Building better rocket engines

Engineers at NASA find that innovative plumbing boosts the performance of liquid-fueled rockets. Current research into a new generation of liquid-fueled rocket designs could double performance over today's rockets while also improving reliability.

In a parallel and separate development, engineers at a Wisconsin research company successfully tested a prototype rocket engine that uses methane fuel and oxygen oxidizer.

Liquid-powered rockets have been around a long time. The first launch, conducted by Robert Goddard in 1926, produced roughly 20 lb of thrust, enough to carry the rocket about 40 ft into the air. Since then, designs have become sophisticated and powerful. The space shuttle's three liquid-fueled onboard engines, for instance, can exert more than 1.5 million lb of combined thrust en route to Earth orbit.

However, to assume that every refinement in liquid-fueled rocket design has been made would be wrong. There is still room for improvement.

Orbitec test fires its methane-fueled engine.

Led by the Air Force, teams of scientists and engineers from NASA, DOD, and industry are working on better engine designs. The program is called Integrated High Payoff Rocket Propulsion Technologies. The scientists are looking at possible improvements, including a new scheme for fuel flow.

The power of flow

A liquid-fueled rocket is a simple concept. A fuel and an oxidizer, both in liquid form, feed into a combustion chamber and ignite. For example, the shuttle uses liquid hydrogen as its fuel and liquid oxygen as the oxidizer. The hot gases produced by the combustion escape rapidly through the cone-shaped nozzle, producing thrust.

The details are more complicated. For example, both the liquid fuel and the oxidizer must be fed into the chamber very rapidly and under great pressure. In 25 seconds, the shuttle's main engines would drain a swimming pool filled with fuel.

This torrent of fuel is driven by a turbopump. To power the device, a small amount of fuel is "preburned," thus generating hot gases that drive the turbopump, which in turn pumps the rest of the fuel into the main combustion chamber. A similar process is used to pump the oxidizer.

Today's liquid-fueled rockets send only a small amount of fuel and oxidizer through the preburners. The bulk flows directly to the main combustion chamber, skipping the preburners entirely.

One of many innovations being tested by the Air Force and NASA is to send all of the fuel and oxidizer through their respective preburners. Only a small amount is consumed there—just enough to run the turbopumps. The rest flows through to the combustion chamber.

This "full-flow staged cycle" design has an important advantage: With more mass passing through the turbine that drives the turbopump, the turbopump is driven harder, thus reaching higher pressures. Higher pressures equal greater performance from the rocket.

Rendering of the Integrated Powerhead Demonstrator shows its innovative plumbing for routing fuel and oxidizer to the combustion chamber.

Such a design has never been used in a liquid-fueled rocket in the U.S. before, according to Gary Genge at NASA Marshall. Genge is the deputy project manager for the Integrated Powerhead Demonstrator (IPD)—a test engine for these concepts.

"These designs we are exploring could boost performance in many ways," says Genge. "We are hoping for better fuel efficiency, higher thrust-to-weight ratio, improved reliability—all at a lower cost."

"At this phase of the project, however, we are just trying to get this alternate flow pattern working correctly," he notes.

Already they have achieved one key goal: a cooler-running engine. "Turbopumps using traditional flow patterns can heat up to 1,800 C," says Genge. That is a lot of thermal stress on the engine. The "full-flow" turbopump is cooler, because with more mass running through it, lower temperatures can be used and still achieve good performance. "We have lowered the temperature by several hundred degrees," he says.

IPD is meant only as a test bed for new ideas, notes Genge. The demonstrator itself will never fly to space. But if the project is successful, some of IPD's improvements could find their way into the launch vehicles of the future.

Methane's promise

The methane/oxygen rocket engine firings conducted by engineers at Orbitec (Orbital Technologies in Madison, Wis.) produced 30 lb of thrust, compared to the 20 lb produced by Goddard's first launch in 1926.

