

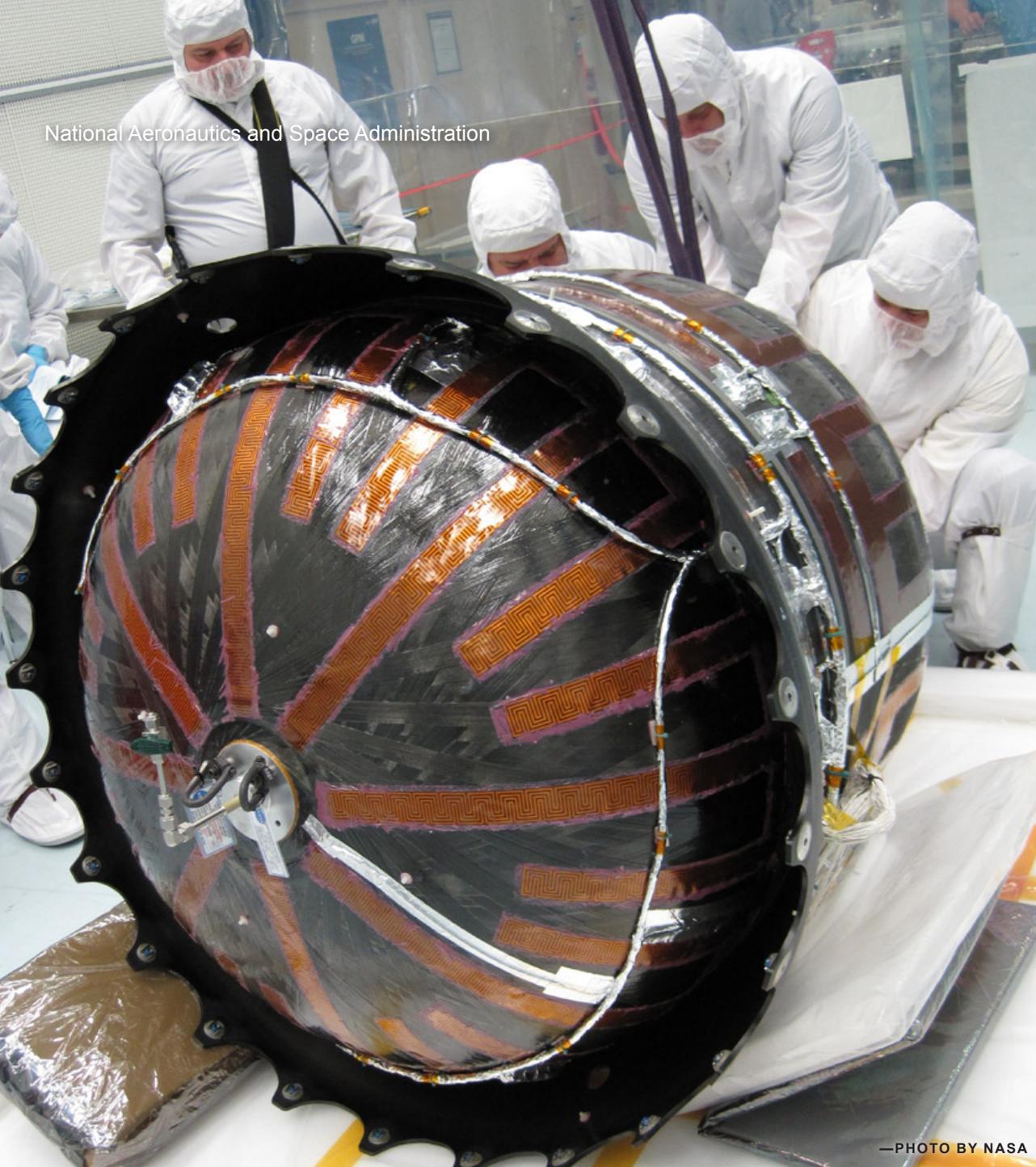


► *The NASA Goddard Propulsion Branch's demisable hydrazine propellant spacecraft tank (GSC-16525-1) is pictured being installed into the Global Precipitation Measurement (GPM) propulsion system. The tank is designed to harmlessly breakup upon reentry, significantly reducing the amount of debris reentering Earth's atmosphere.*

—PHOTO BY NASA

Goddard Tech Transfer News [<http://ipp.gsfc.nasa.gov>]

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—PHOTO BY NASA

Opportunities in Propulsion Systems

**DEVELOPING
GREENER
PROPULSION**

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tech transfer



Nona
Cheeks

[FROM THE *Chief*

From the Chief

Interest in “green” technologies is clearly on the rise, both within the U.S. and globally. People everywhere are actively seeking new ways of doing things, ways that are safer, use renewable resources, and have less overall impact on the environment.

This issue of NASA Goddard *Tech Transfer News* features the work of the NASA Goddard Propulsion Branch. This group develops the in-space systems that provide NASA missions with the high-precision maneuverability required for tasks such as positioning, alignment, and interplanetary navigation for projects that include the Magnetospheric Multiscale (MMS) mission, one of the most challenging ever undertaken by NASA. We look at the NASA Goddard Propulsion Branch’s capabilities, technologies, and facilities, and how they can be leveraged and adapted for future NASA activities and support potential commercialization opportunities.

We also examine how green concepts can get incorporated into the work undertaken by the NASA Goddard Propulsion Branch. One example describes how the NASA Goddard Propulsion Branch reduced its reliance on alcohol as a cleaning agent, replacing it instead with a system that creates nitrogen bubbles in ordinary water and uses these bubbles as scrubbers. This system, which reduces the NASA Goddard Propulsion Branch’s use of alcohol cleaner by as much as 90%, could be very valuable for any facility or process that needs to clean equipment in an environmentally responsible way. Another example involves the NASA Goddard Propulsion Branch’s efforts to reduce its reliance on hydrazine, a hazardous chemical used in a wide variety of commercial industries.

In addition, our regular legal contributors Bryan Geurts (Chief Patent Counsel for NASA Goddard’s Office of Patent Counsel) and Erika Arner (Partner for the law firm Finnegan, Henderson, Farabow, Garrett & Dunner) discuss several questions that are sometimes raised by private companies who may be contemplating a first-time partnership with a government agency such as NASA. Erika and Bryan address these questions, and explain that such partnerships typically present few special risks -- and some very important advantages.

If you have any questions about partnering with NASA Goddard, or would like to learn more about NASA Goddard technologies in general, please feel free to contact the Innovative Partnerships Program Office at techtransfer@gsfc.nasa.gov.

Nona Cheeks

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Propulsion Systems

For NASA space missions, the need for propulsion doesn't end after the rocket leaves the launch pad and the payload is delivered into space. In many cases, the mission may still require high-precision maneuverability for tasks such as positioning, alignment, and interplanetary navigation.

The NASA Goddard Space Flight Center's Propulsion Branch (Code 597) is responsible for developing the next generation of NASA's in-space propulsion systems. These systems will take advantage of new propellants and technologies that are cheaper, safer to handle and transport, and have less overall environmental impact. A number of these may offer technology transfer opportunities to the emerging commercial space flight market. They may also provide opportunities to other commercial markets as well.

History



► Caitlin Bacha

The Propulsion Branch has a long history of designing propulsion systems for NASA Goddard missions. From the 1970's through the late 1980's, propulsion systems were co-operatively designed and built with industry partners. In the early 1990's the NASA Goddard Propulsion Branch began developing in-house propulsion capabilities, including the successful design and development of the first fully in-house monopropellant propulsion system for the Tropical Rainfall Measurement Mission (TRMM).

In the late 1990's the NASA Goddard Propulsion Branch integrated and operated an electric propulsion system for the Earth Observing 1 (EO-1) mission. This system managed orbit momentum during normal operations. In the early 2000's NASA Goddard's Propulsion Branch expanded its

design capabilities by developing the first in-house bipropellant propulsion system for the Solar Dynamics Observatory (SDO). The SDO propulsion system greatly expanded the analytical, design, and build capabilities of the NASA Goddard Propulsion Branch. The propulsion system successfully delivered the SDO observatory to geostationary orbit in 2010.

The NASA Goddard Propulsion Branch has also led several technology development programs. This includes key miniature components for the Space Technology 5 (ST-5) propulsion system. This high-pressure gas propulsion system required several ultra-low power miniaturized propulsion components to achieve the mission requirements. In addition the NASA Goddard Propulsion Branch has done cutting-edge propulsion technology development with Internal Research and Development funding on Micro-Electro Mechanical System (MEMS) thrusters and valves, miniature solid rocket motors, and precision thrust measurement techniques.

The NASA Goddard Propulsion Branch Today

According to Caitlin Bacha, Associate Head of NASA Goddard's Propulsion Systems Branch, in-space propulsion is an area that's ripe for innovation. "For the most part, propellants have historically been chemical based" explains Ms. Bacha. "We've been using essentially the same propellants for the last 50 years, and there hasn't been a great deal of change during that time. We're now trying to break out of that mold."

