SPS Space Propulsion Systems

E' Prime Aerospace Corporation

2009 National Security Space Technology Forum on Suborbital Missions and the Small Unit Space Transport and Insertion (SUSTAIN) Concept

Government Only Briefing – February 26, 2009 – 1600 Hrs -Proprietary

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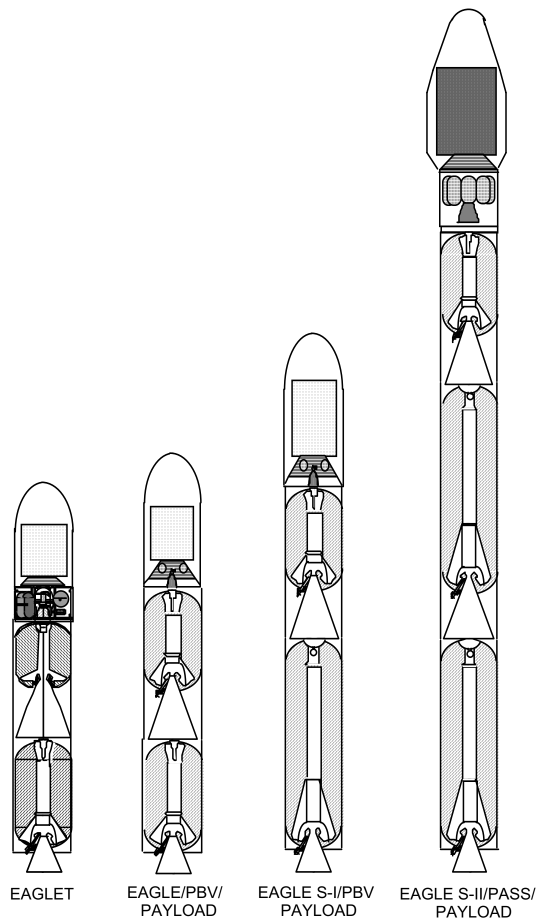
Rapid Deployable Launch Systems

E'Prime Aerospace of Colorado is developing a family of launch vehicles, called the Eagle S-series, based on the LGM-118A Peacekeeper ICBM design. Like the Peacekeeper, this vehicle will be ejected from a ground-based silo, using a compressed gas system. At an altitude of 61 meters (200 feet), the engines will ignite. The smallest vehicle, the Eaglet, could launch 580 kilograms (1,280 pounds) into LEO. A somewhat larger version, the Eagle, could put 1,360 kilograms (3,000 pounds) into LEO. The S1 and S2 are medium single core vehicles with launch capability of 2,948 kilograms (6,500 pounds) and 4,536 kilograms (10,000 pounds) to LEO. The vehicles will use solid propellant lower stages and liquid propellant upper stages. E'Prime has also proposed larger hot pad vehicles, designated S-3 through S-7, with the ability to place considerably larger payloads into LEO and to add a geosynchronous Earth orbit (GEO) capability. The Eagle S-series concept dates back to 1987 when the company signed a commercialization agreement with the U.S. Air Force to use Peacekeeper technology for commercial launch vehicles.



Since the Eagle launch systems are derived from the well-proven and highly successful Peacekeeper ICBM technology, it is the intention of E'Prime to maintain all principal core capabilities of this system, such as cold launch capability, and small ground crew launch servicing requirements, while performing upgrades in materials of construction, mechanical and electronic systems. The projected development time-line of 18-months to 2-years reflects the low-risk, cost and time-savings gained in upgrading an already proven technology; as compared to the much higher risks, costs and times associated with developing and qualifying a totally new and unproven launch system design. E'Prime will also upgrade the Eagle solid propulsion systems, by employing Space Propulsion Systems high performance, safe, and flexible microcellular propellant technology. This approach will provide E'Prime, and the commercial launch industry, a new, uniquely capable, low operational cost launch vehicle in the time of the industries greatest need.

A launch system, and the capabilities of that launch system, is no better than that allowed by the performance capabilities of the propulsion technology used for both access to orbit, and in-space operations. Currently the Peacekeeper is designed using conventional technology solid propulsion systems, which have limited performance, safety issues. Little improvement has been seen in solid propellants in decades. Although mission demands of launch systems have increased over time, propulsion technology, particularly solid propulsion, has stagnated, leading to ever-increasing operational costs to the launch industry. These are some key factors that have led the DoD to indentify the development of new propulsion systems as a Critical Technology Area.

