

Candle wax is rocket science: Paraffin fuels test launch

BY CZERNE M. REID

On Oct. 18, a scorching blaze lit up the moonscape of Nevada's Black Rock Desert as a 10-foot rocket burst 16,000 feet into the air. The launch was powered by an unlikely but potentially safe and effective new rocket fuel -- candle wax.



From left, students Russell Gulman, Hui Kwan Chan, Darin VanPelt, Aaron Buchanan, Jeffrey Hopkins and Mitch Skinner launched a rocket in Nevada's Black Rock Desert on Oct. 18. Their fuel? Paraffin. COURTESY BRIAN CANTWELL



Brian Cantwell

"It surprised me at first because I don't think of wax as a particularly energetic or powerful rocket fuel," said Brian Cantwell, chair of the Aeronautics and Astronautics Department and the Edward C. Wells Professor in the School of Engineering. Cantwell and research associate Mustafa Arif Karabeyoglu developed the paraffin wax rocket fuel, which was also used in history's first paraffin-fueled rocket launch almost four years ago.

Paraffin was previously thought to be weak, easily broken and unsuitable for use as rocket fuel. But Cantwell's team found that it is quite strong -- at least twice as strong as conventional solid propellants. The paraffin they use as rocket fuel is the same material used as hurricane candles and sculptor's wax. "Paraffin" is a generic name for a family of simple hydrocarbons with carbon chain lengths ranging from 20 to 40. Different group members are suited to different applications.

Safer, cheaper

Paraffin fuel can contribute significantly to making it safer and cheaper to get into space. "If that were accomplished, human access to space would become more routine, and the ability to do scientific studies and commercialize the use of space would also increase dramatically," Cantwell said. For example, scientists could undertake as many missions as necessary to clean up accumulated debris in our near-space environment.

Conventional rocket fuels are either solids or liquids, but paraffin fuels are used in a hybrid system combining solid and liquid materials. An oxidizer such as oxygen or nitrous oxide is generally used with all fuel types to aid burning.

Solid fuels include a rubberized material incorporating the oxidizer and other additives such as aluminum or ammonium perchlorate. The fuel-oxidizer composite is dangerous, as it may explode even during shipping and installation. The fuel burns very rapidly in the rocket combustion chamber to generate the rocket propulsion force known as thrust. Once the solid fuel is ignited, the rocket motor cannot be shut off. This is dangerous because there is no chance to ensure adequate thrust build-up before take-off.

Liquid rocket fuels include kerosene and liquefied hydrogen. In these systems, the fuel and oxidizer are held separately in large tanks and then fed into the rocket chamber, where they mix and burn. Valves are used to regulate fuel and oxidizer flow, and increase, decrease or shut off thrust. This allows more control over the launch process than do solid fuels. The system relies on complex and expensive machinery, however, and is subject to catastrophic fires.

Hybrid rocket fuels are considered a safer alternative to traditional solid and liquid fuel systems. In hybrids, the thrust chamber contains only solid fuel. This reduces the potential for devastating fires and explosions. The oxidizer is ignited as it is forced over the fuel surface. Like liquid systems, hybrids can be throttled, but require only one set of valves -- for the liquid oxidizer.

Although hybrids have been in development over the last 50 years, they have not made it into mainstream commercial applications because they did not produce as much thrust as liquid and solid systems. "Hybrid rockets tend to be sort of anemic in their ability to produce thrust," Cantwell said. This is because the fuel burns too slowly, relying on a process limited by the rate at which fuel evaporates and mixes with oxidizer. By contrast, the fuel and oxidizer are forced together in liquid systems and pre-mixed in solid systems.

Birth of a new hybrid

In 1995, the U.S. Air Force began to address this problem with a new type of hybrid fuel -- a simple hydrocarbon, pentane, frozen using liquid nitrogen. The pentane burned three to four times faster than conventional fuels. The Air Force engineers explained their results by saying that less heat was required to gasify the pentane than was needed for conventional solid fuels.

Cantwell and Karabeyoglu felt that this explanation was inadequate in light of the "blocking effect," which limits the amount by which fuel evaporation can be increased simply by increasing the rate of heating. The effect occurs because the increasing evaporation pushes the flame away from the surface and blocks heat transfer even as the heating rate increases.

Karabeyoglu proposed an alternate mechanism. He suggested that as oxidizer flows over it, the surface of the pentane melts to form a low-viscosity liquid layer that becomes unstable and forms waves that are easily pulled off the liquid surface as a spray of droplets that evaporate, mix and burn to produce thrust.

Karabeyoglu then set out to find materials that have the same physical properties as frozen pentane but that are naturally solids at room temperature. The paraffin waxes were the perfect candidates.

The Stanford team first tested paraffin in a laboratory-scale rocket motor in November 1998 and found that like solid pentane, it burned three to four times faster than conventional solid fuels. To date, they have conducted more than 250 laboratory and field tests in collaboration with engineers at NASA Ames Research Center. They have tested rocket motors with 2,500 pounds of thrust, the amount that might be needed for a third stage rocket in a launch system. "Further scale-up tests are needed before paraffin-fueled rockets can be utilized in lower stage rockets requiring thrust levels of 200,000 pounds or more," Cantwell said.

Cantwell projects that commercial application of paraffin fuels could become a reality in as few as three years. Stanford has secured a patent on the use of paraffin in rocket fuel applications, and Cantwell and Karabeyoglu have started Space Propulsion Group Inc., a company geared toward commercializing the technology. David Altman, a consulting professor of engineering who is a co-founder and co-inventor of the technology, heads the company.

Cantwell has high hopes for paraffin-fueled motors. "Solid rocket boosters remain among the most dangerous part of any space shuttle mission," he said. "I think [the paraffin-based hybrid] would be a good candidate for replacing the shuttle solid rocket boosters."

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