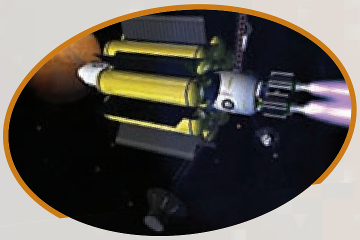

A hot rod for the

A plasma rocket concept that could drastically reduce travel time to deep space destinations passed an important milestone late last year that could lead to testing of the system on the ISS by 2012. If early experiments are successful, such a rocket could someday cover the distance to Mars in little more than a month's time.

If your idea of an advanced rocket factory does not include swaying palm trees, sun-drenched skies, and low overhead, then maybe you should get out more. Far down south, in fact, to the tranquil soil of Costa Rica. There, in a small plant a stone's throw from an airport linked to the U.S. mainland, the employees of Ad Astra Rocket are hard at work on a radical new engine design.

The concept, a plasma rocket called the VASIMR (variable specific impulse magneto-plasma rocket), holds new promise not just for commercial applications in LEO and cislunar space, but also for drastically reducing the transit time between the Earth and deep space destinations such as Mars or the asteroid belt.

The path to VASIMR began more than 30 years ago as the brainchild of Franklin Chang-Diaz, then a graduate student at MIT, where he earned a doctorate in plasma physics. In 1980 he continued to refine his idea at the Charles Stark Draper Laboratory and MIT's Plasma Fusion Center.

Chang-Diaz joined NASA as an astronaut in 1980 and flew seven missions aboard the space shuttle, including a flight to the ISS. From 1993 to 2005 he served as director of NASA Johnson's Advanced Space Propulsion Laboratory, where he refined the plasma rocket concept. In 2005 he left Johnson to form Ad Astra Rocket, with test facilities near the space center and in Costa Rica, his birthplace. NASA Johnson and Ad Astra worked jointly on the VASIMR design, forming a more structured partnership announced in 2008.

A different kind of rocket

All rockets achieve propulsion by expelling exhaust—action and reaction, Newton's Third Law of Motion. In the case of chemical rockets, the exhaust is usually a gas expelled from a specially designed nozzle. Typically it is expelled at great heat and at a high temperature relative to the rocket's structure. A chemical, or thermal, rocket carries fuel on board in the form of either liquid or solid materials, along with an oxidizer that burns the fuel in a controlled combustion. The combined fuel and