E' Prime Aerospace Corporation / Space Propulsion Systems

7 day pour to be "launch ready" using "green" propellant and Throtable Solid Rocket Engine

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E'Prime Aerospace has identified **Space Propulsion Systems, Inc. of Clearwater, Florida** as a major innovator in new solid propulsion systems and technology. SPS's patented Microcellular Solid Propellant Technology concept, and the associated and patented Supercritical Fluids manufacturing process technology, can produce safe, essentially insensitive, solid propellants tailored to specific mission objectives with an exceptional degree of reproducible performance. The inherent safety and processing properties of these microcellular propellants make them uniquely responsive to launch industry needs, since motors can be safely cast at the launch site, reducing launch vehicle preparation times to days, and not weeks or months. Performance improvements and tailorability of these propulsion systems are related to the ability to "process" nearly any combination of fuels and oxidizers into a safe, protected, microcellular environment. The expanded capabilities of formulation of solid propellants allow determination of performance capabilites based more on the designed reaction chemistries of the microcells, rather than physical characteristics of the propellants.

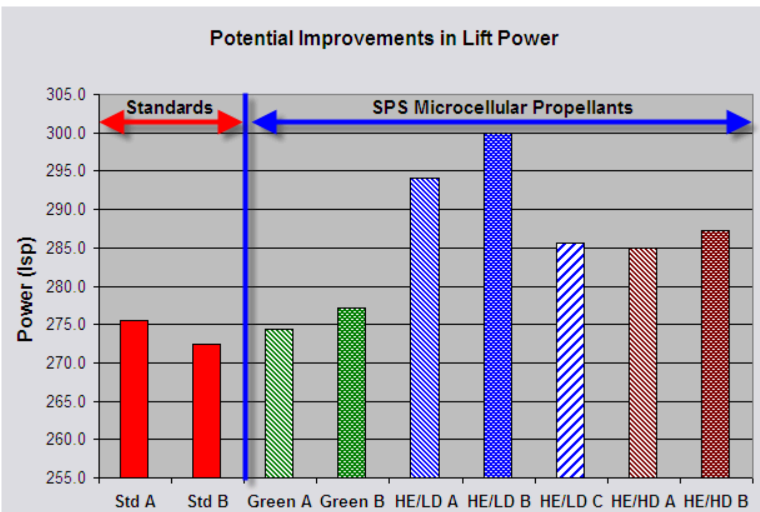


Figure 1.

Figure 1. Legend

Std A (Red) - **Peacekeeper Propellant**

Std B (Red) - Shuttle Propellant

Green A - ADN Based Propellant (Single Phase Flow, No Pollutants)

Green B - HNF Based Propellant (Single Phase Flow, No Pollutants)

HE/LD A- High Energy, Low Density ADN Formulation

HE/LD B - High Energy, Low Density HNF Formulation

HE/LD C - High Energy, Low Density AN/CL-20 Formulation

HE/HD A - High Energy, Compact Engine ADN Formulation

HE/HD B - High Energy, Compact Engine HNF Formulation

The ability to compound propellant formulations from a wider range of energetic materials allows not only the for design of propellants with **improved power and Burn Rates, but propellants that can be either lighter or heavier than current propellants, while maintaining or improving Specific Impulse and Burn Rates as compared to standard propellants**. Figure 1 shows predictive model baseline example formulations of several potential SPS Microcellular propellants compared to two standards – Std A is the solid propellant used in the Peacekeeper missile, and Std B is an Ammonium Perchlorate (AP) propellant formulation (TPH-1148) used in the Space Shuttle solid rocket boosters. In the work presented here, the classes of propellants are designated by the principle oxidizer used in the formulation (ADN is Ammonium Dinitramide, HNF is Hydrazinium Nitroformate, and AN is Ammonium Nitrate). HE/LD C in Figure 1 is AN/CL-20 blend propellant. CL-20, another important oxidizer, can be used to adjust both the propellant density and power of some formulations.

