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Introduction

Solar System Express (Sol-X) is enabling space settlement via increased human capability on Earth. In August 2010, Blaze Sanders founded Sol-X because space should be an environment for everyone, not just Governments and large organizations. Sol-X seeks to enter the emerging markets of commercial space and citizen scientific discovery by creating lower cost products, bringing them to market faster, while embracing a culture of controlled, yet thoroughly tested, risk. We will contribute to these fields by providing simple, reconfigurable systems for learning on Earth and for exploration, safety, orbital debris removal, and scientific discovery in space. The problem this document will be addressing is: **How can engineering students and New Space startups reduce the cost and time to design-build-test-qualify small rocket propulsion systems?**

The Product

Prototyping new technology can be cumbersome and unnecessarily expensive. Sol-X's RL Sol-Spike™ allows for easier, quicker, cheaper prototyping & testing of small rocket propulsion systems. Sol-Spike™ (Figure 1, Table 1) is a hybrid aerospike rocket engine for use in attitude control systems and propulsion of small balloon launched rockets, with payloads to LEO of less than 500 kg[1]. Sol-X is able to achieve efficiency through:

- ability to create the 3D RL Sol Spike™ in four materials (ceramic, sandstone, stainless steel, and titanium)
- zero moving parts and a design that still allows for pitch, yaw, and roll control
- use of safe, low cost paraffin wax (can also incorporate higher cost Hydroxyl-Terminated PolyButadiene (HTPB)) and nitrous oxide as fuel and oxidizer
- incorporation of Sol-X's low cost, open hardware and software space tolerate electronic control board, Gravity Development Board (GDB)

RL Sol Spike™ is small enough (8.1 cm x 8.1 cm x 9.5 cm) to fit inside 1U of a 3U CubeSat, and theoretically can produce; 300 N of thrust, with a specific impulse (I_{SP}) of 400 seconds, and combustion efficiencies in the 95-97% range[1]. RL Sol Spike™ control system uses four high pressure nitrous oxide solenoid valves, one self-pressurized nitrous oxide tank, and a 25 Watt GDB (5.0 cm x 3.3 cm x 1.0 cm). With flexibility to program the GDB in four languages (12 Blocks™ GUI, SPIN, C+, or Assembly), you don't have to decide between ease of coding and efficiency. You can have both!

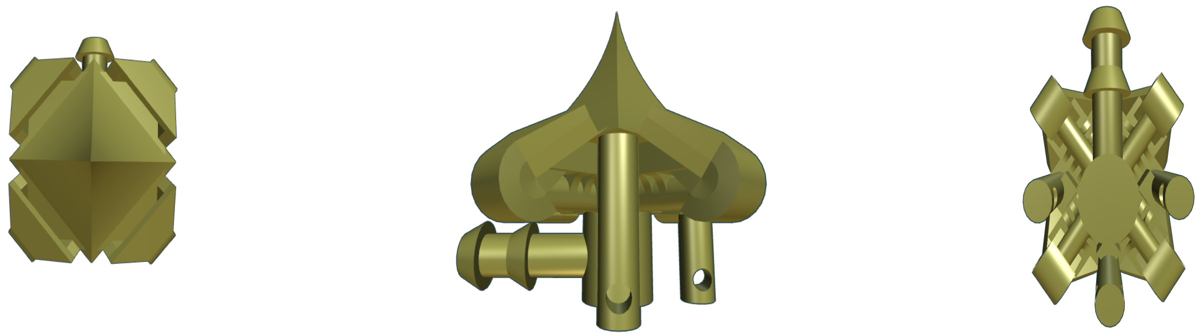

Figure 1 – 3D CAD models (Front, Side, and Back view) of the current RL Sol Spike™ Mark I

Subsystem Name	Purpose	Technical Details
Nitrous Oxide Input Port	Brings nitrous oxide from the main tank to the ports in the four solid fuel cartridges.	Operates at 500 psig with a ¼ inch NPT connector.
Solid Fuel Cartridge	A replaceable fuel system (like a model rocket engine) supported and locked into place via by ribbed supports (See Fig 2B)	5-point Finocyl (star-like) grain geometry that uses HTPB or Paraffin Wax w/ metal additives.
Linear Rectangular Nozzle	Directs the flow of heated gases caused by combustion along the wall on the center plug nozzle.	A linear design allows for stackable combustion chambers, and decreased system volume.
Plug Nozzle	The plug nozzle forms one side of a virtual rocket engine bell, avoiding the random momentum distribution and loss of efficiency found in a normal rocket engine bell.	By blowing a small amount of gas (1% to 2 % of the flow rate) out the center of a truncated spike, performance is preserved without spike tip cooling problems.
Thrust Distribution Columns	Spreads the force generated by the engine into the assembly the engine is attached to.	Engine is locked into place via the holes in columns.

Table 1 – Description of RL Sol Spike™ subsystems

[1] Hybrid Rocket Propulsion

Developmental Milestones

RL Sol Spike™ is currently at a NASA Technology Readiness Level (TRL) of 4 (validated in lab environment). With $175,000 of additional funding, coupled with in-process redesign work being done as part of the DIY Rocket competition, Sol-X can continue with engineering and testing, bringing RL Sol Spike™ up to TRL of 6 (fully demonstrated engineering feasibility) by May 1, 2014. Successful system testing was completed using 70 psi compressed air and no solid fuel. Subject to funding, Sol-X's current development schedule with current key projected testing milestones:

- 140 psi NO2 in September 2013
- 280 psi NO2 in December 2013
- 550 psi NO2 and paraffin wax in May 2014

Sol-X expects to obtain funding from a variety of sources including: 8(a) grants and loans, revenue from the GDB, Mars University Sports and Great Space for Girls summer camps, and hosting new space conferences. Current private sources of Sol-X revenue come from consulting for Phezu LLC, Juxtopia LLC, the JURBAN Google Lunar X PRIZE team, MAVIS LLC, Deep Space Industries, and MTTT LLC.

