How You Can Participate in the Space Program

Centennial Challenges  http://www.ipp.nasa.gov/cc

**August 14, 2009: Tether**
Seattle, WA
**2008 PURSE: $2,000,000**
Super-strength materials
Managed by: Spaceward Foundation
http://www.spaceward.org/elevator2010-ts

**October 17-18, 2009: Regolith Excavation**
NASA Ames Research Center, Mountain View, CA
**2009 PURSE: $750,000**
Robotic devices to excavate simulated lunar soil
Managed by: California Space Education & Workforce Institute
http://regolith.csewi.org/

**Through October 31, 2009: Lunar Lander**
Competitors’ Locations: TBA
**REMAINING PURSE: $1,650,000**
Rocket vehicles simulating lunar takeoff and landing
Managed by: X PRIZE Foundation
http://space.xprize.org/lunar-lander-challenge

**November 2009: Astronaut Glove**
MIT, Cambridge, MA
**2009 PURSE: $400,000**
Innovative spacesuit glove designs
Managed by: Volanz Aerospace, Inc.
http://astronaut-glove.tripod.com/

**Date TBA: Power Beaming**
Location TBA
**2008 PURSE: $2,000,000**
Wireless power transmission
Managed by: Spaceward Foundation
http://www.SpaceElevatorGames.org

**July 2011: Green Flight**
Sonoma County Airport, Santa Rosa, CA
**PURSE: $1,653,000**
Safe, quiet & super-efficient aircraft
Managed by: Comparative Aircraft Flight Efficiency Foundation
http://cafefoundation.org/v2/pav_home.php

On the cover: Orbital Sciences Cygnus spacecraft (lower left) and SpaceX’s Dragon spacecraft (lower right), winners of NASA’s Commercial Orbital Transportation Services competition, are depicted with their possible destinations in the distance: the International Space Station (upper left) and a Bigelow Aerospace habitat (upper right).
Accessible space travel, suborbital vehicles, lunar habitats – the growing commercial space industry creates a strategic opportunity for NASA to leverage private sector resources, commercial markets and free enterprise innovation.

**Commercial Orbital Transportation Services Program Blazes New Trails for NASA**

NASA is partnering with industry to enable the demonstration of commercial space transportation systems and capabilities to enable space station cargo delivery services.

**Commercial Resupply Services Contracts to Benefit Space Station**

Building on the COTS Program, NASA breaks new ground with a firm-fixed-price procurement to provide cargo resupply services to the International Space Station.

**Innovations in Reusable Rocket Engines: Competition and Collaboration**

With its innovative rapid prototyping approach, Armadillo Aerospace won the 2008 Level 1 NASA Lunar Lander Challenge, test flighted a rocket aircraft for the Rocket Racing League and partnered with Johnson Space Center to test LOX/methane engines for lunar travel.

**Astronaut Gloves: Moving Beyond the Challenge**

The winner of NASA's 2007 Astronaut Glove Challenge tells how he approached the contest and provides tips for entrepreneurs wishing to try.
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IPP WELCOMES CHARLES MILLER
Charles Miller joined the Innovative Partnerships Program earlier this year as Senior Advisor for Commercial Space. With experience as an entrepreneur and commercial space advocate, he will help to build and strengthen the relationships between NASA and commercial space entities.
A Message from NASA

UPFRONT with...
Douglas A. Comstock
Director, NASA Innovative Partnerships Program

We have begun to focus each issue of Innovation on a particular theme, and the theme for this issue is something that I am really excited about – Commercial Space. We have many stories about how NASA and the emerging commercial space industry are working together for mutual benefit. There are three key themes that are woven throughout these stories that underscore some of the changes underway in how NASA is engaging the commercial space community:

• Private sector role as partner rather than contractor.
• Government purchase of services instead of hardware.
• Creating broader opportunities for innovation.

First is the shift in relationships between the government and the private sector from the traditional roles of customer-contractor to one of partners. The Commercial Orbital Transportation (COTS) program is a prime example of this, where NASA is partnering with SpaceX and Orbital Sciences to develop new space transportation capabilities. Other examples include licensing NASA technology for development of commercial space habitats and revolutionary propulsion systems, as well as IPP Seed Fund projects where cost-shared technology development among partners advances important technologies of common interest, such as propellant depots and LOX/Methane rockets.

The second important change is the transition to a model where the government is buying services from commercial providers rather than paying for development and operation of hardware. The biggest example of this – for billions of dollars in launch services with commercial service providers – is the Commercial Resupply Services contracts to provide cargo delivery to the ISS. Another example is the Sabatier water production system that is being deployed on the ISS where NASA will pay for services provided rather than for the development of hardware. Looking forward, another story highlights how lunar communications needed in the future could be a commercial service provided to users rather than a NASA-owned system.

The third major shift focuses on the creation of broader opportunities for innovation that address NASAs needs but also those of commercial space and other markets. Such opportunities can be found through NASAs Centennial Challenges competitions that are open to the citizen inventor. We have great stories from some of our winners. Our first winner, Peter Homer, discusses the progress he has made since winning and gives advice for other competitors. Our most recent winner, Armadillo Aerospace, describes how the capabilities demonstrated in winning the Lunar Lander Challenge are leading to opportunities in other markets. Commercial parabolic flight services are being used by NASA’s FAST program to mature innovative technologies in reduced gravity, and NASA is partnering with other agencies and the private sector to conduct research on the International Space Station as a National Laboratory.

As I think you will see when you read the stories in this issue, there is a lot to be excited about! NASA will continue to push the boundaries of aeronautics and space exploration with increasing reliance on – and benefit from – the innovation and new capabilities provided by our business partners and entrepreneurs in commercial space.
Technology Innovation

NASA News Briefs

Ames Director Named Federal Lab Consortium Director of the Year

The director of NASA’s Ames Research Center (ARC), S. Pete Worden, has been named the Federal Laboratory Consortium (FLC) 2009 Laboratory Director of the Year. The FLC was established in 1974 to promote and strengthen technology transfer nationwide and today consists of more than 250 federal laboratories and centers.

Worden has supported the development of competitive mission proposals, licensing of ARC intellectual property and the coordination of an array of educational outreach and internship programs to inspire and recruit future scientists and engineers who are critical to sustaining a robust technology transfer network inside and outside of NASA.

As a strong supporter of small spacecraft and satellites, Worden has given an important role to their development at ARC. It is with this in mind that he created the Small Spacecraft Division, where the small spacecraft system called the Common Spacecraft Bus was developed.

The development of the Common Spacecraft Bus led to an agreement between ARC and Odyssey Moon Ventures LLC, which is developing commercial robotic lander systems for lunar exploration. (See related story on page 21.) Odyssey plans to commercialize this ARC technology to develop a series of robotic missions to the moon. Its initial MoonOne (M-1) lunar lander will use the Common Spacecraft Bus to provide low-cost, frequent access to the moon for private, academic and government customers.

ARC is located at Moffett Field, Calif., in Silicon Valley, and Worden’s vision for the future of ARC strongly emphasizes cultivating partnerships with the center’s neighboring companies. ARC and Google are collaborating on the design of a disaster geospatial imaging system and a Google Earth tool for disaster response, and on another project that will compile and test moon and Mars imagery and update NASA Earth data to include satellite and suborbital data.

ARC and Cisco Systems are developing an online collaborative global monitoring platform to capture, collect, analyze and report data on environmental conditions around the world. And a partnership with Microsoft Corporation will make planetary images and data available to the public through Microsoft’s Worldwide Telescope.

Under Worden’s leadership, ARC has strongly committed to its development as a leader for Green/Clean technologies in Silicon Valley. Numerous partnerships have emerged with private industry, universities and federal laboratories to collaborate on green technologies. (See Technology Innovation Volume 15, Number 1, for information on these initiatives.)

Worden also supported the creation of the Greenspace Initiative (www.nasa.gov/centers/ames/greenspace), which aligns ARC’s green research and institutional activities with NASA missions and green activities at other NASA centers by providing strategy, integration and implementation support for a diverse portfolio of alternative energy and environmental projects.

Another example of Worden’s commitment to promoting partnerships is his support in bringing the International
Space University (ISU) Summer Session Program to ARC in 2009. ARC is providing the ISU student body with a rich, interdisciplinary curriculum along with the mentorship of NASA’s scientists, engineers, researchers and partners from academia and industry. Worden’s vision includes ARC having a key role in developing future leaders in the global space community.

For more information, contact William M. Toscano at Ames Research Center, (650) 604 0894, or William.M.Toscano@nasa.gov.

Please mention that you read about it in Technology Innovation.

**SpaceX Heat Shield Material Passes High-Temperature Tests**

Space Exploration Technologies (SpaceX) recently passed a significant technical milestone in the development of its Dragon spacecraft with the successful arc jet testing of a high-performance heat shield material, PICA-X. Dragon is designed to deliver cargo and crew to and from the International Space Station. (See related story on page 34.)

The Space Technology Division at NASA Ames Research Center originally developed the rigid, lightweight PICA (Phenolic Impregnated Carbon Ablator) material and assisted SpaceX in developing the ability to manufacture PICA-X. The “X” stands for the SpaceX-developed variants that have several improved properties and greater ease of manufacture.

PICA-X was subjected to temperatures as high as 1,980 degrees Celsius (3,600 degrees Fahrenheit) in the Arc Jet Complex at Ames in tests that simulate the reentry heating conditions that the Dragon capsule will experience. Panels of the high-performance carbon-based material will protect cargo and crew during the spacecraft’s return from Earth orbit.

“The arc jet tests represent the culmination of an aggressive six-month development effort, and our goals have been met or exceeded,” said Elon Musk, CEO and CTO of SpaceX. “Dragon will be the first craft to return from low-Earth orbit using a PICA-based thermal protection system.”

The inaugural Dragon spacecraft flight is scheduled for 2009 aboard SpaceX’s new Falcon 9 launcher.

The Dragon capsule will enter the Earth’s atmosphere at around 7 kilometers per second (15,660 miles per hour), heating the exterior of the shield to up to 1,980 degrees Celsius. However, just a few inches of the PICA-X material will keep the interior of the capsule at room temperature.

“It was a great experience working closely with SpaceX over this past year to help them develop their capabilities for design and fabrication of spacecraft thermal protection systems, including PICA-X,” says Daniel J. Rasky, Ames senior scientist and PICA co-inventor.

The Ames Arc Jet Complex has a rich history in the development of thermal protective systems for NASA spacecraft, including Apollo, the space shuttle and robotic missions to Venus, Mars and Saturn. The Arc Jet Complex is uniquely capable of simulating conditions experienced during reentry, and it actively supports emerging space companies such as SpaceX.

NASA’s Innovative Partnerships Program (IPP) Office in the New Ventures and Communications Directorate and Ames technical experts have established good working relationships, effective partnering approaches and streamlined procedures that are compatible with the needs and interests of these new, fast-moving companies.
This Is Rocket Science!

By Tim Glover
Ad Astra Rocket Company

Michele Brekke
NASA Johnson Space Center

The recent interest of commercial and government entities in sending payloads to the moon has generated a substantial, ongoing demand for cost-effective transport from low-Earth orbit to the lunar surface.

One technology that may make lunar transport more economically affordable is being developed by Ad Astra Rocket Company through a partnership with NASA’s Johnson Space Center (JSC) – the Variable Specific Impulse Magnetoplasma Rocket (VASIMR®) engine. Ad Astra’s models indicate that the VASIMR® technology could economically meet the needs of this emerging market.

Ad Astra is based in Webster, Texas, where it has its main laboratory and corporate headquarters and is led by founder Franklin Chang-Diaz, a seven-time space shuttle astronaut and rocket scientist. Ad Astra also owns and operates Ad Astra Rocket Company in Costa Rica. Chang-Diaz developed the VASIMR® concept while with NASA’s astronaut corps. After leaving NASA, he established Ad Astra and partnered with NASA to license, develop and commercialize the technology. As company CEO, Chang-Diaz has directed the technology maturation that comprises the company’s intellectual property portfolio.

In his July 8, 2009, testimony to the U.S. Senate Committee on Commerce, Science and Transportation, NASA’s new administrator, Charles Bolden, said this of Ad Astra’s leader, “Franklin Chang-Diaz, who is my idol, another astronaut who now is in the entrepreneurial space business, has a plasma rocket engine that if it works, and I think it will, will take us to Mars in 39 days instead of eight to 11 months. NASA provided him a very small stipend to get started and to bring his project to what we call the technology readiness level one, two and three. And now he’s at the point where it’s ready to fly. But he has done that with what they call venture capitalists, private investors.”

Ad Astra entered into its first agreement with JSC in 2005, receiving the use of onsite lab space for the initial development of the VASIMR® engine. NASA also provided an engineer, who assisted with facility safety and the development of the super-conducting magnets used in the technology.

The VASIMR® engine operates by heating argon gas to extremely high
temperatures with radio waves in a strong magnetic field. Propulsion is produced as this energized plasma escapes along the magnetic field lines. The argon plasma at the core of the VASIMR® engine reaches temperatures nearly as high as those within the sun – millions of degrees Fahrenheit. At this high temperature, the engine ejects its propellant at speeds more than 10 times those of the best chemical rockets, which makes the rocket significantly more efficient than conventional rockets and even more efficient than high-efficiency electric thrusters.

Use of the highly efficient VASIMR® engine could make lunar base support more economical by greatly reducing the mass of propellant required to transfer payloads from low-Earth orbit to low-lunar orbit. It also should accelerate planetary exploration by reducing flight times and by increasing the mass that can be delivered to other planets with existing launch vehicles.

Ad Astra has, through a privatization agreement with NASA, obtained an exclusive license to the original VASIMR® patents, thereby positioning itself as the premier developer for an electric rocket technology that may one day take mankind to Mars and beyond.

A New Type of Agreement
There is now in place an open-ended agreement that allows NASA to establish specific tasks as the VASIMR® technology and product line mature. JSC is providing Ad Astra with part-time liaison support to facilitate dialogue with subject matter experts. This support facilitated the most recent negotiations with NASA and the International Space Station (ISS), laying the groundwork for the partnership agreement to have the new plasma-based propulsion technology installed and tested on the ISS.

This is the first such agreement for a privately funded payload on the ISS exterior, and it represents an expansion of NASA’s plans to operate the U.S. portion of the space station as a national laboratory. (See article about the ISS National Laboratory on page 57.) The Space Act Agreement for the VASIMR® ISS project specifically describes it as the pathfinder project for external payloads under the National Lab program.

NASA and Ad Astra envision that the VASIMR® engine will be launched to the ISS and tested, for the first time, in the vacuum of space. The Space Act Agreement allows for the feasibility assessment of this venture, ranging from what vehicles will be used to transport the payload (approximately the size of a small car), to how to provide power to run the test firing.

As conceived at present, the engine will be attached to a truss of the space station, where ISS electrical power will be used to trickle-charge a large battery bank. This unique space station payload will operate in 10-minute, 200-kilowatt pulses, directing its thrust slightly off the center of the ISS’s mass and imparting a small torque on the station with each firing. Detection of this small torque by existing ISS equipment will serve as a direct measurement of the VASIMR® thrust, making the entire ISS a sensitive thrust stand.

Once continuous megawatt power levels become available through either solar or nuclear space power plants, the VASIMR® technology could emerge as a great enabler of manned flights to Mars, due to the reduced flight times made possible by its continuous thrust and high exhaust velocity.

