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Nicola Sarzi-Amade, Thomas P. Bauer, and
James R. Wertz
Microcosm, Inc.

Markus Rufer
Scorpius Space Launch Company

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Nicola Sarzi-Amade, Thomas P. Bauer, and James R. Wertz
Microcosm, Inc.
4940 W. 147th St., Hawthorne, CA 90250; (310) 219-2700
namade@microcosminc.com

Markus Rufer
Scorpius Space Launch Company
4940 W. 147th St., Hawthorne, CA 90250; (310) 219-2700
mrufer@scorpius.com

ABSTRACT

The Scorpius low-cost launch vehicle architecture greatly reduces the cost of space access due to its emphasis on designing specifically for low total life cycle cost. Due to its simplicity, a pressure-fed launch vehicle is low in cost compared with pump-fed and solid rockets. The pressure-fed approach in the Scorpius architecture is enabled by the development of all-composite propellant and pressurization tanks, which have about half the mass of metallic tanks. The low-cost Scorpius "Pressurmaxx" composite tanks comprise half the dry mass of the vehicle. In addition, a high-performance pressurization system using heated helium reduces the mass of the pressurization system by half. Ablative, LOX/Jet A engines have acceptable performance and are very low cost. The mass savings of the tanks and pressurization system together with the engines yield a 3-stage launch vehicle that can be much lower in cost than a high-performance (pump-fed) vehicle. Sprite, which delivers 480 kg to LEO, is the vehicle in the Scorpius® family of low-cost, scalable launch vehicles that has progressed the furthest in terms of development. Propellant tanks, the pressurization system, and engines of the size needed for Stages 1 and 2 of Sprite have been built and tested. A prototypical "pod" of Sprite has been flown suborbitally. This paper describes the Scorpius architecture, its scalability into a family of low-cost vehicles capable of payloads to Low Earth Orbit (LEO) from 100 kg through 9000 kg and larger, and the responsiveness of the vehicles. The Sprite configuration is presented, its performance and sample missions are shown, and a market analysis is provided.

KEYWORDS: Scorpius, Sprite, Launch Vehicle, Low-Cost, Responsive, All-Composite, Pressure-Fed, SmallSat

1. INTRODUCTION

Microcosm and its sister company, Scorpius Space Launch Company (SSLC), developed the Scorpius® family of low-cost launch vehicles with the goal of greatly reducing the cost of access to space. The vehicles were developed through SBIR Phase I, II, and III programs, funded mainly by the U.S. Air Force and NASA. The Scorpius® technology is scalable to different sizes; therefore all vehicles can be built using essentially the same technologies. The family of orbital launch vehicles is comprised of the following vehicles:

- Demi-Sprite: 160 kg (350 lbs) to LEO
- Sprite: 480 kg (1,060 lbs) to LEO
- Liberty: 1,920 kg (4,240 lbs) to LEO
- Exodus: 8,940 kg (19,700 lbs) to LEO
- Heavy Lift: 18.1 t (40,000 lbs) to LEO
- Space Freighter: 36.3 t (80,000 lbs) to LEO
- Super Heavy Lift: 90.7 t (200,000 lbs) to LEO

Some of the above vehicles are shown in Fig. 1. The figure also shows the SR-S, SR-Q, and SR-M suborbital vehicles. The orbital vehicles up to the Liberty size are appropriate for small LEO missions, whereas Exodus and Heavy Lift are appropriate for Large LEO missions or typical GEO/Inter-planetary missions. The Space Freighter and Super Heavy Lift vehicles can be used for very large LEO or large beyond-LEO missions[1]. All orbital vehicles use the same vehicle configuration and key technology elements:

- 3-stage expendable vehicle
- 6 outer pods constituting the first stage
- A nearly identical inner pod as the second stage
- 3rd stage and payload, on top

- LOX/Jet A, pressure-fed, ablatively-cooled, essentially identical first and second stage engines
- All-composite propellant tanks
- High Performance Pressurization System (HPPS)

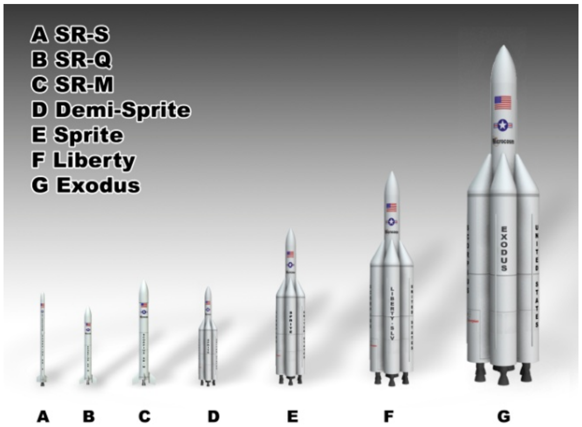

Figure 1. Scorpius® Launch Vehicle Family.