This research includes monopropellant and bipropellant hypergolic systems, as well as electric propulsion based on a pulsed plasma thruster. "Electric propulsion could be very efficient for interplanetary missions" states Ms. Bacha.

Capabilities

NASA Goddard's Propulsion Branch provides services that cover all phases of project development. These include concept formulation, design, analysis, fabrication, integration and test, and mission operations.

- **Concept formulation** is the first stage of the development process. To initiate this, the NASA Goddard Propulsion Branch analyzes the performance requirements for the proposed propulsion system. They also take into consideration issues such as schedule and cost. Part of this analysis involves the identification of new technologies that could be leveraged into the design of the system under development.
- **Design** involves taking the broad concepts identified above and committing them "to paper," formulating a design that will help guide the further development and eventual fabrication of the system. As part of this process, NASA Goddard's Propulsion Branch performs system architecture and optimization, which includes creating a detailed component and manifold mechanical layout. The design stage also entails the creation of a detailed thermal and electrical interface for the system.
- **Analysis** is the stage when the early designs are carefully examined from a variety of perspectives. The NASA Goddard Propulsion Branch's analysis capabilities include fluid flow, plume analysis (including computational fluid dynamics modeling), mechanical and thermal analysis (performed in cooperation with NASA Goddard's Mechanical and Thermal Branches), flight dynamics (in cooperation with the Flight Dynamics Branch), and attitude control (including slosh analysis, in cooperation with NASA Goddard's Guidance, Navigation and Control Branch).
- **Fabrication** involves building the physical propulsion system, as designed. The NASA Goddard Propulsion Branch has a wide assortment of fabrication tools available to build these complex systems. Capabilities and facilities include tube fabrication, precision cleaning and passivation, tube welding, bonding and thermal hardware assembly, Class 10,000 clean rooms, and hydrocarbon cleanliness verification.
- **Integration and test** includes procedures for pressure, flow, and leakage tests; as well as pressure panels, GHe leak detectors, dew point meters, and others. The NASA Goddard Propulsion Branch has a

"We can help companies qualify their products for flight, and even help them come up with their qualification requirements. NASA is also more willing to take the risk of flying new technologies on their first mission. This can really help companies get their products into the market, because flight qualification is a big step in the commercialization process."

**—Kris Romig,
Propulsion Engineer**



► Great care is taken to load propellant for the Solar Dynamics Observatory (SDO) mission. The first bi-propellant propulsion system designed, built and tested at the Goddard Space Flight Center.

—PHOTO BY NASA

“water hammer” laboratory for testing mock-ups of flight systems to measure transient flows due to valve actuation. NASA Goddard’s Propulsion Branch also has access to environmental test facilities, including vibration tables, thermal vacuum chambers, and pressure testing facilities.

- **Launch operations** involve services that the NASA Goddard Propulsion Branch provides for the duration of the active mission. These include propellant loading and system pressurization. NASA Goddard’s Propulsion Branch also has many Self Contained Atmospheric Protective Ensemble (SCAPE) trained engineers and technicians who have played crucial roles in SCAPE operations for both the SDO and LRO propellant loading procedures. The Branch is capable of performing complete propellant loading operations, as well as launch and early operation on-console support.

In support of these developmental stages, the NASA Goddard Propulsion Branch has developed a core set of capabilities and expertise. “We are very good at modeling, testing, and fabrication,” reports Ms. Bacha. “These capabilities also have potential value for other commercial applications, especially for smaller companies for whom advanced facilities such as ours may represent a high financial investment.”

Success Stories

The capabilities described in the preceding section have helped support several highly successful NASA missions. For example, the NASA Goddard Propulsion Branch designed, analyzed, built, and tested the propulsion system for the Lunar Reconnaissance Orbiter (LRO). “The short schedule [for the LRO] was the primary driver for the system design,” states Ms. Bacha, who adds that the LRO’s propulsion system has operated without a single failure.

Another propulsion system developed by NASA Goddard’s Propulsion Branch was for the Solar Dynamics Observatory (SDO). This was the first bi-propellant propulsion system designed, built, and tested at NASA Goddard Space Flight Center; and it remains the largest and most complex propulsion system ever

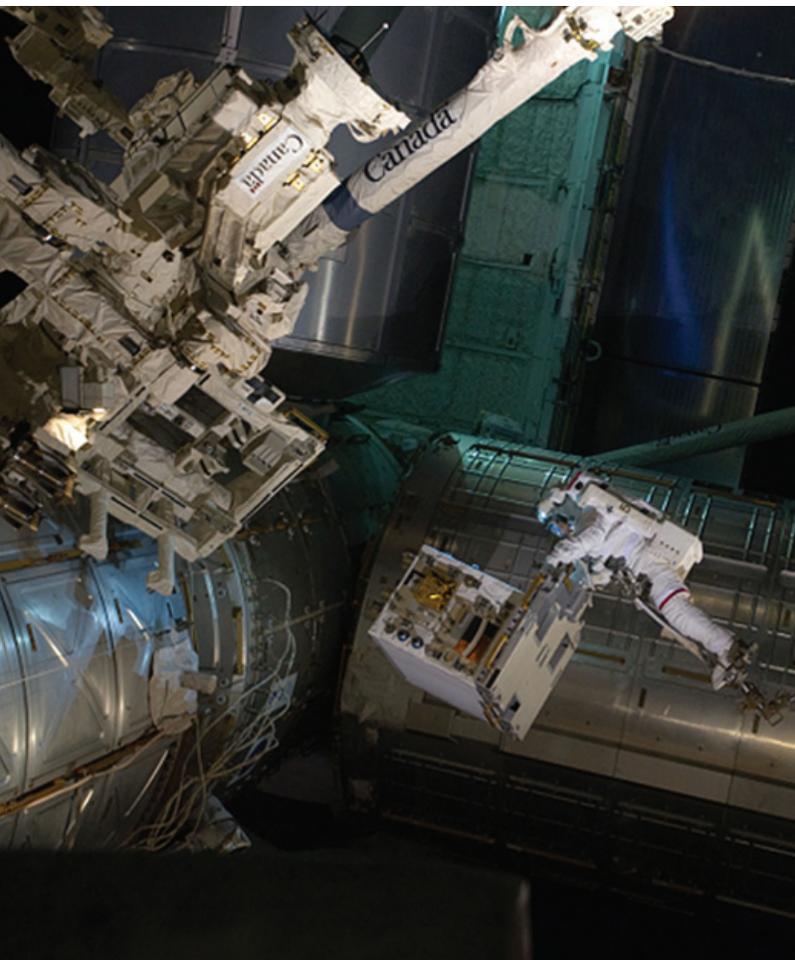


► The Lunar Reconnaissance Orbiter (LRO) uses a regulated monopropellant propulsion system designed, analyzed, built, and tested by the NASA Goddard propulsion team.

—PHOTO BY NASA

developed at the Center, requiring more than 167 feet of titanium tubing connected by 348 welds. Upon the launch of the SDO in February 2010, its propulsion system successfully performed over 4 ½ hours of maneuvers to place the spacecraft into geostationary orbit. The propulsion system continues to support orbit maintenance maneuvers.

More recently, the NASA Goddard Propulsion Branch developed the pump-driven fluid transfer system designed to demonstrate robotic propellant loading technologies for the Robotic Refueling



► *Robotic Refueling Mission (RRM) Transfer to International Space Station*

Mission (RRM) / Fluid Transfer System (FTS). The FTS was successfully integrated with the RRM module, delivered to the International Space Station in July 2011, and moved to its final ELC4 operational location and activated in September 2011. Telemetry indicates that the FTS is in its nominal state and ready for operation.

Ongoing Projects

The NASA Goddard Propulsion Branch is currently involved in a variety of ongoing projects. For instance, the NASA Goddard Propulsion Branch has designed and delivered the blow-down monopropellant system for the Global Precipitation Measurement (GPM) mission. Launch for the GPM is scheduled for early 2014, via a H-IIA launch vehicle from Tanegashima, Japan. “While working

on the GPM, we’ve encountered a number of unique technical challenges,” notes Ms. Bacha. These include developing a “demiseable” propellant tank that will easily break up upon re-entry into the Earth’s atmosphere. Collaborating with an agency in another country is another ongoing challenge. “We need to meet foreign launch vehicle and range safety requirements,” explains Ms. Bacha. “To do this, we work closely with our Japanese partners to develop procedures and perform several ‘dry runs’ to promote efficient communication and collaboration.” Another important facet of the GPM partnership is the need to perform complex propellant loading operations with an integrated NASA-JAXA loading team. The GPM propellant operations could serve as a model for future American spacecraft launching out of Japan.



► *Thruster receiving tests for Global Precipitation Measurement (GPM).*

—PHOTOS BY NASA

Commercialization Opportunities

As we noted earlier, the work of the NASA Goddard Propulsion Branch offers several broad areas of potential opportunity to private industry. For example, the Branch is actively seeking “greener” alternatives for some of their technologies. This research may also be of high interest and value to commercial companies driven by the need to find more environmentally friendly ways to do business in order to meet increasingly stricter governmental regulations and guidelines.

