centers, where proposals are prioritized for submission of to Headquarters. No more than 8 can be submitted from any one Center. Once received at Headquarters, all Mission Directorates are involved in prioritizing proposals addressing technology that each needs. Final selections are made by the Headquarters IPP Office.

In the last two years, an investment of $15.9 million by IPP facilitated the generation of 67 partnerships and was leveraged by a factor of four, providing a total of $62.2 million for the advancement of critical technologies and capabilities for the Agency. 2006 Seed Fund winners are available on the IPP website at http://www.ipp.nasa.gov [9], and results are summarized below:

- 76 proposals received, evaluated by IPP and Mission Directorate experts.
- 29 projects selected, providing $28.3 million for the advancement of critical technologies and capabilities.
- $6.6 million IPP Office funds.
- $7.5 million program, project, Center funds.
- $14.2 million external partner funds.

Technology Readiness Level (TRL) assessments are used to determine the maturity of the technology at the time of the Seed Fund award, and at the conclusion of the Seed Fund project. TRLs reflect a systematic metric/measurement system that supports assessments of the maturity of a particular technology and the consistent comparison of maturity between different types of technology. The TRL approach, with levels summarized below, has been used in NASA space technology planning for many years [10].

Technology Readiness Levels Summary:

TRL 1 Basic principles observed and reported.

TRL 2 Technology concept and/or application formulated.

TRL 3 Analytical and experimental critical function and/or characteristic proof-of concept.

TRL 4 Component and/or breadboard validation in laboratory environment.

TRL 5 Component and/or breadboard validation in relevant environment.

TRL 6 System/subsystem model or prototype demonstration in a relevant environment (ground or space).

TRL 7 System prototype demonstration in a space environment.

TRL 8 Actual system completed and "flight qualified" through test and demonstration (ground or space).

TRL 9 Actual system "flight proven" through successful mission operations.

Planned technology advancement resulting from the 2006 seed fund awards is illustrated in Figure 10. The number of 2006 Seed Fund projects at each TRL is shown in the blue at the time of the award, and in red at the planned level after the one year seed fund project.

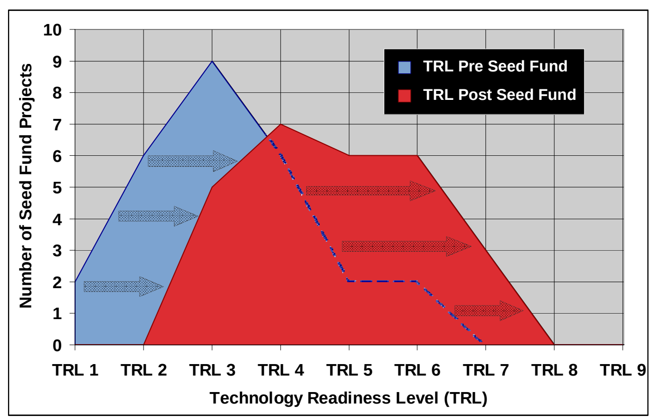

Figure 10. Technology maturation expected from FY 2006 Seed Fund projects.

One notable project from the 2006 Seed Fund awards was a partnership between NASA, the National Science Foundation, and ILC Dover to develop a prototype inflatable habitat. The partnership unveiled the Antarctic-bound prototype on Nov. 14, 2007 at ILC's facility in Frederica, Delaware [11]. The habitat, as shown in Figure 11, will be put through its paces as a component of the McMurdo Station in Antarctica from January 2008 through February 2009. Using reports from explorers braving this harsh environment and data collected from habitat sensors, designers will evaluate the concept of using inflatable structures to support future explorers on the moon or Mars.

Figure 11. The inflatable habitat produced as part of an FY 2006 Seed Fund project, prior to its trip to Antarctica for testing at the NSF McMurdo Station.