The 3-stage design was selected to minimize the cost to LEO. Even though, on one hand, the 3-stage approach has the disadvantage of increasing the overall parts count (e.g., more engines, more tanks) and of increasing the number of mid-air engine starts and separation events, it has several advantages. In particular, the 3-stage approach reduces the delta V required of each stage, decreases the sensitivity to mass, drag, and Isp in the lower stages, and increases the design margins, which drives down cost. For a given burn-out fraction, increasing the number of stages decreases the gross lift-off weight (GLOW) of the entire vehicle primarily because it means carrying less vehicle mass to a high velocity after it's no longer useful. This reduces the stage 1 engine size, which further reduces cost, and allows an Isp more tailored to altitude. To maintain the same GLOW as a 3-stage vehicle, a 2-stage vehicle would need to reduce the burnout mass fraction from 14% to 9%.

The Scorpius® launch vehicles are characterized by 6 identical outer pods (1st stage) and a central pod (2nd stage) that is virtually identical to the 1st stage pods. This means that, by having 7 virtually identical pods in each vehicle, if only 2 or 3 vehicles are produced annually, this is still 15 to 20 pods per year, which creates a small assembly line and the resulting economies of scale. The vehicles have very clean systems with almost no moving parts, and are characterized by very robust performance, being able to go to orbit with 1 engine out.

2. DESIGN FOR MANUFACTURABILITY

The design for manufacturability is a key aspect of the Scorpius® launch vehicle technology. The Scorpius® manufacturing process consists of setting up, maintaining, and using a low-cost launch vehicle manufacturing environment with build-to-inventory and launch-on-demand. Manufacturability, low cost, and assured availability are preferred over the traditional emphasis on performance optimization. In other words, Microcosm and SSLC adopt a throughput orientation versus a mission assurance orientation, they try to achieve a break from tradition, and utilize an industrial production mentality.

Backing off even a small fraction from the optimum and stepping into "robust design," "large margin" and "throughput orientation" territory has enormous benefits and a compounding effect on cost. Even a minimal level of modularization of sub-systems and standardization of interfaces and fasteners makes a significant difference. Adding flexibility to the material flow using multiple-use tools, movable production assets, wheeled setups, and cross trained personnel who work sliding scale and split shift schedules, reduces costly dependencies that are otherwise mandated by the demand for optimization. Reducing the requirements catalog to the essential functions of the product and designing multi-functionality into the production environment, as opposed to into the product, are essential requirements of a design-to-cost approach. Carry-over or adoption of manned flight or military quality standards are eliminated wherever possible. Microcosm and SSLC are breaking the chain of perpetual performance optimization.

In terms of technical performance, this vehicle architecture offers a very low parts count, virtually no secondary structure, high structural stiffness, large performance margins, low thermal effects sensitivity, high shock and vibration tolerance, and good operating agility. In terms of cost performance, in addition to low manufacturing cost, this design has a compounding impact on logistics and operational costs, since it facilitates the application of commercial standards for all non-flight procedures such as storage, check-in/check-out, crating, shipping/transportation, handling, corrosion prevention, and an industrial-type rapid production throughput.

If the commercialization of space is to be an achievable goal, we have to address cost as a key ingredient. The particular culture of the aerospace engineering profession plays a major role in terms of the cost of space missions and is therefore worth examining. For contrast, let's compare the performance optimization design mindset of an aerospace engineer to that of an automotive engineer, whose effort is driven by the need to achieve high Design Efficiency. That means simply, that his design considerations are guided by trades of total manufacturing time and total assembly time (impacting cost and schedule) contrasting the aerospace typical product function and performance optimization (impacting mission assurance). In the automotive world, a certain car model must fit a very narrow cost bracket in the market place, which mandates a highly disciplined design-to-cost approach. All other considerations pale in comparison — for if the car misses its selling price target, it will simply not sell and the development investment will go to waste. In contrast, the aerospace engineer is concerned with optimal vehicle/payload performance and maximum mission assurance, meaning that the design decisions are informed by the performance optimization goals of every part, as well as the mandate that the mission can never fail, with cost typically of significantly less importance. The following, very simple Design for Assembly (DFA) example illustrates the different mentalities (Fig. 2).