“Current propellants are hazardous,” says NASA Goddard Propulsion Engineer, Kris Romig. “They require special handling with protective equipment, and strict rules for disposal. NASA Goddard is highly interested in finding alternatives to using these hazardous chemicals.” Among these chemicals is hydrazine. The Propulsion Branch is currently looking into several replacements for hydrazine due to their lower toxicity, increased performance, and safer handling and transportation requirements. These propellants are LMP-103S, AF-M315E, and NOFBX. And since hydrazine is widely used throughout the industry, NASA Goddard’s efforts to find better substitutes for it could have wide commercial implications. [For more information, see the article “Developing Greener Propulsion Systems” elsewhere in this issue of *Tech Transfer News*.]

In addition to providing technologies that companies can leverage and adapt into commercial products, the Propulsion Branch offers facilities and expertise that can help others further develop and test their own technologies, particularly in the field of aerospace. According to Mr. Romig, “We can help companies qualify their products for flight, and even help them come up with their qualification requirements. NASA is also more willing to take the risk of flying new technologies on their first mission. This can really help companies get their products into the market, because flight qualification is a big step in the commercialization process.”

Takeaways

The NASA Goddard Space Flight Center’s Propulsion Branch develops in-space propulsion systems for NASA missions. NASA Goddard’s Propulsion Branch is involved in all phases of the development of a propulsion system, from early concept through mission operation. Past and present missions include the Lunar Reconnaissance Orbiter (LRO), Solar Dynamics Observatory (SDO), Robotic Refueling Mission (RRM) / Fluid Transfer System (FTS), Global Precipitation Measurement (GPM) mission, and Magnetospheric Multiscale (MMS) mission. Through their involvement and support of these missions, the NASA Goddard Propulsion Branch has developed numerous capabilities that can be adapted into commercial opportunities. Some of these involve technologies of potential use to private industry. The NASA Goddard Propulsion Branch also offers facilities that can help companies design, develop, and test their products.

For more information on NASA Goddard technologies, please contact the Innovative Partnerships Program Office (Code 504), <http://ipp.gsfc.nasa.gov/index.shtm> phone: 301-286-5810, email: techtransfer@gsfc.nasa.gov.



Kris Romig

Code:

597 - Detailed to 504

Years with NASA:

12

Education:

BS Aerospace Engineering, Pennsylvania State University, MS Space Architecture, University of Houston, MS Systems Architecture & Engineering, University of Southern California.

Kris Romig is a Technology Manager in the Innovative Partnerships Program Office at NASA’s Goddard Space Flight Center (GSFC). In this capacity Mr. Romig evaluates new technologies that have been developed by GSFC scientists and engineers and looks for opportunities where these technologies may be used outside of NASA. Prior to joining the IPP Office Kris worked for a variety of organizations within NASA. He spent 9 years as a propulsion engineer and project manager at NASA’s Johnson Space Center in Houston TX, where he supported the Space Shuttle program and worked on numerous propulsion technology development projects for future exploration missions. Mr. Romig then worked for a year at NASA Headquarters as the Deputy Chief Engineer for the Exploration Systems Mission Directorate before coming to GSFC as a propulsion engineer in the Propulsion Branch supporting the development of both in house and out of house propulsion systems.

[NASA GODDARD *Propulsion Laboratory*

Propulsion Laboratory

The NASA Goddard Propulsion Branch maintains a laboratory for analysis, fabrication, integration, and testing of new designs. These capabilities allow NASA Goddard's Propulsion Branch to carry out its primary responsibilities for developing new in-space technologies to support NASA missions. The laboratory may also offer facilities and services that can be leveraged by private industry, to support their own product development efforts.

In this article, we describe a new methodology implemented within the Propulsion laboratory that has helped ensure efficient and clean lab operation. We'll also briefly examine several of the laboratory's core capabilities.

"5S" Methodology

One of the ways the Propulsion laboratory remains high functioning and state-of-the-art is by adopting the "5S" methodology, a system originally developed in Japan. As explained by Michael Wilks, Propulsion Lab Manager, the 5S system consists of five steps:

- Sorting involves taking inventory and determining what is and isn't needed for the operation. During this process, "we got rid of a lot of things we really didn't need," states Mr. Wilks.
- Stabilizing entails organizing all laboratory items. In the case of the Propulsion laboratory, this required 14 separate storage cabinets.
- Shining requires that all work areas and equipment are kept clean. According to Mr. Wilks, this involves thorough cleaning every Monday in the laboratory; with each member of the laboratory taking turns performing the cleaning, and making sure that "there's a place for everything, and everything is in its place."
- Standardizing establishes a core set of practices and guidelines for personnel to follow.

- Sustaining involves making sure that all personnel observe and follow the standards defined in the "Standardizing" step.

Mr. Wilks speaks very highly of the 5S system. "One of the big worries with developing propulsion systems is how to keep everything clean. The 5S method allowed us to identify 'dirty' items, which we now store in one isolated place. This helps keep the rest of the laboratory clean, which provides quality assurance (QA) benefits. And 5S made us much more sustainable and Earth-friendly. For instance, it helped us pinpoint the fact that we were using large volumes of alcohol as a cleaning agent. Alcohol is a hazardous substance, and requires special handling and disposal guidelines. When we realized how much alcohol we were using, it motivated us to devise a cleaning system based on cavitation bubbles, which has greatly reduced our use of alcohol. We're very proud of this."

Mark Fiebig, Associate Head of NASA Goddard's Propulsion Branch, echoes Mr. Wilks' enthusiasm. "The 5S system provides us with a tool for controlling our equipment, and doing this in a way that saves money. It's worked so well, it's being implemented in other NASA Goddard areas. And it could be really useful for smaller companies."

Laboratory Capabilities and Services

The Propulsion laboratory includes a number of key capabilities for developing NASA Goddard's in-space propulsion systems. For example, the laboratory offers tools such as tube fabrication, tube welding, and bonding and thermal hardware assembly. It also offers "clean" capabilities and facilities, including Class 10,000 clean rooms, precision cleaning and passivation, and hydrocarbon cleanliness verification.

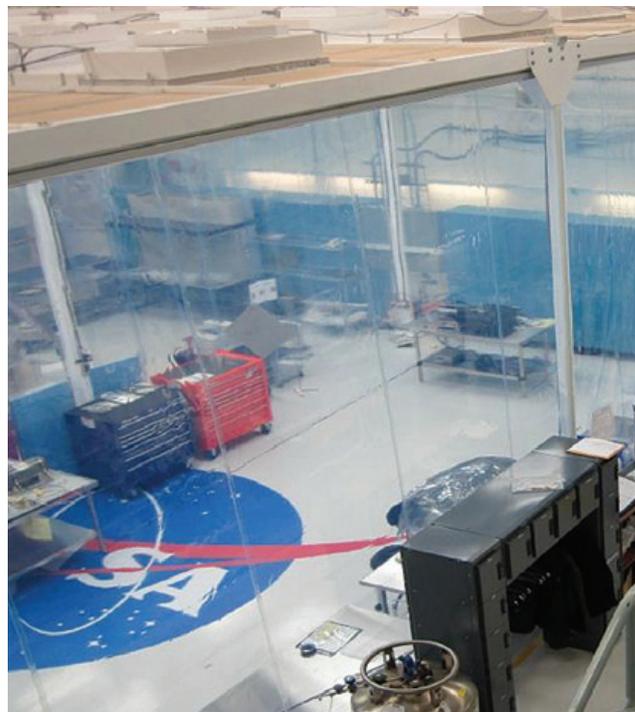
The laboratory is also equipped for modeling and testing. This includes the ability to perform fluid flow, mechanical and thermal analysis, flight dynamics, and attitude control. According to Mark Fiebig, the laboratory includes water surge testing for analyzing fluid dynamics; as well as a high-pressure testing system. The laboratory has also developed procedures for leakage tests. In-house equipment includes GHe leak detectors and dew point meters.



► Here, critical welds are X-rayed on the MMS fluid transfer system.

The Propulsion laboratory also maintains a “water hammer” station for testing mock-ups of flight systems to measure transient flows due to valve actuation. (Water hammer is a potentially damaging condition that occurs in a pipe when any event disturbs the steady state, such as when a flow is brought to an abrupt halt. When the fluid flow reaches the closed end of a pipe, the fluid is forced to stop, creating a pressure increase. This is known as a water hammer pressure spike. These pressure spikes can damage flight hardware.) Other environmental test facilities include vibration tables and thermal vacuum chambers.

One of the critical services the laboratory can perform is in-flight qualification. The laboratory can qualify technologies for flight, including products developed by



► The NASA Goddard Propulsion Branch has led several technology development programs within their clean room facilities.

—PHOTOS BY NASA

outside companies. In-flight qualification is an important step in the development of technologies designed to be used in space. In this way, the laboratory can offer a valuable service for commercial companies who want to develop technologies intended for the in-space market.