2007 Seed Fund partnership awards span 30 states, include nine universities, 23 small to medium-sized businesses, 17 large corporations and all 10 NASA Centers. Summaries of winners, topics, and states are available on the IPP website [12] and results are summarized below:

- 75 proposals received, evaluated by IPP and Mission Directorate experts.
- 38 projects selected, providing $33.9 million for the advancement of critical technologies and capabilities.
- $9.3 million IPP Office funds.
- $12.1 million program, project, Center funds.
- $12.6 million external partner funds.

Planned technology advancement resulting from the 2007 seed fund awards is illustrated in Figure 12. The number of 2007 Seed Fund projects at each TRL is shown in the blue at the time of the award, and in red at the planned level after the one year seed fund project.

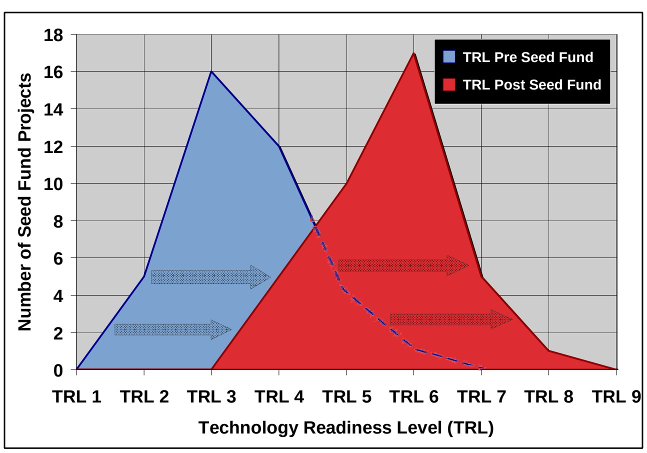

Figure 12. Technology maturation expected from FY 2007 Seed Fund projects.

There are several technology demonstrations planned for Seed Fund projects, in addition to the inflatable habitat demonstration previously discussed. A summary of some of the notable demonstrations planned for the coming year is provided below in Figure 13.

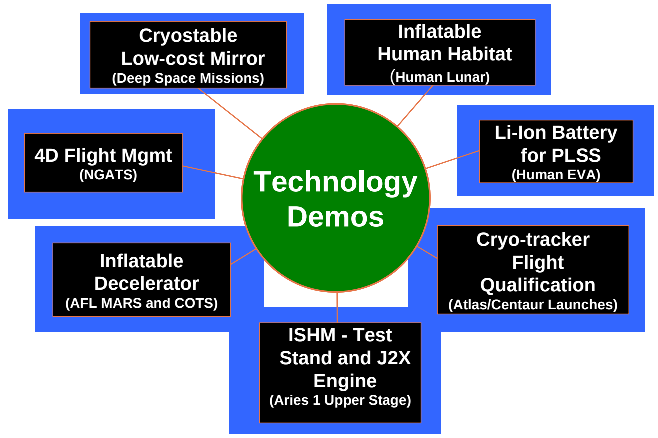

Figure 13. Examples of technology demonstrations expected during 2008 from ongoing Seed Fund projects.

4. CENTENNIAL CHALLENGES

Centennial Challenges is NASA's program of prize contests to stimulate innovation and competition in solar system exploration and ongoing NASA mission areas. By making awards based on actual achievements, instead of proposals, Centennial Challenges seeks novel solutions to NASA's mission challenges from non-traditional sources of innovation in academia, industry and the public. Current Centennial Challenges competitions are listed in Table 2 on the following page.

The purse amounts in the summary represent the total purse amounts and the amount available in 2008 competitions (several challenges are multi-year competitions so only a portion of the total purse is available in 2008). NASA has partnered with five different Allied Organizations to conduct the seven Centennial Challenge competitions. NASA provides the prize money, and the Allied Organizations conduct the competitions with no operational funding from NASA.