Possible commercial applications include reboost of space stations in low-Earth orbit to cancel the effects of atmospheric drag. Simple cost models demonstrate that continuous thrust by a VASIMR® thruster would keep stations in orbit at much lower cost than periodic reboosting with chemical rockets.

The partnership between Ad Astra and NASA’s Innovation Partnerships Office allows Ad Astra to gain situational awareness of NASA’s commercial space concepts, with the IPP Office as a resource to the company. Meanwhile, NASA is able to stay abreast of commercial space propulsion concepts and to better understand commercial business practices.

Tim Glover is director of development for Ad Astra Rocket Company, and Michele Brekke is director of the Innovation Partnerships Office at NASA’s Johnson Space Center.

For more information contact Tim Glover at tim.glover@adastrarocket.com.

Please mention that you read about it in Technology Innovation.
Space Habitats
Opening New Frontiers for Business in Microgravity

By Donna P. Anderson
NASA Johnson Space Center

Destination: low-Earth orbit; the commodity: microgravity. Bigelow Aerospace plans to be the first to provide a commercial microgravity environment using expandable habitats.

Having launched Genesis I in 2006 and Genesis II in 2007, Bigelow Aerospace celebrated Genesis II’s 10,000th orbit this past spring. “We have learned that the durability of our system is extremely robust. Despite the years in orbit, the leak-rate on our spacecraft is still undetectable,” says Mike Gold, a director at Bigelow Aerospace.

Genesis I was the first expandable space habitat technology on orbit, and the first spacecraft produced by Bigelow Aerospace. Genesis II represents the second deployment of an expandable habitat and contains a number of systems, additional cameras, sensors and new subsystems not flown aboard Genesis I, such as a reaction wheel.

Bigelow Aerospace also offered the general public the opportunity to participate in the “Fly Your Stuff” commercial program by allowing people to pay to send small objects into space aboard Genesis II.

Genesis II has 22 cameras on the interior and exterior of the craft, magnetic torque rods, GPS and sun sensors, plus the aforementioned reaction wheel system providing altitude control and stabilization. Genesis II does not have any propulsion mechanisms of its own.

Mission control for Bigelow Aerospace is in north Las Vegas, Nev., where its corporate headquarters is based. The company operates four ground communication stations that provide relays between its spacecraft and mission control.

Bigelow Aerospace was founded in 1999 by Robert Bigelow, and the company’s relationship with NASA Johnson Space Center (JSC) began in 2002 when the company entered into a series of Space Act Agreements that primarily consisted of short-term technical personnel exchanges. Bigelow Aerospace now has an active Space Act Agreement with JSC, and several exclusive and partially exclusive licensing agreements for NASA technologies associated with inflatable habitats.

“Bigelow Aerospace is a pioneer for the emerging commercial space market. NASA is excited to be partnered
with them,” says Michele Brekke, director of the JSC Innovation Partnerships Office.

Bigelow has identified a wide variety of potential markets for its services, according to Gold, and initially is focusing on two of them — microgravity research and development, and international astronaut corps. “We are particularly intrigued by the potential in the biotech and pharmaceutical markets. There is a vast amount of R&D dollars in this area and it’s a very promising market to tap,” says Gold.

“The ability to conduct scientific and commercial R&D in a microgravity environment will open up a new possibility for industry and government that can be conducted for a fraction of what NASA or large corporations spend,” Gold adds.

At issue however, is reliable transportation to and from the habitats. Gold says that the single greatest Achilles heel that Bigelow now faces is a lack of crew transportation. “Both the private sector and the government need a reliable, safe and affordable means of transporting crew to and from low-Earth orbit,” Gold says. NASA’s Commercial Orbital Transportation Services (COTS) program was a step in the right direction, in Gold’s opinion, but he says that much more needs to be done.

Several countries have a strong desire to develop their own native astronaut corps, according to Gold. He anticipates that Bigelow will be able to provide turn-key opportunities where, for pennies on the dollar, foreign nations will be able to have their own dedicated modules and essentially their own human spaceflight programs. “If the costs are kept reasonable this will unquestionably be an extremely exciting market,” Gold says.

A Bright Future
On the horizon for Bigelow is launching Sundancer, the node bus and the full-standard habitat. Sundancer will be approximately the size of a large Greyhound bus initially, although Gold muses that he expects “the views from the windows to be much better.”

The habitat will grow with each launch through modules that will provide useable space that exceeds the space for the International Space Station, according to Gold. Again, the schedule for launch depends upon reliable transportation. Bigelow has relied upon the Russians and some very creative and unique arrangements to launch each of the previous Genesis habitat pathfinder prototypes. Gold would not predict at this time when Sundancer and other Bigelow systems will launch, since they are dependent on the development of a commercial crew transportation system.

In working with NASA, Gold says that private companies need to be forewarned, and prepared, to deal with the delays of working with a government bureaucracy. Gold continues, stating that there are some excellent attorneys at JSC in particular, and NASA folks who want to be innovative. However, Gold asserts that NASA Headquarters and NASA leadership need to figure out how to empower individual NASA mid-level managers, and partnerships with commercial projects, to work through the “bureaucratic process [that] currently takes an extraordinary amount of patience.”

“New frontiers offer many challenges,” says NASA JSC’s Brekke. “Developing a solid working structure between partners is a part of the process. We are working in exciting times, on the forefront of new discoveries and advancements.”

Ultimately, Bigelow Aerospace wants to see crewed space activities transformed in the same way that telecom has been from the domain of the government to a booming commercial market. “There is no other company globally that has made even a fraction of the investment or the progress that we have in developing and proving expandable space habitat technology, all on our own dime,” Gold says.
Commercial Communications Achievable in NASA’s Lunar Science & Exploration Programs

By James Schier
NASA Headquarters
Robert Kelso
NASA Johnson Space Center
Lawrence Petak
ASRC Management Services
Peggy Slye
Futron Corporation
Jon Michael Smith
Jon M. Smith and Associates

During the Apollo era in the 1960s, NASA was the only “customer” for the moon, and the United States government did everything itself, using traditional procurement approaches for creating the capability and infrastructure for lunar missions. NASA owned all of the flight and ground hardware except for systems provided by the Air Force and Navy, procuring what it needed from prime contractors who worked for NASA. The Agency funded all testing and development. It defined not only what was required, but also how it was to be built in terms of design and implementation. Buying systems and components from industry, NASA led the integration, testing and operations for its missions.

Now, as NASA prepares to return to the moon by 2020, the environment is different. NASA is no longer the only party that wants to engage the moon. Many space-faring nations, commercial groups and academic institutions also are planning to reach for the moon. While the communications and navigation systems are among the least costly of all the systems to implement in the national lunar science and exploration programs, the success of commercial satellite communications in Earth orbit opens the opportunity for new types of public-private partnerships (PPP) that can substantially reduce the cost of space activities for NASA.

In describing NASA’s lunar exploration initiatives at the 2nd Space...
Comparison of Apollo Era and Next Generation Characteristics

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Exploration Conference (December 2006), Agency leaders explained that NASA would focus on space transportation as its leadership role. It also would provide Extravehicular Activity (EVA) suits and basic communications and navigation services for mission support, while encouraging partners to provide augmented or high bandwidth capabilities. Everything else would be open to provision by international or commercial partners.

Industry has already shown that it believes that it has the technical capacity to design and operate systems to provide commercial communications and navigation services, an interest in growing into this new lunar market and the ability to marshal the resources for such a venture if NASA sets up the means and commits to its success.

NASA wants to open the door to commercial partners and has congressional direction to do so. By involving the commercial sector and by encouraging everyone to contribute what they do best, the potential exists for more progress, lower cost and faster implementation in returning to the moon.

Study Backs Commercialization

In 2007, NASA began a series of studies to determine if the time was right for a new collaboration with the communications industry (“Commercial Lunar Communications and Navigation [C&N] Study Final Report,” NASA Space Communications and Navigation [SCaN] Program, James Schier, ed., March 2009). The studies concluded that commercial lunar communications is feasible, the time to act is now and industry is ready and able to participate. NASA has developed new
Cumulative Lunar Missions in the Next Decade

and innovative ways in which it could engage the communications industry in collaboration, as shown in the table on page 13 comparing Apollo to the new era of exploration.

The public-private partnership arrangement envisioned is similar to INTELSAT. In 1962, President Kennedy signed the Communications Satellite Act with the goal of establishing an international satellite system. The International Telecommunications Satellite Consortium (INTELSAT) was established in 1964 when agreements were signed by governments and operating entities. By 1965, *Early Bird 1* was launched as the world’s first commercial communication satellite. INTELSAT became a private company in 2001.

In the new commercial era, NASA would collaborate with the “best in class” members of the communications industry to provide innovative lunar communications for the second generation of lunar exploration by both NASA and industry, allowing both parties to benefit from operations at the moon.

Together, NASA and industry would explore the benefits of lunar operations for science, astronomy and entrepreneurial endeavors such as searching for new sources of energy. NASA could provide innovative seed-fund investments to aid industry in developing lunar communications capabilities. In this new era, NASA would decide what communications services it needs, and industry will decide how to provide the services. This would allow NASA to purchase...
only the services that it needs at a lower cost that is shared among the lunar customers.

Marketing studies by both NASA and the communications industry show that the early lunar explorers, driven by prize money and unique opportunities, are commercial firms, and they are expected to begin as early as 2011 in pursuit of the Google Lunar X Prize. These entrepreneurs will be followed by scientists interested in learning more about the nature of the moon and solar system. During the next decade, more commercial firms, governments and academic institutions will join in the moon’s economic growth. There will be an increasing growth opportunity for all who conduct lunar operations, and all will require communications services (see graph on page 14).

**New Role for NASA**

NASA would provide the innovative leadership for this collaboration, but not necessarily its control. One promising option is for a public-private partnership to control the lunar assets, whereby NASA becomes just one of the government-industry partners. In the early years, NASA could behave as a lead tenant in the partnership as a senior partner with the most need for communications services. The partnership’s communication system would be used as the primary support to NASA’s operations, with additional capacity sold to international and commercial users. A similar arrangement was made with Western Union in 1976 when NASA leased commercial service for 10 years on the Tracking and Data Relay Satellite System (TDRSS). NASA could provide basic communications and navigation infrastructure as backup to ensure crew safety and mission success.

Additionally, NASA will also transfer advanced, innovative communication technologies, such as optical communications, to industry to accommodate the growing communications needs of the community, in much the same way that NASA does for industry now.

As the partnership matures, NASA can turn its attention to Mars and further develop innovative ways to provide for communications needs for martian exploration.

If NASA achieves this strategic goal of re-entering the lunar market from an entirely new perspective, as a partner and collaborator with the global commercial space communications industry, the Agency would attain some additional significant goals. By leveraging its experience in partnering with industry and other space-faring nations to create this innovative business model designed for the challenges of a new lunar era, NASA would reap tangible benefits in the critical program management areas of cost efficiency, risk minimization and avoidance, and improved time to market for the requisite new technical capabilities.

These business model improvements would not only aid the scientific and human exploration programs in which NASA has been the historic leader. They also would foster parallel development of innovative space capabilities, which are valued at $1-5 billion in the near term in an independent assessment conducted by Futron Corp., as part of the Commercial Lunar Communications and Navigation (C&N) Study. They would pave the way for the commercialization of an entirely new market sector. By leveraging the lessons gathered through 50 years of technical experience and redefining the essential business paradigm for future exploration programs, NASA could create a robust and resilient model in which government and commercial partners can succeed by continuing to do what they do best individually.

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**James Schier** is systems engineering and integration manager in the Space Communication and Navigation Office, NASA Headquarters; Robert Kelso is manager of commercial lunar services, NASA Johnson Space Center; Lawrence Petak is senior systems engineer, ARSC Management Services; Peggy Suye is president, Futron Corporation; Jon Michael Smith is president, Jon M. Smith and Associates.

For more information, contact James Schier at James.schier 1@nasa.gov or (202) 358 5155.

Please mention that you read about it in Technology Innovation.
Technology for Orbital Propellant Depots

One of the problems to be overcome with long-duration space exploration is the long-term storage of high-performance propellants—oxygen and hydrogen—at cryogenic temperatures. Heating from the sun in space can cause loss of propellant through "boiloff" of the cryogenic liquids if they are in space for only a matter of hours. Human missions using cryogenic propellants will need much longer duration storage—months or even years—particularly if using concepts such as propellant depots, which would be on-orbit gas stations that could be supplied by commercial or international launches. Such a robust infrastructure could add flexibility and enhance exploration options and capabilities to explore many destinations including near-Earth objects, Mars and beyond.

For NASA, the need for such technology is becoming critical with the advent of Constellation and planned future space travel. A proposed solution is to develop a space-based, deployable sun shielding device that would keep the cryogenics at a constant temperature and support extended...
cryogenic storage without boiloff. The significance of such an innovation is that not only would it extend cryogenic-based exploration, but it also would aid in the development of other space-related inflatable structures such as human shelters, antennas, solar power arrays and reentry shields.

Enter the NASA Innovative Partnerships Program (IPP) Seed Fund, which assists with funding and oversight development by partnering with industry to take a concept from the demonstration model to a full-scale test article. NASA Kennedy Space Center’s Technology Programs and Partnerships Branch used the seed fund to partner with United Launch Alliance (ULA) and ILC Dover Corporation. In doing so, it built upon these companies’ common interests and helped them with design, development, and testing and risk analysis of the sun shield, materials, components and assembly. Actual flight is still a few years off, but a test article will be ready for a full-scale flight test sometime in the near future.

The overall system design is a six-petal configuration, three-layer shade that has a roller assembly, vertical boom and columnator and sleeve. A 25-degree cone angle was selected for thermal performance. The fairing is jettisoned prior to the sun shield deployment. Extensive research was conducted in order to select the appropriate materials for the shield, and testing was done in extremely cold temperatures in different loading conditions and configurations.

Space-based, long-term cryogenic storage of large amounts of cryogenic fluids is an old concept but still in its infancy regarding technology maturity. Current capabilities for long-term storage of space-based cryogenics is limited to small amounts on payloads that typically use multi-layer materials for insulation and cryogenic refrigeration to extend use. These methods do not lend themselves to large-scale operations as they would be too heavy. Lower-weight shielding concepts to reduce heat gains from the sun passively, and active large-scale cooling systems are needed. Sun shields will be an important part of future systems.

NASA’s interest in sun shields dates back quite a long time, including looking at a shield for Sky Lab and for the Orbital Space Plane (OSP) Program. In order to increase the in-space longevity for the existing Atlas V and Delta IV second stages, NASA’s Launch Services Program conducted the Advanced Cryogenic Evolved Stage (ACES) project. The project was intended to reduce the long-term boiloff of cryogenic propellants. The results showed that extending storage of cryogenic propellants could be accomplished for periods of eight months passively and nearly an unlimited time thereafter with active cooling. One of the critical technologies recommended by the ACES project for further development was the deployable sun shield.

As a result of the ACES project, ULA and ILC Dover had already developed a full-scale proof-of-concept model; however, the companies needed help taking the concept from a Technology Readiness Level of 4 (TRL-4) to a full-scale test article with a TRL-6. The IPP Seed Fund has helped to further mature this important technology, and the next step will be flight testing.

