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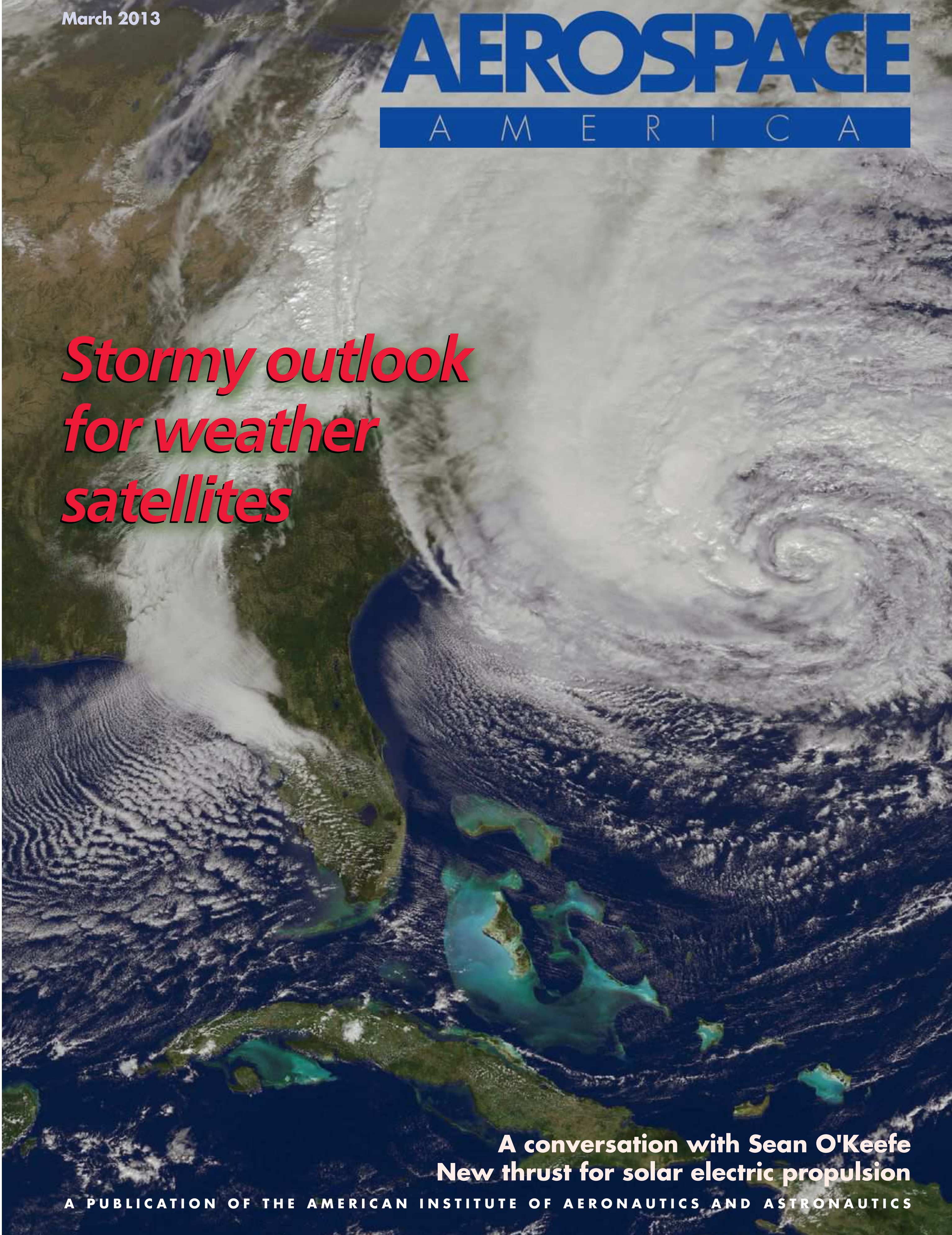

Stormy outlook for weather satellites

A conversation with Sean O'Keefe

New thrust for solar electric propulsion

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Making spaceflight greener

A MAJOR CHALLENGE FOR SPACEFLIGHT organizations worldwide is to replace as far as possible today's most commonly used liquid monopropellant, hydrazine, which has the chemical formula N_2H_4.

First used as a propellant in WW II to power Nazi Germany's Me-163 Komet rocket-powered fighter, hydrazine has fueled a wide range of spacecraft thrusters since the 1960s. However, it has a big disadvantage in that it is difficult to handle. This adds to the cost of missions that employ hydrazine (or several commonly used hydrazine derivatives) as a monopropellant or bipropellant fuel. Today these include most missions involving satellites and other spacecraft with thrusters of 1 N, 5 N, and 22 N, as well as those of 100 N or more.

Highly toxic, carcinogenic, and corrosive to living tissue, hydrazine can partially evaporate at room temperature. It can also ignite at relatively low temperatures, according to scientists at NASA Marshall. This makes fueling of spacecraft with hydrazine a dangerous, expensive, and time-consuming business. Everyone performing the fueling must wear a spacesuit-like outfit called a self-contained atmospheric protective ensemble, or SCAPE suit, as it is known in the spaceflight industry.

