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# AEROSPACE AMERICA

## Flying farther on less

## From visions to voyages

## Juno to Jupiter: Piercing the veil

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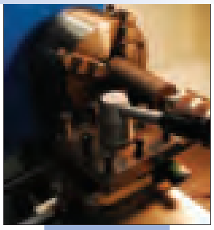


# Microwave launch idea heats up

A credit-card-size piece of graphite in a lab at NASA Ames could be the start of something big in the world of rocketry.

The graphite is being tested as a potential linchpin in a concept called microwave thermal propulsion, which calls for focusing microwaves onto the belly of a rocket to heat hydrogen fuel coursing through its walls. The heat would increase the pressure of the hydrogen, and the resulting hot gas would shoot out a nozzle, generating thrust without combustion.

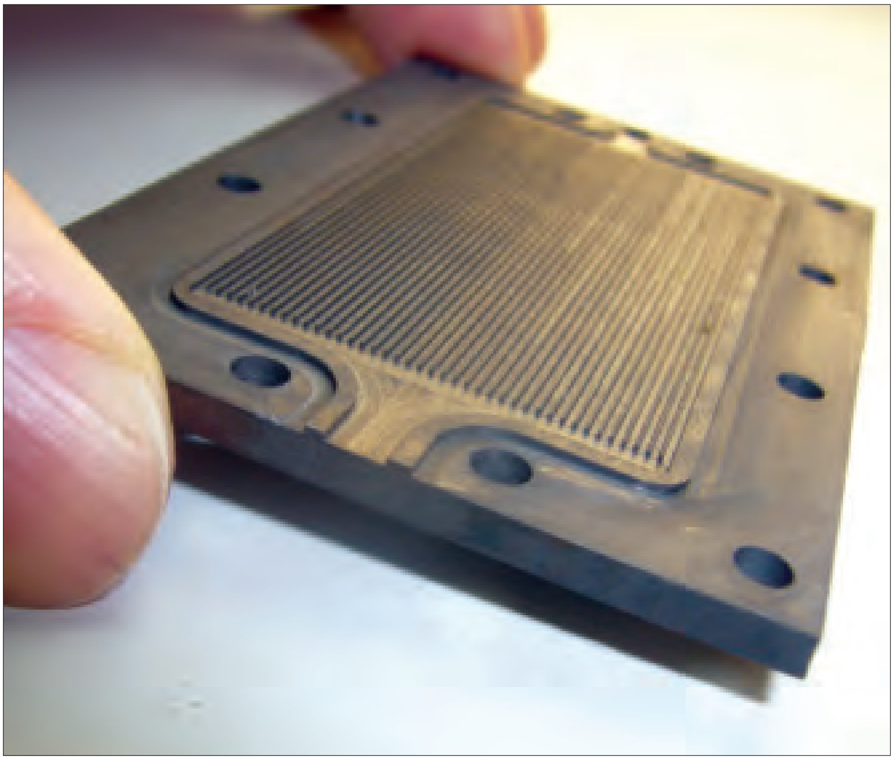
Exploring the concept is a loose alliance of physicists, students, and engineers from Stanford University, Carnegie Mellon, and the startup company Escape Dynamics, which is funded by one of the founders of the Quiznos restaurant empire.

However, if the rocket industry is about to witness a revolution, it is one at its earliest stages.

### Uncomplicated, safe

David Murakami, a Ph.D. candidate at Stanford, is conducting thermal tests on the piece of graphite using a 20-kW theater lamp. Ceramic is another potential material for the device, called a heat exchanger. Whichever material is chosen, it must be able to withstand temperatures of 2,500 K to generate the required thrust. If graphite turns out to be the material of choice, Murakami or other engineers would have to figure out how to manufacture channels into it and fill them with helium as a surrogate for hydrogen. The subscale heat exchanger would have to prove the feasibility of transferring heat to hydrogen fuel with the required efficiency.

*Channels are machined into a credit-card-size segment of graphite for subscale testing. (Photo credit: David Murakami and Kevin Parkin.)*



For now, the name of the game is simplicity and safety. "We're using helium because that's almost as good a working fluid as hydrogen, with the benefit that it won't explode," explains Murakami.

While Murakami's tests are under way, officials at NASA and DARPA are discussing the concept's funding future. In January, advocates of microwave thermal propulsion finished contributing information to NASA Ames, which is working with DARPA on a review of options for externally powered rockets.

