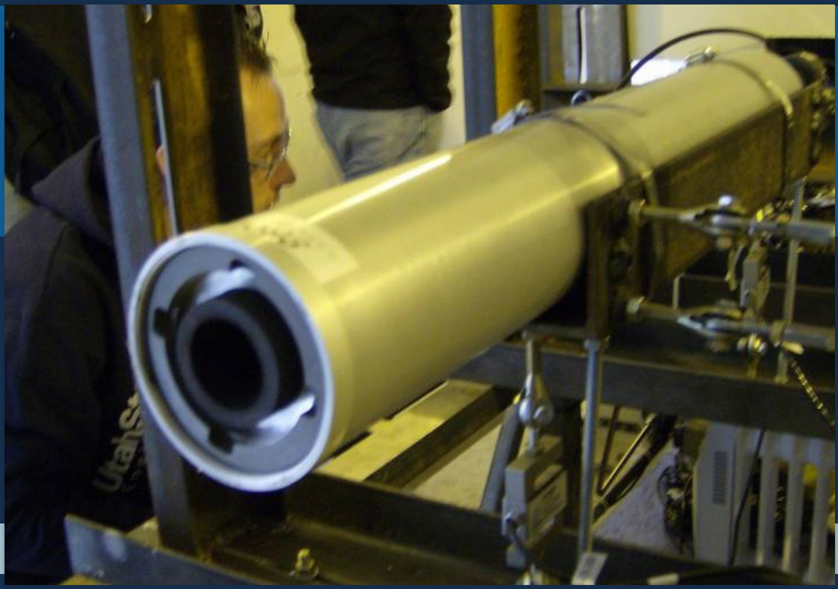
IT´S ROCKET SCIENCE



Hybrid Rocket Engines Use Additive Manufacturing to Combine the Advantages of Solid and Liquid Propellants

"Additive manufacturing technology has been the key to producing fuel grains with higher consistency at a lower cost and shorter leadtimes than was possible in the past."

— Ron Jones, President and Chief Technology Officer, Rocket Crafters Inc.

D-DART™ rocket motor mounted on the test cell

Today, solid rockets dominate most military applications because they take up relatively little space, can be launched on a moment's notice and offer a high thrust-to-weight ratio. Meanwhile, liquid bipropellant rockets enjoy the lion's share of orbital launch vehicle and spacecraft propulsion system use because they are more fuel efficient, offer a higher specific impulse and can be throttled and restarted when needed.

Hybrid rocket engines, which combine a solid fuel with a liquid oxidizer, offer the best of both worlds including immediate launch capability and the ability to be throttled and restarted. More importantly for commercial space transport use, they offer significantly greater safety than either solid or liquid rocket engines. But hybrid motors have been studied for many years and have seen little use for a number of reasons including high motor-to-motor performance variability, high development costs, poor performance efficiencies and inability to scale to high volume production.

Part of the challenge is that traditional methods of casting synthetic rubber and wax fuels to form solid grains are labor intensive, require expensive mold tools and mandate extensive use of internal webbing materials to improve the grain's ability to withstand stress loads. These methods are also prone to grain defects and are not scalable to support the anticipated high flight rate requirements of the emerging commercial space transport industry.

Hybrid solid fuel grains are typically fabricated as long cylinders with one or more internal ports that run the length of the grain. Liquid oxidizer flows through these ports to blend the fuel and oxidizer together. This mixture, in the presence of heat, generates high chamber pressures that produce thrust as the expended gasses pass through the rocket's nozzle. A liquid oxidizer such as nitrous oxide (N20) is stored separately in a tank. The fact that the liquid oxidizer and solid fuel are in two different states is what makes a hybrid rocket much safer than other types of rockets.

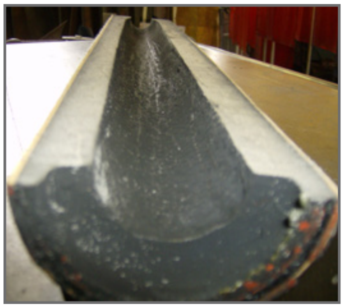
Rocket Crafters, Inc. was founded in October 2010 by Paul Larsen, Ron Jones and Steve Edwards. Rocket Crafters' Direct-Digital Advanced Rocket Technology (D-DART™), which is protected by a pending patent, employs the unique advantages of additive manufacturing, including its ability to create complex structures with unprecedented accuracy, to manufacture high-performance hybrid rocket fuel grains. Unit production costs are estimated at 50% lower and delivery times are expected to be 60% better than competing hybrid rocket motors that are made using manual casting methods.

"We evaluated a number of different additive manufacturing methods and materials," said Ron Jones, president and chief technology officer of Rocket Crafters. "We determined that Stratasys' Fortus 3D Production Systems platform and acrylonitrile butadiene styrene (ABS) thermoplastic offered the ideal combination of an industrial scale fabrication platform capable of producing large grain sections in a high modulus, chemically stable polymer with excellent accuracy and throughput. Our tests have validated the advantages of Fused Deposition Modeling (FDM) and ABS in this application." Powering all Fortus 3D Production Systems is FDM Technology - an additive manufacturing process that builds thermoplastic parts layer by layer, using data from CAD files.

D-DART™ rocket motor test at Utah State University.

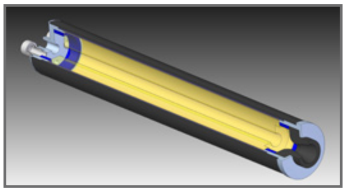
ABS thermoplastic's high butadiene content, when compounded with additives, offers the potential to create much higher thrust and specific impulse than traditional hybrid fuels like hydroxyl-terminated polybutadiene (HTPB) and paraffin waxes. FDM Technology easily scales to any required level of production without requiring additional skilled labor simply by the purchase of additional Fortus Systems.

D-DART also employs a second CAD-driven robotic system – Composite Filament Winding to wrap the fuel grain and other motor components (pre-combustion chamber, post-combustion chamber and nozzle) in high-strength carbon fiber to form the solid section of the rocket. The combination of FDM and Composite Filament Winding robotic equipment creates a highly efficient two-step production process. And, because the process is entirely CAD driven, customized rocket motors can be quickly and inexpensively fabricated for different types and sizes of launch vehicles, spacecraft, and missiles.



Sectioned ABS fuel grain after 10 second burn. Note no signs of the erosive burning characteristic of traditionally cast HTPB grains.

Initial ground-based hot fire tests conducted at Utah State University compared the performance of D-DART fuel grains with traditionally cast HTPB grains. The D-DART grains exhibited a 97.5% run-to-run consistency rate compared to 87% for the HTPB grains. Further, the D-DART grains provided a specific impulse comparable to HTPB. Rocket Crafters, with assistance from former NASA rocket propulsion scientist Stephen Whitmore, PhD, Utah State University, and the firm's many industry teaming partners, including Stratasys, plans to begin flight testing its rocket motors on university-built sounding rockets later this year and then begin commercializing its new rocket technology in 2012 for both military and commercial applications.



CAD Illustration of a D-DART™ hybrid rocket motor featuring a carbon fiber wound case and FDM-fabricated ABS fuel grain.

"Rocket Crafters is creating the enabling technology for hybrid rockets to become the preferred choice for commercial spaceflight and many military applications," Jones concluded. "Additive manufacturing technology has been the key to producing fuel grains with higher consistency at a lower cost and shorter leadtimes than was possible in the past."

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