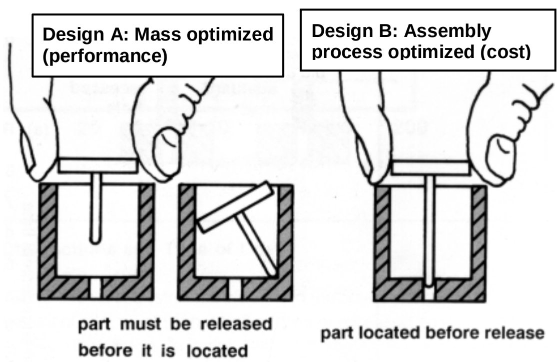

Figure 2. Aerospace and Automotive Part Design Comparison.

Example A: (aerospace) is a design guided by performance optimization, where the short pin helps to reduce mass at the expense of difficult insertion and a high operator skill requirement. Although not visible in this example, it can be safely assumed that this part would be made of some ultralight specialty alloy, probably machined out of a block of material, and that numerous inspections and material certifications would guarantee the flawless function that is demanded by the near 100% mission assurance requirement (i.e., typically > 99% even for unmanned missions). Considerations for such factors as ease of manufacturing, assembly, storage, cost, and availability do not rise to a level where they can compete with the mass optimization demands. Example B: (automotive) is a design for the same part, guided by cost goal demands, thus affecting aspects such as features that accommodate quick and error-free assembly at the cost of slightly higher mass. Although not visible in this example, it can be safely assumed that this part would be made of very common off-the-shelf materials and that it would include no additional treatments or processes that don't add direct value for the customer. The commercialization of space will create a market, namely the space commerce market, which will eventually be ruled by the same forces as the car market: price, availability, accommodation of customer needs and reasonable quality/reliability of the product.

3. BREAKTHROUGH TECHNOLOGIES OF THE SCORPIUS® FAMILY OF LOW-COST LAUNCH VEHICLES

The Scorpius® technologies, developed by Microcosm and its sister company, Scorpius Space Launch Company (SSLC), enable a low-cost architecture for the family of orbital launch vehicles. The three main technologies are the all-composite cryogenic tanks, the high-performance pressurization system, and the composite ablative engines. They not only are low-cost in themselves, but they also greatly reduce the vehicle's overall life cycle cost, including manufacturing, integration, and launch operations. These technologies make a high-performance pressure-fed propulsion system possible, therefore greatly reducing cost compared to pump-fed propulsion systems and solid rockets. In particular, pump-fed systems use turbopumps and regenerative cooling systems that make the vehicle as much as an order of magnitude more expensive than a pressure-fed system. Similarly, solid rockets use expensive and polluting propellant, are heavy and dangerous during ground operations, cannot be shut down or restarted, and require expensive steering mechanisms for controlled flight, making the pressure-fed system the option with the lowest cost; also, generally, compared with pressure-fed LOX/Jet A systems, solid motors for orbital launch have inferior performance. More details on the differences between pressure-fed and pump-fed propulsion systems are provided in Chakroborty and Bauer[2]. The key Scorpius® technologies are described more in detail below.

3.1 All-Composite Cryogenic Tanks

Microcosm and SSLC have developed an innovative line of all-composite, linerless, cryogenic tanks called Pressurmaxx®, which is characterized by a common carbon fiber material and SSLC's proprietary cryogenic resin formulation, termed Sapphire77. One of these tanks is shown in Fig. 3. The tanks can be built in a wide range of sizes and aspect ratios (Fig. 4), not only for the Scorpius® family of launch vehicles, but also for other applications such as spacecraft (manned and unmanned), aircraft, cryogenic fluids storage and transfer, high-pressure storage, unmanned aircraft systems (UAS), unmanned underwater vehicles (UUV), automotive, oxygen & air supplies, medivac vehicles, military ops, and Special ops diving. The tanks have been successfully tested with nitrogen at cryogenic temperatures down to –321 deg F, and at burst pressures up to 7,200 psi. This high performance is achieved with a shorter lead time than traditional composite-overwrapped pressure vessels (COPV) or metallic tanks, while maintaining very low cost. Another key characteristic of the tanks is their low weight, approximately half of that of metallic tanks of the same volume; a consequence of this advantage is that the tanks constitute only about half of the dry weight of any of the vehicles of the Scorpius® family.

Figure 3. Pressurmaxx® All-Composite Tank.

Figure 4. All-Composite Tanks of Different Sizes and Shapes.

The Pressurmaxx® composite tanks are characterized by unique technologies such as all-composite polar bosses, integration of external structural stringers (circumferential or longitudinal) and internal slosh baffles, and tooling production. Additive manufacturing techniques are employed for these integrated features (Fig. 5), which are not externally attached but built from "inside out." Thanks to these breakthrough technologies, the tanks are effectively unibody structures and can therefore become the primary structure of a launch vehicle or a spacecraft[3].