Carol Anne Dunn is a project specialist in the Technology Projects and Programs Branch at Kennedy Space Center.

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Please mention that you read about it in Technology Innovation.
Water Production Services for the ISS

By Jason Crusan
NASA Headquarters

Marybeth Edeen
NASA Johnson Space Center

Kevin Grohs
Hamilton Sundstrand

As NASA nears the end of the Space Shuttle Program and the beginning of full science operations on the International Space Station (ISS), it prepares to test some of the most unique and complex space flight hardware. But NASA is conducting more than just science aboard the ISS. The Agency is using the ISS as an engineering testbed for hardware on orbit, and also is testing new acquisition models that could be used for future space programs.

While NASA’s missions are familiar to most Americans, the process by which key infrastructure is supplied to enable those missions is often less clear. Here is an example of an innovative new method used by NASA to acquire space flight services, rather than buying hardware.

New Way of Doing Business

For a crew of six to survive aboard the ISS, systems to recover water and produce oxygen had to be designed, developed and tested. This hardware was necessary to minimize use of cargo space for consumables, thus maximizing the space for science payloads and engineering experiments. However, this hardware development serves another purpose in that it provides a testbed for on-orbit assessment of key technologies that are needed to continue human exploration of the solar system.

Most of the regenerative environmental control and life support systems are now in place and operational aboard the ISS. They were developed by NASA’s Marshall Space Flight Center and Hamilton Sundstrand. However, one remaining system is required to close the loop in the oxygen and water regeneration cycle. Currently, the ISS systems remove carbon dioxide and create oxygen on orbit. These processes create by-products of carbon dioxide and hydrogen, which are simply vented overboard. But since all materials are precious once in orbit, a system that could use these by-products to generate additional water for ISS was desirable.

The Sabatier Reaction System, now under contract to be developed by Hamilton Sundstrand (www.hamiltonsundstrand.com) of Winsor Locks, Conn., has been planned for this function since the ISS was first designed. NASA and the general technical community have been conducting research on Sabatier systems for more than 20 years through various advanced development initiatives. NASA’s Space Operations Mission Directorate (SOMD), which manages the ISS, felt the need for procuring this system would be a good opportunity to test not only the technology, but also an innovative acquisition method for space flight services.

The technology was already well
understood, thanks to extensive, previously conducted development work. Also, all of the systems with which the Sabatier would be interfacing were already built, so all interfaces were well defined. This allowed SOMD to limit the technical, financial and schedule risk that is often associated with traditional acquisitions of systems. The approach is based on having the complete Design, Development, Test and Evaluation (DDT&E) of the Sabatier System conducted and financed by the contractor (in this case, Hamilton Sundstrand). In return, NASA pays for water production service on orbit and is not responsible for any payments to the contractor if the system fails due to Sabatier-related hardware and/or software issues. In effect, NASA pays for the availability of the water production service while the contractor is responsible for maintaining system operability for a given period of time.

Historically, this type of requirement would be procured using a cost reimbursable “hardware” type of procurement. In this case, however, a service contract was desirable for several reasons. It significantly limited NASA’s risk related to technology, cost and schedule, but it still enabled NASA to hold Hamilton Sundstrand accountable for the successful performance of the service requirements.

NASA has completed many service contracts, fixed-price contracts, and performance-based contracts in the past. The unique aspect of this procurement was the combination of all these principles into a single procurement.

Other unique aspects of the contract, to meet the needs of this innovative procurement approach, included the use of termination liability, funding obligations in a non-traditional manner, performance-based look-back provisions, and truly limiting NASA’s role to safety and interface requirements. This approach relies on the contractor's willingness to accept additional technical and financial risk. In return, the contractor has the potential to realize financial returns commensurate with its risk, provided that the service obligations of the contract are met (in this case, on-orbit water generation). It also reduces NASA’s overall program cost structure by limiting its oversight requirements to just the areas of critical importance, such as safety.

Through this innovative contracting approach, which directly ties the contractor’s financial returns to technical performance, NASA can be sure that its requirements for space flight are met.

Tailoring of Requirements
Since NASA was not procuring a traditional hardware system, the Agency defined the requirements that would enable Hamilton Sundstrand to meet...
the technical interfaces as well as NASA’s safety requirements. More than 70 percent of NASA’s standard flow-down requirements were removed from the specification. Verification of the remaining requirements was left as flexible as possible, and specific verification criteria were defined only where they were absolutely required. In many cases, certificates of compliance from Hamilton Sundstrand will be accepted as verification compliance. Items such as the failure mode and effects analysis (FMEA) and hazard analysis were retained, along with the requirements of the normal safety review panels. Another unique aspect of the contract is that NASA did not commit to a specific launch date, or even launch vehicle, for the hardware, and the Agency supplied launch loads that would meet several vehicle options. NASA left itself a six-month window from the final delivery to launch the hardware and to perform the on-orbit check out.

Hamilton Sundstrand is on track to meet the delivery date of October 31, 2009, for the Sabatier System and November 30, 2009, for the system’s process and motor controllers.

Performance-Based Payments
One of the more commonly used approaches in contracting is performance-based milestones and performance awards. This contract used this general concept but made the entire contract value performance based. However, Hamilton Sundstrand was given milestone-based payments throughout the contract’s period of performance. To ensure that Hamilton Sundstrand would still take on the majority of the risk, the milestone payments made before on-orbit activation of the system are subject to a 100-percent look-back penalty if the system does not operate when first activated on orbit. Since experience has shown that initial activation of a system on orbit is always challenging, there is a small grace period in the contract to allow Hamilton Sundstrand to work through any start-up issues. Specific protocols have been agreed upon between NASA and Hamilton Sundstrand governing the use of any resources that will be required for initial system operation, such as crew time.

The performance-based criteria do not stop after activation – there are performance criteria throughout the entire on-orbit life cycle. To simplify the criteria, a system was created for calculating the number of days during which the system is available for water production, versus the days during which the system is not available. The performance payment for any given year is a simple calculation that defines upfront the maximum payment and subtracts any down days as a direct percentage of the overall days in the year. Specific protocols also have been agreed upon, covering a series of contingency scenarios associated with addressing system inoperability issues, related to either NASA interfaces or the Hamilton Sundstrand Sabatier System.

All of this allows for a true service provider-based model that is much like ground-based services.

Lessons Learned
From the perspective of Hamilton Sundstrand, two factors were critical for success in establishing this innovative contracting approach. First, clear and open lines of communication between the respective organizations allowed both to understand the other’s goals and challenges more clearly. This understanding enabled more efficient collaboration toward the common goal and resulted in the negotiation of a mutually acceptable agreement that ultimately met all parties’ objectives. Second, an unwavering team commitment from both organizations made it possible to work through unexpected difficulties that arose as new contracting approaches were generated and ultimately implemented. Without this joint commitment toward realizing the common objective, any one of several significant obstacles had the potential to stop the project.

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Please mention that you read about it in Technology Innovation.
The 21st-Century Pony Express to the Moon

NASA Ames Research Center is providing technical data and engineering support to Odyssey Moon Ventures for the development of the MoonOne (M1) lunar lander.

A new partnership between NASA and Odyssey Moon Ventures is leveraging NASA research and development to help create a “pony express” delivery service to the moon. Just as the pony express helped expand this country’s exploration and settlement of the west, so too could this new spacecraft development offer a low-cost way of reaching the moon.

A Reversal of Roles

Recent commercial success stories, such as the winning of the Ansari X Prize in 2004 and the successful flight of SpaceX’s Falcon 1 launch vehicle in 2008, have emboldened a new generation of private space explorers. Odyssey Moon Ventures (OMV) LLC (www.odysseymoon.com), a U.S. company developing commercial systems for lunar exploration, is one such
company. OMV has partnered with NASA Ames Research Center for the development of a robotic lunar lander. This unique public-private partnership combines NASA expertise with an entrepreneurial company’s innovative approaches to commercial space systems, resulting in new industrial capabilities for the company and benefits to the American space program.

In many NASA spaceflight programs, NASA purchases technology from private industry. But in this agreement, the roles are reversed as OMV will be leveraging NASA technology to aid in the company’s commercial efforts. NASA will provide technical data and engineering support to OMV to aid the company’s efforts to develop its commercial MoonOne (M-1) small robotic lunar lander. M-1 is planned to have the capabilities of delivering both internal- and external-mounted payloads to the surface of the moon in support of science and commercial endeavors. NASA has been offering this technology to industry on a broad basis, and OMV is the first to seize this opportunity.

OMV is planning a series of robotic missions to the moon during the International Lunar Decade, which extends through 2019. The company already has signed on to two commercial organizations for the mission and has received proposals for payloads from customers worldwide.

The tremendous response from both the private sector and government agencies proves that a new value-added paradigm is possible with private sector involvement in space exploration.

This partnership between NASA and OMV, as well as NASA’s program for Commercial Orbital Transportation Services (COTS) are two examples of how the Agency is trying to reduce the costs for spaceflight through collaborations with private industry. (See article on pg. 34.)

“The prospect for commercial delivery of NASA science and exploration instruments to the moon is consistent with the precedents already set by the NASA COTS program supporting commercial supply for orbital operations,” remarks S. Pete Worden, director of Ames Research Center. “Extending commercial supplier concepts and relationships to advance NASA’s mandates for exploration and permanent operations on the moon is a logical next step.”

Jay Honeycutt, president of Odyssey Moon Ventures and a veteran space executive, says, “I am extremely pleased and excited to be working on getting us back to the moon in a sustainable way. I believe the private sector has an important role to play in a permanent and affordable lunar program. We look forward to working with NASA as both partners and customers in this effort.”

**Background**

NASA is developing small spacecraft capable of landing on the lunar surface to help advance space exploration capabilities. Small lunar landers can undertake critical precursor mapping, infrastructure and in-situ resource utilization missions prior to and coincident with human return to the moon.

Studies of small spacecraft missions have highlighted their value, pointing out their significantly lower cost, and rapid development and deployment schedules. As a result, a greater number of missions can be flown within a set budget and timeframe, as compared with programs involving larger spacecraft. Such attributes also have stimulated interest in the burgeoning commercial spacecraft industry, which NASA is helping to nurture.

Ames Research Center is leading NASA’s efforts to develop small, low-cost spacecraft. As part of that effort, the Ames’ Small Spacecraft Division designed the Common Spacecraft Bus (CSB) to serve as a vehicle to support a range of missions designed for small spacecraft. The CSB’s modular design provides a spectrum of capabilities that can be adapted to meet specific mission parameters. The system can be configured as an orbiter or as a lander using common off-the-shelf components arranged in modular segments. Both the lander and orbiter configurations share common propulsion, avionics and structural modules. As a lander, the CSB can be outfitted with legs. An additional module can be inserted into the spacecraft to give it extra payload capacity. The orbiter version can be outfitted with reaction wheels for sta-
bilizing the spacecraft when in orbit. The technology enables the development of lunar surface missions that cost less than $100 million, including the cost of the launch vehicle, and orbiting missions for a fraction of their current cost.

By making the CSB available and supporting its adoption by commercial firms, Ames will accelerate the further development of system variants, increase the number of components/sub-systems produced by suppliers, reduce costs in future missions and increase the availability of spares. NASA described the CSB technology at the Google Lunar X Prize Team Summit in May 2008 and announced its willingness to share the technology with any interested U.S. parties.

**Partnership**

To encourage the agreements, Ames released a term sheet in May 2008 that described how potential partners could learn more about the CSB technology and enter into a working relationship with Ames. Using the term sheet facilitated the development of an agreement between ARC and OMV by addressing many of the standard questions that arise during the initial phase of partnership development.

The partnership between NASA Ames and OMV was formalized though a Reimbursable Space Act Agreement (RSAA) October 30, 2008. Under the agreement, OMV will reimburse NASA for technical assistance provided by Ames’ Small Spacecraft Office regarding CSB plans and specifications. The company also will provide valuable feedback on the viability of the CSB for commercial applications.

The term sheet allowed NASA to offer the technology to all interested parties in an equitable manner. In the context of the Google Lunar X Prize, several of the competing teams have expressed interest in adopting the Ames design. The final agreement is also consistent with NASA’s goal to provide the CSB on a non-exclusive basis to U.S. commercial and private sector entities.

**Benefits**

While OMV will reimburse Ames for all technical assistance through the RSAA, the benefits of the partnership extend far beyond the monetary transaction.

Having an outside entity take the lead in developing the capability allows the design to mature faster than it would in a normal development process inside NASA. With industry playing a collaborative role in developing this lunar lander, NASA is able to shorten the development time and learn how private industry streamlines its engineering processes.

Ultimately, OMV might be in a position to provide NASA with a fast turnaround delivery service to the moon and other destinations, creating an entirely new niche in lunar science. Currently, it can cost hundreds of millions of dollars to send scientific experiments into space, taking many years to come to fruition. The success of OMV could make it possible to fly rapid-turnaround experiments for less than $10 million, leading to a great increase in the amount of science that could be conducted.

Taking this approach also allows NASA to focus less on infrastructure and more on its fundamental research and missions. At the same time, creative partnerships like this allow NASA to see its innovative breakthroughs pave the way to the future.

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*Sidney Sun is a project manager at NASA Ames Research Center, Christopher Bushnizen is a project engineer for Logyx LLC, Philip Davies is a business development consultant at Bay Area Economics, Robert Richards is CEO of Odyssey Moon Limited and Larry Barone is a research scientist with the Bay Area Environment Research Institute.*

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*Please mention that you read about it in Technology Innovation.*
NASA and the Air Force Research Laboratory (AFRL) are collaborating on a technology exchange forum that will support the growth and success of a U.S. commercial space transportation industry while bolstering respective agency goals. This jointly planned and conducted event is the Commercial and Government Responsive Space Access Technology Exchange (C/RASTE), to be held October 26-29, 2009, in Dayton, Ohio (www.usasymposium.com/raste/default.htm). Looking ahead to next year, the 2010 C/RASTE workshop will be held at NASA Ames Research Center.

Leading up to the creation of C/RASTE, NASA and AFRL have been involved independently in similar commercial space forums. NASA sponsored two successful commercial space transportation workshops, at Langley and Glenn research centers, for the purpose of encouraging partnerships among commercial space transportation firms, as well as between industry and NASA. AFRL independently supported General Dynamics Information Technology’s two successful Responsive Access to Space Technology Exchanges (RASTE), which were conducted to develop and encourage partnerships between commercial space transportation firms and to transfer AFRL-funded technology to industry.
Building on these experiences, the two agencies agreed on the new, common brand name – C/RASTE – for these workshops. The event will have the following objectives:

1. To provide an opportunity for the members of the commercial space industry to become familiar with NASA- and AFRL-relevant capabilities (such as rocket propulsion testing at Stennis Space Center) as well as technologies under development in currently funded programs,

2. To identify and develop approaches to expediently transfer available technologies to commercial space organizations where needed and aligned with the organization’s needs. This includes promoting technology interchange between commercial space access technology providers and the commercial space access community.

3. To explore and pursue, where appropriate, NASA/AFRL/commercial space industry partnerships to accelerate the technology development and transfer process, and

4. To provide opportunities for commercial space organizations to tap into the wealth of knowledge that NASA and AFRL possess relevant to technologies that are beneficial to the commercial space community.