Burning Rates for SPS Microcellular Solid Propellants can be estimated through both comparison of increased chamber temperature due to more energetic, heat generating reactions in the formulation (chamber temperatures achieved for formulation less chamber temperature reported for the oxidizer component alone), as well as by application of the approximate rule that for each 2% of pyrophoric Aluminum present in the formulation, burning rate is increased by about 1 mm/sec. Figure 2 shows the results obtained for this approximation for aluminized formulations of the microcellular propellants compared to the Burn Rates for the standards estimated for Aluminum concentrations of 10%. Since burning rates of SPS non-aluminized propellants are significantly higher than for non-aluminized AP or HMX based propellants, this technology offers the potential to eliminate or

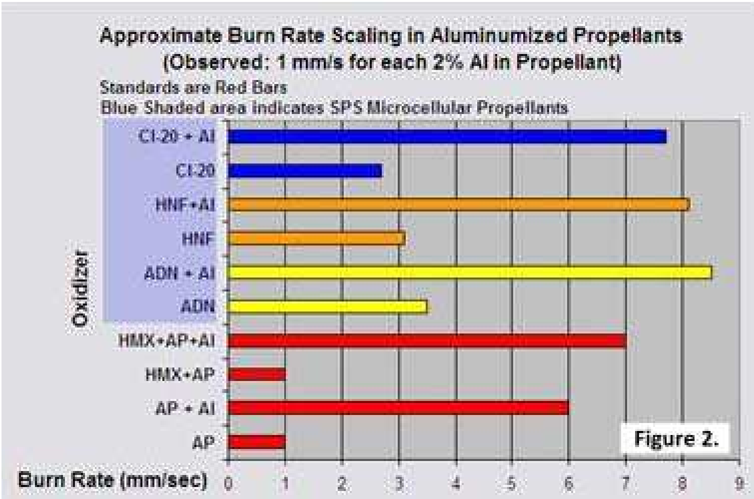


Figure 2.

significantly reduce the need to use Aluminum for burn rate control altogether. Problems associated with Aluminized propellants such as particulate exhaust pollution, nozzle erosion, two-phase flow, and pooling of aluminum melt in the engine could be significantly reduced or completely eliminated.

Other than flexible formulation of tailored performance propellants, microcells used in production of the SPS microcellular propellant grains are made independantly of the grain casting process. Once manufactured, the essentially insensitive microcells can be shipped safely using conventional shipping processes for highly flammabile materials (hydrogen, gasoline, etc) to any suitable location for storage or grain casting, even at the launch site. This will lead to cost savings and enhanced response capability for the E'Prime Eagle series of launch vehicles.

November 14, 2007, U.S. Department of Transportation, Federal Aviation Administration,"…determined that EPAC's canister launch Program does not jeopardize U.S. national security or foreign policy interests. Therefore, policy approval is granted for EPAC's canister launch program…"

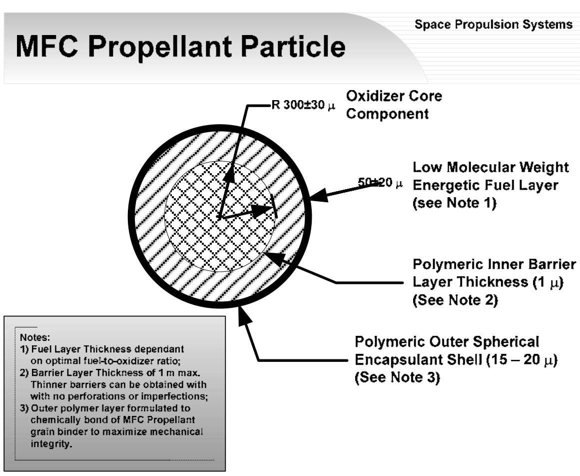
SUSTAIN/NASA/Commercial

Space Propulsion Systems Microcellular Solid Propellant Technology

Space Propulsion Systems of Clearwater, Florida and Prof. Aydin Sunol's group at the University of South Florida, Tampa, Florida, have **successfully completed the initial R&D development phase (Phase I)** of the company's new patented microstructured composite solid rocket propellants and the novel Supercritical Fluids (SCF) process that facilitates meeting the stringent targeted manufacturing specifications for a green, scalable, flexible, and cost effective production technology. This patented microstructure solid propellant **manufacturing process incorporates well-proven materials processing capabilities** of SCF materials throughout the manufacturing cycle. The **SPS Flex-Launch Logistics Program** is based upon this new propellant technology, and will provide the commercial launch industry significant cost savings through streamlining of launch operations, faster launch response times, improved and flexible propulsion systems performance which can be designed to mission requirements, and improved safety in all propellant related launch operations. **SPS has concluded a Strategic Alliance Agreement with E'Prime Aerospace for adaptation of their family of Peacekeeper-derived Eagle launch vehicles to SPS's new propulsion technology.**

