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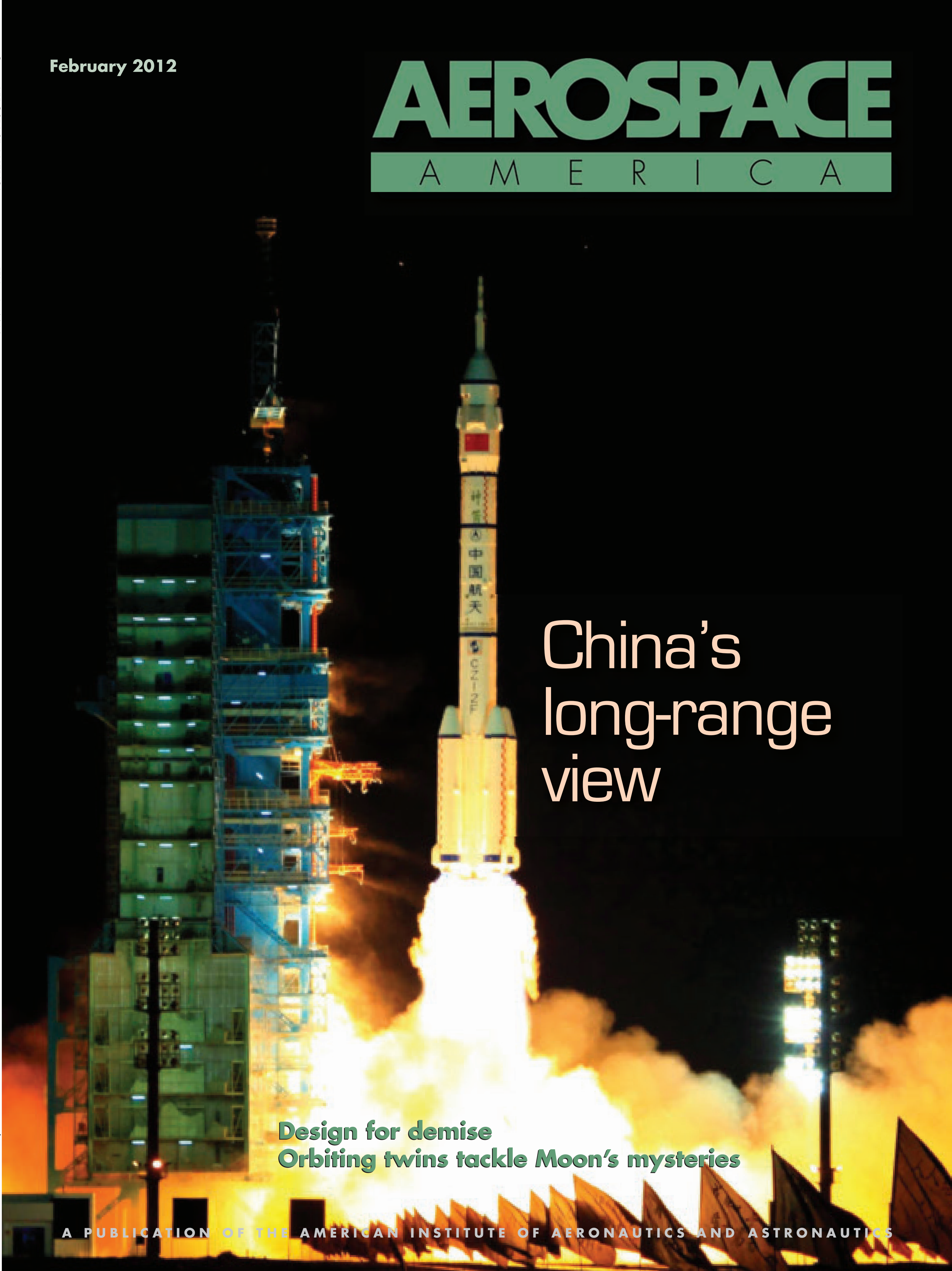
AEROSPACE AMERICA



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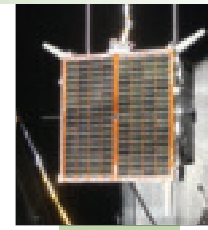
The greening of satellite propulsion



TWELVE YEARS AGO, ENERGY EFFICIENCY advocates Amory Lovins, L. Hunter Lovins, and Paul Hawken published *Natural Capitalism*, which argued that a new industrial revolution is coming, based on the reengineering of everything from automobiles and paper products to the design of homes, commercial buildings, and city cores. A key contention of the book, which has prompted energetic discussion in the environmental and engineering communities, is that waste in products can be radically reduced, and that society can benefit from new approaches to the way products are made and services managed, thus creating a positive new business model across industrial sectors.

Previous pieces in this series on green engineering have highlighted innovative, environmentally benign approaches to rocket propulsion, jet fuel, and the air oxygen and water regeneration systems onboard the ISS. We now turn to Sweden, famed for its green approach to product design, to introduce the concept of high-performance green propulsion (HPGP) for satellite operations.

