The·future·of rocket

RPI

A model of a lightcraft, illuminated from below by a laser beam.

In an era of rapid technological innovation, it is amazing how some technologies have almost stood still during that time. The latter half of the 20th century saw incredible improvements in computing, communications, and biotechnology, among other fields. This has enabled everything from the mapping of the human genome to the development of the Internet.

The same is not true, though, for launch vehicles. Although spacecraft have revolutionized everything from communications to weather forecasting, the rockets that launched those satellites have seen only relatively modest changes since the beginning of the Space Age. While there have been considerable technological improvements to rockets over the years, those changes have been evolutionary in nature: a modern-day Ariane, Proton, or Delta, or even the space shuttle, has far more in common with the R-7 that launched Sputnik 1 in 1957 than one might expect.

As a result of this technological stagnation, space remains nearly as inaccessible today as it was at the dawn of the Space Age. Rockets are complex, temperamental beasts with little margin for error: the failure of a key component at an inopportune time can result in the loss of the rocket and its payload. This helps keep the price of space access so high — up to $10,000 a pound — that it becomes the primary barrier to the exploration and development of space. For those exposed to science fiction images of people gallivanting across the galaxy using warp drives or hyperspace, the lack of progress can be very frustrating and depressing.

This is not, however, an intractable quandary. Launch vehicles have stuck with the same type of chemical propulsion systems used for decades because of the lack of alternatives that can get spacecraft into space effectively. Now, though, there are several promising lines of research into advanced propulsion technologies — some ripped from the pages of science fiction — that may one day supplement or replace chemical propulsion. These technologies could reduce the cost of space access by a factor of 100 and open up Earth orbit and the solar system to exploration and settlement.

Advanced Chemical Propulsion

The current focus of NASA's Space Launch Initiative is the development of a "second-generation" reusable launch vehicle (the space shuttle is a first-generation RLV.) Those vehicles would likely use engines closely derived from existing systems, like the aerospike engine developed for the now-cancelled X-33. However, the space agency is also looking at more advanced chemical propulsion technologies for future third-generation RLVs.

Among the technologies under investigation are replacements for the propellants currently in use, like liquid hydrogen, kerosene, and liquid oxygen. One possibility is a high-performance monopropellant to replace the separate fuel and oxidizer propellants in use today. Such systems could reduce the complexity of propulsion systems by eliminating much of the tankage and plumbing needed for dual-propellant systems. NASA is also looking at possible replacements for kerosene, the primary non-cryogenic fuel used by launch vehicles. Some alternatives could provide higher performance than kerosene and would also be denser, allowing for smaller propellant tanks.

The use of liquid propellants at all is being reconsidered. One NASA effort is investigating the use of gaseous propellants. A combined-cycle pulse detonation engine would combine gaseous hydrogen and oxygen without the need for complex,

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By Jeff Foust

science

expensive turbopumps used on conventional engines. Moreover, such an engine could get the oxygen it needs directly from the atmosphere at low altitudes, reducing the amount it would have to carry onboard.

While such technologies may not be ready for the second generation RLVs to be built in the coming decade, Denny Kross, director of the Space Transportation Directorate at NASA's Marshall Space Flight Center, believes it is important to work on these advanced technologies now. "It's important to do research today to support third-generation RLVs, so that when the time comes, we'll be ready," he says. "If we just focused on second generation RLVs, our investment would be shortsighted."

Moreover, it's possible that some breakthroughs with these advanced technologies could have near-term benefits. "My prediction is we're going to make discoveries in third-generation research that will pay off earlier," says Kross.

Lightcraft

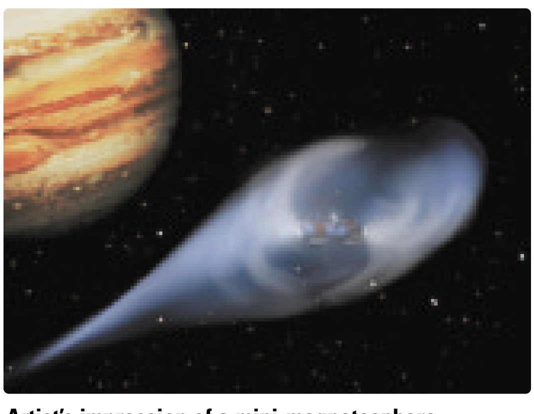
Advanced chemical propulsion is not the only solution, however. A key focus of a number of research efforts is with doing away with propellant altogether, at least in the conventional sense. One such project would use ground-based lasers to accelerate payloads into orbit. Such a "lightcraft" would use air itself as the propellant for much of its flight. The forward section of the specially-shaped vehicle would compress air into an engine inlet. The rear section of the lightcraft would reflect laser light into an annular focus, heating the air. The heated, expanding air would push against the lightcraft, providing the thrust needed to accelerate it. At higher altitudes the air will become too thin to generate sufficient thrust; the vehicle would then switch to a small supply of onboard liquid hydrogen to fly the rest of the way to orbit.