NASA and the AFRL have discussed opportunities to expand the collaboration in support of commercial space transportation beyond the joint technology exchange events. In particular, opportunities may exist for joint funding of development and demonstrations of technologies and capabilities that are required to achieve the mission objectives of both NASA and AFRL. Also, both organizations have identified a potential need for a commercial space access technology roadmap that would provide the government with insight on the consensus technology needs of the emerging commercial space transportation industry. A commercial space access technology roadmap would supply both NASA and AFRL with additional information that might be useful when considering their individual technology investment portfolios. The knowledge that a particular technology might also be useful to industry could be incorporated by each agency into its respective technology investment decisions. Finally, this process may also identify opportunities for NASA and AFRL to combine resources on technology development for areas of common need and interest.

Bruce Thieman is the responsive space access capability lead at the Air Force Research Laboratory and chairman of the C/RASTE 2009 steering committee. He can be reached at bruce.thieman@wpafb.af.mil.

Robert “Joe” Shaw is chief of the Business Development and Partnership Office at NASA Glenn Research Center and the NASA representative on the C/RASTE steering committee. He can be reached at robert.j.shaw@nasa.gov.

Those interested in developing other joint NASA AFRL actions to support the emerging space transportation industry should contact Charles Miller, NASA senior advisor for commercial space, in the Innovative Partnerships Program (IPP) Office, at charles.miller@nasa.gov.

Please mention that you read about it in Technology Innovation.
S
ingle atoms of oxygen can pick a surface clean. That corrosive power can be harnessed for beneficial purposes, such as removing organic contaminants from a centuries-old oil painting. But it’s bad news for satellites.

Low-Earth atmosphere – the stratum where satellites orbit – is rife with atomic oxygen. To extend the useful life of satellites that are intended to remain in orbit for years, scientists and engineers must select exterior polymer surfaces composed of substances that resist highly reactive atomic oxygen.

Which materials work best? NASA and commercial aerospace companies have teamed up to answer that question quickly and cost effectively.

NASA’s Glenn Research Center has atomic oxygen exposure facilities to test and evaluate protective coatings in a simulated space environment, providing accurate information about how well the materials will hold up in space. In addition to their use for NASA, Glenn’s facilities are available to commercial companies, a collaboration that gives businesses and NASA researchers valuable knowledge and benefits society as well. For example, by testing mirror coatings for ITT Corporation optics, Glenn contributed to the success of the satellites in the NextView program.

Opening NASA Facilities to Businesses
ITT Corporation’s Space Systems Division was selected in 2003 to build the advanced imaging systems for WorldView-1 and, the following year, for GeoEye-1, both satellites in the NextView program, which is sponsored by the National Geospatial-Intelligence Agency (NGA). WorldView-2 will launch in fall 2009, while GeoEye-2 is expected to launch in 2012.

NextView aims to ensure the availability of high-resolution imagery from the next series of U.S. commercial satellites. NGA sponsors the construction and launch of these satellites to fill imagery and geospatial needs for military, intelligence, foreign policy, homeland security and civil users.

Utilizing Glenn’s testing facilities and the expertise of Glenn’s researchers over the past 11 years has strengthened ITT’s reputation for quality and reliability, according to Rob Mitrevski, vice president and director of commercial and space sciences for ITT’s Space Systems Division.

“Through this collaborative relationship, we can make great use of our technology and Glenn’s capabilities to assure that we have a very robust product,” Mitrevski says.

Glenn’s Unique Testing Facilities
In the early 1980s, Glenn’s Electro-Physics Branch (now called the Space Environment and Experiments Branch) constructed its first ground facility that employed atomic oxygen to test the durability of materials that would be used to build the International Space Station (ISS) and NASA satellites. Glenn researchers Bruce Banks and Sharon Miller were among the first to recognize the benefits of using protective coatings to prevent erosion of polymers to be used in low-Earth orbit and to develop ground-based facilities in which to test them.
Work that Banks and Miller patented on the protective coatings used on the solar arrays of the ISS have yielded significant savings for NASA — more than $15 billion by one estimate. Banks and Miller published more than 70 papers on that research and earned Glenn’s largest Space Act Award in recognition of the significant savings.

Glenn now has atomic oxygen testing simulators of varying sizes. The largest accommodates a 5x7-foot testing area, which offers unique capabilities in that it is considerably larger than commercially available testing facilities. This facility allows researchers to test an entire component instead of small samples of material, a particular advantage in equipment with complex parts that are difficult to disassemble. The testing apparatus, in a vacuum chamber, can expose components to atomic oxygen and can accommodate larger samples than commercial testing sites can handle.

“Our facility can simulate a full mission dose of atomic oxygen over a larger area and at lower cost than commercial sites,” Banks says.

In addition to being larger and having a high atomic oxygen exposure rate, Glenn’s facilities can operate around the clock. “That way, we can simulate more years of exposure in less time and at a reasonable expense,” Banks adds.

Putting the Power to Work
The WorldView and GeoEye satellites are designed to have a useful life of seven years. But ITT asked Glenn to test its materials with an atomic oxygen dose equivalent to 10 years’ exposure in space.

“Most of ITT’s demands for high doses of atomic oxygen exposure would be extremely expensive to perform in most commercial facilities,” Miller says. “Glenn has one of the few facilities in the country that could provide the dose they wanted. Exposure of materials in most commercial facilities would require shorter duration tests and extrapolation to predict durability in space.”

The data analysis that ITT requires is much more complex than the material’s longevity in a corrosive environment, according to Vincent Smoral, ITT’s manager of commercial remote sensing programs.

“We have Glenn look for certain parametric degradations that may be important to our mission performance,” Smoral says. “With reflective surfaces of mirrors, for instance, we want to make sure not only that the coatings don’t degrade but that their light reflectance properties, like scattering, don’t change.”

The work that Banks and Miller have done with atomic oxygen has been applied in a number of innovative ways. The technology has been used to restore damaged oil paintings by removing organic materials of soot and lipstick, and to identify alteration of hand-written documents. In the biomedical field, atomic oxygen can be used to improve adhesion of cultured bone cells, to remove contaminants from the surfaces of orthopedic implants and to create a device that provides a faster, cost-effective and less-painful method of testing blood glucose.

Forming Collaborations Quickly
In order to access Glenn’s atomic oxygen and other unique facilities, companies work with Glenn’s Technology Transfer and Partnerships Office (TTPO) to establish Space Act Agreements. In fact, the TTPO offers a singular service that businesses find appealing. For projects that cost no more than $50,000, Glenn uses a Simplified Space Act Agreement form that can be completed quickly and speeds the approval process.

“Customers want to get started quickly and get their data back soon,” Miller explains. “The TTPO has been very helpful in making sure the process happens fast and we’re kept aware of any issues.”

NASAs willingness to open its doors to commercial companies benefits business and society. “Having a national asset like Glenn allows us to make use of an existing capability and core competency that has been years in the making,” Mitrevski says. “The testing by Glenn helps us capture new business and retain the industrial base capability that we’ve demonstrated through our commercial remote sensing program.”

Laurel J. Stauber is lead technology commercialization specialist, and Cindy Dreibelhis is award liaison specialist in the Technology Transfer and Partnership Office at NASA’s Glenn Research Center; Nancy Oates is a writer from Fuentek LLC.

For additional information on this technology, as well as information on the variety of ways you can partner with GRC, please visit http://technology.grc.nasa.gov/ or e mail TTP@grc.nasa.gov or call (216) 433 3484.

Please mention that you read about it in Technology Innovation.
Commercial Space: Critical to NASA’s Future Success

By Charles E. Miller, NASA Headquarters

Now, perhaps more than ever, commercial space is vital to achieving NASA’s future goals. The United States is confronted with significant federal budget deficits. In the next few years, the pressure to reduce federal spending will increase as baby boomers start retiring in large numbers, and the costs of Medicare and Social Security continue to grow. NASA’s plans to send humans to the far frontier may not be affordable unless the Agency can hand off some of its existing responsibilities on the near frontier in Earth orbit to private industry. Doing so may allow NASA to focus its limited resources on the exciting and unique challenges of exploration beyond.
For this reason, NASA needs a healthy, growing and thriving U.S. commercial space sector. Charles Bolden, the new NASA Administrator, recognized the importance of innovation and the commercial sector during his confirmation hearing before the Senate. Both he and the new Deputy Administrator of NASA, Lori Garver, noted they understand “the necessity to involve commercial entities” in NASA’s efforts.

Bolden said the “government cannot fund everything that we need to do, but we can inspire and open the door for commercial entrepreneurial entities to become partners with NASA” in research and development that will enable advancement in space.

During the hearing, Bolden explained that he understands the vision of many entrepreneurs whose goal is making space travel accessible to the American people, noting: “I dream of a day when any American can launch into space and see the magnificence and grandeur of our home planet Earth as I have been blessed to do.” He also said the agency will utilize the International Space Station to “allow commercial entrepreneurial ventures to have a place where they can seek to carry cargo and one of these days maybe even carry crew.”

In this manner, Bolden made clear his understanding of the strategic opportunity for NASA to leverage the innovative capacity of the American commercial sector.

Encouraging and stimulating the commercial space sector can mean many things at NASA. It may mean consideration of commercial-style firm-fixed price arrangements to contract with private firms for goods and services. It could mean the Agency uses innovative means to partner with numerous commercial firms, leverage private sector investments, and achieve Agency and national goals. It could mean NASA will stimulate the emerging space transportation industry, just as the Agency’s predecessor – the National Advisory Council on Aeronautics – stimulated and supported the growth of the then-emerging aeronautics industry. It may mean NASA will play a larger role in catalyzing key technology demonstrations, as it did with the commercial communications satellite technology. It certainly means the Agency should work to understand the needs of the American commercial space industry.

As noted above, NASA is learning how to effectively hand off to private industry activities historically owned and operated by the government.

When it is in the strategic interests...
of the nation and NASA, and where private sector markets are failing to develop a new capability on their own, the NASA Space Act provides “other transactions authority” allowing NASA to “co-invest” with commercial entities. This can happen in a number of circumstances, such as the following:

- Where markets are potentially quite large, but are undeveloped, unproven and not effectively growing on their own,
- Where the barriers to entry are prohibitive, and
- Where the total package of business risks (technical, political, regulatory, customer demand, financial) are too high to justify large-scale private investment from traditional sources of capital.

For these reasons, NASA created the Commercial Orbital Transportation Services (COTS) program and the ISS Commercial Resupply Services (CRS) program to develop new space transportation capabilities focused on International Space Station (ISS) cargo delivery. (See articles on pages 34 and 38.) In addition, NASA will utilize funding from the 2009 American Recovery and Reinvestment Act to fund firms to demonstrate orbital commercial crew service technologies.

NASA’s Current Commercial Space Projects

The articles in this issue of Technology Innovation offer many examples of how NASA is learning to leverage private investments and to take advantage of commercial efficiencies. You can read about how:

- The ISS recently signed $3 billion would-be inventors will benefit from his advice on innovation.
- The $500 million COTS program is utilizing NASA’s original “other transactions authority” to fund Space Act Agreements with private industry to develop new capabilities.
- The ISS program arranged to buy commercial water delivery services in orbit. Ask yourself, “If NASA can buy a commercial water service at the ISS, what else can NASA do on a commercial basis?”
- NASA is looking at expanding the commercial model to buying commercial communication and navigation services for the moon. The Agency is even looking at stimulating development of commercial lunar rovers, landers and oxygen production.
- Two private commercial ventures, SpaceX and Odyssey Moon, in a reversal of roles, are acting as customers for unique NASA technical services.

In conclusion, NASA has been making great strides in learning how to partner with the commercial space industry for the benefit of the nation. We now have the policy direction and the leadership we need to use that knowledge to catalyze innovation, create new industries and help open the space frontier for the American taxpayer. ■

Charles E. Miller is the Senior Advisor for Commercial Space in NASA’s Innovative Partnerships Program.

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The following is a summary of some of the existing legal and policy guidance given to NASA on the issue of commercial space.

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<td>“shall ... seek and encourage, to the maximum extent possible, the fullest commercial use of space.”</td>
<td>“Use U.S. commercial space capabilities and services to the maximum practical extent; purchase commercial capabilities and services when they are available in the commercial marketplace and meet United States Government requirements...”</td>
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<td>To the maximum extent practicable, the Federal Government shall plan missions to accommodate the space transportation services capabilities of United States commercial providers;” that “a priority goal of constructing the International Space Station is the economic development of Earth orbital space;” and that “competitive markets... should therefore govern the economic development of Earth orbital space.”</td>
<td>“In carrying out the programs of the Administration, the Administrator shall ... work closely with the private sector, including by ... encouraging the work of entrepreneurs who are seeking to develop new means to send satellites, crew, or cargo to outer space.”</td>
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<td>“To exploit space to the fullest extent ... requires a fundamental transformation in U.S. space transportation capabilities,” and “the United States Government must capitalize on the entrepreneurial spirit of the U.S. private sector,” and “dramatic improvements in the reliability, responsiveness, and cost of space transportation would have a profound impact on the ability to protect the Nation, explore the solar system, improve lives, and provide for commercial purposes.”</td>
<td>“In order to stimulate commercial use of space, help maximize the utility and productivity of the International Space Station, and enable a commercial means of providing crew transfer and crew rescue services for the International Space Station, NASA shall make use of United States commercially provided International Space Station crew transfer and crew rescue services to the maximum extent practicable.”</td>
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SpaceX completes all milestones for COTS Phase 1 and delivers Falcon 9 to KSC

Orbital Sciences completes Cargo Module PDR

ESMD and IPP

Seed Fund support includes lunar drilling robotics and oxygen from simulated lunar regolith

Commercial water production services contract for ISS signed with Hamilton Sundstrand that will be using a Sabatier based reactor system

Contract with Zero G for aircraft parabolic flight services

Earth science activities involving commercial remote sensing

NASA Lunar Science Institute established, including commercial ISRU initiatives

Spin off of advanced optics and detectors to industry

Research on broad spectrum of fundamental technologies (e.g. materials, computation fluid dynamics, vehicle health maintenance) with possible applicability to commercial space

Research on technologies relevant to launch and return of reusable spacecraft

SBIR and STTR efforts including docking sensors, power systems, avionics and others

IPP works with NASA Mission Directorates on Seed Fund projects for ISS research, lunar tires, cryogenic fluid management, Li Ion Batteries and others

Peter Homer wins $200K Astronaut Glove Challenge

IPP Seed Fund support of lunar habitat development including inflatable technologies

Armadillo Aerospace wins $350,000 Level 1 prize of Lunar Lander Challenge

FAST sponsors technology development for several SBIR companies in a simulated space environment on parabolic aircraft flights

KSC commercial launch site, and SpaceX Falcon 9 at KSC; work on launch pad at Complex 40

Key to Abbreviations: ATM Air Traffic Control  ARMD Aeronautics Research Mission Directorate  COTS Commercial Orbital Transportation Services  DOD Department of Defense  ESMD Exploration Systems Mission Directorate  EVA Extra Vehicular Activity  FAA Federal Aviation Administration  FAST Facilitated Access to the Space Environment for Technology Development and Training  IPP Innovative Partnerships Program  ISS International Space Station  LEO Low Earth Orbit  MOU Memorandum of Understanding  NEO Near Earth Object
Current and Planned Near Term Activities