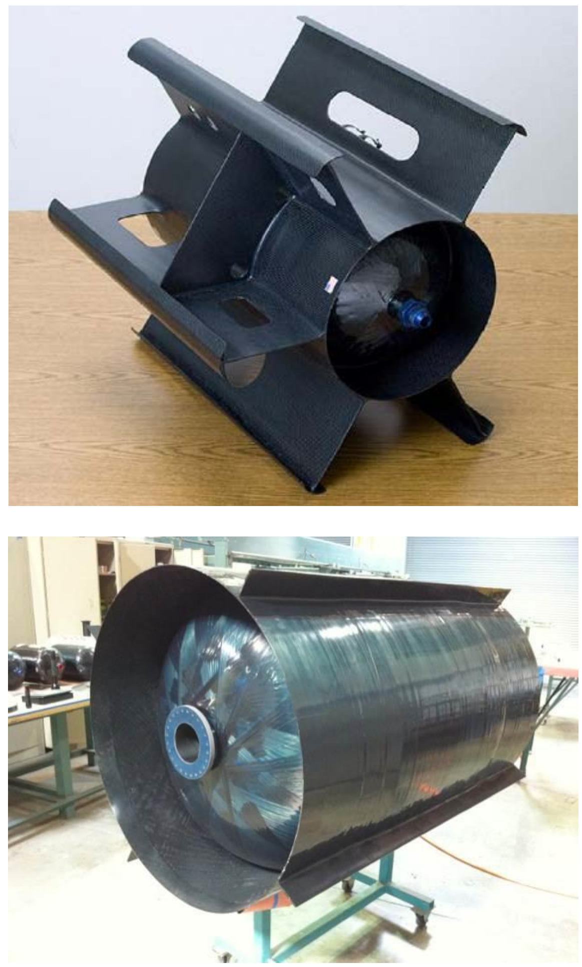

Figure 5. All-Composite Tank with Skirts and Longitudinal Stringers.

Tanks have been built from 0.5 cuft to 200 cuft volume for propellants, gases, pressurants, and cryogens up to 3,600 psi maximum expected operating pressure (MEOP), which translates into 7,200 psi burst pressure given that the tanks, currently, are built to a safety factor of 2.0. Figure 6 shows an example of a 200 cuft tank that was transported on a regular truck trailer, providing evidence of the great robustness and ease of handling of the tanks, which really is a revolution compared to current metal tanks used for space applications. Figure 7 shows an application of the PRESSURMAXX® all-composite tanks with the Armadillo Aerospace rocket vehicle, used in the X Prize Northrop Grumman Lunar Lander Challenge Level 2, for which two of our high-pressure helium tanks at 2,200 psi MEOP were used, allowing Armadillo to successfully complete the challenge.

Several qualification tests have been conducted on the tanks to date[3]:

- Chemical compatibility: compatibilities include petroleum-based fuels, e.g., kerosene; alcohol based fuels, e.g., ethanol; cryogens, e.g., liquid oxygen and nitrogen; various gases, e.g., methane, helium, oxygen, nitrogen; and propellants, e.g., turpentine, hydrazine, and AF-M315E green propellant.
- Pressure tests: pressurant tanks operating at 3,600 psi (7,200 psi burst rating) are in use, for which 50 fill/discharge cycles were performed.
- Temperature range: 25 temperature cycles and rapid chill-down testing have been conducted with nitrogen from +175 deg F to –321 deg F.
- Load / Impact / Vibration tests: a vibration test has been conducted on a spacecraft bus characterized by a unibody composite pressurized structure.
- Radiology tests: NASA White Sands Test Facility (WSTF) shearography, pressure, and leak tests have been conducted.

Figure 6. Local Transport of a 200-cuft., 500-psi LOX Tank.

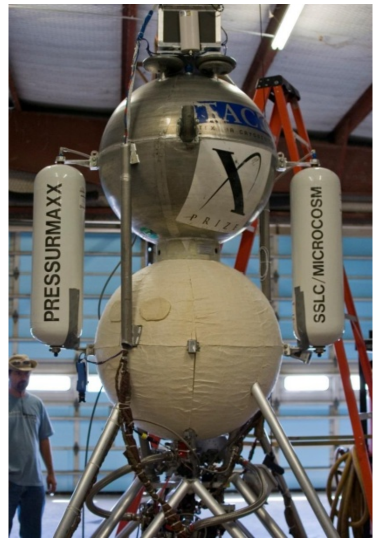

Figure 7. Prize Winning Armadillo Lunar Lander GHe Tanks, 2,200 psi MEOP.