The key advantage of a lightcraft is that it carries virtually no propellant: only about 1 kilogram of liquid hydrogen would be needed to place spacecraft weighing up to 100 kilograms into low Earth orbit, using a 100-megawatt ground-based laser. Such a system could reduce launch costs by a factor 50.

The pioneer of such lightcraft, Leik Myrabo of Lightcraft Technologies, has been working on the technology since the 1980s, and has successfully flown a number of small-scale test models. In October 2000 one such vehicle flew 71 meters high during a 13-second test flight, the best test flight to date. The vehicle, 12.2 centimeters in diameter and weighing 51 grams, used a 10-kilowatt laser at White Sands, New Mexico. Myrabo hopes to increase the altitude of the test flights to 150 meters or more in the coming months. Such systems could eventually be scaled to carry larger cargoes and even people into space.

Solar Sailing

Solar sail propulsion is one advanced technology whose time may have finally come. The concept of harnessing sunlight to propel a spacecraft dates



University of Washington

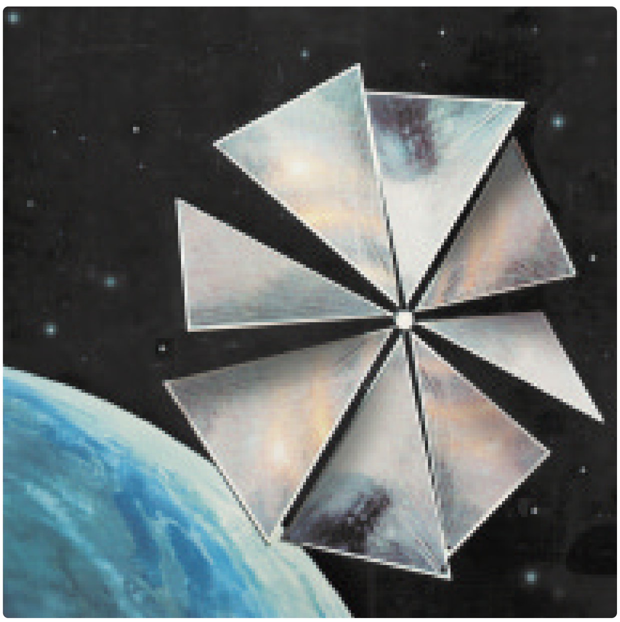
Artist's impression of a mini-magnetosphere deployed around a spacecraft.

back to the 1920s, when spaceflight pioneer Konstantin Tsiolkovsky proposed a spacecraft that used large but thin sheets of mirrors to reflect sunlight for travel over interplanetary distances. In the 1970s NASA considered using a solar sail on a mission to Comet Halley, but that mission was later cancelled. Efforts in the 1980s to organize a solar sailing race by teams in the U.S., Soviet Union, and France eventually sputtered out because of a lack of funding.

Prospects for solar sails have been on the upswing in the last year, however. In early 2001 The Planetary Society, in conjunction with Cosmos Studios and Russian aerospace firm Babakin Space Center, announced plans to fly a solar sail prototype, Cosmos 1, in Earth orbit. The sail, composed of eight blades of aluminized Mylar spanning 30 meters, will be deployed after the 40-kilogram spacecraft is placed in Earth orbit by a sub-launched Volna rocket. The sail will then be used to gradually move the spacecraft into a higher orbit over the course of the mission, scheduled to last several weeks.

"This could be a pivotal moment for space exploration," says Louis Friedman, executive director of the Planetary Society and the Cosmos 1 project director. "Solar sailing is a grand adventure as well as an important leap in technological innovation."

Cosmos 1 suffered a setback in July, though, when a suborbital flight designed to test the deployment mechanism for the solar sail failed. The problem was traced not to the sail itself but to a glitch with the third stage of the Volna rocket that prevented the spacecraft from separating. The project announced in August that it will forego another suborbital test flight and instead launch the full solar sail in early 2002.



Babakin Space Center, The Planetary Society

An illustration of the Cosmos 1 solar sail deployed in orbit.

Cosmos 1 is not the only solar sail project in the works. Team Encounter, a company headed by veteran space entrepreneur Charles Chafer, is planning its own privately-funded solar sail mission in 2004. The spacecraft would be launched into Earth orbit as a secondary payload on an Ariane 5 booster, and then propelled out of Earth orbit by a solid-propellant engine. It would then deploy a square Mylar sail, 70 meters on a side, that will accelerate the spacecraft to escape velocity, sending it out of the solar system.