- New commercial initiatives include Low Impact Docking System and development of lunar surface systems
- Studying feasibility of using suborbital missions for microgravity research including life & physical sciences & technology development
- Stimulate commercial human spaceflight capabilities
- ISS serving as engineering testbed for future commercial communication technologies, including recent testing of Delay Tolerant Networking (DTN) to enable ISS to serve as an internet node for cloud computing on orbit
- Currently testing sub systems demonstrations for solar electric power conversion that have ground based and space based applications

Future Activities

- Applying the COTS model to new areas consistent with ESMD commercial space policy
- Lunar, Mars, NEOs/Asteroid, and other exploration with commercial space partnering
- Space tourism complementing exploration
- Space resource commercialization, such as ISRU and/or space solar power for lunar applications
- Commercial LEO and lunar habitats complementing NASA missions
- On orbit satellite servicing, space debris management, on orbit fuel depots and other commercial space operations services
- Remote sensing instruments as secondary payloads on commercial systems
- Partnerships on instruments and technology development, or small science investigations
- Enabling commercial space weather information products such as warning to communications systems operators
- Further development of technologies to facilitate reusable access to space
- Research for point to point suborbital flight including commercial global flight projects such as DOD Small Unit Space Transport Insertion (SUSTAIN)
- IPP programs supporting commercial LEO and lunar resource utilization such as lunar regolith programs, space solar power for lunar operations, micro gravity and others; Earth viewing/global monitoring initiatives
- Commercial space partnerships with U.S. and/or international entrepreneurs, including work complementing Spaceport America in New Mexico

Lunar Habitat Concept

Solar Power Concept

Evaluation of re entry technologies, including those that support reusable applications

- Centennial Challenges prizes advancing innovation and technology needed for commercial space
- IPP Seed Funding work with NASA Mission Directorate involving universities, private sector and other agencies, and SBIR/STTR efforts related to commercial space

FAST will use commercial suborbital services as they become available

Development of Wallops Flight Facility Mid Atlantic Regional Spaceport (MARS) for commercial launch such as COTS Orbital Sciences Taurus II

Commercial space partnerships with U.S. and/or international entrepreneurs, including work complementing Spaceport America in New Mexico

Virgin Galactic’s SpaceShip2

XCOR Aerospace’s Lynx
Commercial Orbital Transportation Services Program Blazes New Trails for NASA

By Valin Thorn
NASA Commercial Crew & Cargo Program

Howard Runge
Orbital Sciences

Max Vozoff
SpaceX

From Lewis and Clark to the commercial aviation industry, government has often provided the initial impetus for the exploration and development of new frontiers, followed by rapid commercial development and expansion once the trail is blazed. NASA’s new Commercial Orbital Transportation Services program (COTS) continues that tradition (www.nasa.gov/offices/c3po/home/index.html).

COTS will enable the creation of new, cost effective commercial space transportation systems and demonstrate capabilities to provide these services to orbit for cargo and eventually crew.
Through COTS, NASA is creating partnerships with American industry and taking essential steps toward more routine access to space that will transform our world.

While NASA forges paths to the moon, Mars and beyond in the Constellation program, COTS will allow commercial partners to deliver cargo and crew to already-established destinations.

“Once those trails are blazed and the path is made, then it is natural that you turn that over to industry, who can operate those services in what should be a more efficient manner, and a profitable manner,” says Alan Lindenmoyer, program manager of NASA’s Commercial Crew and Cargo Program (C3PO), which manages COTS.

COTS was developed to overcome the cost barrier that currently limits space transportation, and to serve as a catalyst for new ideas, new technologies and a new way of doing business by engaging the innovation, imagination and drive of American industry.

Once COTS partners have made sufficient progress developing cargo transport capabilities and funding is approved, the C3PO will initiate the COTS Crew Transportation phase of the program.

**Implementing COTS**

With a “walk before running” incremental strategy, the initial focus of COTS is on helping the private sector develop and demonstrate space cargo transportation capabilities.

NASA is using Space Act Agreements to help fuel the private sector’s imagination and drive with technical support from NASA’s nearly 50 years of human spaceflight.

After industry competitions for the highest level of NASA assistance, C3PO granted up to $500 million over four years to two companies – Orbital Sciences (www.orbital.com) and Space Exploration Technologies, or SpaceX (www.spacex.com).

In a separate industry competition, the International Space Station Commercial Resupply Services market was offered to the private sector with potential revenue in the hundreds of millions of dollars each year. (See article on page 38.)

“This was set out from the beginning not to be a traditional research and development cost contract. This was going to be a partnership – we’re sharing the cost; we’re sharing the risk,” Lindenmoyer says.

For COTS, NASA did not dictate design solutions. Rather, overall performance objectives were established with the needs of the International Space Station (ISS) serving as a representative orbital destination. The COTS partners have maximum latitude to freely innovate and optimize their launch vehicles and spacecraft designs and operations.

“We had the need, we had some seed money, we had the interest and we had the technical expertise,” Lindenmoyer says. “And you put that all together with some very capable suppliers and providers, then we had the basis for what could be a very successful program.”

**Orbital**

Just about 100 miles up the coast from where the Wright brothers first flew their airplane at Kitty Hawk, Orbital Sciences is planning to launch its COTS system at the Mid Atlantic Regional Spaceport, or MARS, at NASA’s Wallops Flight Facility in Virginia. Wallops is part of NASA Goddard Space Flight Center.

Orbital Sciences was founded in 1982 with the goal of making space technology more affordable, accessible and useful to millions of people on Earth. The company has grown to become the world’s leading developer and manufacturer of smaller, more affordable space and rocket systems. Orbital pioneered new classes of launch vehicles, satellites and other space technologies.

Orbital’s COTS program involves full-scale development and flight demonstration of a commercial cargo delivery system. It consists of the following elements:

- **Taurus II**, a new medium-class launch vehicle,
- **Cygnus**, an advanced maneuvering spacecraft capable of carrying up to 2,700 kg of cargo to the ISS, and
- Ground systems for ISS cargo integration, launch and spacecraft on-orbit operations.
Taurus II

Designed to provide responsive, low-cost and reliable access to space, Taurus II is a two-stage rocket (with optional third stage) capable of launching up to 7,600 kg into low-Earth orbit. Internally funded by Orbital, Taurus II is under development, with its first mission slated to demonstrate commercial re-supply capability of the ISS under the COTS program. The Taurus II launch system utilizes management approaches, engineering standards, production and test processes common to Orbital’s family of highly successful small-class launch vehicles, along with hardware from one of the world’s leading launch vehicle integrators. Taurus II is designed to achieve a 98 percent or greater launch reliability.

Cygnus

Orbital’s Cygnus advanced maneuvering spacecraft is a low-risk design incorporating elements drawn from Orbital and its partners’ existing, flight-proven spacecraft technologies. Cygnus consists of a common service module and a pressurized cargo module. The service module incorporates avionics systems from Orbital’s Dawn interplanetary spacecraft, plus propulsion and power system from Orbital’s flight-proven STAR GEO communications satellites. The pressurized cargo module is based on the Multi-Purpose Logistics Module, developed by Thales Alenia Space for NASA. The module will carry crew supplies, spare parts and scientific experiments. The Cygnus spacecraft will be capable of delivering up to 2,700 kg of cargo to the ISS and disposing up to 2,700 kg of cargo during entry.

A demonstration flight of Orbital’s COTS system is scheduled for early 2011.

SpaceX

At Florida’s Cape Canaveral, within sight of the launch pads where every NASA human spacelift mission has originated, SpaceX is planning to launch its COTS system.

Established in 2002 by Elon Musk, the founder of PayPal and the Zip2 Corporation, SpaceX is well into the development of two new launch vehicles and has already established an extensive launch manifest. By keeping the vast majority of manufacturing in house, SpaceX reduces costs, keeps tighter control of quality and ensures a tight feedback loop between the design and manufacturing teams.

The system that SpaceX has developed under NASA’s COTS project offers a simple, elegant solution for cargo delivery services to the ISS and the return of cargo to Earth. Like all of SpaceX’s developments, this design is driven by two fundamental requirements — high reliability and low cost. The SpaceX COTS system consists of the following three main elements: the Falcon 9 launch vehicle; the Dragon spacecraft; and the ground segment, including the launch pad, control centers and ground support systems. All three segments are designed, fabricated and tested almost exclusively in-house at SpaceX.

Falcon 9

The Falcon 9 launch vehicle is designed to deliver Evolved Expendable Launch Vehicle (EELV) class launch capability with significant improvements in reliability, responsiveness and cost over existing vehicles. Its design philosophy emphasizes architectural simplicity and resulting minimization of failure modes. Falcon 9 is a two-stage vehicle powered by liquid oxygen and rocket-grade
The Dragon spacecraft is fully autonomous and capable of delivering more than 3,300 kg of pressurized and unpressurized cargo to the ISS, and returning 2,500 kg of pressurized cargo back to Earth. It is composed of two main elements — the capsule for pressurized cargo; and the unpressurized section, or “trunk.” The capsule is fully recoverable and performs all the functions of a “service module,” with a passive common berthing mechanism on top for berthing with ISS. The 15 m³ of pressurized volume contains a modular cargo rack system designed to accommodate pressurized cargo in various form factors. The trunk houses unpressurized cargo on flight-releasable grapple fixtures that the ISS robotic arm can access once Dragon is berthed to station. The trunk is jettisoned after Dragon performs the de-orbit burn.

Although initially targeted to meet NASA’s ISS cargo logistics needs, Dragon is designed to meet NASA’s “Human Rating” requirements with only minor upgrades to allow transport of crew to and from ISS. SpaceX also offers Dragon as a commercial free-flyer for microgravity research, with mission durations up to two years. “DragonLab” will debut in late 2010 with a broad manifest of science and engineering payloads from both government and commercial customers.

As with the Falcon 9, the vast majority of Dragon subsystems were designed, manufactured and qualified in house by SpaceX.

SpaceX’s COTS cargo transportation demonstration flights will begin in 2009 and conclude with a third demonstration to the ISS in 2010.

The era is coming in which people can travel to space in much the way they now travel by airplane or ocean liner. To achieve this, space transportation has to become much more routine, much cheaper and much more reliable. The COTS program’s definitive goal is to help U.S. companies make this a reality.

Valin Thorn is deputy program manager, NASA Commercial Crew & Cargo Program (C3PO); Howard Range is COTS/CRS mission systems engineer, Orbital Sciences; and Max Vozoff is senior mission manager and Dragon product manager, SpaceX.

For more information contact Valin Thorn at valin.b.thorn@nasa.gov.

Please mention that you read about it in Technology Innovation.
Commercial Resupply Services Contracts to Benefit Space Station

By William H. Gerstenmaier
NASA Space Operations Mission Directorate

Kathryn L. Lueders
NASA Johnson Space Center, ISS Program Office

Steven A. Mirmina
NASA Office of the General Counsel

NASA’s procurement of Commercial Resupply Services (CRS) is important to the Agency, vital to the success of the International Space Station (ISS), and unlike any other procurement undertaken in NASA history. During the procurement process, NASA used myriad ways to encourage industrial participation through contract strategy, creation of a competitive environment, use of an innovative approach to intellectual property, and other features such as payment milestones, a guaranteed minimum on the contract, and a creative on-ramp clause that would allow additional providers the opportunity to develop capabilities and participate in future ISS commercial resupply opportunities.
Background
On January 14, 2004, then-President Bush set a new course for the U.S. space program and gave NASA “a new focus and vision for future exploration.” One element of this U.S. Space Exploration Policy was the direction to NASA to “pursue commercial opportunities for providing transportation and other services supporting the International Space Station and exploration missions beyond low Earth orbit.”

Since that time, the U.S. Space Transportation Policy of 2004 and National Space Policy of 2006 both strongly support commercial activities. The 2006 policy says that U.S. government departments and agencies shall: “Use U.S. commercial space capabilities and services to the maximum practical extent; [and] purchase commercial capabilities and services when they are available in the commercial marketplace and meet United States Government requirements…”

Additionally, the NASA Authorization Act of 2005 (P.L. 109-55) states that: “In carrying out the programs of the Administration, the Administrator shall … work closely with the private sector, including by … encouraging the work of entrepreneurs who are seeking to develop new means to send satellites, crew, or cargo to outer space.”

In that light, NASA created the Commercial Orbital Transportation Services (COTS) Program, discussed in this issue on page 34, and this eventually led to the development and execution of the CRS procurement, discussed here.

What is the CRS?
The purpose of the CRS procurement is to provide critical cargo resupply services to the ISS from the end of the Space Shuttle Program (2010) to the end of the ISS Program (currently 2015, although discussions and studies are underway to examine the possibility of extending the life of the ISS). The critical supplies comprise air, water, food, clothing, medicine, spare parts and scientific experiments — all to support a six-person crew on the ISS. While NASA is continuing to procure crew transportation and rescue services from Russia, the Agency plans to discontinue the purchase of Russian Progress cargo resupply services, upon conclusion of the existing contract, at the end of calendar year 2011. NASA’s European partners, with the Automated Transfer Vehicle (ATV), and NASA’s Japanese partners, with the H-II Transfer Vehicle (HTV), will provide some cargo upmass as part of their contributions to the ISS Program, but these spacecraft alone would still be unable to provide for all of the station’s needs, particularly with a six-person permanent crew and three major science laboratories on board.

Why is CRS important to NASA?
NASA is responsible for providing cargo services to the ISS pursuant to international agreement. While the U.S. Space Exploration Policy mandated the retirement of the space shuttle in 2010, it did not relieve NASA from the obligation for ISS cargo services. To date, the ISS partner nations have invested tens of billions of dollars and over 15 years of effort. On-orbit today are more than 610,000 pounds of structure stretching 308 feet in width and 243 feet in length, and containing more than 10,600 cubic feet of habitable volume.

To support the research in and standard maintenance of these new research facilities, the full-time crew of the ISS increased from three to six in May 2009 when the ISS reached full operability. This increased crew size is critical to the continuing performance of research and maintenance in these new international research facilities. If NASA cannot provide cargo transportation, the U.S. cannot meet its obligation to its international partners to support and use the ISS for science, technology and research.

NASA timed the CRS procurement to take into account the production cycle for resupply spacecraft (approximately 24–27 months), since NASA needs these CRS services to be available in December 2010. New space vehicle production is a high-risk enterprise with a high probability of delay. Once the space shuttle retires, there are currently no other alternative sources that could meet NASA’s requirement to resupply the ISS.
The Procurement Strategy

The planning for the CRS procurement began in March 2007 and resulted in the release of a Request for Proposal (RFP) in April 2008. NASA engaged industry in many ways through the strategy development and used its input in designing an RFP that met both NASA’s and industry’s needs.

Allowing competition and maintaining a contract format that is as commercial as possible were key input themes from industry. NASA took those inputs and developed an RFP structured for a “FAR Part 12” fixed price IDIQ services contract. FAR stands for the Federal Acquisition Regulation (FAR), which is the regulation governing how the government buys goods or services. FAR Part 12 governs how the government buys commercial items from the marketplace. U.S. law (the Commercial Space Act, 42 U.S.C. Section 14701(5)) specifies that the government must buy space transportation services as a “commercial item” for purposes of applicable acquisition laws and regulations. An “IDIQ” contract refers to a contract for indefinite delivery and indefinite quantity – NASA determined that an IDIQ contract was appropriate for this procurement,
because NASA could not predetermine the precise quantity of services it will require during the contract period, above a certain minimum.