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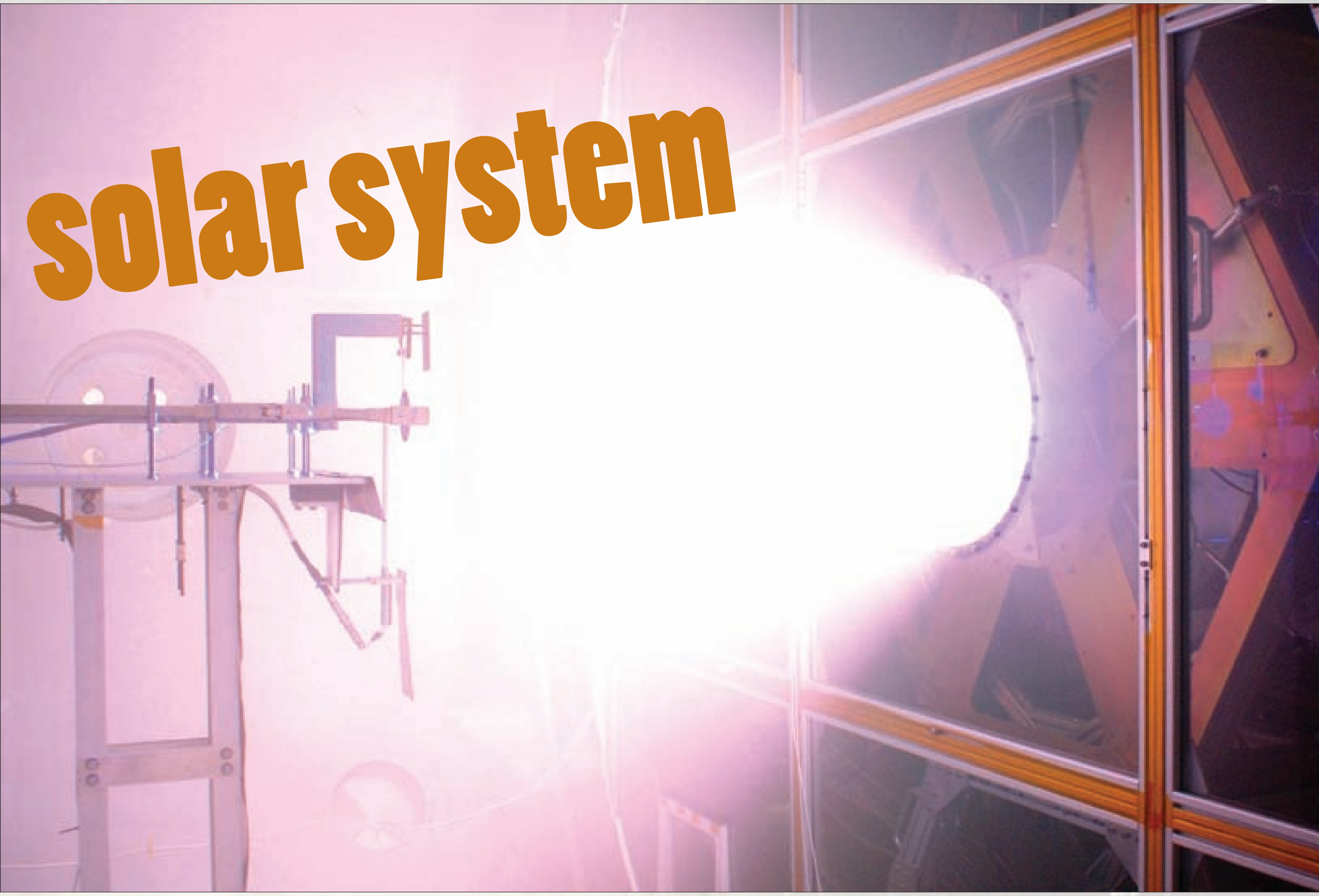


The plasma plume exits the rear of the rocket at extremely high temperatures and speeds.

oxidizer make up most of the vehicle's weight; its structure and usable payload account for the relatively small remainder.

The exhaust velocity generated by chemical rockets is powerful enough for lifting the rocket vehicle into space to speeds that allow escape from the Earth's gravity field. But the velocity achieved does not make for high-speed travel, and the flow rate of the burning of the propellant usually is so high that most of the chemicals are consumed in the early stages of powered flight.

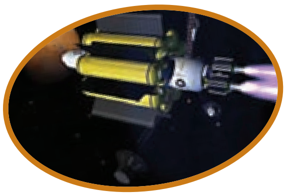
But engineers have been able to create much higher exhaust speeds using a plasma-powered rocket. Here, a gas is heated by means of electrical energy, producing an electrically charged exhaust, or plasma plume. Temperatures of plasmas usually exceed 10,000 C, but in laboratory test beds they are sometimes much higher, comparable to that of the interior of the Sun. Because no known structure could withstand these temperatures, a plasma rocket "delivers" its exhaust by means of a magnetic or electrical field that is used to control, heat, and direct the plasma plume created by the heating of feedstock gas such as hydrogen or argon.

Via a special type of engine magnetic nozzle, the plasma plume exits the rear of the rocket at extremely high temperatures and speeds, an order of magnitude higher than those produced by a chemical rocket engine.

In lieu of chemical energy, the plasma rocket requires large amounts of electrical energy to produce and heat the plasma and produce thrust.

The VASIMR

The rocket engine design consists of three linked magnetic cells. The plasma source cell contains the main injector of a gas and the ionization system that converts it into a plasma plume. The RF booster cell acts as an amplifier that further energizes the plasma to the temperature desired for the mission, using electromagnetic waves. The magnetic nozzle cell converts the energy of the plasma ions into directed motion and thrust.