Unlike Cosmos 1, which is primarily a technology demonstration mission, the Team Encounter spacecraft is using a solar sail to enable its main mission: carrying messages, images, and even DNA samples of up to 4.5 million customers beyond the solar system. "We're merging the desire that millions of people have to go into space with some really advanced technology, such as solar sails," says Chafer.

NASA is also investigating solar sails. Space Technology 7, part of the agency's New Millennium Program to flight test advanced technologies, will test a solar sail on a flight scheduled for 2004 or 2005. In July the program selected several contractors, including JPL, Arizona State University, and Swales Aerospace, to begin concept studies for the sail. Those involved with private solar sail efforts realize NASA can bring a lot of resources to bear on the project, if they so desire. "We're a little bit ahead of NASA right now," says Team Encounter's Chafer, "but I expect they'll catch up with us pretty quickly."

M2P2

Solar sails work best in the inner solar system, where sunlight is strongest. Beyond the orbit of Jupiter the amount of sunlight available per square meter drops to a point where solar sails are no longer effective. Some have proposed turning the solar sails into "light sails," illuminated by Earth-based lasers that can continue to propel the sail through the outer solar system. Depending on the size of the sail and the amount of additional velocity needed, this may require very large, powerful groundbased or spacebased lasers.

Another type of sail, however, may provide even faster propulsion through the outer solar system

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A time-lapse photo of a nighttime test of a lightcraft model at White Sands, New Mexico.

without the need for an external power source. Scientists at the University of Washington have been investigating the ability of a magnetic sail — in essence a miniature version of the magnetosphere that surrounds the Earth and other worlds — to propel spacecraft at extremely high speeds through the solar system.

The core of the Mini-Magnetosphere Plasma Propulsion (M2P2) system is a strong magnet mounted on a spacecraft. A plasma chamber on the spacecraft would generate a flow of superheated charged particles to inflate the magnetic field into a bubble up to 40 kilometers across, creating a miniature magnetosphere. Charged particles from the Sun, travelling at hundreds of kilometers per second, would reflect off the magnetosphere, transferring force to the spacecraft and pushing it forward, in much the same way that light reflecting off a solar sail moves it ahead.

Unlike a solar sail, however, an M2P2 system would work well in the outer solar system, and at much higher velocities: a small spacecraft using an M2P2 system could travel at up to 80 kilometers per second. Such a spacecraft could travel from the Earth to the edge of the solar system in just a few years.

M2P2 garnered considerable attention a couple years ago when the concept won a research contract from NASA's Institute for Advanced Concepts. Since then project scientists have conducted vacuum chamber tests of small-scale versions of magnetospheres. Robert Winglee, the University of Washington professor leading the project, says that laboratory measurements of the magnetic field inflation closely match their theoretical predictions. "I believe we are firmly on track," he says. "We hope over the next year to measure the thrust achievable by the prototype."

Breakthrough propulsion physics

While solar sails and mini-magnetospheres may seem like the stuff of science fiction, they are based on conventional, well-understood physics. At the fringes of our current state of knowledge, however, lie tantalizing concepts that may be able to revolutionize spaceflight. For the last several years, NASA's Breakthrough Propulsion Physics (BPP) Project, headquartered at the Glenn Research Center, has been supporting several lines of research into advanced physics concepts, ranging from quantum vacuum energy to antigravity.

In 1999 the BPP Project received 80 proposals to investigate various lines of research into advanced propulsion physics; the project funded five. The results of those research efforts have been mixed: some concepts have shown promise, while others are either still inconclusive or have been ruled out. Marc Millis, the former BPP project manager, is satisfied with the progress to date. "Things take longer than you hope, but that happens with about everything," he says. "What has been nice is the clarity we are getting in some of the work, regarding what lines of research may be dead ends and the difficulties people encounter."

The project is in the process of establishing a BPP Research Consortium at the Ohio Aerospace Institute that will help run the project and also foster collaboration with universities and other research centers. The consortium should be up and running by the end of 2001, according to current BPP project manager Peter Ouzts, and will issue a second call for research proposals in the first quarter of 2002.

Some have wondered whether NASA should be devoting any resources at all to such projects, given that the payoffs from the science being investigated by the BPP Project is many years, if not decades, down the road. Millis notes that the project requires only a small amount of funding: about $500,000 a year, a tiny fraction of the hundreds of millions a year budgeted for the Space Launch Initiative.

"To not address these things at all would be an omission," he says. "Who's to say that one of these anomalous physics effects isn't something that could one day be turned into a solution to overcome the current limitations of launch technology?"