Microwaves and lasers are considered the most viable options. In the 1960s and early 1970s, engineers conducted ground tests to show how hydrogen could be heated by a nuclear reactor, in a project called NERVA (nuclear engine for rocket vehicle application). Linking the concepts is a desire to generate thrust without lugging oxygen aboard a rocket for combustion.

So far, NASA Ames has provided initial research funds for the microwave concept through a cooperative agreement with Murakami's mentor, physicist Kevin Parkin of Carnegie Mellon. As a graduate student at Caltech in 2002, Parkin had become convinced that microwaves were the best option for externally propelled rockets, and the idea was the subject of his 2006 Ph.D. thesis.

"I was looking at many different ways of getting to orbit and trying to pick something that had a big performance increase and was near term, and [I] arrived at microwave thermal rockets that way," he says. "We're trying to demonstrate all of the things we need to demonstrate at very low cost and small scale, and build things up incrementally that way."

### A 'no brainer'

Parkin's microwave thermal research is funded by NASA, but the physicist is also a volunteer adviser to Escape Dynamics. The company was founded in 2010 by Dmitriy Tseliakhovich, a doctoral candidate at Caltech, and Richard Schaden, cofounder of Quiznos.

"Right now, we're all privately funded," says Tseliakhovich, but "we are looking for partners in research institutions and academia for 2012."

Tseliakhovich went to Canada from Belarus and now hopes to become a U.S. citizen. As an entrepreneur and scientist, he looked at the state of the technology and concluded that microwaves were the most promising option. He approached Parkin for help.

Tseliakhovich's opinion about microwaves came down to dollars and cents. After examining today's energy sources, the choice of microwaves was a "no brainer," he says. "Lasers require much more subtle and complicated control optics. Microwaves cost at least 100 times less than energy in the laser beam," he explains.

Which is not to say the system will be easy to develop. After years of studying and drafting papers on the physics of microwave thermal propulsion, the alliance knows it must prove the key elements of the system. "We need to show delivery of power from source to heat exchanger, and transferring this energy efficiently enough in the power of the jet," Tseliakhovich explains.

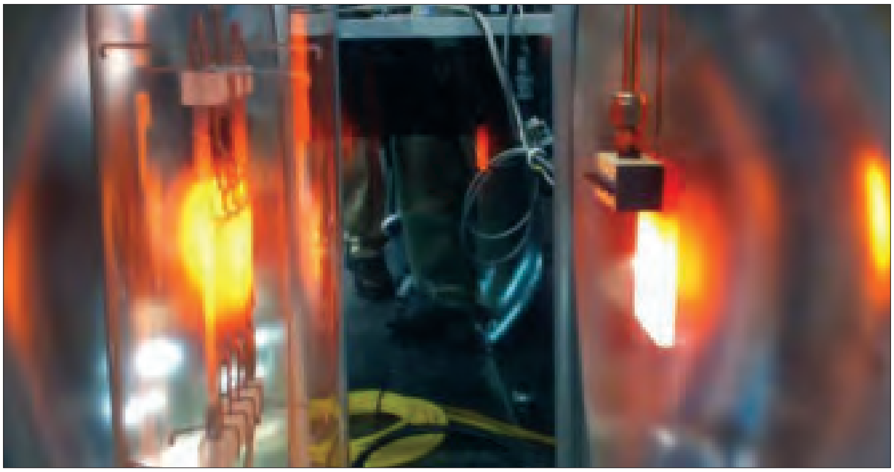
## Keep it simple

The alliance's strategy is to remove as many technical challenges as it can from its proposed design. In the first iteration, a rocket would be airdropped from an altitude of about 20 km to avoid the problem of heating the rocket at liftoff, says Parkin.

Projecting microwaves at low altitude would be difficult, because objects on the ground would reflect the energy. So, for the first stage of the ride to orbit, "We're looking at some sort of variation on Global Hawk or WhiteKnightTwo as a carrier vehicle," says Parkin.

The alliance has not given up on the idea of having a single-stage vehicle someday, but for now the rocket would be dropped into the path of microwaves beamed by about 100 ground-based dishes. These would be focused on the surface of the rocket.

Tseliakhovich says the rocket's payload could be protected from the microwaves by a metal Faraday cage—the same technique used to contain microwave energy in a microwave oven. And even with precautions, he has no illusions about launching people or large payloads to space any time soon. "It will take a long time to go from small payloads to human flight—years and years," he says.