Additionally, Microcosm and SSLC have developed tanks incorporating a positive expulsion device (bladder), which is used for spacecraft in-space propulsion[3]. The positive expulsion device, or PED, is made from an EPDM (ethylene propylene diene monomer) rubber material that has already been qualified by both NASA and ESA and has flown to space on multiple missions. The development effort of the Microcosm/SSLC bladder tank technology was funded by NASA Glenn Research Center. This tank uses the linerless all-composite PRESSURMAXX® unibody technology already successfully demonstrated in various applications, and is designed for use in either blow-down or external accumulator mode. The bladder and tank body are Hydrazine and AF-M315E green propellant compatible. This technology does not require standard propellant management devices (PMD's), and is therefore simple and reliable.

3.2 High-Performance Pressurization System

The high-performance pressurization system (HPPS) developed by Microcosm and SSLC is based on Tridyne, which is a concept first developed in the 1950's by Rocketdyne (hence the name) in Canoga Park, CA. Microcosm and SSLC improved this concept, first through extensive analytical work and comprehensive test programs under IR&D, and then through various government contracts. These contracts were issued as part of the DARPA FALCON program, and they substantiated the viability of the system. The system configuration is illustrated in Chakroborty *et al*.[4]

Heating the helium through this process was shown experimentally to reduce the mass and volume of the required helium and the associated tankage by nearly 50% compared to a cold gas system, resulting in substantial payload gain. Figure 8 shows one of the tests: the tank on the right (white) is the regulated propellant, while the one on the left (black) is the actual Tridyne tank. There are virtually no moving parts in the system. Successful liquid oxygen (LOX) expulsion tests with a flight-like HPPS system validated the technology for a Sprite size vehicle. This technology qualification program also verified the scalability of the system to both smaller and larger sizes.[4]

Figure 8. High-Performance Pressurization System Test.

Thanks to Microcosm's HPPS, uniform and constant pressure is maintained in the launch vehicle's propellant tanks (LOX and Jet A). Therefore the performance is predictable all throughout the flight. The successful tests show that this system is expected to work in space without issues.

3.3 Composite Ablative Engines

The Scorpius® ablatively cooled engines are designed by both Microcosm and Scorpius Space Launch Company (SSLC) and are built in-house by SSLC. An image of the Scorpius® 20K lbf thrust engine is shown in Figure 9. These engines are characterized by an external layer (structural) of carbon fiber and Sapphire77® cryogenic resin, and an internal ablative layer. The simple design of the engine enables very low cost production. These engines have almost no moving parts and do not need expensive components like the turbo pump or the regenerative cooling system. The preferred propellant combination for the propulsion system is LOX/Jet A, both very low cost and compatible with the ablative layer. The SSLC-built engines are characterized by an ease of production and integration. Engines providing 5K lbf of thrust and 20K lbf of thrust have been built and tested. In particular, the 5K lbf engines have flown on two successful suborbital flights, the SR-S (1999) and SR-XM (2001), both from the White Sands Missile Range, NM. Examples of 20K lbf engines are shown in Figure 10 (these are the engines used by the Sprite vehicle). Microcosm has conducted firing tests on both the 5K lbf and the 20K lbf thrust engines (Fig. 11).

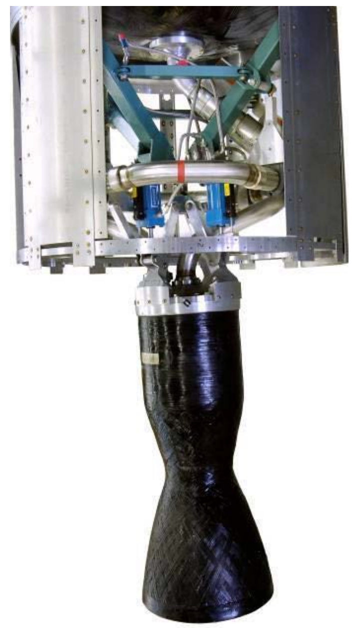

Figure 9. 20K lbf Thrust Engine Apparatus.

Figure 10. 20K lbf Thrust Engines.

Figure 11. 20K lbf Thrust Engine Firing Test (Edwards Air Force Base).

The specific impulse of the 1st stage engines is 286 sec. (vacuum) for all vehicles. The Scorpius® engines have moderate performance compared to other liquid propellant engines; however, the Scorpius® engines have the advantage of being much lower in cost. Additionally, the manufacturing process of these engines is relatively simple compared to pump-fed engines, because the Scorpius® engines have almost no moving parts (only valves and gimbals can move), making this system very low cost.