The “FAR Part 12” fixed price IDIQ services contract was a very different contract vehicle than that typically used, and it enabled both mature and emerging space transportation providers to propose to provide new capabilities.

Other features that NASA added in response to both industry inputs and NASA needs were: a) flexibility to propose the financing milestones, b) increasing the standard minimum contract award to 20 metric tons, c) awarding task orders through 2015, d) adding a limited on-ramp clause, and e) allowing contractors to retain all intellectual property developed under the contract, with NASA retaining only a government purpose license in any inventions made and data produced under the contract.

All of these changes were made to make the CRS procurement attractive to industry and to expand the potential market for commercial space transportation.

Award of the Contracts

The central goal of the CRS procurement was to buy safe and reliable cargo resupply to the ISS. Currently, no commercial U.S. vehicle has demonstrated the ability to deliver resupply services to the ISS. Therefore, it was key to NASA to award contracts to more than one company. Having multiple providers mitigates the risk of NASA being dependent on a single provider in this emerging and currently unproven market. In addition, having multiple awardees permits continued competition and a method of dissimilar redundancy throughout the contract performance. Moreover, competition between the two providers was critical, so that a single competitor would not become complacent and therefore less reliable or timely. In other words, should one contractor be unsuccessful, the fate of the ISS program would not be as severely impacted.

Three proposals were received by NASA on June 30, 2008: from Orbital Sciences Corporation (Orbital); PlanetSpace, Incorporated (PlanetSpace); and Space Exploration Technologies (SpaceX). NASA ordered eight flights valued at $1.88 billion from Orbital and 12 valued at $1.59 billion from SpaceX. The maximum potential value of each contract is $3.1 billion. Based on known requirements, the value of both contracts is projected at $3.5 billion total. Each contract calls for the delivery of a minimum of 20 metric tons of unpressurized or pressurized cargo to the ISS, as well as the return or disposal of cargo from the orbiting complex.

On January 13, 2009, PlanetSpace protested the award of the two contracts, but on April 22, 2009, the United States Government Accountability Office (GAO) issued its decision denying the protest in its entirety. The denial of the protest clears the way for NASA to move out unobstructed in its continued efforts to find prudent ways to commercialize outer space.

Looking to the Future

The ISS represents a new market in low-Earth orbit, and NASA’s CRS contracts represent the first steps in creating a commercial market to resupply the ISS, beginning initially with critical cargo and leading, perhaps one day in the future, to commercial crew transport. Additionally, the new vehicles being created by Orbital and SpaceX under NASA’s innovative CRS program may one day also serve additional markets, apart from the ISS, such as through the provision of frequent, low-cost access to space for NASA’s scientific missions. If these vehicles are ultimately successful, they will serve to improve both the cost and reliability of spacecraft transportation.


For more information, please contact Steven Mirmina at steve.mirmina@nasa.gov.

Please mention that you read about it in Technology Innovation.
Innovations in Reusable Rocket Engines: Competition and Collaboration

By Phil Eaton
Armadillo Aerospace

Jacob Collins
NASA Johnson Space Center

Eric Hurlbert
NASA Johnson Space Center

2008 was an eventful year for Armadillo Aerospace. First, the company applied its rapid prototyping ability to win the $350,000 prize for Level 1 NASA Lunar Lander Challenge (LLC). Then the same innovative mindset that helped win the Challenge was applied again in serving the needs of two new customers—the Rocket Racing League and the Propulsion Systems Branch at the NASA Johnson Space Center (JSC).
Based in Caddo Mills, Tex., Armadillo operates with a core strategy that gives the company its competitive advantage – rapid prototyping, the building and testing of hardware used to accelerate the learning curve based on empirical data. Armadillo’s in-house computer numerical controlled (CNC) machining capability allows it to try new injector designs as often as twice per week, with modifications to the design implemented and manufactured in less than three days. Designs are turned into hardware and tested faster than drawings can be produced for the parts that are manufactured.

This ability to quickly go from prototyping to building and testing is a key to what makes the Armadillo approach effective. Throughout the year, with only three full-time and five part-time employees, the team kept on pace developing a propulsion module that would be robust and reliable for use on an aircraft for rocket racing purposes. More than 20 different injectors were tested and fine-tuned for the Armadillo liquid oxygen (LOX)/alcohol engine alone, which would power the company’s LLC vehicles. Concurrently, the team began developing the LOX/methane engine for its project with NASA.

Armadillo’s approach is somewhat counterintuitive — first, the team quickly designs and tests an engine, and only when it is working properly will the design be committed to a drawing. For this reason, the design process is not burdened with documentation revisions. Instead, the test data hold the revised information. Drawings and documentation revisions begin once an engine is performing as expected. This is completely at odds with the current approach seen in the aerospace industry.

In traditional aerospace development programs, a large amount of design and analysis is performed, and then drawings are made. Only then is hardware fabricated and committed to test. This approach drives up the time and cost to test and it creates a negative feedback loop by adding the incentive to conduct more analysis before performing further testing. The cost of testing increases and reduces the number of tests conducted.

Lunar Lander Challenge

Armadillo Aerospace’s involvement in the NASA Lunar Lander Challenge (LLC) began in April 2006. During the Space Access Society conference, John Carmack of id Software, the sole source of funding for Armadillo Aerospace and one of the company’s original co-founders, was inspired with an idea for a new style of vehicle that he thought might have the ability to accomplish both the Level 1 and Level 2 challenges – a quad-style vehicle, which utilizes a readily available ship-building material, aluminum alloy 5083, spun into 36-inch hemispheres.

The Armadillo team immediately began construction of the quad-style vehicles. James Bauer, the Armadillo team master welder, developed a process to weld hemispheres of 5083 aluminum into the tanks, and they proof-tested near the theoretical strength of the material. The first of two vehicles was completed by June 2006, only two months after the original design was sketched.

However, Armadillo’s attempts at the Level 1 prize were unsuccessful in 2006 and again in 2007. Even though the team had already demonstrated the full Level 1 LLC profile early in 2007, many challenges arose regarding regulations and flight conditions, and those challenges were not revealed until the time of the competition. In spite of this, the team continued to apply the practical data that it had accumulated and created a much more robust
modular vertical takeoff vertical landing (VTVL) design.

The team continued refinements of its engine technology through 2008 and developed a lighter-weight, more robust design utilizing an all-welded stainless steel construction. The engine also was used on a new project for the Rocket Racing League as the team installed and performed several test flights of one of the league’s prototype aircraft.

The 2008 LLC event was not without its own challenges. Due to regulatory issues, the team was unable to conduct its usual tethered vehicle testing. Permission to fly was obtained 10 days before the event, and the team rapidly took the vehicles through a series of tests. A few issues remained when the deadline came, but the team decided to continue with the flight attempts. Working through complications with flight windows and a last-minute requirement to reduce tank pressures, Armadillo won the Level 1 LLC in Las Cruces, N.M., and a prize of $350,000.

Following on its demonstrated VTVL vehicle successes in 2006, 2007 and 2008, Armadillo forged a collaborative relationship with NASA through the Agency’s Innovative Partnerships Program (IPP). The partnership involved Armadillo working with the Propulsion Systems Branch in the Energy Systems Division at JSC, the Spacecraft Propulsion Systems Branch at the Marshall Space Flight Center, and the Propulsion and Cryogenics Advanced Development Project at the Glenn Research Center to convert the company’s lander vehicle to use liquid methane rather than alcohol as the fuel.

With NASA’s renewed interest in returning to the moon, the Agency is investigating new technologies that may yield a more efficient and sustainable transportation system than the one created 40 years ago. A LOX/methane propulsion system is of interest to NASA as a technology that could meet that need.

Liquid methane represents one of the most abundant sources of green energy on Earth. It can be manufactured on the surface of Mars, allowing an exploration vehicle arriving on that planet to refuel for the return journey by refining methane from the martian atmosphere. In addition, LOX can be processed from both the martian and lunar environments. As compared with traditional fuels, both LOX and methane offer several other advantages for human spacecraft, such as space storability, fluid commonality with life support and power systems, reduced power consumption compared to Earth-storable propellants, lower toxicity and higher density.

Initial tests indicated that the conversion would not be difficult, but as testing progressed, the team discovered that the liquid methane injector had to
Both NASA and Armadillo know their business very well and are eager to share their technical knowledge and resources to achieve mutual success.

safe operation, and flight data had been collected, the engine was sent to nTech Inc. for a specially formulated high-temperature coating that would reduce the amount of heat transferred into the chamber walls.

Armadillo Aerospace gained valuable data by running its engine design in the altitude test chamber at the NASA White Sands Test Facility (WSTF) in New Mexico. The cooperative work was beneficial for NASA as well. Jennifer Allred, a NASA engineer at WSTF, offered these observations:

“The WSTF engineers were able to watch Armadillo’s test team in action, as the group of five took an engine design from concept to testable hardware in two days. Their secret – a skilled, cohesive workforce, simply manufactured parts and a strong drive to meet their goals every day. Within the two-day visit, the Armadillo team successfully completed multiple design iterations and performed hot-fire testing of their final concept.

“This partnership is a great demonstration of how two organizations that generally function in very different manners are able to approach a common goal. Both NASA and Armadillo know their business very well and are eager to share their technical knowledge and resources to achieve mutual success. The NASA Test Team has certainly benefited from the alliance and I think the same can be said for Armadillo.”

Several technology firsts were accomplished during the IPP partnership, including these:

• The first hot-fire test of a dual-bell nozzle at altitude while simulating an ascent profile, which allows the engine to run over-expanded at sea level up to full expansion at altitude,
• The first LOX/methane pyrotechnic ignition at altitude, and
• The first self-pressurized throttling LOX/methane lander.

Due to rapid prototype flexibility, Armadillo also successfully integrated and tested the J2X pyrotechnic ignition module at no additional cost to NASA. The J2X engine is a derivative of the Apollo-era J2 engine that is intended for use in the Ares launch vehicles. The igniter was tested successfully for the first time during a static test at Armadillo Aerospace’s facility. Less than two hours later, the engine assembly was removed from the test stand and installed on one of the modules. It was flown successfully on a tethered vehicle using the same pyrotechnic module. Cycle times of 15 minutes can be attained between flights lasting up to 200 seconds.

During the methane engine testing process, Armadillo Aerospace developed its first prototype of a LOX/methane coaxial swirl injector, which has a significant increase in performance over the like-impinging design. It is being tested in a self-pressurized configuration without the need for any pressurizing gases such as helium. The vehicle has been flown successfully with this injector and it can be used to power Armadillo upper stage modules in the future.

Phil Eaton is a founding member of Armadillo Aerospace. Jacob Collins and Eric Hurlbert are aerospace engineers at NASA Johnson Space Center.

For information on the NASA Armadillo collaboration on LOX/methane propulsion, contact Jacob Collins at jacob.collins1@nasa.gov. For information on rapid rocket engine prototype testing, contact Phil Eaton at (214) 585 9953, or visit www.armadilloaerospace.com. For information on the N1008 coating that was applied to the engine, contact David Burton at (336) 447 2000, or visit www.ncoat.com. For information on the Lunar Lander Challenge and other NASA prizes, contact Andrew Petro at NASA Headquarters, andrew.j.petro@nasa.gov, or visit http://www.ip.nasa.gov/cc/.

Please mention that you read about it in Technology Innovation.
After winning the NASA Astronaut Glove Challenge in 2007, Peter Homer founded Flagsuit LLC and developed modified versions of the glove, such as this one.
extended wear, and can be reused many times, the notion of owning a personal space suit becomes increasingly attractive. Until now, such a suit was more science fiction than reality. My goal is to change that.

Several years ago, NASA created a series of Centennial Challenges (www.ipp.nasa.gov/cc), reaching out to non-traditional sources of innovation for new ideas to solve some tough, lingering problems. This contest is part of a rich history of prize competitions sparking the development of new industries. Charles Lindberg’s crossing of the Atlantic Ocean to win the Orteig Prize became a tipping point in the shift of air travel from novelty to transportation industry. More recently, the Ansari X Prize, offered to the first non-government organization to succeed in launching a reusable manned spacecraft into space twice within two weeks, has begun a transformation of space travel.

Underlying each of these contests is a philosophy that, by offering a significant cash prize for solving a challenge, incentive is created that spurs private investment by multiple competing teams. Historically, the dollar value of combined investment by all competitors exceeds the prize amount at least sevenfold. NASA potentially benefits from the generation of novel ideas, even when no prize money is awarded. If a challenge is met, NASA’s out-of-pocket cost is still well below that of more traditional research-and-development activities.

A few years ago, one Centennial Challenge caught my eye as both an interesting technical challenge and something that could be pursued within the confines of my small “garage” workspace. I entered the Astronaut Glove Challenge and in 2007 became the first recipient of a Centennial Challenge cash prize. At the time there was no thought of pursuing anything beyond competing, and I was not expecting to win. My motivations were strictly personal—hoping to come up with something clever, to put in a good showing, and perhaps maybe even to impress one of the NASA observers. In the end, my design achieved all of that and more.

What was developed for the contest is a unique, yet highly effective “soft hinge” that allows the pressurized fingers of a space suit glove to flex more easily and predictably, with less workload than the current NASA Phase VI glove. The design is attractive not only because of its flexibility, but also because it has few parts and can be fabricated from a range of different membrane materials. It can be applied to any articulating joint of a space suit, bringing improvements in overall astronaut mobility, comfort and work efficiency. The manufacturing process includes the capability to make adjustments according to an astronaut’s exact body measurements, producing garments off the line that literally fit like a glove. Because of their simplicity, gloves and suits made using this new technology will only require one tenth the effort to produce and can utilize mass production processes, making the prospect of an affordable personal space suit very real.

Soon after the contest ended, Rick Tumlinson, founder of the Space Frontier Foundation and vocal proponent of space privatization, opened my eyes to all of the progress occurring since SpaceShipOne captured the X Prize in 2004. Rick had recently formed Orbital Outfitters with a vision to become the Levi Strauss of the private sector space rush by producing space suits for the emerging New Space launch services. Orbital Outfitters was interested in using my flexible glove technology in their new suits.

In 2007 I founded Flagsuit LLC (www.flagsuit.com) to commercialize the patent-pending soft hinge design, and to develop dexterous gloves and flexible pressurized structures for commercial applications. Today our focus...
is not only outfitting passengers and crews for the first suborbital space flights, but also enabling new terrestrial uses for pressure-capable suits and gloves. The latter provides many avenues for developing robust technology that can be adapted for use in space. Opportunities currently being pursued or investigated include hands-on educational space glove exhibits for museums and schools, a wearable pressure chamber for hyperbaric therapy, a deep sea diving suit that allows faster ascents to the surface, a positive pressure suit for hazardous materials handling, and protective wear for working within a full or partial vacuum.

Many people believe that the glove that won NASA’s contest would automatically become standard issue in the U.S. space program, but that is unrealistic. The competition was a catalyst, but significant additional privately funded development is needed to raise the technology maturity to a level where NASA can seriously consider and evaluate it to address specific mission needs. Prize competitions represent a step toward embracing open innovation within NASA, but there still remain many barriers to dealing directly with the small firms and individual innovators that these events are intended to attract. NASA’s Innovative Partnerships Program is actively working to address these obstacles.

