Microwave thruster makes for clean-burning jet

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I usually approach papers on the subject of alternative thrusters with a certain degree of cynicism. But we've finally been given a study on microwave thrusters that doesn't rely on impossible physics. Instead, it used a plain old plasma thruster.

Plasma thrusters have generally been thought of as a means of propulsion in space, but now one has been designed to operate under atmospheric conditions. According to the researchers involved, it's an air plasma thruster that has the potential to produce the same thrust as a commercial jet engine.

Combustible air?

A jet engine is just a form of internal combustion engine: combine fuel and air and compress the living hell out of the mixture. The resulting ignition rapidly heats the gas (most of which is nitrogen and doesn't burn), forcing it to expand explosively. The rapid expansion can be used to power fans that generate thrust or used directly to provide thrust. But, the key point is that the gas needs to be rapidly heated to very high temperatures so that it can expand. The fuel of a jet engine is just the energy source for heat.

The age of steam relied on the same concept, as do modern steam turbines. Heat water to a very hot gas, then allow it to expand to do work. Again, the key is getting all that energy into the gas so that it can rapidly expand. A steam engine, though, is an external combustion engine, with the combustion heating the water before the water is sent into the place where it does work.

Now, a group of researchers has demonstrated a kind of external/internal plasma combustion engine. The essential idea is that air is ionized to a plasma, which is rapidly heated and allowed to expand to generate thrust.

To do this, the researchers used a magnetron to generate relatively high-powered microwaves (about 1kW). The microwaves travel down a waveguide (a rectangular metal tube) that gets progressively thinner and then expands again (see picture). A quartz tube is placed in a hole in the waveguide at the narrowest point. Air is forced through the quartz tube, passes through a small section of waveguide, and then exits the other end of the quartz tube.

At the entry to the tube, the air passes over electrodes that are subject to a very high field. This rips electrons off some of the atoms (mostly the nitrogen and oxygen), creating a low-temperature, low-pressure plasma. The air pressure from the blower at the entry of the tube pushes the plasma further up the tube so that it enters the waveguide.

Enlarge / Microwave-powered plasma thruster.
In the waveguide, the charged particles in the plasma start to oscillate with the microwave field while rapidly heating. The ions, atoms, and electrons collide with each other frequently, spreading the energy from the ions and electrons to the neutral atoms, heating the plasma rapidly. As a result, the researchers claim that the plasma rapidly heats to well over 1,000°C.

The thrust of the measurement

The heated plasma creates a torch-like flame as the hot gas exits the waveguide, generating thrust. Measuring the gas pressure (thrust) turned out to be difficult. Most pressure sensors and barometers tend to complain when placed into something akin to a blowtorch.

So the researchers got inventive. They closed the quartz tube with a hollow sphere that had a small hole in it. If the plasma thrust was sufficiently high, it would cause the sphere to rattle around on top of the tube. By progressively adding mass to the sphere, it would eventually settle on the tube and stop rattling. The researchers estimated the total force from gas by balancing it with the force due to gravity. I’m pretty

sure there are better ways to measure thrust (and still stay low-tech), but as long as the researchers were consistent, the systematic offset will be the same for all measurements.

In the end, the team was able to show that they get thrust of about 28N/kW, which seems to be quite close to that produced by a modern turbofan (by my rough calculations, a modern turbofan produces about 15N/kW). The thrust efficiency is corrected for the thrust simply due to the blower's airflow as well.

The question is one of scaling. At the air flow rates (around $1m^3/h$) and microwave powers (less than 1kW) that the researchers tested, everything scaled very nicely. But the airflows are in the region of about 15,000 times lower than those for a full-sized engine. The thrust also has to scale by about four orders of magnitude (meaning the power does, too). Extrapolating linear trends over four orders of magnitude is a good way to be disappointed in life.

I also believe that the warning signs are already in the paper. If you look carefully, there are some missing data points. For instance, at the highest microwave power, only lower flow rates are tested, while for low microwave power, all flow rates are tested. That seems like an odd omission. I suspect the plasma is not stable at high flows and high powers.

If you're thinking this work might help save engine weight, I wouldn't be so sure. If the plasma thruster becomes part of a turbofan engine, I suspect it will be heavier. In a non-bypass configuration, it might be lighter. Still, this is very cool work, and I hope it works out.

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