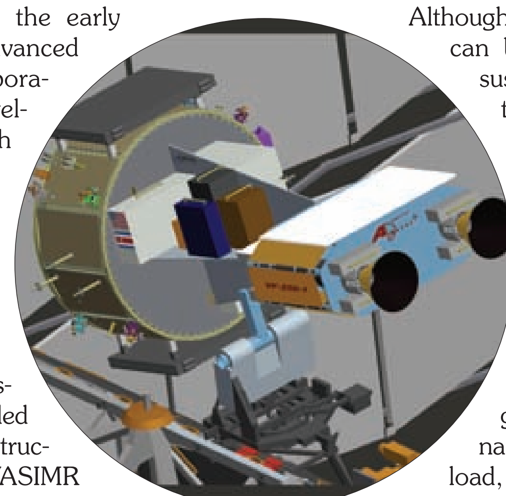
In the overheated gas plume, electrons, which hold a negative charge, and ionized atoms, which hold a positive charge, are mixed together to produce a "soup" of charged particles called a plasma. No known rocket structure could contain the temperatures produced by the electromagnetically charged plasma. This job is performed by the engine's magnetic field.

Chang-Diaz notes that the VASIMR's ability to vary its thrust and specific impulse is unique to electric plasma rockets. The engine is controlled by electromagnetic waves and thus has no electrodes that contact the hot plume. This, he says, results in a safer combustion process and higher reliability as compared to other chemical or plasma rockets.

For LEO missions, solar array technology would be sufficient to produce the electricity required. For long-duration deep space missions, thermonuclear power systems would be required. A 200-MW version of the VASIMR with extreme temperature plasma exhaust could propel a manned spacecraft from the Earth to Mars in about 39 days, a fraction of the 7-10-month-long one-way trajectories typical of chemical rocket propulsion.

Test and engine evaluation

In the 1990s, during the early years at the NASA Advanced Space Propulsion Laboratory, the project developed partnerships with a number of universities and the national laboratories at Oak Ridge and Los Alamos. These relationships resulted in advances in understanding the controlling physics of the concept and led to the design and construction of the VX-10 (VASIMR experiment at 10 kW), which derived from the early MIT experiment and became the first experimental physics test bed at NASA.



The company plans to take a flight test version of the VX-200 to the ISS for test firings.

Then, in 2005, the newly formed Ad Astra Rocket Company took the project from NASA, upgraded it to 50 kW (the VX-50), and tested new technologies in antenna design and solid-state radio frequency power generators. These experiments led to the VX-100, a 100-kW test engine built in 2007 that used a magnetic field created by conventional water-cooled electromagnets. Each of the magnet's coils consisted of hollow copper conductors wound around a composite mandrel. The magnets were inexpensive and durable, could be switched on and off quickly,and did not need to be cooled to cryogenic temperatures.

Inside the magnet bore, a helicon plasma generator and an ion cyclotron plasma booster produce and heat the plasma respectively by means of electromagnetic waves. Individual components could be easily replaced, developing a test-bed record for system performance and durability. These results were factored into the development of the more powerful VX-200, a 200-kW system that went into operation in May 2007.

Unlike the previous experiments, the VX-200 is much more flight-like, featuring a superconducting magnet and integrated systems in an engine package that operates in a vacuum. Partner Nautel of Canada provides the solid-state RF generators; the superconducting magnet was manufactured by Scientific Magnetics of Oxford, U.K. The system also tests prototypes of onboard computer control software and hardware. Testing is done in the 150-m^3 vacuum chamber "El Monstruo" at the company's headquarters in Houston.

Missions

Although the plasma rocket engine can build to high-temperature sustained thrust, its low thrust-to-weight ratio makes it unsuitable for use as a booster stage engine to lift a rocket and payload from the ground into orbit. Instead, VASIMR is envisioned for use in upper-stage rocket designs, propelling cargo to in-space destinations such as geosynchronous orbit or lunar escape, where a high-payload, albeit prolonged, multimonth cruise to the Moon is more economically attractive than the conventional chemical approach.

"We aim to fill a developing high-power transportation niche for orbital maintenance for the maneuvering of satellites and positioning of large space structures for commercial space projects, such as space hotels or space tourism," Chang-Diaz says.

Ad Astra plans to take up a flight test version of the VX-200 for test firings at the ISS. The rocket and its associated battery system would be launched aboard either the Orion crew exploration vehicle or a COTS derivative, using a commercial launch booster to reach and rendezvous with the ISS. Diaz says the unit could also be packaged for launch aboard the space shuttle if they are still in use. But a commercial lift to the ISS—or Orion—seems like the more likely vehicle to take the VASIMR into space for the first time, possibly as early as 2012.