Takeaways

The NASA Goddard Space Flight Center's Propulsion laboratory provides tools and services for developing in-space propulsion systems. The laboratory has recently deployed the 5S methodology, which has helped streamline their operations, reduced the use of hazardous materials, and lowered costs. The design, fabrication, and testing facilities and capabilities provided by the laboratory can be leveraged by private companies to help them develop their own technologies and products for space flight applications.

For more information on NASA Goddard technologies, please contact the Innovative Partnerships Program Office (Code 504), <http://ipp.gsfc.nasa.gov/index.shtm> phone: 301-286-5810, email: techtransfer@gsfc.nasa.gov.

DEVELOPING *Greener Propulsion Systems*

Greener Propulsion

The drive to develop “greener,” more environmentally sensitive ways of doing things currently permeates government, industry, and society in general. We’re now scrutinizing a broad array of long-standing technologies and processes, with an eye towards finding possible substitutes that are less toxic, safer, and (ideally) cheaper. NASA Goddard Space Flight Center is no exception. In recent years, the move towards greener technologies has become an area of particular focus within the Center.

“The NASA Goddard Propulsion Branch is very committed to the idea of incorporating green alternatives with our missions,” states Caitlin Bacha, Associate Head of the NASA Goddard Propulsion Branch. “Our own Deputy Center Director for Science and Technology, Dr. Christyl Johnson, has personally gotten involved to advocate and infuse green propulsion technology into our line of business and within industry. This year alone there were two calls to the industry by the NASA Office of the Chief Technologist (OCT) that show a real commitment to investigating green propulsion.”

In this article, we’ll look at examples of how the NASA Goddard Propulsion Branch is actively seeking greener alternatives to their technologies, some of which have been in use for years or even decades. In the process, this research may offer potential value to the commercial sector, to help private companies develop and implement business processes and practices that satisfy the government’s increasingly stricter environmental regulations and guidelines.

Replacing Hydrazine Propellant

An important component of NASA Goddard’s Propulsion Branch’s push for greener technologies is its ongoing research into

developing propulsion systems that do not require hydrazine as a propellant. Hydrazine (chemical formula N_2H_4) has a variety of applications within industry. At NASA, hydrazine and hydrazine derivatives have been a mainstay of US in-space chemical propulsion for nearly 50 years. While providing consistent performance and reliability, hydrazine and its derivatives are highly toxic and present risks and hidden costs (manufacturing, storage, transportation, operations, and disposal) associated with ensuring the safety of humans and the environment. “We’ve used hydrazine since the 1970’s,” says Rich Driscoll of the NASA Goddard Propulsion Branch (Code 597), “and from a performance standpoint it works well. But it’s very toxic and hazardous, and requires a special protective suit to handle. Unfortunately, replacing a core technology such as hydrazine with another is a long and involved process.”



► Deputy Director
Christyl Johnson
looks on at a
possible replacement
for Hydrazine

—PHOTO BY NASA

Due to its highly toxic nature, hydrazine requires strict procedures for shipping, handling, and disposal. In addition to its safety and environmental issues, the special preparations required for working with hydrazine can add significant time and difficulty to the development of a new propulsion system. These procedures can also be expensive. Facility upgrades, storage/monitoring and sampling, waste disposal, and Self Contained Atmospheric Protective Ensemble (SCAPE) maintenance are very expensive; and these costs affect small missions. With the current budgetary climate, the increasing hydrazine lifecycle costs are a real concern. In addition to the significant reduction in personnel health risks, greener propulsion technologies could lower operating costs associated with propellant handling and disposal.

As a result, NASA Goddard is focused on using propellants other than hydrazine. One possible alternative is a propellant called LMP-103S, which is significantly less toxic than hydrazine. Developed in Sweden, LMP-103S is a blended monopropellant which contains ammonium dinitramide (ADN). It also offers more stability and lower storage cost. According to Dr. Driscoll, this technology has an advantage over other potential propellants in that it has already demonstrated its effectiveness in space. "LMP-103S is currently flying on PRISMA, a Swedish National Space Board funded mission. And so far, it's working fine."

Other propellants being considered for NASA Goddard propulsion systems include NOFBX, a nitrous oxide blended monopropellant from Firestar Technologies, and AF-M315E, a blended monopropellant being developed by the U.S. Air Force. "NASA Goddard doesn't develop propellants in-house," notes Dr. Driscoll. "But we can play an important role in their development. For example, we can help provide in-flight qualification."

Hydrazine alternative demonstrations indicate an increase in performance over standard hydrazine systems. According to Caitlin Bacha, "increased on-orbit performance directly translates to extended on-orbit lifetime and reduced mass and volume requirements. Reduced propulsion mass and volume increases the mass and volume available which increases the available mass and volume for science. Every gram saved in the propulsion system mass is another gram available for a payload!"

Finding a viable replacement for hydrazine also has important implications for the commercial sector. According to Dr. Driscoll, "a new propellant can be rapidly migrated into the commercial satellite industry. It could also replace hydrazine for applications such as aircraft escape systems." In addition, a hydrazine replacement technology might offer promise in non-propellant applications, such as auxiliary power units.

Cleaning with Bubbles

Another component of the NASA Goddard Propulsion Branch's green efforts may have wide applicability within the commercial manufacturing sector. This involves a new method for cleaning equipment with nitrogen bubbles. "We conducted a thorough review of our processes," explains Michael Wilks, NASA Goddard Propulsion Branch Lab Manager, "and we discovered that we were using large volumes of alcohol as a cleaning agent -- 1000 gallons for the SDO mission alone." This represented a significant expense, because alcohol is an expensive cleaning agent due to its cost to procure and its strict disposal requirements.

To reduce their use of alcohol cleaning agents, Mr. Wilks and his team developed a system that creates nitrogen bubbles within water through a process called gas agitation. By combining the use of both water and pressurized gas, the cleaning system creates a gas agitation effect in which the pulsing water and gas bubbles "scrub" the inside surfaces of the tube more thoroughly than water alone.

"This system has reduced our use of alcohol cleaner down to 50 or 60 gallons for an SDO-sized mission," reports Mr. Wilks. "It's completely green, since we're creating bubbles from nitrogen. And it's very cheap, since it requires no additives, special shipping, handling, storage, or disposal. It's easy to imagine this system being used by anyone who needs a safe, environmentally friendly, and inexpensive cleaning system for their hardware and equipment."

Takeaways

The NASA Goddard Propulsion Branch is aggressively seeking new and greener alternatives to current technologies and processes. This includes replacing hydrazine as a propellant, and a cleaning system that uses nitrogen bubbles created through gas agitation. These technologies could potentially be leveraged into commercial applications and markets.

For more information on NASA Goddard technologies, please contact the Innovative Partnerships Program Office (Code 504), <http://ipp.gsfc.nasa.gov/index.shtm> phone: 301-286-5810, email: techtransfer@gsfc.nasa.gov.

DEVELOPING THE *Demiseable Fuel Tank*

Demiseable Fuel Tank

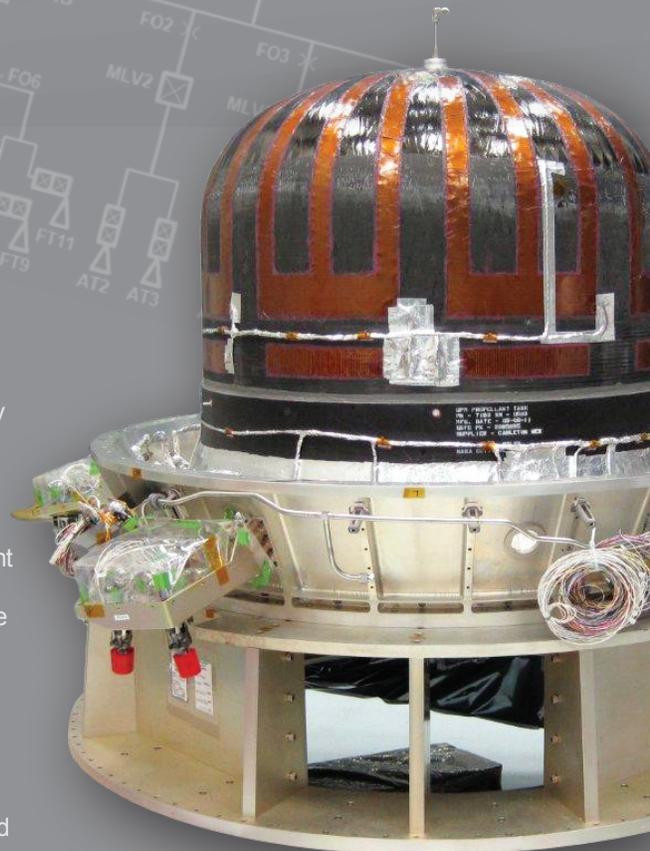
NASA Procedural Requirements 8715.6, NASA-STD-8719.14, and NASA Safety Standard 1740.14 provide guidelines for the safe disposal of spacecraft that have completed their missions. One way to achieve this goal is to design spacecraft that demise upon entering the atmosphere. A key barrier to meeting this requirement is the propellant tank, which can easily account for 10% to 20% of the allowable spacecraft debris.