To date, NASA's Allied Organizations have conducted nine competition events and NASA has awarded prize money at two of the events. The first prize was awarded in May 2007 for the Astronaut Glove Challenge, and prizes were also awarded at the Personal Air Vehicle Challenge (now renamed the General Aviation Technology Challenge) in August 2007. The ongoing MoonROx challenge isn't tied to a particular event and hasn't yet been won.

Table 2. Summary of Centennial Challenge competitions.

Challenge Date	Challenge Name	Purse 2008/ Total	Allied Organization
August 2-3, 2008, at Cal Poly San Luis Obispo	2008 Regolith Excavation Challenge	$750K $750K	California Space Education & Workforce Institute (CSEWI)
August 2-10, 2008, Santa Rosa, CA	2008 General Aviation Technology Challenge	$300K $2M	Comparative Aircraft Flight Efficiency (CAFE) Foundation
Expires Jun 1, 2009	Moon Regolith Oxygen Extraction (MoonROx) Challenge	$1M	California Space Education & Workforce Institute (CSEWI)
2008 (Date TBD)	2008 Beam Power Challenge	$900K $2M	The Spaceward Foundation
2008 (Date TBD)	2008 Tether Challenge	$900K $2M	The Spaceward Foundation
2008 (Date TBD)	2008 Astronaut Glove Challenge	$400K $1M	Volanz Aerospace Inc./ Spaceflight America
2008 (Date TBD)	Lunar Lander Challenge	$2M	The X PRIZE Foundation

Peter Homer of Bangor, Maine, was the first recipient of Centennial Challenges prize money when he won the Astronaut Glove Challenge (Figure 14). The New York Times Magazine ran a cover story about Centennial Challenges, featuring Peter Homer's capture of the Astronaut Glove Competition [13]. Homer's glove technology relates to the pressure-containing inner layers.

Figure 14. Peter Homer (left) and one of the judges at the Astronaut Glove Challenge test his winning glove.

Among the potential benefits of the winning glove design are that it requires less torque to bend than the Phase 6 glove design currently in operational use; therefore, it may be less fatiguing to use. In addition, the finger joint flexes at a predictable repeatable location allowing each finger to be patterned to the individual astronaut's unique hand dimensions. Homer's next steps are to continue refinement of the glove design to further reduce bending torque (hand fatigue), improve sizing and fit, refine manufacturing processes, investigate the potential for applying finger joint technology to other mobility joints of the space suit, and explore ways to incorporate glove innovation into layers of the space suit. Since winning the Astronaut Glove Challenge, Homer has been hired as a consultant to Orbital Outfitters, a firm commercially developing a pressurized space suit for suborbital space flyers.

Hamilton Sunstrand and ILC Dover, the current manufacturers of NASA's spacesuits, were actively involved in sponsoring the competition and provided much of the test equipment. One of NASA's foremost spacesuit experts from JSC was also in attendance and quite impressed. While innovations from the competition haven't yet been infused, discussions are underway. Potential uses for NASA human space missions include: launch and re-entry safety/survival suits; suits for on-orbit extra vehicular activity (EVA); suits for planetary and lunar surface operations; and high pressure (zero pre-breathe) spacesuits (since the greater joint flexibility can allow for higher suit pressures).

The Lunar Lander Challenge has had two years of competitions in conjunction with the X-Prize cup although the prize has yet to be won. Nonetheless, capabilities are being demonstrated and new innovations are coming from competitors in the challenge. Armadillo Aerospace, which flew their 'pixel' vehicle in 2006 and their 'mod' vehicle in the 2007 competition (Figure 15), is applying their innovations in other areas. Armadillo was selected in the recent 2007 Seed Fund awards to demonstrate a liquid oxygen (LOx)/Methane engine. IPP and the Exploration Systems Mission Directorate are partners with Armadillo in this new Seed Fund project.

Figure 15. The Armadillo Aerospace 'Mod' vehicle lifts off in the third of four attempts at winning the Lunar Lander Challenge during the X-Prize Cup at Holloman Air Force Base, New Mexico in October, 2007.