4. SPRITE CONFIGURATION AND PERFORMANCE

The configuration of the Sprite launch vehicle is shown in Fig. 12, and some of its key characteristics are presented in Table 1. Sprite's payload capacity to low Earth orbit (100 nautical miles altitude with launch due east) is 1,060 lb (480 kg). The launch price is less than $6.0M, in 2014 dollars, which is a very appealing aspect of the vehicle. Sprite uses pressure-fed engines that are small, light-weight, and simple. The vehicle has 3 stages, the first of which is made of 6 identical pods each with a 20,000 lbf of thrust engine, 1 fuel tank, 1 oxidizer tank, and 2 Tridyne tanks. The outer pods surround the core pod, which is the vehicle's 2nd stage. This pod is almost identical to the outer pods, as the only real difference is the slightly dissimilar engine configuration. On top of the 3rd stage sits the payload bay surrounded by a bi-conic fairing. Each pod and the 3rd stage are 42 inches in diameter, and the whole vehicle is 11.2 ft in diameter; additionally, the vehicle's height is 54.2 ft, and its gross lift-off weight (GLOW) is 80,500 lb (9,300 lb dry weight).

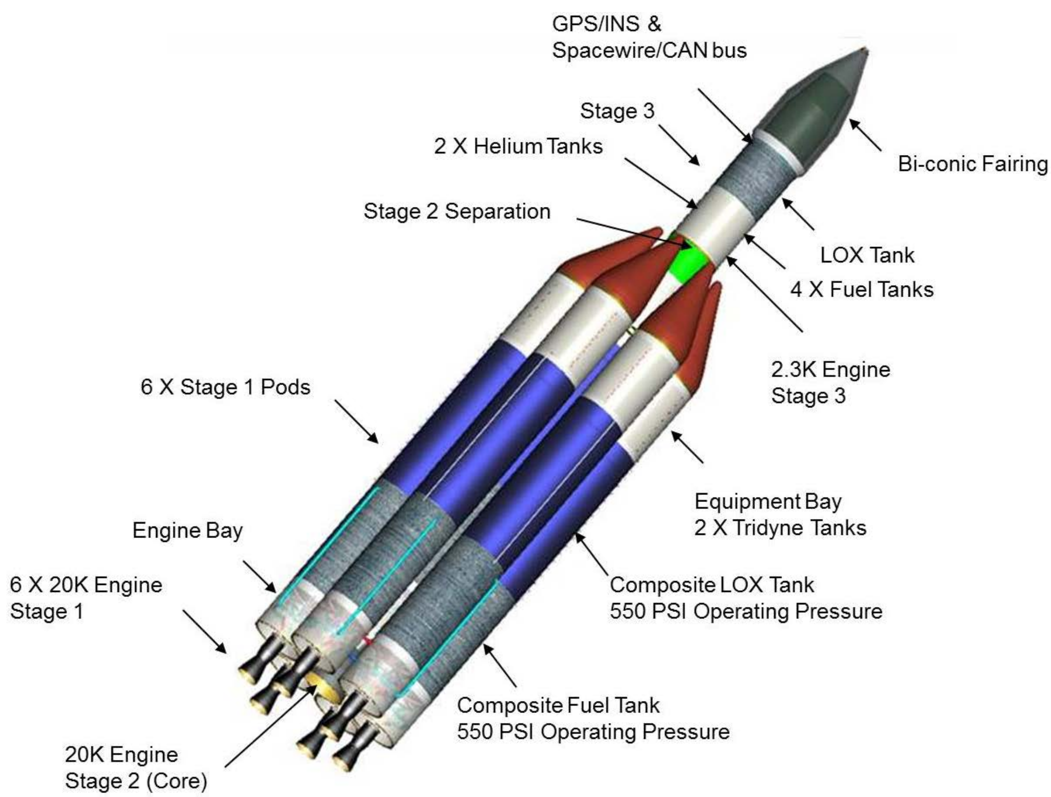

Figure 12. Sprite Configuration.

Table 1. Key Characteristics of the Sprite Launch Vehicle.

Characteristic	Sprite
LEO Payload (100 Nmi due East)	1,060 lb
Launch Price	< $6.0 M ($FY14)
Overall Height	54.2 ft
Pod Diameter	42.0 in
Vehicle Diameter	11.2 ft
GLOW	80,500 lb
Dry weight	9,300 lb
Propellant	LOX/Jet-A
Pressurization	Tridyne
Max Axial g's	5.9
Engine Configuration	
Stage 1	6 × 20K
Stage 2	1 × 20K
Stage 3	1 × 2.3K
Stage 1	
Number of pods	6
Thrust, vac (lbf)	120,000
Thrust, sl (lbf)	101,000
Gross Mass (lbm)	65,600
Stage 2	
Number of pods	1
Thrust (lbf)	22,300
Gross Mass (lbm)	10,900
Stage 3	
Thrust (lbf)	2,300
Gross Mass (lbm)	3,005