To address this issue, the NASA Goddard Propulsion Branch developed and tested the so-called “demiseable” fuel tank in conjunction with Cobham Pressure Technology Solutions. A demiseable tank is one specifically designed to break up harmlessly when re-entering the Earth’s atmosphere. The Propulsion Branch’s demiseable hydrazine propellant spacecraft tank (GSC-16525-1), initially developed for the Global Precipitation Measurement (GPM) mission, is the first fuel tank designed to fully demise upon reentering the atmosphere. This removes the hydrazine tank from the list of surviving items that must be accounted for when designing a demiseable spacecraft.

The tank is designed to contain up to 45,226 cubic inches of hydrazine (32,978 in blowdown mode) while meeting all relevant safety and mission requirements. A key innovation of the tank is its use of an aluminum lined composite overwrapped pressure vessel with a highly “wettable” treated aluminum propulsion management device (PMD). This PMD is specially processed and maintained to provide wicking properties similar to those of industry standard titanium PMDs. Unlike titanium, however, the aluminum will disintegrate upon re-entry into the atmosphere.

Note that the demiseable tank offers important advantages beyond its reduced environmental impact. For example, a demiseable spacecraft can be lighter than “traditional” craft. This means that more of its mass can be devoted to payload. In addition, the mission can be provided a longer lifetime, since more propellant can be dedicated to maneuvering.

Commercial vendors producing low earth orbiting spacecraft will likely be interested in this demiseable tank technology, as will other government agencies and organizations that fly Earth observing and similar missions. The treatment process that allows aluminum to become more wettable may also have potential commercial applications.



—PHOTO BY NASA

Takeaways

The NASA Goddard Propulsion Branch has developed a “demiseable” fuel tank that will break up harmlessly upon re-entry. This significantly reduces the amount of debris that results when a satellite re-enters Earth’s atmosphere. This technology could potentially be useful in commercial applications.

As described elsewhere in this issue of NASA Goddard Tech Transfer News, the NASA Goddard Propulsion Branch develops in-space propulsion systems for NASA Goddard missions. In the process, they have created a number of technologies and capabilities that may have potential application in commercial industries. Some of these technologies may be directly relevant to the growing commercial space flight sector. Others can be leveraged into markets that have little or no connection with space flight.

In this article, we'll briefly examine the budding commercial space flight industry. We'll then look at a few NASA Goddard Propulsion Branch technologies and capabilities that could be leveraged into this industry, and into other markets that also have a need for lighter and cleaner solutions.

Commercial Space Flight and NASA

In recent years, there has been a trend for NASA to look to the private sector to help develop technologies that can assume "routine" space flight tasks, such as flying crews to and from the International Space Station. With the retirement of the Space Shuttle program, the U.S. now relies on Russia to perform this service, at an expense of approximately \$60 million per person. To help the development of an alternative "space taxi" option, in 2011 NASA funded seven companies to fly suborbital science experiments. The combined cost of these two-year contracts is a relatively modest \$10 million, and is seen as a major "kick start for the industry" according to Neil Milburn, VP of Program Management for Armadillo Aerospace.

One of the challenges facing the commercial spaceflight industry is propellant. According to John Pike, Director for GlobalSecurity.org, "There's been no significant improvement in the last 50 years in how many pounds of thrust a pound of propellant can produce."

Solving such technical issues could open a large global market for commercial space flight. As Alan Stern, former NASA associate administrator states, "There is a huge appetite for routine affordable space access. It's not just the United States. It's all the countries who have not been able to get involved in space because the prices were just too astronomical." Therefore it appears that technologies such as those under development in NASA Goddard's Propulsion Branch may be of high value and interest to this emerging market.

Better and "Greener" Propulsion Systems

As we've noted elsewhere in this issue, NASA Goddard's Propulsion Branch does not develop new propellants in-house. Instead, their responsibilities include developing systems that can make use of new propellants developed outside, especially propellants that are safer, less toxic, and more ecologically friendly in terms of manufacturing, testing, and handling. For example, the NASA Goddard Propulsion Branch is actively looking into developing systems that use chemicals other than the "traditional" hydrazine as a propellant. Among the substitute propellants being considered are LMP-103S, AF-315E, and NOFBX, which are less toxic, more stable, and allow for lower storage, transportation, and disposal costs than hydrazine. Non-hydrazine propulsion systems could be of significant value to companies

involved in commercial space flight, since they could avoid the danger, effort, and expense of working with hydrazine.

Another NASA Goddard Propulsion Branch technology that may be of direct applicability to commercial space flight is the “demiseable” propellant tank. This tank is designed to break up upon re-entry into Earth’s atmosphere, thereby reducing the danger of debris striking the ground. [See the separate article on the demiseable tank in this issue of *Tech Transfer News*.]

In addition, the NASA Goddard Propulsion Branch has developed a novel cleaning system based on creating nitrogen bubbles in ordinary water, and using these bubbles as a “scrubbing” agent to clean equipment. This system is designed to reduce the NASA Goddard Propulsion Branch’s use of alcohol as a cleaner, which it has done very successfully (reducing the use of alcohol by an estimated two orders of magnitude or more). This offers the potential of a completely green and inexpensive cleaning system that requires no additives, special shipping, handling, storage, or disposal. This system may be of use by any company that requires a safe, environmentally friendly, and cheaper cleaning system. [For more information on the NASA Goddard Propulsion Branch’s focus on more ecologically sensitive technologies, see the article “Developing Greener Propulsion Systems” in this issue of *Tech Transfer News*.]

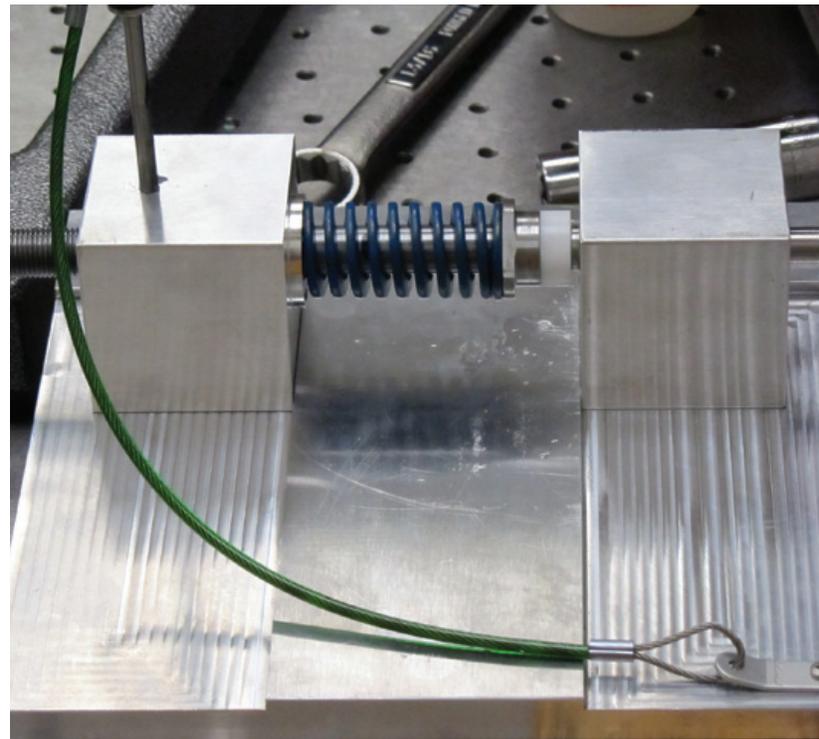
Normally Open Permanent Isolation Valve (NOVA)

One technology that appears to be useful in commercial spaceflight and potentially many other applications is the “Nitinol-Actuated Normally Open Permanent Isolation Valve (NOVA)” [GSC-16336-1]. This is a zero-leak permanent isolation valve designed for liquid propellant service on in-space propulsion systems with operating pressures less than or equal to 500 psia. NOVA is a replacement to the currently used pyrovalve for all chemical propulsion systems.

Despite its widespread use in spacecraft fluid systems, pyrovalves have produced unacceptably high failure rates in qualification testing. To address this problem, NOVA incorporates nitinol, a “shape

“There is a huge appetite for routine affordable space access. It’s not just the United States. It’s all the countries who have not been able to get involved in space because the prices were just too astronomical.”

**—Alan Stern,
former NASA associate
administrator**



► Here a seal mockup is used to test the sealing capabilities of the valve.

—PHOTO BY NASA

memory” material that can be shaped and then compressed; when heated the nitinol recovers its original shape. In the NOVA, heat is applied when the valve needs to be closed. The nitinol then assumes its original shape, creating a leak-tight seal. Power is only applied to the valve during actuation to heat the nitinol.

NOVA is compatible with all storable propellants, and is simpler and safer than a similar pyrovalve valve. NOVA's actuator is non-explosive and therefore intrinsically safer than the explosive actuator used in the pyrovalve (which potentially could ignite the propellant, possibly causing catastrophic failure of the spacecraft). In addition, NOVA may be adaptable to other applications, including terrestrial, wherever there is a need for a safer, heat-activated valve of this type.