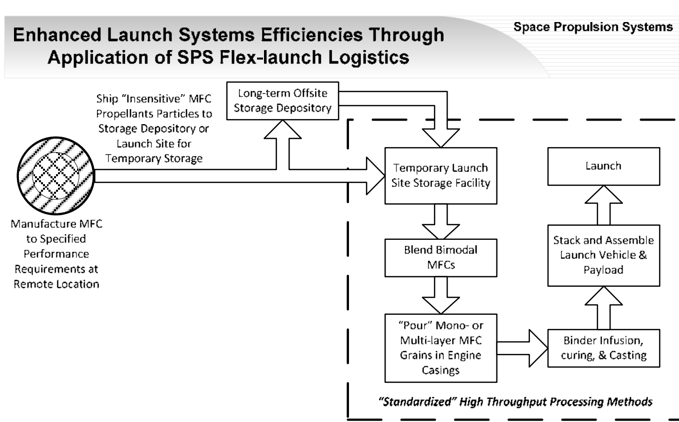
Sufficient funding has been committed for completion of a new SPS laboratory and demonstration manufacturing facility capable of supporting small-scale engine test firing of the new microcellular solid propellants. This new SPS facility should be **operational by the third quarter**, or early fourth quarter of 2009. Completion of the Phase II final development of propellant grain casting methodologies and initiation of the Phase III large engine propellant qualification testing program is planned for mid- to late-2010, after which the new propellants will be commercially available.

The current solid propellant production technology uses explosion proof high-shear mixers, similar to bread dough mixers, which combine all the propellant ingredients in a single blend. Since the concentrations of the energetic solid material (oxidizer) needs to be very high, the inclusion of highly energetic fuels is not possible since they would be mixed within an unprotected environment, where they would come in contact with the oxidizer reactant and destabilize the propellant. Thus only low-energy fuels (polymers) or stable fuels such as pyrophoric aluminum, can be safely used in these formulations. These mixtures have very high viscosities, with the consistency of bread dough made with too much flour. Small quantities must be made at one time, and then carefully blended into larger quantities for casting of the propellant grains, to ensure adequate homogeneity of the propellants. Engines must be carefully cast with this thick mixture, avoiding void formation in the propellant grain, **which can result in catastrophic failure during engine firing.** With the high oxidizer concentrations required and mixing limitations, chemical formulations with optimal performance characteristics are nearly impossible to attain. This production process produces toxic waste streams, adding a significant environmental cost in solid propellant production. This grain **casting process is dangerous** and must be performed at a remote location, and large engines must be segmented and shipped to the launch site. These engines are dangerous to transport, requiring special handling procedures.



Propellant Characteristic	SPS Microcell Propellants	Conventional Solid Propellants
Range of Formulations	**Broad** – SCFs can process a broad range of highly energetic fuels and oxidizers and microcell production is standardized.	**Limited** – Current manufacturing technology imposes severe limitations on the types of fuels and oxidizers that can be processed.
Burn rate range of propellants	**Broad** – Controlled by reaction chemistry of microcell formulations. Reliance on reaction kinetics can broaden the current range of propellant burning rates, with potential increases in burn rates by a factor of 10 attainable.	**Limited** – Manufacturing process imposes tight limitations on formulations, restricting burn rate control to particle size dimensions
Range of Energetics	**Broad** - Controlled by reaction chemistry of microcell formulations. Improvements of specific impulse up to 15 % can be achieved.	**Limited** - Manufacturing process imposes tight limitations on formulations, restricting energetics to permitted oxidizers (mainly AP)
Environmental Impact	**Low.** SCF Manufacturing Process is "green", essentially no environmental impact; Flexible propellant formulation allows design of high performance commercial propellants using oxidizer/fuel combinations with no polluting combustion products.	**High.** Current manufacturing process produces toxic wastes and waste streams. Best commercial propellants produce significant particulate pollution (Aluminum Oxide) and clouds of corrosive gases (Hydrochloric Acid).
Safety	**High.** Propellant casting is a relatively safe process, performed under combustion inhibiting conditions. Microcell propellant ingredients are protected till ignition; the most "sensitive" ingredients (oxidizers) are isolated from the external environment.	**Low.** Dangerous to manufacture and cast propellant grains. Sensitive to impact and static discharge.
Thrust profiling	Thrust profiles can be controlled by layering of microcells of different chemical composition in the grain. Only cylindrical ports required.	Thrust profiles controlled by port geometry. More complex port geometries produce un-burnt propellant slivers, and reduce propellant mass.