Sprite provides true launch-on-demand service from a flat pad with minimal infrastructure within 8 hours of arrival of the payload at the launch site, and it is capable of all-weather launch through 100-kt ground wind and 99.9% of winds aloft. This capability is possible thanks to Sprite's squat configuration and, therefore, low moments of inertia, which allow much better steering control, and also thanks to its very strong all-composite tanks which are also the load-bearing structure of the vehicle. Additionally, Sprite is scalable to much larger (or smaller) vehicles using the same technology and basic vehicle design. Finally, all the Scorpius® launch vehicles are very easy to launch, because they do not need a flame bucket, just a flame deflector, so they can launch from virtually anywhere. These key properties make Sprite and the other vehicles of the Scorpius® family extremely responsive and ready to meet any of the world's launch needs. Specific applications of the Sprite vehicle are presented in Sec. 6.

One of the scaled-down versions of Sprite, called Demi-Sprite, can put up to about 160 kg into LEO for a recurring launch cost of about $3.6 M. The main application consists of launching NanoEye or equivalent category spacecraft to LEO.

5. SPRITE'S STATE OF DEVELOPMENT

Sprite is the Scorpius® vehicle that has progressed the furthest in terms of development, both in terms of design and testing. The technology for Sprite has been revised since Chakroborty *et al.*[5] resulting in an increase in LEO payload performance from 318 to 480 kg (700 to 1060 lbs.) mostly thanks to the advancements in the tank technology. The metallic bosses of the first generation of composite tanks have been eliminated, resulting in truly all-composite propellant and pressurant tanks, which saves weight. Factor of safety of 2 has been established providing ample margin and assurance for the ranges. A high density ablative chamber has been incorporated to provide longer life. The avionics system has been updated taking advantage of ongoing developments in electronics that save weight, power, and size. Moreover, subsequent efforts have increased the confidence in the technology and approach through extensive analyses, simulation, wind tunnel testing, Tridyne expulsion testing, and 20K engine testing. As mentioned, considerable experience at building all-composite tanks in a variety of sizes for a range of applications with different pressures, temperatures, and fluid types has increased maturity in this most crucial of the Scorpius technologies. A GPS-based range operation has been adopted, which reduces range cost and flight hardware.

The SR-M suborbital launch vehicle is shown in Fig. 13. This vehicle is very similar to Sprite's 2nd stage, and has already been designed and built by Microcosm and SSLC, but has not yet flown. The SR-XM suborbital launch vehicle, which has successfully flown in 2001 (Fig. 14), represents a prior version of the SR-M launch vehicle, and therefore, of a pod of Sprite. The SR-XM was assembled, erected, fueled and ready to launch within 8 hours of arrival at the launch site (West Center 50, White Sands Missile Range).

Figure 13. SR-M Suborbital Launch Vehicle.

Figure 14. Scorpius® SR-XM.

6. SPRITE VEHICLE — SAMPLE MISSIONS

The performance of the Sprite launch vehicle to various LEO orbits is depicted in Figure 15. Representative missions in LEO include launch of small satellites up to 480 kg for observation, remote sensing, science, and military. Another application is to launch to Sun-synchronous orbits (SSO) from dedicated locations such as the Vandenberg Air Force Base in California (for example for weather monitoring missions); additionally, Sprite can launch to transfer orbits for the International Space Station (ISS, circular orbit in a range of 330 km – 435 km altitude) with the purpose of delivering commodity cargo (e.g., water, food), to the station itself. Microcosm's NanoEye spacecraft, whose baseline configuration is in the nano/microsatellite category,[6] could potentially perform most of the above missions.

Sprite can also deliver payloads to orbits beyond LEO. For example, payloads can be delivered to Geostationary Transfer Orbit (GTO, 168 kg maximum payload); in particular, applications in Geostationary orbits (GEO) can include communication satellites, space situational awareness (e.g., space debris monitoring), or scientific observation missions. A longer-term application could be the launch of small satellites to GPS transfer orbits to allow future generations of GPS satellites to either replace or augment existing, much older satellites. Finally, with a Scorpius® upper stage, Sprite can launch small satellites to interplanetary orbits (i.e., very high energy orbits); in particular, small satellites like Hummingbird[7], in the 100 kg mass range, could be launched to escape orbits (and then the satellite can use its own propellant to maneuver to a desired interplanetary orbit). Additionally, smaller satellites, up to 54 kg, can be launched directly to a Mars transfer orbit. Potential missions for the Sprite launch vehicle are summarized in Table 2.