Floating Orbital Weld Head Support Arm

As commercial spacecraft systems become more prevalent, there is likely to be an accompanying need to develop and manufacture in-space propulsion systems more effectively. This includes welding expensive, delicate equipment in a way that maintains high precision and ensures a low failure percentage due to misalignment or porosity.

In response, the NASA Goddard Propulsion Branch has developed the "Floating Orbital Weld Head Support Arm" [GSC-16522-1]. This invention, based on commercially available technology first used to support cameras at sports events, aids in the critical alignment of the orbital weld head into the welding fixture and uses no extra fixturing to support heavy weld head cables. The arm acts as a zero gravity weld head support, making spacecraft propulsion manufacturing on the ground much easier and faster.

The support arm allows the operator to reach inside the spacecraft structure, which historically has been largely inaccessible and difficult to support. The arm is self-supporting, retractable, and safe to operate.

Development and Testing Facilities

In addition to the technologies described above, the NASA Goddard Propulsion Branch also provides laboratory facilities that other companies can leverage to help the development of their own products. This includes flight qualification, a critical step for technologies designed for use in space. Potential services include modeling, testing, and fabrication. These can be highly valuable to smaller companies who may not have the resources necessary to easily absorb the expense typically associated with these capabilities.



► First used to support cameras at sporting events, the support arm now aids in the development of mission critical propulsion components.

—PHOTO BY NASA

Takeaways

The NASA Goddard Propulsion Branch has developed a number of technologies that could be of direct value to the emerging commercial space flight industry. This industry is currently being actively supported by NASA, and could represent a significant market opportunity. NASA Goddard's Propulsion Branch technologies that could be leveraged into this market include new and greener in-space propulsion systems, the Normally Open Permanent Isolation Valve (NOVA), and the Floating Orbital Weld Head Support Arm. The NASA Goddard Propulsion Branch also offers laboratory and test capabilities that could help smaller companies develop and qualify their space technologies. In addition, some of these technologies and capabilities could be leveraged to applications other than space flight.

For more information on NASA Goddard technologies, please contact the Innovative Partnerships Program Office (Code 504), <http://ipp.gsfc.nasa.gov/index.shtm> phone: 301-286-5810, email: techtransfer@gsfc.nasa.gov.

[THE *Magnetospheric Multiscale (MMS) Mission*

MMS Mission

One of the more ambitious projects in which the NASA Goddard Propulsion Branch is currently involved is the Magnetospheric Multiscale (MMS) mission. The MMS mission presents several unique and demanding requirements for scientists, engineers, and others involved in its design, development, fabrication, and testing. Addressing these requirements has been a major challenge for the NASA Goddard Propulsion Branch, one that has provided strong motivation for examining several new methods and approaches for designing and executing a complex, large-scale development project. In this article we review the MMS mission and its goals. We also describe how the NASA Goddard Propulsion Branch developed the in-space propulsion system for the MMS to help ensure this mission successfully meets its goals.

MMS Overview

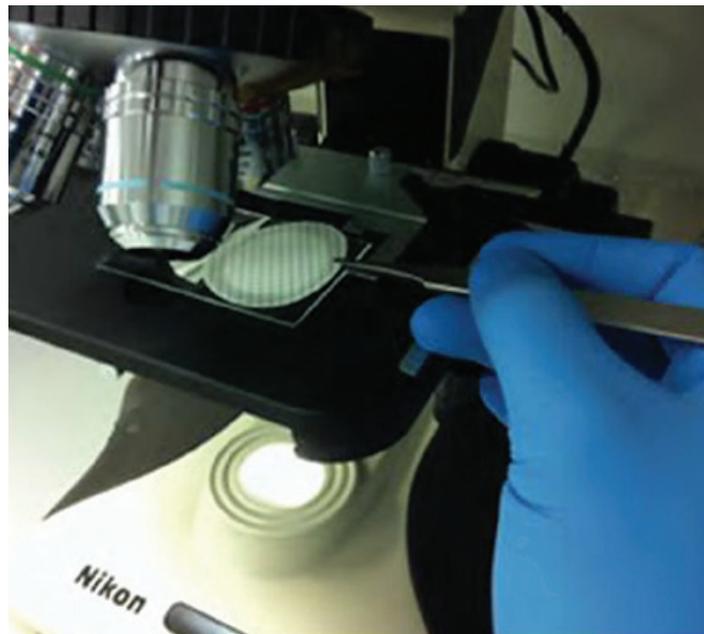
The MMS mission is designed to study three processes that can affect the Earth's magnetosphere: magnetic reconnection (which causes solar flares, coronal mass ejections, and other phenomena that can imperil Earth-orbiting spacecraft and terrestrial power grids), energetic particle acceleration, and turbulence. These processes, which occur in our Sun and other astrophysical plasma systems, play important roles in the phenomenon known as "space weather." The MMS will provide insight on these three processes by monitoring and observing their effects on the Earth's magnetosphere. To do this, the MMS will employ four identical spinning satellites flying in tight tetrahedral formation in a highly elliptical Earth orbit. Maintaining the required formation will require a very precise in-space propulsion system for maneuvering and making orbital corrections as necessary. The MMS mission is scheduled to be launched in mid-2014.

In addition to advancing our knowledge of space phenomena, the MMS mission also offers

potential value to Earth-based applications. Data provided by the MMS may help us better understand and predict the effects of solar storms and similar activity that could damage high-altitude electronics, power grid equipment, and other sensitive components. For example, magnetic reconnection affects the magnetic confinement of fuel in nuclear fusion reactions; a better understanding of this process could help accelerate the development of commercial-scale fusion energy.

Developing the MMS Propulsion System

The NASA Goddard Propulsion Branch has designed and is currently building four "blow-down" monopropellant systems. This has



► High precision cleaning of the MMS spacecraft fluid lines.

—PHOTO BY NASA



► *Cleaning, welding, x-ray inspection, and systematic pressure testing are done routinely at NASA Goddard's Propulsion Branch.*

—PHOTO BY NASA

presented several novel technical and procedural challenges. For example, the parallel fabrication of four spacecraft simultaneously requires a high level of coordination across a large team. "The MMS mission is the largest project we've ever had," says Dr. Eric Cardiff, the MMS Propulsion Team Lead. "The mission requires us to build four propulsion subsystems, including four load-balanced tanks. This is the first time our group has been required to perform parallel builds in this way." To ensure that these builds proceed with tight coordination, the NASA Goddard Propulsion Branch has assigned a dedicated production control engineer to the project.

To complete the MMS propulsion system, the NASA Goddard Propulsion Branch developed components such as thruster modules, flow control modules, and fill and drain modules. This modular approach simplified and accelerated an otherwise very complex integration schedule. The NASA Goddard Propulsion Branch is also responsible for the development of the propellant tank, as well as a system for measuring how much propellant remains in the tank. This involves a novel heat capacitance technique that Dr. Cardiff describes as significantly more accurate and sensitive than other methods for end-of-life situations where small changes in the amount of the remaining propellant can have a large impact on determining when to end the mission. Traditional techniques have accuracies between 16 and 18 kg for MMS; but the thermal capacitance technique has an accuracy of 2 kg at the end of the mission. To achieve this accuracy, the temperature of the tank is slowly increased with a known amount of heater power; and the temperature response is compared to model and test data to determine how much propellant is left to absorb the heat. This heat capacitance system also has potential use in other commercial applications.

The scale and scope of the MMS project has also prompted the NASA Goddard Propulsion Branch to review its facilities and processes, to ensure that they are optimally prepared to undertake a project of this complexity and magnitude. According to Michael Wilks, Propulsion Lab Manager, the anticipated requirements of MMS was a factor in the laboratory adopting the "5S" methodology. [See the separate article "NASA Goddard Propulsion Laboratory" in this issue of Tech Transfer News.]

This effort has resulted in new capabilities to the NASA Goddard Propulsion laboratory, including a "smart" cleanroom that provides an environment largely free of dust, aerosol particles, and chemical vapors that could damage highly sensitive science instruments and hardware. The cleanroom developed for the MMS provides an environment that allows for no more than 10,000 particles per cubic foot of air, filtering out contaminants while consuming 30% less energy than similar facilities. This reduction in energy can save NASA Goddard thousands of dollars annually in electricity costs. Saving energy is an especially critical consideration in cleanrooms, since they typically require high levels of power to keep essential functions such as air flow functioning properly.

Conclusion

As we've seen, the MMS presents several very significant challenges for the NASA Goddard Propulsion Branch and its facilities. Meeting these challenges has allowed the NASA Goddard Propulsion Branch to improve its systems and processes, while developing new technologies and capabilities that can now be leveraged to other missions and applications.