The SPS Microcellar (MFC) concept of solid propellant design removes limitations on performance of solid propellants (Specific Impulse and burn rates) by providing a protected environment within a spherical structured particle of no more than 1,000 micron diameter, where a wide portfolio of highly energetic non-polymeric fuels, oxidizers and combustion modifiers can stably co-exist for extended periods, meeting the stringent MilSpec requirements for stability and shelf life. The SCF manufacturing process has been designed to accurately control the chemical compositions, dimensions, and structural properties of the microcells that comprise the final propellant grain. Although ignition temperatures of the microcellular propellant grains conform to those of current solid propellants, the microstructure of the propellants provides for **increased safety in handling, storage and use** of both the microcells and the cast propellant grains. Additionally, since the microcells are produced independently of the grain casting process, **casting of propellant grains can be performed safely at any suitable location**, **even at the launch site**. These microcells flow like low-viscosity fluids, and are easy to pour and pack in an engine mold of any dimensions, then infused with a low-viscosity binder polymer, and, cured into a solid monolithic propellant grain using either UV irradiation or thermal curing.



The new SPS solid microcellular propellants technology, based on tried and proven modern manufacturing technologies and well-known and accepted principles of propellant chemistry, offers the aerospace industry **a new generation of flexible propulsion technology (SPS Flex-launch Logistics Program) that can be designed to specification.** Fast preparation and turnaround of launch vehicles, ability to **make current launch systems more responsive to needs for fulfilling different mission requirements**, standardization of critical launch operations, **increased safety in operations**, and improved, reproducible, tailored performance due to the ordered structure and formulation capability of microcellular propellants, on the sub-millimeter scale, are all features of this new technology which will significantly **benefit both the operations and cost of operation** of the commercial launch industry.

Although only an **18-month Phase II program** is planned, SPS is confident they will be able to successfully demonstrate the ability of this scalable SCF based manufacturing technology to meet the current production capacity requirements of the aerospace industry, as well as accommodate the potential industry growth resulting from wide-scale adoption of this new technology. Additionally by the end of Phase II, since the required processing characteristics of a broad range of desirable fuels and oxidizers in SCF are already known, SPS plans to clearly demonstrate to industry the capability of this new technology to flexibly formulate safe propellants which posses a broad range of performance properties. Finally, by the end of this Phase, **since there is nothing truly "new" in the methods proposed for casting of propellant grains from microcells**, a safe grain casting process is expected to be avalailable for casting the microcellular propellant grains required for the Phase III large engine qualification testing program of the company. **These time estimates have been based on numerous rigorous technology reviews which have been conducted by independent expert authorities from both the government and private industry.** None of these reviews have found any technical impediments to achieve the promise of this new technology. Based on the above considerations, SPS believes that the risks for successful development and commercialization of this new propulsion technology are no more than those that are common to any new technology endeavor.

The microcellular propellant technology is a dual-use technology, and high levels of interest have been expressed by government, including NASA, the military and commercial entities, from which contracts are expected to be derived within the near future. Within the past 18-months, SPS has concluded a Strategic Alliance Agreement with E'Prime Aerospace to seek mutually beneficial opportunities and to provide new solid propulsion systems, which were approved for use by the US Air Force, for the Peacekeeper-derived Eagle family of launch vehicles.

An additional near-term application to propulsion systems using the SPS propulsion technology concept is the **development of new engines** based upon the fluidic properties of the SPS solid propellant microcells. The SCF manufacturing process can manufacture the spherical microcells with balanced chemical compositions, producing stand-alone, performance optimized solid propellant particles. Additionally, the solid propellant particles produced by the SCF manufacturing process have extremely narrow particle size distributions. All these features lend themselves to the development of a truly **throttleable solid propellant engine that is capable of multiple starts and shutdowns, thus performing as a liquid engine**, but with none of the difficulties observed in the use of hypergolic liquid engines. These features would be highly attractive as propulsion for reusable launch vehicles using flyback boosters, in-orbit spacecraft/spaceplane operations, and safe in-orbit propellant storage and automated or manual refueling of spacecraft/spaceplanes and satellites.