*A segment of graphite is heated to 2,000 K by a 20-kW light during a February test at NASA Ames. Later tests will add channels and helium to simulate hydrogen propellant. Photo credit: David Murakami and Kevin Parkin.*

## Enormous efficiency gains

If the concept works, the efficiency improvements could be enormous. Since the hydrogen would not be heated by combustion, there would be no need to carry liquid oxygen; that should make the microwave rocket more powerful pound-for-pound than a chemical rocket.

"A mix of hydrogen and oxygen is much less efficient than just hydrogen, because of the molecular weight," explains Tseliakhovich.

In conventional rockets, some of the energy released by the chemical reaction is wasted moving the oxygen atoms carried in an oxidizer tank and in the exhaust gas.

Parkin calculates that when hydrogen is burned with oxygen, about 16 MJ of energy are released per kilogram, versus 30-40 MJ for a pure hydrogen system.

On the specific impulse efficiency scale, the best a conventional rocket can do is about 450 sec, a unit that refers to the amount of time a given mass of propellant can produce a certain level of thrust. Calculations show that a pure hydrogen rocket could break 1,000 sec, Murakami says.

## Choices ahead

It sounds great, but Parkin, Tseliakhovich, and Murakami acknowledge they are just at the beginning.

"There are two big challenges," Murakami explains by email. "Beaming large amounts of electromagnetic energy to a target many kilometers away, and a heat exchanger system that can transfer that energy to the working fluid."

Conducting a full-up microwave demo involving megawatts of energy will not be easy. So the first task is to find a material that can take the heat, since the hotter the fuel, the higher the pressure, and the faster it will shoot out the nozzle. Murakami is testing graphite, but Tseliakhovich also likes refractory ceramics.

Thermally testing materials is most important, and at this point, Murakami is agnostic about how that heat gets generated. "From the heat transfer and

*Carbon fibers can be woven into hollow channels to conform to the curve of a rocket. Photo credit: Kevin Parkin.*

fluid mechanics standpoint, the type of radiation you're using to heat it up (microwaves, millimeter waves, lasers, or our 20-kW light bulb) doesn't matter much as long as it gets absorbed and converted into heat," he says. "So we decided to go with the most cost-effective system we could find," which was a light bulb.

For the required thrust, Murakami needs to get the material to about 2,500 K; he has demonstrated 2,000 K so far.

"Success would be, after exploring the options and testing, being able to build (on a small scale) a heat exchanger system that actually produces the impressive values of specific impulse, thrust to weight, etc., that Kevin's analyses say should be possible," Murakami says, referring to Parkin of Carnegie Mellon.

In its strategy of not reaching too far, the microwave alliance is eschewing not just single-stage-to-orbit flight, but also reusable rockets and large payloads.

Parkin initially thought the rocket should have a flat surface to absorb the microwaves. He coauthored a paper proposing to use the lifting body shape of NASA's canceled X-33 single-stage-to-orbit spaceplane.

"We're not using X-33 aeroshell any more," he says emphatically.

He came to that conclusion after looking at materials for the heat exchanger. A flat surface would be unnecessary because of the advent of graphite fibers. "You can weave them into all kinds of strange shapes you never thought were possible. Wrapping it around the tank is no problem. You can do it in a conformal way," Parkin says.

That should help to simplify the aerodynamics. "Once you realize you could wrap the heat exchanger around the tank, there's no reason to go to a kind of aeroshell that requires strange tank configurations or winglets or anything like that," he says.

The latest version of the concept calls for a cylindrical rocket with a fuel tank 3 m in diameter and 6 m long. "That's the target," says Parkin.

Not to be underestimated is the challenge of beaming the microwaves to the rocket. Microwave sources can be ordered, but this would require building a large facility consisting of dishes capable of forming high-power microwave beams. There are microwave sources, "and there are various technologies to create high-powered microwaves. But the two have not yet been combined. So that's where the challenge is on the beam facility side," Parkin says.

If the microwave alliance can overcome these challenges, the payoff could be enormous. Today, when a rocket blasts off toward space, just 2% of its total mass consists of useful payoff, says Tseliakhovich. In theory, 20% of the microwave thermal rocket could consist of payload. The microwave alliance plans to prove it.

**Ben Iannotta**
biannotta@aol.com