A head-to-head competition

A year after the publication of *Natural Capitalism*, the government-owned Swedish Space Corporation (SSC) and Volvo Aero founded ECAPS to develop green-propulsion-based products for space applications. This followed five years of studying new propulsion concepts for small satellites with the objective of reducing cost and risk.

In August 2011, ECAPS (now a subsidiary of SSC) and Moog's Space and Defense Group (Moog is one of ECAPS' two U.S. providers of HPGP technology; ATK is the other provider) announced the results of a year-long series of in-space tests comparing their HPGP propellant, LMP-103S, and a standard hydrazine propulsion system. LMP-103S—a relatively benign blend of ammonium dinitramide, water, methanol, and ammonia that mainly decomposes into water vapor—won the head-to-head in-space competition against the hydrazine propellant, demonstrating greater performance and improved ground processing characteristics. From an environmental perspective, hydrazine, although a proven propellant for satellite operations for more than 50 years, is classified by the EPA as a Group B2, probable human carcinogen.

Prisma is mounted on the adapter and final electrical tests are performed. Image courtesy of SSC.

As a result of the test, the HPGP system achieved technology readiness level (TRL) 7, which the U.S. government defines as actual demonstration of a system prototype in space, deeming it ready for implementation on future missions. This first in-space head-to-head competition between an HPGP system and hydrazine is an important step in the development of green propulsion.

Other companies, including Boeing, Aerojet, Northrop Grumman, Ogden Engineering & Associates, and Busek Advanced Space Propulsion, have conducted significant research on green propulsion systems for space applications as well, both in Earth orbit and in human and robotic planetary exploration.

Strong in-space performance

The HPGP and hydrazine propellants were tested aboard the Mango satellite, part of a joint SSC/Swedish National Space Board project called Prisma. Its purpose was to test new technologies on two small satellites, Mango and Tango, launched in June 2010 aboard a Ukrainian Dnepr rocket from Yasny, Russia.

After analyzing the on-orbit performance of the HPGP technology and hydrazine systems, Kjell Anflo and Ben Crowe of ECAPS reported on the results at the 25th Annual AIAA/Utah State University Conference on Small Satellites in August 2011: "HPGP technology has emerged as an enabling technology for improved performance, enhanced volumetric efficiency, reduction of propellant handling hazards, and significantly shorter launch preparation operations," they said.

Moreover, according to their report, engineers found that the HPGP technology achieved, on average, an 8% higher specific impulse than hydrazine for steady-state, single-pulse, and pulse-mode firings. They also found that the increase in specific impulse combined with the HPGP propellant is 24% denser than hydrazine, and the HPGP system is able to offer about 32% more propellant than hydrazine for any mission delta-V.

A NASA analysis posted on its Ask the Academy website says that in comparison with hydrazine and bipro-

ECAPS' 1-N engine (HPGP) is tested on Prisma. Image courtesy SSC.

pellant systems, "the HPGP system falls between the two regarding the ability to change a spacecraft's velocity without increasing its complexity or the cost of the overall system." Engineers measured specific impulse onboard Mango with the help of accelerometers, GPS, and precision propellant gauging.

Ground processing benefits

The benefits of processing HPGP on the ground were also significant. While ground fueling of the more toxic hydrazine propellant required a crew of five using protective gear, supported by 20 specialists, and evacuating the fueling hall for two days, HPGP fueling required only a three-person crew, with no need for special protective gear or halting of other mission-related work. Furthermore, HPGP fueling took one-third of the time needed for hydrazine fueling. In addition, HPGP can be stored for up to 20 years.

Faster, easier fueling is important, notes Paul King, engineering manager for spacecraft fluid controls at Moog's Space and Defense Group. "For example," he says, "when you start getting into applications like an ESPA [EELV secondary payload adapter] ring, where you are populating a bus with six satellites that are all propulsive, you don't want several days of not being able to do things in parallel while you are doing the propellant loading."

King also points out the significance of the HPGP flight test from the in-space performance level: "It's one thing to state you have a green technology, but unless you can actually provide meaningful performance, the green part of it will be kind of thrown aside, because there's a technology out there right now, hydrazine, that provides a certain level of performance accepted by the industry. They [ECAPS] had to find that balance point of saying, 'Hey, we can not only offer you something that's green, but it also can perform to a level equal to or better than hydrazine.'"

King goes on to explain that leading up to the test, "The two fundamental things that were developed were a new fuel that balances the green aspects vs. performance, and a thrust chamber and catalyst that would be able to use that fuel. These went hand in hand. Because HPGP operates at a higher temperature, a new thrust chamber had to be developed, and a new alloy was brought into play to handle the higher temperatures; a new catalyst was also developed to be able to decompose it and operate at those high temperatures."

ECAPS definitely believes the market niche for green satellite propulsion technologies is promising. Anflo notes that the "Swedish National Space Board is particularly interested in low TRL developments that have the potential to be a game changer, in terms of cost reduction in the long run, for users of space infrastructure. HPGP fits well with this ambition."