RL Sol Spike™ will be an open hardware and software system, enabling anyone to create real life space hardware and vehicles. For example, Sol-X implemented RL Sol Spike™ in our own space skydiving suit R&D program at Johns Hopkins University, where it was printed on a Z150 printer using a high performance composite / ceramic like material. This open environment and affordable price lowers the financial barriers for students, entrepreneurs, and small technology firms to innovate, research, and create limited only by their imagination. Implementation of a five unit beta release has already started, and will be launched September 2014, at Johns Hopkins University's Hardware Hack 2014 event.

The Market

Since the RL Sol Spike™ can be created by rapid, lower cost prototyping methods using 3D printing, it will appeal to large innovating technology firms with Skunk Works teams, small technology firms, and 43.6 million secondary and post-secondary students with limited design time for their science fair or senior design team projects. Sol-X's partnerships with local high schools and universities to sell low-cost, academic versions of the RL Sol Spike™ will lead to broad student appeal via word-of-mouth advertising and a reputation for great user documentation.

Sol-X expects that many of projects utilizing Sol Spike™ will be launched via CubeSats. Estimates [2] project that the CubeSat market will increase 300% - 500% from 2012 to 2020. Most of the increase will be in the science and technology missions, and university and commercial segments. Over the past 13 years, launches carrying CubeSat projects averaged 14 / year. This number is expected to significantly increase to 114 / year for the period 2013 - 2015 with a continued upward trend to a high estimate of 188 launches in 2020. Because over 50% of these CubeSat projects are expected to be 1U, Sol-X engineers designed both Sol Spike™ and GDB with these size constraints in mind. Sol-X is positioning Sol Spike™, along with the GDB, as primary components of choice for project developers.

Management

Sol-X is a small group of space entrepreneurs with high aims and realistic short term goals. Our mission focus not only lies beyond the stars, but here at home with community outreach programs for Science, Technology, Engineering, and Mathematics (STEM) education. Our Sol-X team is a blend of superior engineering expertise to create the next generation of technological advances coupled with savvy business minds focused on long term growth.

Competitors - Small Satellite Propulsion Industry

Propulsion Method	Pros or Neutral points compared to the RL Sol Spike™	Cons compared to the RL Sol Spike™
RL Sol Spike™	• Requires 25 W of electrical (elec.) power • Single simple motor (zero moving parts) and no exotic materials • Uses inert (0% TNT equivalency), space storable, and non-toxic (paraffin wax or HTPB) propellants • High thrust (330 N), I_{SP} of 400	

[2] Space Works "Nano / Microsatellite Market Assessment", Feb 2013

	seconds, at efficiencies of 95-97% ● Differential throttling with start/stop/restart capability	
Nitrous Oxide monopropellant thruster[3]	● Simple monopropellant system ● Use inert, space storable and non-toxic propellant with efficiencies of 98% ● Start/stop/restart capability	● Requires multiple thrusters, which increase system mass ● Lower I_{SP} of 127 seconds ● Lower thrust 125 mN (non-throttling) ● Requires higher electrical power (100 W)
MicroThruster[4]	● Lower mass (200 grams) ● Simple motor with zero moving parts ● Uses renewable energy source (solar) at very low power (< 20 W)	● Very lower thrust level (50 µN) requires the use of complex SEPSSMA* trajectory analysis. ● Efficiency has not been determined
Arcjets[6]	● I_{sp} of 320 to 600 seconds possible ● Start/stop/restart capability ● Simple motor with zero moving parts ● Use inert, space storable and non-toxic propellant	● Requires 400 W of elec. power ● Efficiencies of only 25% to 42% ● Lower thrust ● Exotic materials to withstand high voltage sparks
Pulsed Plasma Thrusters (PPT)[7]	● Only requires 30 W of electrical power ● Inert, non-toxic propellants ● The ability to use the same thruster over a wide range of spacecraft power levels without sacrificing performance is main advantage of PPT ● I_{SP} of 1,000 to 2,000 seconds possible	● Efficiencies of only 25% to 42% ● Exotic materials to withstand plasma environment ● Very lower thrust level requires the use of complex SEPSSMA* trajectory analysis.

Table 2 – Competition

*Hohmann transfers were used for the impulsive, high thrust maneuvers. Higher order effects of gravity losses and off-pointing thrust vectors were not included. Low thrust mission analyses were performed using a spreadsheet code called Solar Electric Propulsion Spacecraft System and Mission Analyzer (SEPSSMA). This code permits parametric modelling of the spacecraft and mission to establish the final spacecraft mass as a function of thrusting time. The code can also evaluate specific mission scenarios assuming spacecraft mass, power, and full power thrust time. This study included the effects of both atmospheric drag and shading, and neglected array degradation.[9]

Closing

Sol-X's RL Sol-Spike™ is the embodiment of creating the future and reaching for the stars. We believe our rocket engine provides a unique niche product that can be sold to makers all across the globe. We know it has the capacity to improve the human condition on Earth and lead us to the stars.

[3,6,7,8,9] http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=2650&context=smallsat
[4] http://web.mit.edu/newsoffice/2012/microthrusters-could-propel-small-satellites-0817.html