Takeaways

The Magnetospheric Multiscale (MMS) mission is one of the largest and most complex ever undertaken by the NASA Goddard Propulsion Branch. To support this mission, the NASA Goddard Propulsion Branch developed technologies such as the thruster modules, flow control modules, and fill and drain modules. The NASA Goddard Propulsion Branch also developed a new method for measuring the amount of propellant remaining in the tank. This technique, based on heat capacitance, is highly accurate, especially near end-of-mission. In addition, the MMS's parallel development required the NASA Goddard Propulsion Branch to adopt special processes for the project, such as the "5 S" method. The mission also prompted the development of advanced cleanroom facilities that make efficient use of electricity. These capabilities and technologies can now be applied to other areas, including possible commercial applications.

In this edition of Patenting Perspectives, we discuss several questions that potential licensees sometimes raise when contemplating licensing IP from NASA Goddard Space Flight Center and other government agencies. These include so-called “march-in rights” and the pursuit and enforcement of IP infringement.

Offering their perspectives on this topic are attorneys Bryan Geurts (Chief Patent Counsel for NASA Goddard’s Office of Patent Counsel) and Erika Arner (Partner for the law firm Finnegan, Henderson, Farabow, Garrett & Dunner).

Q. *What are some of the circumstances under which a licensee might lose their rights to government IP?*

Bryan: There’s actually a list of things that could impact previously granted rights to government-funded IP, as spelled out in Section 209 of the Patent Statute. These differentiate us from other licensors, and in some respects represent uncharted territory.



► *Bryan Geurts*

One of the biggest potential issues is march-in rights. Basically, the government can terminate a license if the licensee is not carrying out their approved business plan for the technology.

Although this may sound rather harsh, there’s a good reason for it. Since the IP has been paid for by the public, the government has a vested interest in seeing the technology actually developed. Some licensees want to obtain IP primarily as an anti-competition measure. They may or may not intend to develop it; but as long as they hold the IP, no one else can develop it either. The government wants to avoid this happening to any technology for which the public pays.

Erika: This highlights an important distinction between licensing IP from the government and what patent rights usually confer. In non-government patenting, the competitive aspect

is very important. Many companies get patents to exclude their competitors, whether or not they actually commercialize the technology themselves. But when companies license government-funded IP, they cannot simply put the IP on a shelf. They must lay out a business plan for developing or commercializing the IP and they must follow through. Therefore licensing IP from the government serves very different objectives.

Bryan: Bear in mind, many of NASA Goddard’s technologies are cutting edge, and therefore they’re not necessarily yet ready for “prime time.” Licensees will likely need to do a lot of additional development, at their own expense, before the technology is fully ripe as a ready-for-market product. Some companies may be reluctant to take on such an investment if they think there’s a risk the government will pull back the license.

Q. *How important is timeliness? For instance, how long can a technology be in development before the government takes back the rights to it?*

Erika: That depends on the technological area, and the overall cost of development. In areas where there’s lots of development, it makes sense for the government to allow more time for licensees to develop the technology. In other areas, such as software, not as much time needs to be allowed. In any case, the development schedule should be covered in the business plan; although coming up with an accurate schedule is something that licensees sometimes have difficulty defining and implementing.

Q. *How often are march-in rights invoked?*

Bryan: Historically, not often at all. The government rarely has any interest in ever invoking march-in rights. We’re much better off allowing the licensee to simply run with the technology; so we frequently tend to be lenient when it comes to modifying the original business plan, if that becomes necessary. Our main interest is to get the technology into the commercial sector.



► Erika Arner

Erika: There are some companies who struggle with the concept of public/private partnerships. A few try to “game the system” and use government IP as a way to exclude potential competition from developing similar technology. But most licensees enter into these partnerships with a spirit of collaboration, with the same goal

that the government has: to develop this publicly-funded technology into a commercial product.

Q. One question that potential licensees often ask is: if we discover that someone may be infringing on the licensed patent, will the government help us enforce it?

Bryan: That’s a really good question.

Erika: And it’s one I haven’t run into yet.

Bryan: According to our licensing template, if the license is non-exclusive then the government will be the enforcer. If the license is exclusive, then the licensee will have first crack at enforcement, after which the government will become involved if necessary.

Erika: Enforcement is a common issue to be negotiated with all IP licensing, not just situations that involve the government.

Bryan: While negotiable, more often than not we try to stick with the language used in the template. In terms of practical enforcement, an infringement issue must be handled by the Justice Department; NASA Goddard is involved, but more as support to the attorneys at Justice. Usually, in the case of an exclusive license it is up to the licensee to determine whether or not to go forward with a potential infringement issue.

Erika: When the Justice Department gets involved, there’s more uncertainty from the licensee’s perspective. Political issues can start becoming part of the mix, which leads to things getting more and more muddled. It’s more straightforward when the licensees pursue an infringement case on their own; although because of the cost involved, this isn’t always preferable.

Q. So far we’ve only discussed licensing. Do other partnering legal instruments raise their own concerns?

Bryan: Yes they do. For example, a CRADA [Cooperative Research and Development Agreement] is a fairly well-known type of collaboration agreement between government and industry. At NASA, the preferred instrument is the Space Act Agreement, because it’s more flexible. But there are two downsides to a Space Act Agreement. First, some potential

partners may be somewhat uncomfortable with it, simply because it’s a relative unknown compared to a CRADA. The second issue is that with a Space Act Agreement, it isn’t always easy to establish up-front that a vested Space Act Agreement partner will have access to IP that will be developed by NASA under the Agreement. In such cases, potential partners may be understandably reluctant if they can’t pre-define what happens to any resultant IP.

That being said, the Space Act Agreement remains the preferred partnering instrument at NASA, and the one we use most often, literally hundreds per year. And when a potential partner expresses reluctance, we just refer them to previous partners who have successfully entered into Space Act Agreements with us. I personally spend a lot of time doing PR for the Space Act Agreement.

Q. Partnering with NASA Goddard sometimes involves access to the innovators of the technology. How often is this included?

Bryan: We probably provide access to the inventor and the inventor’s know-how more often than not.

Erika: This is a valuable distinction between partnering with the government and partnering with a private entity. Between businesses, relationships can be adversarial, as companies compete with each other. Your partner may not want to provide any access to their inventors, since this know-how may represent a competitive advantage they don’t really want you to know about. With the government, competition isn’t typically an issue, so access to expertise is usually a lot easier to obtain.

Q. In a recent public IP auction, three lots of NASA Goddard IP were offered. Part of this process involved NASA Goddard approving each successful bidder. How often is such approval withheld?

Bryan: To my knowledge, this has never happened while I’ve been at NASA; we’ve never turned down a bona-fide purchaser. Again, our main goal is to make licensing deals work; it’s probably the best way for us to get our IP into the commercial sector. So we tend to treat all potential partners with kid gloves. Still, we do need to acknowledge that as a government agency, NASA is governed by rules and regulations that we cannot simply waive for the bidder.

There is one additional issue that occasionally comes up, and that’s the preference given to U.S.-based manufacturers. Other government agencies tend to be slightly stricter than NASA in this regard. We do have a preference for U.S. companies, but it’s not necessarily an absolute -- if there’s no U.S. licensee available, we will partner with a non-U.S. firm. But the issue does get raised from time to time, and it sometimes causes us a little heartburn to address.

ICAP Ocean Tomo Live Auction

(MARCH 28-29, 2012, RANCHO PALOS VERDES, CA)



NASA Goddard's Innovative Partnership Program Office (IPPO) attended a March 29th auction hosted by ICAP Ocean Tomo LLC of Chicago, successfully auctioning licenses to several of its advanced software patents. The auctioned software development lots included technologies created to minimize the time and effort required to develop software programs and consisted of 6 US patents and 1 US application. The software patents within the lot address a means to automatically generate formal specifications and working code from informal input, or conversely, to transform existing source code into a formal mathematical model. These tools can enable software dependability in purpose specific, complex systems and can help create systems that are easier to use and maintain in the face of growing system complexity. NASA Goddard's partnership with ICAP Ocean Tomo helps to augment NASA's licensing program. ICAP Ocean Tomo's auction platform is considered by many to be the premier live forum for the open and public exchange of intellectual property. To expedite the assimilation, use and adaptation of the auctioned technology, winning bidders may gain access to the inventor through a reimbursable agreement with NASA.

Spirit of Innovation Awards Conrad Foundation

(MARCH 29-31, 2012, MOFFETT FIELD, CA)

The Conrad Foundation is based on the rich legacy of the late Apollo 12 astronaut and entrepreneur, Charles "Pete" Conrad. His wife, education activist Nancy Conrad, founded the organization in 2008. The Conrad Foundation

is dedicated to fundamentally shifting how science, technology, engineering and math (STEM) are taught in K-12 schools and across socioeconomic levels. It is the only not-for-profit, 501(c)(3) organization of its kind to combine education, innovation and entrepreneurship to spark student interest in STEM careers and



sustain a knowledge-based economy. Representatives from the NASA Goddard IPPO attended the Conrad Foundation's 2012 Spirit of Innovation Summit

on March 29th - March 31st at Ames Research Center to explore opportunities for collaboration involving the potential infusion of Goddard developed technologies into future student projects. For more information about the Conrad Foundation, go to <http://www.conradawards.org/>.