Anflo adds that while the Mango HPGP propellant had a small, 1-N-thrust capability, "development and hot firing tests of 5-, 22-, 50-, and 220-Newton HPGP thrusters have been ongoing for several years, and they have reached various TRL levels. The development of a 400-N thruster is currently being assessed [for maneuvers requiring large thrust by geosynchronous satellites]. As the propellant has been formulated and verified to be compatible with most hydrazine commercial-off-the-shelf components, there are no major issues with respect to using existing equipment.

"Discussions with several potential users are ongoing to establish flight opportunities for these thrusters." King says that qualification of a 5-N thruster can be expected within the next 18 months, with a 22-N thruster soon to follow. Both are now at a TRL of 4 or 5. "That puts us into a near-term focus on smaller satellites on the order of, say, 40 kg up to maybe 1,000 kg."

A more 'European-centric' reason for ECAPS' interest in HPGP, observes Anflo, is that the "European Chemical Agency, the driving force among regulatory authorities in implementing the EU's chemicals legislation for the benefit of human health and the environment, has identified hydrazine as one of 53 substances to be of high concern. This will lead to severe restrictions and a possible ban for using hydrazine in the future, especially if an alternative exists."

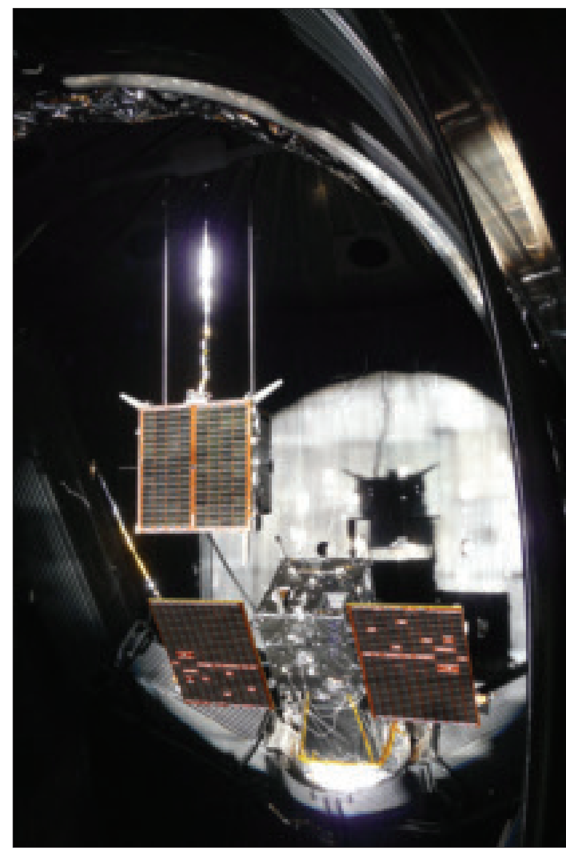
NASA interest

In the U.S., NASA's Office of Chief Technologist, Crosscutting Technologies Division, is funding a study of HPGP technology at Ames. "NASA is interested in green propulsion technologies," says Hugo Sanchez, aerospace engineer for flight systems at Ames. "Based on the study, HPGP has the simplicity of a traditional monopropellant, equal or greater ISP, and a higher density. For the same mass or volume, you can create more thrust, more delta-V. We know how traditional monopropellants react, and we know how to handle them, but they are hazardous. By studying green propellant technology, NASA may open doors for other institutions such as universities and small businesses that just can't afford to invest money in hazardous propellant management."

Future uses

Future applications of HPGP will include its use on Proba-3, the third in ESA's series of formation-flying satellite missions for validating developments of new space systems. ECAPS' 1-N engines are baselined in the design of two satellites for the commercial Cicero atmospheric and surface remote-sensing mission. King has said that since the successful PRISMA test, several satellite prime contractors and government agencies, including NASA and the DOD Operationally Responsive Space (ORS) Office, have shown interest in HGPG for technology demonstration missions and multisatellite constellations. "ORS is interested in HPGP because this is another piece of the puzzle that can help them get to a faster response for getting payloads into orbit," says King.

As to the prospect of greater federal investment in the technology, he says, "It would definitely help if there were programs pushing for it. We've done it in Europe, but playing in the U.S., you've got to find that first foothold, someone saying, 'Yes, we're going to fly that here as well.' It will probably be a technology demonstrator the first time out. NASA's Office of the Chief Technologist is studying the potential demonstration of HPGP on a mission called Planetary Hitch Hiker under the agency's Edison program.



Mango and Tango shine in the sunbeam of the space simulator in early 2009. The test's main purpose was to calibrate the thermal mathematical model, but also to check system functions. Image courtesy SSC.

"Developing green propellants could change the tide," says Sanchez. "You can affect not only the agency's future, but potentially the industries' future, hopefully for the better. It's an exciting first step. As soon as that mission is realized, it's exciting to think about the potential applications that will be enabled in the future."

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