The Orbitec engineers recently completed a series of tests of a prototype rocket engine that uses methane fuel and oxygen oxidizer. Eric Rice, Orbitec's president and CEO, says the tests were successful.

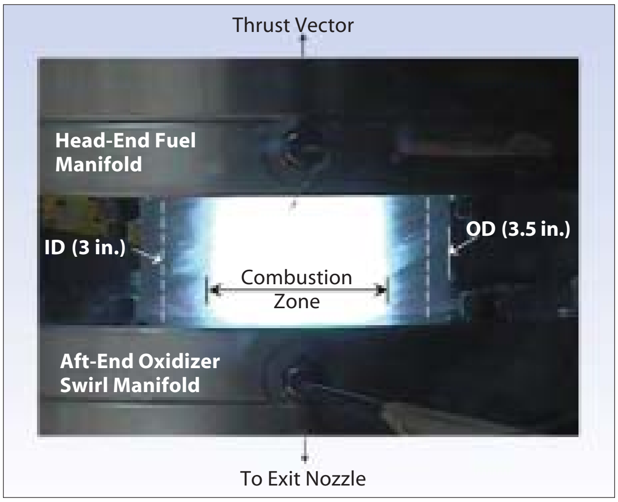
According to Rice, methane is currently of interest as a potential fuel for NASA's space exploration activities and for future USAF launch vehicles. It requires smaller propellant tanks than hydrogen, is very light, and has a higher specific impulse than hydrocarbon fuels such as kerosene. In addition, it can be used as a fuel for exploration. Methane and oxygen could be produced on the Moon and Mars from in-situ resources. NASA is interested in applying liquid methane/liquid oxygen propellants for lunar and Mars landing and other transport vehicles. The Air Force is interested in methane for future use as a fuel for launch vehicles. Rice says that Orbitec is interested in applying it to commercial small launch and space tourism vehicles.

Robert Goddard stands beside a 1920s-vintage liquid-fueled rocket. Source: Space History.

A cooler approach

The Orbitec engine uses the company's patented vortex-cooled combustion process to eliminate combustion chamber heating. In this method, the oxygen injector is used to generate a pair of coaxial vortices in the combustion chamber. The outer vortex consists of cold oxygen that protects the chamber surfaces, while combustion is confined to the inner vortex. The swirling flow field provides efficient combustion. This technique overcomes the need for complex, expensive injectors and reduces the excessive heat loads of conventional rocket engine chambers. Orbitec engineers believe this approach promises to provide lightweight engines with simplified overall design, extended lifetime, low cost, and a high degree of maintainability and reliability.

In vortex cooling, the oxygen swirls up against the inside surface of the chamber, keeping the wall of the acrylic chamber at a cool 60 C, while the flame within the chamber burns at 3,000 C.



Rice further explains that in vortex cooling the oxygen swirls up against the inside surface of the chamber, keeping the wall cool. In one test using an acrylic test chamber, the outside wall registered a cool 60 C, while the flame within the chamber burned at 3,000 C.

Orbitec conducted more than 70 hot firings with the vortex-cooled methane engine to refine the design of the propellant injectors and combustion chamber. This program resulted in a design that provides very high performance—98% that of an ideal rocket—with no significant chamber heating upstream of the exit nozzle. The chamber operated at a thrust of approximately 30 lb and a chamber pressure of 150 psia. Similar testing with hydrogen in a larger chamber also demonstrated very low chamber heating at pressures of 500 psia and high performance.

Orbitec has also conducted successful methane/oxygen ignition system developments and has applied them to its larger rocket engine testing. The company previously performed successful engine firing tests of solid methane and solid methane-aluminum in cryogenic solid hybrid rocket engines with gaseous oxygen.

Rice notes that the engine used in the methane/oxygen test firings is a relatively small one. However, he says the company is working on larger 7,000-lb-thrust and 30,000-lb-thrust engines for the Air Force. Orbitec will soon begin testing a 1,000-lb-thrust engine that will use propane and liquid oxygen in a bipropellant configuration.

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