Recently, Flagsuit teamed with Orbital Outfitters and Texas A&M University on a NASA contract to develop new “soft shoulder” concepts for future space suits. This project gave Flagsuit increased visibility with the NASA space suit designers in Houston. Three concepts were fabricated and tested—an Apollo EVA suit derivative, and two new designs from Flagsuit. Testing revealed that both of...
the Flagsuit designs were an order of magnitude more flexible than the Apollo derivative. The design that emerged as the best performing of the three was essentially a scaled-up version of the Flagsuit glove joint that won the Centennial Challenge. This design exhibited zero hysteresis—a measure of a joint’s dynamic drag, hence workload. According to one NASA manager, this was an industry “first,” proving the effectiveness of Flagsuit’s soft hinge design.

Time will tell whether NASA’s investment to develop innovative new astronaut glove technology will pay off for the Agency. It likely will be several more years before the new technology can be incorporated into flight hardware, if at all. A second round of the Astronaut Glove Centennial Challenge is scheduled for late 2009. Regardless of whether Flagsuit succeeds in capturing another prize, we remain committed to finding ways to help solve the challenges of living and working in space. When mankind returns to the heavens, Flagsuit plans to be there, too.

Lessons Learned
For those interested in competing, the following tips may be helpful. They all revolve around two key concepts – focusing on effort that adds the most benefit, and managing your time:

- Clearly define the problem you are trying to solve, and your goal. Simplify as much as possible. For the Astronaut Glove Competition, I reduced the problem statement to, “How can a (glove) finger be flexible while simultaneously restraining pressure load?” Solving that simple problem gave me all I needed to construct the complete glove. While it is exciting to design hardware for future space missions, remember that your goal at this stage is to win the contest. Make sure you clearly understand and address all of the competition rules, and save the extras for later.

- Do something every day. Many competitors come close to completing their hardware, only to run out of time just before contest day. The number of little tasks that crop up will confound you, so put some time in the bank by getting ahead early.

- Build! I spent the first nine months developing ideas on paper, and wound up with one design and no new knowledge. But once I started making prototypes, I quickly began to learn and understand what the real issues were. I built dozens of crude designs in just nine days. All of them taught me something and helped me move closer to my final design. Innovation is an iterative process, like Edison and the light bulb. Don’t make the mistake of assuming that your initial prototype will work perfectly. Allow enough time in your project schedule for at least one complete rebuild – you’ll need it!

- Research the problem, but don’t expect to find the solution in the literature. If the answers were there the problem would already be solved. Again, limit your time. Until I became intimately familiar with the subtle issues (through prototyping), I wasn’t educated enough to understand the information I was finding.

- Don’t worry about protecting your intellectual property until you have a properly functioning prototype. Through the process of building a working model, you will make changes to your original design anyway. A provisional application gives you “patent pending” status – the same as a full patent application – for a lot less money and effort, and you can file one in as little as one day. I used the book Patent Pending in 24 Hours by Richard Stim and David Pressman.

Peter K. Homer is founder and president of Flagsuit LLC and the winner of NASA’s 2007 Astronaut Glove Centennial Challenge. For more information, contact him at info@flagsuit.com.

For information on NASA’s Centennial Challenges, visit www.ipp.nasa.gov/cc

Please mention that you read about it in Technology Innovation.
The initial group of FAST projects on the September flights included five technologies funded through NASA's Small Business Innovative Research (SBIR) program. The flights also carried several experiments in the FASTTRACK test platform, the result of a partnership between NASA and Space Florida.

The following are firsthand accounts of several of these flight-test experiences.

**Honeybee Robotics**

Honeybee Robotics (www.honeybeerobotics.com) has a strong SBIR legacy with NASA centers, including the Jet Propulsion Laboratory, developing technologies currently used on both Mars Exploration rovers and the Mars Phoenix lander. Honeybee is now developing a pneumatic system for excavating and moving regolith or soil on the moon or Mars. Previous proposals for using gas for excavation met with general reluctance due to the perceived need to bring a considerable supply of gas from Earth. However, during NASA SBIR Phase 1 research with Kennedy Space Center, Honeybee Robotics demonstrated that when the method is employed at near-vacuum pressures and gas dispensation is carefully controlled, 1 g of gas can lift as much as 3 kg of soil. These results were very promising, but questions about the effect of gravity remained.

Honeybee Robotics received, through the NASA FAST program, an opportunity to test pneumatic excavation at reduced gravity. An aircraft-ready vacuum chamber, loaned by NASA's Langley Research Center, enabled Honeybee to perform pneumatic mining experiments at both reduced gravity and reduced pressure. This arrangement helped to bring the technology readiness level (TRL) of the pneumatic system from 4/5 to a 6, and to bring the technology much closer to flight. These experiments would not have been possible without the opportunity...
The initial experiments showed that excavation efficiency increases dramatically in reduced gravity. Preliminary results revealed that 1 g of gas can transport more than 6 kg of regolith. These high excavation rates make the pneumatic system a viable option for space applications. At the same time, numerous sources of gas have been identified including pressurant gas from a propulsion system (which otherwise would be vented) and burning residual propellant in a rocket thruster and collecting the exhaust gas.

The flight experience itself was tremendous – it provided a firsthand experience of the way the system behaves under lunar gravity. It became immediately obvious that digging and excavating hard, compacted regolith will be challenging unless novel means of excavating are developed. This experience provided insights that inform Honeybee’s development of a percussive digging technology that enables digging force reduction by an order of magnitude and more. Percussive digging and pneumatic soil transfer form a highly synergistic system.

— Kris Zacny, Director, Drilling and Excavation Systems, Honeybee Robotics
Jack Craft, Project Manager, Honeybee Robotics

Metis Design Corporation
Metis Design Corporation (MDC) (www.metisdesign.com) is a small, technical consulting firm focused on custom sensor systems, providing a unique alternative to commercial-off-the-shelf instrumentation.

Traditional instrumentation of aircraft is complex and time-consuming. Once the sensors are installed, long wires for power and data must be routed to a central data-collection location, adding weight and cost, and increasing the probability of introducing error. At the data-collection location, several large electronic components are often found, including signal conditioning boxes, amplifiers, data acquisition boards, laptops, power supplies and often, at least one person to supervise the testing. The need for this infrastructure limits the number and types of sensors that can be used.

MDC’s SensorLogger™ is a standardized data acquisition hub that dramatically increases instrumentation efficiency for aircraft testing, developed under SBIR with the Dryden Flight Research Center. It serves as a durable sensor infra-

structure capable of autonomously facilitating remote testing for multiple sensor sources of various types. This data can be stored statically on internal flash cards or transmitted in real time through aircraft telemetry with little or no wiring.

While good engineering practice was used in the design and fabrication of this device, no amount of marketing can be as compelling as true flight data. Operation in the intended environment increases the technology maturity and provides confidence in mission survivability and stability. The FAST program provides SBIR/STTR companies with this opportunity, a chance to obtain validation data by flying their NASA-sponsored research on a zero-gravity aircraft.

Being able to indicate that the SensorLogger™ functions were performed in a true flight environment has exponentially increased interest in this product from large aerospace companies.

For MDC, the FAST program was an educational experience, training a relatively young group of engineers on how to certify equipment for flight experiments. Going through the required documentation and other gates of approval provided hands-on experience that will benefit not only the SensorLogger™, but future MDC designs as well. Other SBIR/STTR companies would be wise to consider this opportunity to validate flight-worthy hardware.

— Seth S. Kessler, President & CEO, Metis Design Corporation

Sierra Lobo
Sierra Lobo Inc. (SLI) (www.sierralobo.com) conducted testing to validate a new and innovative liquid-vapor detection sensor for use in low-gravity fluid systems. The new sensor is based on SLI’s heritage Cryo-Tracker® probe. The NASA Kennedy Space Center Launch Services Program assisted with development of the new sensor. NASA plans to use the new sensor on launch vehicles to directly measure the liquid slosh dynamics in a reduced-gravity environment. The Florida Institute of Technology (FIT) developed the test tanks used in the flight experiment and used sensors tested in the flight to validate their Computational Fluid Dynamics sloshing models.

The opportunity to fly personnel with the experiment was an ideal way to instill excitement about the space business
among the younger engineers. From an experimental point of view, it was very important to have the researchers involved in the experiment. For example, video camera adjustments were critical during the flight to capture the dynamic fluid motion as it related to our sensor validation.

SLI is a small business, and the cost of flight-testing would have been a significant barrier towards validating our technology. This flight-testing has enabled SLI to present data and video confirmation that the new sensor works. This data enables SLI to market the technology to NASA and industry and decreases the time to arrive at market. SLI believes this technology will revolutionize the way we do business in space by providing direct measurement of propellant conditions while on orbit. The FAST program is enabling this technology.

—Mark Haberbusch, Director, Research and Technology, Sierra Lobo Inc.

Kennedy Space Center
The Kennedy Space Center (KSC) project team developing the FASTRACK™ Space Experiment Platform successfully tested an engineering unit aboard the September FAST flights. The experiment rack is designed to support two standard space shuttle mid-deck lockers, or a single double locker. It was developed jointly by KSC and Space Florida as an IPP Seed Fund project for use on commercial suborbital flight vehicles. It will accommodate experiments flown aboard parabolic aircraft and may be adapted in the future for use on orbiting vehicles and facilities.

KSC’s engineering unit was a rack with three science investigations to help verify interfaces, procedures and performance characteristics prior to final design and production of the flight units. The following three science investigations were performed:

- Baseline characterization of the microgravity environment with instrumentation from NASA’s Glenn Research Center,
- Fluid dynamics experiment by the University of Central Florida to study Faraday wave interfaces in microgravity, and
- Tests of a biomedical sensor that performs continuous, non-invasive monitoring and recording of human hemodynamics during changes in gravity.

Members of the project team flew with the apparatus and accomplished all engineering test objectives, verifying the unit’s compatibility with the Zero-Gravity aircraft and its ability to support multiple experiments. Since the flight, KSC and Space Florida have produced two flight units of the rack and are ready to offer it for use. KSC is working with commercial vehicle developers to provide FASTRACK™ as a capability supporting the NASA user community, while Space Florida will be working with them to offer that same capability commercially to industrial, academic or other groups.

FASTRACK™ will enable investigators to test experiments, apparatus and techniques in hardware compatible with the International Space Station. It also will allow them to perform science during the reduced gravity available for brief periods during aircraft parabolas, including those participating in NASA's FAST program.

KSC and Space Florida both contracted with the Bionetics Corporation to accomplish design, fabrication and testing of the experiment rack.

—James Ball, Center Development Manager, NASA Kennedy Space Center

For more information on the FAST Program, contact Andrew Petro, FAST program manager, at andrew.j.petro@nasa.gov, or visit http://ipp.nasa.gov/ii/fast.htm.

Please mention that you read about it in Technology Innovation.
Unleashing the Genius

By Lynn Harper
Human Suborbital Flight Project
NASA Ames Research Center

Brett Alexander
Commercial Spaceflight Federation

“We must unleash the genius of private enterprise to secure the United States’ leadership in space.” — Barack Obama, “Advancing the Frontiers of Space Exploration,” August 2008

A new era of space exploration and development began October 4, 2004, when SpaceShipOne and its intrepid citizen pilot, Brian Binnie, blasted into history with the first private manned spacecraft to exceed an altitude of 328,000 feet twice within the span of a 14-day period. SpaceShipOne set two world records, won the $10 million Ansari X Prize, and plowed a road beyond Earth that opened the space frontier to everyone.

Standing on the giant shoulders of almost 50 years of government-sponsored, manned space flight, today’s new breed of space entrepreneurs has committed their lives and personal fortunes to providing space transportation services for private citizens. The rocket test firings have begun. The passenger capsules are being designed. The FAA has been engaged. Congress has passed enabling legislation. New programs and policies are being formulated. All of this is being done to enable Americans to realize their own dreams and bring their unique creative genius into space. In the next five years, if you have the money, you will be able to purchase a ride to visit space on a commercial suborbital transportation system.

“We must unleash the genius of private enterprise to secure the United States’ leadership in space.” — Barack Obama, “Advancing the Frontiers of Space Exploration,” August 2008

NASA is the first federal agency to step forward to sponsor commercial suborbital passenger transportation for research. Intrigued by the potential, NASA’s then-acting administrator, Christopher Scolese, along with all of NASA’s associate administrators, signed a Program Decision Memorandum December 16, 2008, creating the Human Suborbital Flight Program (http://suborbitalex.arc.nasa.gov/). This new program will conduct science and technology research into areas of interest to NASA’s Innovative Partnerships Program, Exploration Systems Mission Directorate, Space Operations Mission Directorate and other organizations.

A Wealth of Interest

The opportunities for hands-on research on suborbital vehicles have generated significant interest among scientists and their organizations. The Commercial Spaceflight Federation (www.commercialspaceflight.org/), the Universities Space Research Association (www.usra.edu/) and NASA Ames Research Center sponsored meetings on the topic in December 2008 and May 2009, and both attracted standing-room-only audiences of scientists, technologists and educators. Attendees came to hear how they might make a traverse through one of the least understood parts of Earth’s atmosphere and then acquire four minutes of personal discovery time in one of nature’s most elusive of environments – microgravity.

Astronauts have demonstrated that there is a unique potential for breakthrough when innovative scientists are able to conduct their own hands-on research in space. They see
possibilities that untrained eyes often miss, and they follow leads that are impossible for robotic or teleoperated devices to utilize. The first-hand experiences of creative minds armed with today’s new technologies have revolutionary possibilities.

Commercial entities want not only to fly passengers in space, but to fly them often. Flight frequency has been the single most limiting factor in developing the power of the space laboratory sciences. On Earth, the biotech revolution’s mantra was “Fail fast, fail often. Learn fast, learn often.” Laboratory science is iterative. A scientist conducts an experiment, observes what happens, changes a variable, does it again … and again … and again … until a breakthrough occurs. The space laboratory sciences are the kinds of “frequent fliers” who will be ideal early customers for commercial space flights.

For numerous applications, the 23 seconds of microgravity gained from parabolic airplane flights is not enough, while four minutes of microgravity is. For example, four minutes is enough to characterize many of the elusive initiating events that lead to the remarkable changes in physiology seen when Earth organisms live in space. Some of these are of interest to biotech and medicine.

The aerospace medical community is particularly excited about the opportunities offered by commercial suborbital passenger flights. Four minutes of microgravity allow the space doctors to perfect life-saving medical procedures for use in
orbit and beyond. Studying the effects of gravity transitions among the larger and more diverse passenger populations, many of whom will be older and less physically fit than the astronaut corps, will provide new information that will be important for selecting and training the next generation of space explorers.

In addition, suborbital missions enable the following scientific research:

- Fluid, material, physiologic and gravitational biology investigations throughout the dynamic altered gravity phases and their transition zones,
- Astronomical and Earth observations at wavelengths and special observing geometries not accessible from the ground,
- Unique observations related to fundamental physics and biology, and
- Repeated sampling of atmospheric regions that neither spacecraft, balloons nor aircraft can reach (called the “ignorosphere” by some).

But there is more. Technologies for science missions, commercial satellites and military spacecraft can be tested in space before being committed to high-performance, orbital or interplanetary flight. This opportunity offers a significant reduction in risk that enables potentially high-performing but unproven technologies to be incorporated in future missions.