Other competitions have been very successful at advancing knowledge and driving innovations as well, although prize money has not yet been won. An example is the Regolith Excavation Challenge that took place in a 4m by 4m 'sandbox' with 6 tons of JSC-1a lunar regolith simulant. This was the first time ever that this amount of lunar regolith simulant was used, leading one of NASA's experts who was present at the competition to state that he learned more in two days 'playing in this sandbox of JSC-1a' than he has in two years reading and studying about regolith properties.

5. OBSTACLES

The biggest obstacle to technology infusion is the perceived risk by program/project managers (or their systems engineers) of adopting a new technology. They like to have technologies with flight heritage and don't want to take on any more risk than they feel they have to. If the benefits of a new technology don't clearly outweigh the risks in the mind of a decision-maker, than that technology will likely not be infused. If additional development is required, then cost and/or schedule can be other obstacles. Projects generally desire technologies to be at least TRL 6 by their preliminary design review (PDR). IPP is doing several things to address these obstacles. A key element of achieving TRL 6 is demonstrating a technology in the relevant environment, including the gravity environment – from microgravity to lunar or Martian gravity levels. Space technology development can stall at the mid-technology readiness levels due to lack of opportunities to test prototypes in relevant environments. In addition, limited testing opportunities often have high associated costs or require lengthy waits.

NASA just completed a procurement to select a commercial service provider for parabolic aircraft flight to simulate multiple gravity environments, awarding the contract to the Zero Gravity Corporation on January 2, 2008. IPP is working with NASA's Strategic Capability Assets Program (SCAP) and the Glenn Research Center (GRC), to use this IDIQ contract for parabolic aircraft services to initiate a new activity – Facilitated Access to the Space environment for Technology development and training (FAST). FAST will provide more opportunities for reducing risk and advancing TRLs by providing partnership opportunities to demonstrate technologies in these environments [14].

FAST will purchase services through this new procurement mechanism and provide partnership opportunities aimed at reducing risk by advancing needed space technologies to higher technology readiness levels (TRL). This will demonstrate the business model for purchasing services commercially, and advance technology readiness for NASA's research and technology needs. The objective is to provide advanced technologies with risk levels that enable more infusion, meeting the priorities of NASA's Mission Directorates and their Programs and Projects.

6. BEST PRACTICES

The key to successful infusion is satisfying the technology user, a.k.a. customer or decision-maker, that the benefits of infusing a new technology or innovation outweigh any additional cost or risk. Someone will need to make a decision at some point that yes, this technology is something that will be infused. This discussion of best practices will refer to that person as 'customer.'

There is no standard recipe for infusion success, but a number of practices that if followed, will increase the likelihood of infusion. Not all must necessarily be followed, but the more the better.

1) Develop a technology that is needed.

   Communicate with the customer in order to understand their needs and how your technology might address those needs better than other options. IPP works hard to ensure our portfolio of technologies is integrated with the needs of NASA's Mission Directorates, and complementary to their other technology investments.

2) Cultivate interest with the customer as technology is being developed.

   Seek to have 'skin in the game' from the customer, as this validates that they are, in fact, interested. IPP seeks to do this through the Seed Fund, and has started a new Phase 2E feature in SBIR, to encourage cost-sharing from the Mission Directorates.

   Communicate with customers as the technology is being developed, keeping them apprised of milestones and demonstrations. Recognize that technology priorities and needs can be dynamic and keep abreast of changes in their needs.

3) Develop an infusion plan early, and keep updating it as the technology matures.

   Actively consider and plan for infusion as the technology is being developed, not as an afterthought once it has been successfully demonstrated. Throwing the technology ball over the fence and hoping that someone on the other side will catch it is not a good strategy for infusion. This infusion plan should include funding options for the duration of development and demonstration needed. In the case of most IPP projects, they are of limited duration and the IPP funding is but one link in a longer chain of events that must occur to lead to successful infusion. SBIR/STTR funding is 3 years, Seed Fund is 1 year. Technology development is typically a much longer process and it should be thought of as such and planned for with that in mind.