Satellite 2012 Conference & Exhibition

(MARCH 12-15, 2012, WASHINGTON, DC)

The Satellite 2012 Conference is an annual commercial telecommunications conference that focuses on the latest trends in the commercial spacecraft industry. Conference topics range from satellite subsystem



technologies to existing and future market trends, hosted payload opportunities and government/commercial partnerships. Representatives from NASA Goddard's IPPO attended the Satellite 2012 conference on March 12th - March 15th to investigate potential partnership opportunities in the areas of communication, guidance navigation and control as well as propulsion technologies.

NTRS and Patents

NTRS

- ▶ REQUIREMENTS IN TIME AND FREQUENCY DOMAINS

Eddie Akpan

- ▶ DIRECT OBSERVATION OF NANO-SCALE CONTACTING SURFACES

Timothy Longson

- ▶ MUTI-BEAM OPEN-PATH FIBER-TO-FIBER COUPLER

Emily Steel, Gordon Blalock, Kenneth Cory

- ▶ OPTIMIZED CARBON NANOTUBE GROWTH ON SELF-CATALYZING METAL FOILS FOR THERMAL INTERFACE APPLICATIONS

Timothy Longson, James Maddocks, Ali Kashani

- ▶ A DATA FUSION APPROACH FOR GLOBAL ESTIMATION OF FOREST CHARACTERISTICS FROM SPARSE LIDAR DATA

James Tilton, Bruce Cook, Paul Montesano

- ▶ A HIGH CROSS-POL ISOLATION MULTI-FREQUENCY ANTENNA FOR CLOUD AND PRECIPITATION RESEARCH

James Carswell

- ▶ A HYBRID FIBER/SOLID-STATE REGENERATIVE AMPLIFIER WITH TUNABLE PULSE WIDTHS FOR SATELLITE LASER RANGING

Demetrios Poullos, Donald Coyle

- ▶ A RETURN TO ZERO PSEUDO NOISE LIDAR MODULATION TECHNIQUE FOR MAKING RANGE RESOLVED ATMOSPHERIC MEASUREMENTS

John Burris

- ▶ AUTOMATED EVALUATION SOFTWARE (AES) WEB APPLICATION

April Hildebrand

- ▶ CRUQS A MINIATURE FINE SUN SENSOR FOR NANOSATELLITES

Scott Heatwole, Carl Snow, Luis Santos

- ▶ FASR - FEEDBACK AUGMENTED SUB-RANGER

Gerard Quilligan, Charles McClain

- ▶ GRAPHENE BASED IMPERMEABLE BARRIER LAYER FOR CRYOGENIC TANKS

Mahmooda Sultana, Jeffrey Stewart, Stephen Scotti, Theodore Johnson, Emilie Siochi

- ▶ GREEN PRECISION CLEANING SYSTEM

Michael Wilks

- ▶ HELIOS: EXTREME WEATHER VULNERABILITY WARNING SYSTEM

Austin Stanforth, Vijay Lulla, Daniel Johnson

- ▶ HIGH SPEED VISIBLE AND NIR CAMERAS AND GPU BASED FAST WAVE-FRONT CONTROL ELECTRONICS FOR BALLOON BORNE AND GROUND BASED DIRECT EXO-PLANET IMAGING

Richard Lyon, Peter Petrone, Udayan Mallik

- ▶ HIGH-POWER HIGH SPEED SLECTRO-OPTIC PCKELS CELL MODULATOR

Phillip Battle, Justin Hawthorne

- ▶ INTEGRATED GENOMIC AND PROTEOMIC INFORMATION SECURITY PROTOCOL

Harry Shaw, Brian Gosselin

- ▶ LARGE-AREA, UV-OPTIMIZED, BACK-ILLUMINATED SILICON PHOTOMULTIPLIER ARRAYS

Vinit Dhulla

- ▶ LOW COST MLI THERMAL BLANKET FOR HIGH TEMPERATURE APPLICATIONS UP TO 1400AND#730;C

Michael Choi

- ▶ LYMAN ALPHA DOPPLER IMAGING INTERFEROMETER (LADII)

Phillip Chamberlin, Qian Gong

- ▶ ON-ORBIT MODULATION TRANSFER FUNCTION CHARACTERIZATION OF TERRA MODIS USING THE MOON

Taeyoung Choi

- ▶ PHASE CHANGE MATERIAL FOR TEMPERATURE CONTROL OF IMAGER OR SOUNDER ON GOES TYPE SATELLITES IN GEO

Michael Choi

- ▶ PRACTICAL UAV OPTICAL SENSOR BENCH WITH MINIMAL ADJUSTABILITY

Paula Gonzales, Jeffrey Pilgrim

- ▶ RADIATION HARD BY DESIGN (RHBD) ELECTRONICS

Gary Maki, Sterling Whitaker

- ▶ SAM/MSL CONTAMINANTS SPECTRAL LIBRARY

Prabhakar Misra, Raul Garcia-Sanchez, Paul Mahaffy, John Canham, Doris Jallice

- ▶ SCIENCE ANALOG BOARD

Seshagiri Nadendla

- ▶ THE RECOVER BURNED AREA EMERGENCY RESPONSE DECISION SUPPORT SYSTEM CONCEPT, DESIGN, ARCHITECTURE, AND OPERATION

John Schnase

- ▶ THREE CANTED RADIATOR PANELS TO PROVIDE ADEQUATE COOLING FOR INSTRUMENTS ON SLEWING SPACECRAFT IN LEO

Michael Choi

- ▶ TRANSLATIONAL MODULATORS FOR LINEAR POLARIZATION TRANSFORMATION OPERATING VIA THE INTRODUCTION OF A VARIABLE PHASE DELAY BETWEEN RIGHT- AND LEFT-HANDED CIRCULAR POLARIZATION STATES

David Chuss, Edward Wollack, Kongpop U-Yen, Giampaolo Pisano

- ▶ USING PRE-MELTED PHASE CHANGE MATERIAL TO KEEP PAYLOAD WARM WITHOUT POWER FOR HOURS IN SPACE

Michael Choi

- ▶ WIDE BAND, DUAL POLARIZED ULTRA-LOW NOISE FOCAL PLANE ARRAY FEED FOR ACTIVE/PASSIVE MICROWAVE REMOTE SENSING

Manohar Deshpande

Patents Issued

- ▶ BLOCKING CONTACTS FOR N-TYPE CADMIUM ZINC CADMIUM ZINC TELLURIDE (CDZNTZ)

Bradford Parker, Feng Yan, Sachidananda Babu, Carl Stahle

- ▶ OTOACOUSTIC PROTECTION IN BIOLOGICALLY-INSPIRED SYSTEMS

Michael Hinchey, Roy Sterritt

- ▶ SPACEFLIGHT KA-BAND HIGH RATE RAD HARD MODULATOR

Jeffrey Jaso

- ▶ SPACE LINK EXTENSION RETURN CHANNEL FRAMES (SLE-RCF) SERVICE (USER SIDE) SOFTWARE LIBRARY

Vuong Ly, Timothy Ray

- ▶ FORMULATION FOR EMOTION EMBEDDING IN LOGIC SYSTEMS (FEELS)

Steven Curtis

- ▶ HILBERT-TFORM-BASED PHASE REFERENCING ALGORITHM FOR WIDE-FIELD IMAGING INTERFEROMETRY

Stephen Rinehart, Nargess Memarsadeghi, Richard Lyon, David Leisawitz

- ▶ LOW FREQUENCY WIDEBAND STEP FREQUENCY INVERSE SYNTHETIC APERTURE RADAR FOR 3-D IMAGING OF INTERIOR OF NEAR EARTH OBJECTS/PLANETARY BODIES

Manohar Deshpande

- ▶ FLIGHT MIRROR MOUNT AND FLIGHT MOUNTING PROCEDURE FOR AN ULTRA-LIGHTWEIGHT HIGH-PRECISION GLASS MIRROR

Thomas Wallace, Shane Wake, Scott Antonille, David Content

- ▶ CROSSED SMALL DEFLECTION ANALYZER (SDEA) FOR WIND/TEMPERATURE SPECTROMETER (WTS)

Theodore Finne, Federico Herrero

- ▶ THE CORNER CATHODE: MAKING COLLIMATED ELECTRON BEAMS WITH A SMALL NUMBER OF ELECTRODES

Federico Herrero, Patrick Roman

Provisional Patents Filed

- ▶ MINIATURIZED HIGH SPEED MODULATED X-RAY SOURCE

Keith Gendreau, Zaven Arzoumanian, Steve Kenyon, Nick Spartana

- ▶ ADVANCED PLANETARY ATMOSPHERE-MAGNETOSPHERE MASS SPECTROMETER (APAMMS): ASTID FUNDED FOR EUROPA

Edward Sittler

ICB Awards

- ▶ AUTOMATIC EXTRACTION OF PLANETARY IMAGE FEATURES

Jon Benediktsson, Sebastiano Serpico