The VF-200-1 flight engine will consist of a pair of 100-kW units with opposite magnetic dipoles to have a "zero torque" magnetic system. Electrical energy will be provided at the ISS, stored in batteries carried aloft with the rocket unit and used to fire up the test unit at the station, throttling to 200 kW of power.

Partnerships with NASA

"We see it as the type of project that is a perfect partnership with commercial space companies," says Michele Brekke, director of innovative partnerships at NASA Johnson. Brekke says NASA has been studying ion and plasma rocket engines since the 1980s, with Glenn developing the ion engine for spacecraft propulsion on interplanetary probes.

On December 8, 2008, following years of work between the company and NASA Johnson, the agency announced an agreement defining the terms of the spaceborne test flight. Under the structure of a Space Act Agreement, NASA and Ad Astra will develop the flight test version of the VF-200-1 under what Bill Gerstenmaier, NASA associate administrator for space operations, called a series of performance "gates." These were built into the agreement to allow the parties "to assess the requirements on an incremental basis while at the same time proceeding to flight.

After completion of the developmental milestones set forth in the agreement, such as sustained test firings in a vacuum chamber simulating space conditions, the VASIMR would be flown to the ISS. A specially trained station crew would install the rocket on an ISS truss. The engine would be ignited and fired up to varying power levels, with a maximum of 200 kW. Each engine burst will be restricted to 10 min at maximum power settings, with the batteries trickle-charged from ISS power stores.

At some point during the test firings, the VASIMR will be used to demonstrate a station reboost capability, much like that performed by the Russian Soyuz and Progress and the European ATV. "This will be the first time a high-power electric rocket thruster has been used on a manned spacecraft," says Diaz.

Ad Astra will be responsible for designing the training procedures for the station crew, and will work at Johnson to prepare the astronauts for the flight. "We haven't manifested [the VASIMR] yet, but a flight in the 2010-2012 period is probable," Brekke says. She also says that Johnson and Chang-Diaz are still early in designing the training protocols for the project. Following a successful ISS demonstration, the unit would be ready for commercial deployment.

Reaching a milestone

Late in 2008, the engine test bed reached a major development milestone. Using argon gas as the propellant, the VX-200 first stage reached a full power setting of 30 kW at the Houston facility. The helicon first stage generates the initial plasma that is subsequently accelerated by the second stage to produce the sustained thrust.

With the milestone achieved, the engine's 170-kW ion cyclotron resonance heating second stage was integrated with the first stage. The second stage completes the heating process and expels the plasma plume out of the rear of the rocket in a sustained, controlled thrust. The first stage's 30 kW and the second stage's 170 kW combine to produce the full 200 kW of power. As of this writing, the VX-200 has achieved a record total power of 149.2 kW in tests. In contrast to a chemical multistaged rocket, in the VASIMR both stages fire nearly simultaneously.

Chang-Diaz defined the test milestone as a major challenge for his design. It marked an

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absolute record for power, using the RF solid-state power generator developed by Nautel, which also makes the RF generator for the second stage. “We worked for weeks to integrate the first and second stages,” he explains. New computer algorithms were developed to control and stabilize the plasma.

“Another challenge was the startup phase, because of the extreme changes in the electrical environment that accompanies the initial plasma,” he says. The new control algorithms “overcame these difficulties” and allowed the power ramp-up to continue. These new control systems will be used extensively in the continued evolution and development of the more powerful second-stage system.

Testing is done in the company’s facility in Houston, Texas.

Long-term prospects

Chang-Diaz points to the series of commercial space projects now in development that could make use of the VASIMR system to maneuver and position large space structures, or carry cargo packages to the lunar surface.

“For lunar missions without humans on board, a slow cruise using very small amounts of fuel but sustained thrust would be an effective way of moving large payloads between the Earth and a lunar base,” he predicts. He also says the Moon’s surface would be an ideal place for a VASIMR test facility, to mature the the multi-megawatt engines required for deep space human missions.

And if the U.S. ever decides to begin planning seriously for humans to travel to Mars, the VASIMR might well be ready for use. The former astronaut and bona fide rocket scientist is optimistic. After all, he points out, Ad Astra means “to the stars.”