The Players and the Score

The number of brilliant entrepreneurs from many fields of world commerce who have committed their personal fortunes to developing the enterprise of commercial suborbital passenger services is remarkable. Many American companies are building and flying real hardware, and have credible plans to begin commercial flights on or before 2012. Here is a sample:

Armadillo Aerospace (www.armadilloaerospace.com) is led by legendary computer game graphics entrepreneur John Carmack, who is primarily known for the games “Quake” and “Doom.” While Armadillo’s initial goal is suborbital tourism, this Texas company’s stated long-term goal is to extend passenger access to Earth orbit. Armadillo’s concept is a vertical takeoff/vertical landing (VTVL) space tourism vehicle. In October 2008, the company won the first stage of the Northrup Grumman Lunar Lander Challenge, one of NASA’s Centennial Challenges. (See story on page 42.)

Blue Origin (www.blueorigin.com), a company started in 2000 by billionaire Amazon.com founder Jeff Bezos, is developing vehicles for vertical takeoff, vertical landing (VTVL) suborbital passenger flights. The Blue Origin Web site states, “We’re working, patiently and step-by-step, to lower the cost of spaceflight so that many people can afford to go and so that we humans can better continue exploring the solar system.” Blue Origin is conducting test flights of its New Shepard spacecraft design at the company’s Culberson County, Texas, facility.

Founded in 2004, Masten Space Systems (www.mastenspace.com) is an aerospace startup company in Mojave, Calif. (formerly Santa Clara), that is developing a line of reusable vertical takeoff and landing (VTOL) rockets. Led by high-tech engineer David Masten, the company in May 2009 began flight-testing the reusable VTOL Xombie as the next step in its process to design, develop and prove the capability to control a VTOL launch vehicle. Masten is focused on smaller microgravity payloads, and anticipates providing experimental payload space to customers by the end of 2009.

On September 25, 2004, English industrialist Sir Richard Branson announced that his space tourism company, Virgin Galactic (www.virgingalactic.com), would license the technology behind SpaceshipOne to take paying passengers into suborbital space. SpaceshipOne was funded by Microsoft co-founder Paul Allen and designed by Scaled Composites, which is led by legendary American aeronautical engineer Burt Rutan. Virgin Galactic now is selling tickets to the public, at $200,000 each, for a suborbital trip aboard SpaceshipTwo to 100 km. The carrier aircraft for SpaceshipTwo, named WhiteKnightTwo, completed its first test flight in December 2008.

XCOR Aerospace (www.xcor.com) is a private liquid rocket propulsion and vehicle development company founded in 1999 in Mojave, Calif. Led by CEO Jeff Greason, XCOR developed two generations of rocket planes, the EZ-Rocket and the X-Racer, flying them at EAA’s Oshkosh Airventure in 2002 and 2008, respectively. XCOR’s initial prototype suborbital reusable launch vehicle, the Lynx Mark I, is being designed to take off and land horizontally and to carry its pilot and a passenger or payload on flights to 65 km several
times per day. The Lynx Mark II will have the same small airplane form factor, but it will fly to roughly 110 km. The Mark II also is being designed to launch nano-satellites into low-Earth orbit using an expendable upper stage mounted on the back of the vehicle. The Lynx’s first engine firing was successfully completed in December 2008, the first cockpit test article came off the mold in March 2009, and XCOR has completed the first stage of a three-stage wind tunnel test campaign.

This is by no means a complete list of all the American companies who are contributing to open the space frontier, but it highlights the power of a particular dream. These entrepreneurs have committed their own resources to give us all the opportunity to travel beyond Earth and realize our own dreams in space.

Very different futures are available to a nation whose citizens can reach beyond their home planet versus those whose destinies are constrained to a single world. Soon, entrepreneurs will complete the first commercial bridge across the great divide from Earth to the still-mysterious regions of space. Many will pay for their tickets and leave Earth for a few tantalizing life-changing minutes. As astronauts and cosmonauts have done before them, they will bring back uniquely personal perspectives that will generate novel ideas, and new solutions for crafting better futures. Eventually, those few minutes will become hours, days and weeks, and citizen travel will extend to the moon. When that will happen is still conjecture. But one thing is certain: space is not just for rocket scientists anymore.


For more information contact Lynn Harper at lynn.d.harper@nasa.gov, or John Gedmark at john@commercialspaceflight.org

Please mention that you read about it in Technology Innovation.
Commercial Biomedical Research Aboard the International Space Station – A National Laboratory Pathfinder

By Bradley M. Carpenter
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Timothy G. Hammond
Durham Veterans Administration Medical Center

Jeanne L. Becker
Baylor College of Medicine

Once completed, the International Space Station (ISS) will serve as a multidimensional, multifunctional facility that will help humans solve many of the issues that we face now and that we will face in the future, on Earth and in space.

NASA’s primary mission for the ISS is to resolve the health risks of long-duration space flight, and to validate the technologies required by future generations of space exploration. As Earth’s only outpost in space, the ISS provides many unique facilities required to prepare for missions to Mars and other potential destinations.

Also essential for the long-term future of humans in space is the opportunity that the ISS affords to explore and expand the range of activities that can be usefully conducted in space. Humans have only begun to identify activities in space that add value to society. Some, like satellite-based communications and Earth observations, are part of daily life of our planet. What others are waiting to be discovered? In what other ways will space enterprise contribute to our well-being, and how? The answers to these questions will largely determine the long-term future of humans in space, and for this reason the ISS has a critical role in shaping the future of human space flight.

Once the ISS becomes available for full-time utilization, a pivotal opportunity will open to engage our national resources in a broad and robust program to identify and develop uses for space. Congress recognized this in the 2005 NASA Authorization Act, when it designated the U.S. assets on the ISS as a National Laboratory. With the Act, a historic corner was turned, and NASA was directed to open the resources of the ISS under the National Laboratory, for use by other federal agencies, the business community and academia, with non-NASA financial sponsorship.

The ISS National Laboratory (www.nasa.gov/mission_pages/station/science/nlab) is poised to evolve into a major component of ISS utilization after assembly is complete in 2010. During initial Laboratory development, federal agencies, including the National Institutes of Health and the Department of Agriculture, reached agreements with NASA to develop ISS-based research projects. A number of private-
sector efforts have already flown to the ISS as pathfinders, demonstrating positive proof of concept for research and development activities after assembly is complete in 2012.

Astrogenetix Inc. (www.astrogenetix.com), a biotechnology company established to take advantage of the unique environment of microgravity in developing therapeutic products, has a Space Act Agreement with NASA to use the ISS National Laboratory in research and development activities. One of the company’s major efforts focuses on the development of effective vaccines and therapeutics for bacterial pathogens that are serious public health problems today, including Salmonella and Staphylococcus aureus.

Astrogenetix was formed by Astrotech Inc., a company previously known as Spacehab and recognized for its expertise in payload management and research support, to pursue commercial development of a discovery made through space research.

Scientists examining the effects of the space environment on bacteria have observed that bacteria grown in space alter their virulence profiles, making the microbes more pathogenic, or better able to cause disease. Using space experiments to identify the bacterial components responsible for increased virulence, Astrogenetix plans to produce a commercial vaccine for Salmonella, which is a common cause of food poisoning and a major cause of childhood death in the third world.

With resources provided under the ISS National Laboratory Pathfinder program, Astrogenetix flew experiments on three shuttle flights in 2008 and identified potential targets for development of a Salmonella vaccine. Flight hardware was provided by BioServe Space Technologies (www.colorado.edu/engineering/BioServe/), a center of the University of Colorado, Boulder.

Astrogenetix and its partners, Duke University, Duke Veterans Administration Medical Center, Baylor College of Medicine, the National Space Biomedical Research Institute and the Max Planck Institute for Infection Biology, have begun a comprehensive investigation of the response of pathogenic bacteria to the space environment. The outcome of this work may lead to the production of effective vaccines and antimicrobial therapeutics. Beyond Salmonella, the Astrogenetix team is examining virulence profiles of methicillin-resistant Staphylococcus aureus (MRSA), Listeria monocytogenes, Enterococcus faecalis, and Candida albicans. As antibiotic-resistant pathogens like MRSA and E. faecalis become more common in hospitals and other medical settings, these therapies could offer an important alternative in the future.

In working with NASA, Astrogenetix and its partners have found these best practices to be of great importance to their successful partnership:

- Be adaptable in terms of launch dates, with built-in contingencies for conduct of the science if the dates are shifted.
- Maintain open communication among all team members and NASA to ensure maximum potential for successful payload outcome.
- Set up asynchronous ground controls to allow for any in-flight anomalies that may occur to be adequately mocked in on-ground operations.

The Astrogenetix project has an important role for NASA as a pathfinder for future use of the ISS National Laboratory by commercial enterprises. By demonstrating that the ISS National Laboratory can meet the needs of commercially driven research for timely access to space and cost-effective experiments, NASA hopes that the next decade will see a broad new wave of creative thinking in commercial use of the ISS.

Bradley M. Carpenter is technical engineering operations manager at NASA Headquarters; Timothy G. Hammond is associate chief of staff for research and development, at Durham Veterans Administration Medical Center; and Jeanne L. Becker is associate professor in the departments of obstetrics and gynecology and surgery at Baylor College of Medicine.

For more information about this initiative, contact Jeanne Lynn Becker at jbecker@bcm.tmc.edu.

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Opportunities for Partnership

Technologies are available for licensing and joint development at each of the NASA Field Centers through their Innovative Partnerships Program (IPP) offices. Provided here are details on one of numerous available technologies. Read more about other new technologies each month in NASA TechBriefs (www.techbriefs.com), and for a comprehensive list, go to http://ipp.nasa.gov.

Hydrogen Reclamation and Reutilization Technology

NASA’s John C. Stennis Space Center (SSC) seeks innovative solutions for efficient, cost effective, in-situ methods to recapture, clean, pressurize and store hydrogen boiloff for reuse. Research into technologies in these areas, demonstration of the technology capability and conceptual design for the technology installation at SSC are desired to assist in the hydrogen recovery and reuse.

Background

SSC provides rocket engine propulsion testing for NASA’s space programs, and every space shuttle main engine (SSME) has undergone acceptance testing at SSC before integration into the shuttle.

The SSME is a large cryogenic engine fueled by liquid hydrogen (LH2). As NASA moves to the new Ares V launch system, the new vehicle’s main engines, as well as the upper stage engine, are currently base lined to be cryogenic rocket engines that also will use LH2. The main engines will be larger than the SSME, while the upper stage engine will be about half that size. Significant quantities of hydrogen will be required during their development, testing and operation.

Technology Needs

Currently, most of the LH2 is brought to SSC by trucks or barges. During transfers from the trucks or barges, as well as during storage and transfers when conducting test operations, about half of the LH2 is lost. Much of the loss is due to boiloff as the heat in the systems causes the LH2 to phase into gaseous hydrogen, which is vented to test facility flare stacks.

Most of the boiloff is burned in the facility flare stacks as a safety precaution. However, the capability to safely reclaim and utilize it could save millions of dollars annually. The emerging hydrogen economy has developed systems and technologies that could make use of this lost hydrogen if methods were developed to recover at least a portion of the boiloff for reuse. A potential reutilization would require systems to capture, clean, pressurize and store boiloff for reuse by the test facility. Options for reuse could be as GH2 in the test facility or other alternate energy uses.

Technology Challenges

• Safely capture, process and store the large amounts of gaseous hydrogen released during test operations.

• Develop an on-site system capable of recycling the captured hydrogen to the cleanliness standards requirements.

• Determine the appropriate utilization of the recaptured hydrogen for test operations or alternative energy uses.

The technologies developed must be cost effective and able to perform the recycling process in an in-situ rocket engine test area environment. They will be required to comply with all required safety and quality standards.

For more information, or to discuss ideas about this concept, contact Stennis Space Center at (228) 688 1929 or ssc technology@nasa.gov.

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(continued on page 62)
Innovative Partnerships Program Offices at each of NASA’s 10 Field Centers represent NASA’s technology sources and manage center participation in technology transfer activities.

Affiliated Organizations support NASA’s IPP objectives.

Centennial Challenges Allied Organizations
## National Aeronautics and Space Administration
### Innovative Partnerships Program (IPP) Network

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Working with NASA to advance the objectives of the Innovative Partnerships Program.

#### National Technology Transfer Center (NTTC)
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### Allied Organizations
Partnering with NASA to manage prize competitions for the citizen inventor.

(see pg. 2)

**The X PRIZE Foundation**
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**Volanz Aerospace, Inc.**
Spaceflight America
Owings Mills, MD
http://www.astronaut-glove.us

**The Spaceward Foundation**
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http://www.spaceward.org/

**California Space Education & Workforce Institute**
Pasadena, CA
http://lsewi.org/

**Comparative Aircraft Flight Efficiency Foundation**
Santa Rosa, CA
http://cafefoundation.org/
System Health Monitoring Software

NASA’s Ames Research Center has developed an innovative software application that uses data mining techniques to produce real-time health monitoring capability for complex systems. The Inductive Monitoring System (IMS) was developed to provide an alternative to model-based and rule-based system health monitoring applications that typically require a significant amount of system knowledge and effort for development, verification and maintenance. IMS combines elements from machine learning, data fusion and model-based reasoning in a novel manner to provide a unique system health monitoring capability that is effective and easy to use.

Technology Details

IMS automatically learns typical system behavior by discovering parameter relationships in archived nominal data and constructing general classes representing normal system operation. Operational data is then compared with these classes to detect off-nominal system behavior and to alert operators or other automated systems to possible subsystem failures or impending failures.

IMS uses a flexible technique applicable to most domains with adequate data collection capability including mechanical, electrical, thermal, environmental, biological and hybrid systems. Successful NASA applications of IMS have ranged from real-time monitoring of aircraft engine and control systems to anomaly detection in space shuttle wing temperature sensors from STS-107 launch data.

Benefits

• An innovative approach to system monitoring
• Economical systems modeling - automatically builds system models from archived data
• Detects unanticipated interactions by characterizing normal parameter relationships
• Decreases operator workload - automatic identification of faults, anomalies and system behavior changes
• Enhances monitoring capability with analysis of interactions between multiple parameters
• Increases operating efficiency with the detection of subtle system degradation
• Detects small problems before they become big problems
• Helps maintain safe, efficient operations
• Widely applicable
• Rapid, low-cost monitoring system development
• Compact and efficient with low computing resource requirements

Applications

IMS can be used to monitor nearly any system with recurring behavior and appropriate data collection. This allows application to any number of system monitoring tasks. IMS applications under development include telescope subsystems, uninhabited aerial vehicles, spacecraft and aircraft. Other potential applications include the following:

- Aeronautics
- Air Traffic Control / Navigation
- Alternative Energy Production
- Transportation: Automobiles, Trucks, Trains, Ships
- Medicine
- Research Facilities and Data
- Environmental Data Analysis
- Infrastructure
- Conventional and Nuclear Power Plants and Power Distribution
- Pipelines
- Communications
- Manufacturing Monitoring
- Process Industries Control and Monitoring
- Military/Security
- Wind Tunnels

For more information and details about licensing this software please contact William M. Toscano in the Entrepreneurial Initiatives Division of NASA Ames Research Center at (650) 604 0894 or William.M.Toscano@nasa.gov. Please reference Case Number ARC 15058 1.

Please mention that you read about it in Technology Innovation.
Your Guide to NASA’s Technology Needs, Partnership Successes and Partnership Opportunities

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