4) Understand the technology as part of the system it may be infused into, and be prepared to communicate that understanding.

   Communicate understanding of the issues of importance to the customer or technology user, as they deliberate on which technologies to infuse. To the extent possible, anticipate their questions and have responses in hand.

There is a common theme to all the items listed above – communications. Without communications there will be no infusion – it is that simple. To communicate effectively, there are several things that should be understood. In order to be successful at infusing technology, the technology developer must understand the issues and concerns of the technology user – typically a project manager or systems engineer conducting tradeoff analyses of multiple candidate technologies for various systems and subsystems. In order to understand the issues facing these decision makers, the more knowledgeable the individual or organization seeking to infuse a particular technology is, the greater the likelihood of successful infusion. The technology must be good, but if its attributes are not effectively communicated, it may never be infused.

To put a technology in the best position for infusion, it is desirable that there be certain levels of knowledge relative to the key issues on the minds of decision-makers – related to performance, schedule, cost, and risk. The questions summarized below are indicative of the types of questions typically asked by decision-makers, and while not all must be know, the more that are known the more likely that perceptions of risk can be reduced and infusion may occur.

<u>Performance</u>

- What impact will this technology have on the overall performance for the system (e.g., power savings, mass savings, higher resolution, increased Isp, etc.)? Can the benefits be quantified?
- Has (or will) this performance improvement been demonstrated? If a demonstration is planned, invite decision-makers to the demonstration.
- Are system impacts from the technology infusion understood (i.e., heat, vibration, mass, power, environmental, safety, etc.)?
- What level and quality of experience can the technology developer demonstrate?

<u>Schedule</u>

- Are the project need date and all key milestones known (e.g., PDR, launch, etc.)?
- Is the technology maturity consistent with need dates (e.g., rule of thumb TRL 6 by PDR at latest)?
- Are there opportunities to accelerate the maturity and deployment of the technology?

<u>Cost</u>

- Is there a reasonable estimate of the cost for infusing this technology?
- How does the cost estimate compares relative to other options in the trade space?
- Are there opportunities to reduce cost for additional development through partnerships?

<u>Risk</u>

- What is the current TRL in the context of TRL history and projections for this technology?
- Has credibility with the project been established?
- How well understood or commonly used are competing technologies in the trade space?
- Has a champion for this technology been identified and cultivated?
- What are the risks from infusing this technology? Are there mitigation strategies or workarounds for this technology?
- What are the broader benefits of this technology outside of the specific project? (If it has many applications and would be of benefit to the Agency generally, the level of risk acceptability may be higher than if it is just for a specific project.)
- Has a project representative seen the technology in person, visited the contractor site, or has the contractor visited the project and demonstrated the technology? (This is critical in addressing perceptions of risk.)

7. SUMMARY

IPP is seeking to add value to NASA's Mission Directorates and their programs and projects, through technology development and infusion to meet mission needs. IPP's technology portfolio provides benefits through several sources. There is a track record of success, with a few examples of the many successes provided in this paper, but IPP is aggressively pursuing better integration and more infusion. IPP is also working to better identify priority needs across the Agency, to help shape the portfolio of investments and partnership opportunities. IPP has a highly dedicated workforce at each of the 10 Field Centers. They are working hard to build even stronger connections to programs and projects to better understand needs, strengthen working relationships, and increase infusion.

REFERENCES

[1] Comstock, D. A., "NASA's Innovative Partnerships Program: Matching Technology Needs with Technology Capabilities," *High Frontier, Journal of the Air Force Space Command*, Vol. 3, No. 3, pp. 22-26, May 2007, http://www.afspc.af.mil/shared/media/document/AFD-070524-021.pdf.