Because of hydrazine's high toxicity—which affected three U.S. astronauts aboard the Apollo-Soyuz mission as their capsule neared splashdown on July 24, 1975—any hydrazine fueling activity in a given facility requires the entire building to be evacuated while the work takes place. As a result, all other work on the spacecraft must stop while it is being fueled. Since the hydrazine fueling process entails six to eight different operations, it substantially slows other preparation work on the spacecraft.

In addition, says Randy Lillard, program executive for NASA's Technology Demonstration Missions Program, hydrazine's potential lethality means those who do the fueling must have a large support team in place, and substantial safety infrastructure, to prevent accidents and respond immediately to any fueling incidents. Up to 30 medical and other staff members are needed as backup personnel to support fuelers loading hydrazine into a spacecraft.

The GPIM spacecraft uses a Ball Aerospace BCP 100 platform.

Looking for replacements

In the 1990s, the Air Force Research Laboratory (AFRL) in the U.S. and researchers in Sweden independently began investigating how hydrazine might be replaced by cheaper, safer, and far less toxic spacecraft fuels that could also offer higher specific impulse values. For a fuel with a higher specific impulse, a lesser fuel flow would produce the same thrust force as hydrazine in a given time, or the same amount of fuel flow would produce a greater force.

AFRL and the Swedish researchers both identified a promising avenue of green-fuel research that focused on energetic ionic liquids (EILs). These fuels were stable at room temperature, required catalytic substrates to ignite, and burned at flame temperatures in the 1,600-1,900-C range, producing strong exothermic reactions.

The Swedes and AFRL used different routes to develop their respective green monopropellants. The European researchers used an EIL based on the salt ammonium dinitramide dissolved in water to develop a fuel now known as LMP-103S. This fuel, after igniting catalytically, burns with a flame temperature of 1,600 C. In the U.S., AFRL developed an EIL-based fuel that uses a different salt and is liquid at room temperature. Called AF-M315E, it has a much lower freezing point than hydrazine, although—somewhat inconveniently—it turns into a stable, noncrystallizing glass at very low temperatures such as those found in the vacuum of space.

Is AF-M315E the answer?

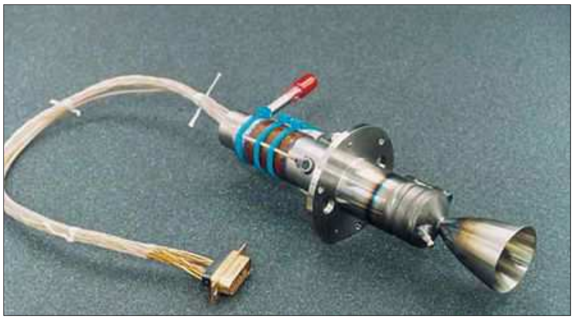
Extensive AFRL ground testing of AF-M315E established that it had a much lower vapor pressure at room temperature than did hydrazine. This meant the fuel produced very little discernible vapor at room temperature when its container was open to the air, another valuable quality. AF-M315E was also found to be far less carcinogenic, corrosive, and toxic than hydrazine.

In addition, AF-M315E did not ignite explosively, but only burned with a mild flame, when cooked in a fire. Its flame temperature in a strong exothermic reaction was about 1,800 C, yielding higher performance than hydrazine, which burns with a flame temperature of about 880 C. Like hydrazine, the fuel burned strongly only when passed over a catalytic substrate. Lillard says the proprietary catalyst used for AF-M315E took many years to develop and was "the next big hurdle" after the AFRL researchers figured out that the fuel was substantially nontoxic and much safer to handle than hydrazine.

All this was very promising. Should AF-M315E be found suitable as a hydrazine replacement for any thruster class, fueling would become a simple operation requiring much less safety infrastructure and only two or three backup staff for the fuelers, according to Lillard. The fuelers themselves would not need to wear SCAPE suits. In all likelihood there would be no need to evacuate the building during fueling, and other spacecraft preparation and loading tasks could continue throughout the process.

Ground testing using instrumented heavy thrusters also established that AF-M315E was not only about 45% denser than hydrazine, but also that its specific impulse density was about 10-15% greater. This meant AF-M315E had a volumetric impulse nearly 50% greater than that of hydrazine, according to Lillard. Assuming AF-M315E is found to be a suitable monopropellant for spaceflight-quality hardware, its higher specific impulse will mean "you can either reduce [fuel] mass or keep the mission in orbit longer for the same mass," he says.

In addition, AF-M315E's low vapor pressure enables the use of comparable or thinner tank thicknesses, which optimizes the amount of fuel available. However, one significant difference between AF-M315E and hydrazine, according to Lillard, is that while the older fuel does not corrode ferrous metals, AF-M315E is slightly corrosive to them. Accordingly, any missions using AF-M315E would need to store the fuel in nonferrous tanks in the spacecraft and burn it in thrusters made from nonferrous materials such as titanium, iridium, or rhenium. This would also be true of a successor fuel under development by AFRL that would have an even better specific impulse but be just as stable and nontoxic.



Aerojet, a member of the GPIM project, is a major manufacturer of small thrusters. This is a 22-N hydrazine thruster made by the company.

Should the U.S. space industry be able to demonstrate that a fuel such as AF-M315E can reliably and safely replace hydrazine in any of its current uses as a monopropellant for spacecraft thrusters, the results could have great economic significance, says Lillard. In the past few years, about 75% of the thrusters manufactured have been 1-N thrusters, 15% of them 5 N, 10% 20 N, and 5% of them 100 N and above. "The bulk of the thrusters built are small thrusters, which form part of almost every satellite's on-orbit propulsion system," he says.

Green Propellant Infusion Mission

In August 2012, NASA obtained authority to proceed with a technology demonstration of the high-performance AF-M315E 'green' propellant. After conducting a solicitation and peer-review selection process, NASA chose the Green Propellant Infusion Mission (GPIM) proposal from a team led by Ball Aerospace.

AF-M315E was just one of the propellants the company considered. "We went through and made the selection that we think makes the most sense for the U.S. spacecraft industry and went with it," says Ball's Chris McLean, principal investigator for the mission. The Air Force's long experience with the propellant was the biggest reason to choose it, he says. In addition, AF-M315E offers a 50% higher density specific impulse than hydrazine. Small satellites without room for adequately sized hydrazine tanks and thrusters will be able to carry the new AF-M315E system, he adds.

NASA then authorized the team to undertake the three-year development program to fly a mission in 2015 using a Ball spacecraft with small thrusters fueled by AF-M315E, not hydrazine.

Lillard says GPIM will fly as a sec-

An Aerojet lab technician handles the green fuel AF-M315E.

ondary payload on a launch vehicle. NASA was expecting to conclude by the end of 2012 its negotiations over the specific vehicle that would carry GPIM and the date it would fly. In addition, GPIM will itself probably include a small tertiary payload that will demonstrate other space technologies.

Using the already proven Ball Configurable Platform (BCP) 100, a spacecraft Lillard calls "ideal for propulsion demonstrations," GPIM will use 1-N and 22-N thrusters made by Aerojet, a highly experienced thruster manufacturer and a member of the GPIM project. Through its Space Technology Program, NASA will provide $45 million for the mission, and the various GPIM team members will provide additional cost-sharing.

Other members of the GPIM program are AFRL teams at Edwards AFB in California; the Air Force Space and Missile Systems Center at Los Angeles AFB, which will handle mission operations and the mission's ground segment; NASA Glenn in Cleveland, the agency's major center of rocket and jet propulsion research; and NASA Kennedy in Florida, where the launch is expected to take place.

Preparing for GPIM

Lillard says the three-year lead time provided by the GPIM mission's 2015 launch date is typical for space technology development programs. Ball and Aerojet will need to go through at least a couple of design cycles in developing the spaceflight-qualified, lightweight thrusters, tanks, and other hardware required to flight test AF-M315E. The hardware will need to be thoroughly tested in vacuum chambers, a process that probably will take 18 months overall. "Because launches are few and far between, you need to have rigor in the process," he says. As a one-shot mission, GPIM will have to work properly in space the first time.

While the hardware development and testing process continues, NASA will need to purchase the flight hardware. "The typical demonstration mission begins purchasing flight hardware 18-24 months before delivery to the launch vehicle so there is time to integrate and test the flight system," says Lillard. In addition, team members will need to deliver the GPIM package (and its unrelated hosted payload) to the launch operator some three to four months before the planned launch date, for integration into the launcher.

Once GPIM reaches orbit, the mission will test different burn durations and burn pulse patterns, says Lillard. The GPIM team will also allow the BCP 100 platform to sit for long periods between burns to demonstrate that the AF-M315E-fueled thrusters activate reliably and that the fuel burns normally after a long cold soak.

NASA's goal for GPIM is to optimize its investment in the mission by replacing hydrazine in its most common uses, says Lillard. The mission's main target in the nearer term is to demonstrate that AF-M315E can make hydrazine obsolete for one or more classes of small thruster. However, at this early date in AF-M315E's operational history, "We're not sure how high in thrust this AF-M propellant can go," he notes.

Ultimately, NASA hopes to make hydrazine obsolete for as many thruster applications as possible, but Lillard says the organization realizes "it is not possible to do a flight test of all the [potential] hydrazine replacements in one demonstration." Since the 1960s, the space industry has developed a multitude of thruster applications for hydrazine, not only as a monopropellant. It is possible hydrazine may never be completely replaced in space use.

But should AF-M315E perform as expected in GPIM, NASA expects the new fuel to stimulate the entire U.S. spaceflight industry. Successful GPIM testing with AF-M315E will lead to the U.S. industry gearing up to manufacture the propellant, build nonferrous hardware, and create thruster designs capable of storing and burning the fuel. As Lillard points out, NASA invests in space technology for three major reasons: to enable new missions, to stimulate the U.S. economy, and to provide new technologies to the spaceflight industry.

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