[2] Comstock, D.A., and Lockney, D., "NASA's Legacy of Technology Transfer and Prospects for Future Benefits," AIAA SPACE 2007 Conference & Exposition, AIAA-2007-6283, September 18 – 20, 2007.

[3] The SBIR and STTR programs were established by public law, as amended, in 1982 (P.L. 106-554) and 1992 (P.L. 107-50) respectively.

[4] Detailed taxonomy listing can be found online at: http://sbir.gsfc.nasa.gov/SBIR/sbirsttr2007/solicitation/taxonomy.html.

[5] Sunada, E., Langford, K., et al, Paraffin-actuated heat switch for Mars surface applications, STAIF 2002, February 6, 2002, and *NASA Tech Briefs*, May 2002.

[6] More details are available at http://www.invocon.com/EWB_MicroTAU_tech_overview.html.

[7] More SBIR/STTR success stories are available at http://sbir.gsfc.nasa.gov/SBIR/success.htm.

[8] SBIR/STTR technologies currently funded by Phase 2 contracts are searchable at the NASA TechSource website: https://sbir.gsfc.nasa.gov/sbir/search/fundedTechSearch.jsp.

[9] Seed Fund winners from the 2006 Call are at: http://www.ipp.nasa.gov/06_seed_fund_partner.htm.

[10] Mankins, J., "Technology Readiness Levels: A White Paper," Advanced Concepts Office, Office of Space Access and Technology, NASA, April 6, 1995.

[11] See the NASA press release: http://www.nasa.gov/home/hqnews/2007/nov/HQ_07251_Inflatable_Lunar_Habitat.html, and for pictures see: http://www.nasa.gov/mission_pages/exploration/multimedia/inflatable_habitat.html.

[12] Seed Fund winners from the 2007 Call are at: http://www.ipp.nasa.gov/07_seed_fund_partner.htm.

[13] Hitt, Jack, "The Amateur Future of Space Travel", *New York Times Magazine*, July 1, 2007

[14] Comstock, D.A., and Scherbenski, J., "Facilitated Access to the Space environment for Technology development and training (FAST)," AIAA Aerospace Sciences Meeting and Exhibit, AIAA-2008-0798, January 7-10, 2008.

BIOGRAPHY

Doug Comstock *is the director of NASA's Innovative Partnerships Program (IPP). The IPP provides leveraged technology for NASA's mission directorates, programs and projects through investments and technology partnerships with industry, academia, government agencies and national laboratories.*

Comstock is responsible for directing the IPP portfolio of technology investments and partnering mechanisms including Small Business Innovation Research, Small Business Technology Transfer, Centennial Challenges and the IPP Seed Fund. Additionally, he is responsible for intellectual property management and technology transfer that will provide broad societal benefits from the nation's investment in NASA's space and aeronautics missions, and for encouraging and facilitating partnerships with the emerging commercial space sector including the agency's purchase of emerging commercial services.

Comstock previously served as the NASA Comptroller, responsible for the preparation, tracking, presentation and defense of NASA's budget to the White House Office of Management and Budget (OMB) and the Congress. As the founding director of NASA's Strategic Investments Division, he was responsible for integrating NASA's strategic planning and program analysis supporting budget decisions into a single organization.

Before coming to NASA, Comstock was a program examiner in OMB, with responsibility for NASA's human space flight activities, biological and physical research and personnel. Prior to his government service, he was Director of Engineering with the Futron Corporation, a Bethesda, Md.-based technology consulting firm, and began his career with General Dynamics Space Systems Division, conducting preliminary design and systems analysis for numerous aerospace systems, from strategic defense to advanced space transportation.

Comstock has undergraduate degrees from the University of Washington in Seattle, Washington, in both mechanical engineering and architecture. He did his graduate studies at the Massachusetts Institute of Technology in Cambridge, Massachussetts, and received masters degrees in both aeronautics and astronautics, and technology and policy.

He resides in Ashburn, Va. and is married to the former Susan Louk. They have two children.