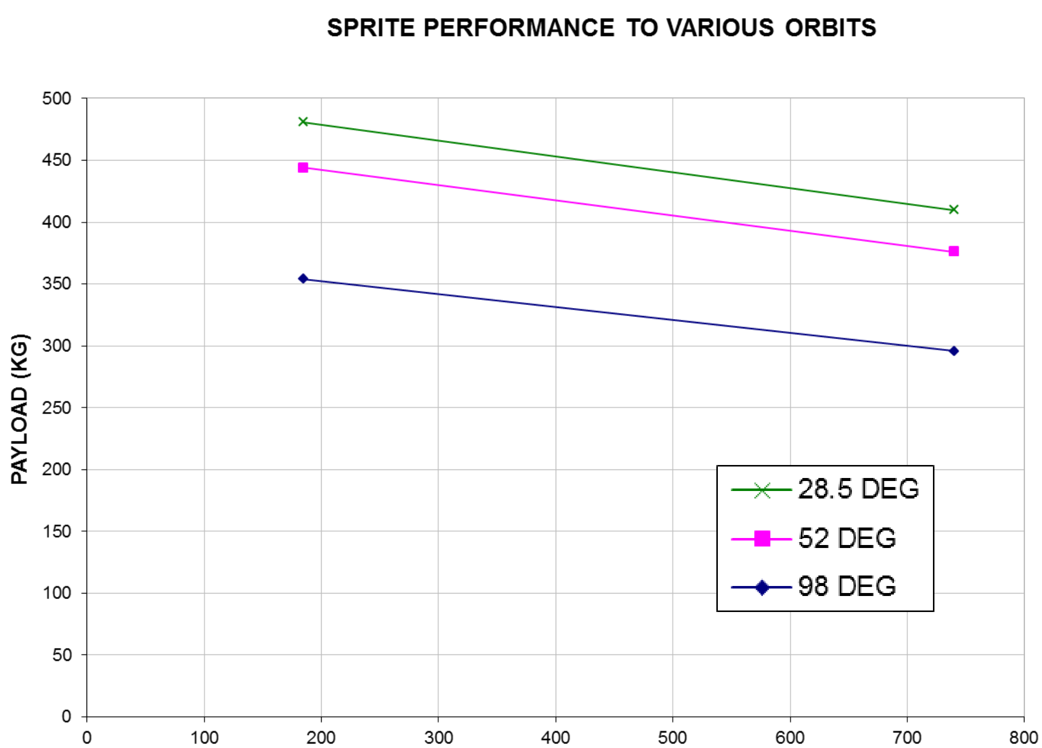

Figure 15. Sprite Performance to LEO.

Table 2. Potential Missions for Sprite.

Mission	Inclination (deg)	Altitude (km)	Payload (kg)	Note
NanoEye	= Target Latitude + 5	200 × 500	434	At 45 deg
Earth Observation	98	740	296	Sun-Synchro-nous
Experimental Satellite	35	400	443	
Comm Satellite	52	615 × 750	383	Satellite = 172 kg
ISS	52	330	426	
GPS Transfer Orbit	55	191 × 20,182	100	
GTO	28	185 × 35,746	168	w/Scorpius Stage 4
Mars Transfer	28	Escape	54	w/Scorpius Stage 4

7. MARKET ANALYSIS

Microcosm has reviewed several recent studies of the market need for low-cost access to space for small satellites. The main sources of information that were found by Microcosm are Snow *et al.*[8], Buchen and DePasquale[9], Bauer *et al.*[10], and Foust *et al.*[11]

SpaceWorks made an assessment of the 2013 global launch vehicle market[8] and an assessment of past and future nano/microstellite launch demand.[9] In particular, SpaceWorks projected the global launch demand in the nano/microsatellite market segment from 2014 to 2020 (note that SpaceWorks placed no value judgment on whether developers will successfully meet their announced launch date). The satellites' masses considered range from 1 kg to 50 kg (Fig. 16); this range can be served by several of the Scorpius® vehicles, in particular Sprite and Demi-Sprite. The Sprite vehicle can potentially deliver several nano/micro satellites to LEO with just one launch. A thorough study for payloads weighing up to 480 kg (i.e., small satellite range, 100–500 kg), which is Sprite's capability to LEO, has not yet been conducted, but Microcosm expects that the market trend will be very similar to that of nano/micro satellites (nominally, 1–100 kg).

The data source for this study is the SpaceWorks Satellite Launch Demand Database (LDDB), a continually updated database cataloging historical and future satellite missions; spacecraft masses included in this database range from less than 1 kg to over 10,000 kg, with over 3,800 historical and planned satellites identified. The nano/microsatellite projection was developed from a combination of two data sets: publicly announced projects and programs, and quantitative and qualitative adjustments to account for the expected sustainment of current projects and programs, as well as the continued emergence and growth of commercial companies.

The projections based on announced and future plans

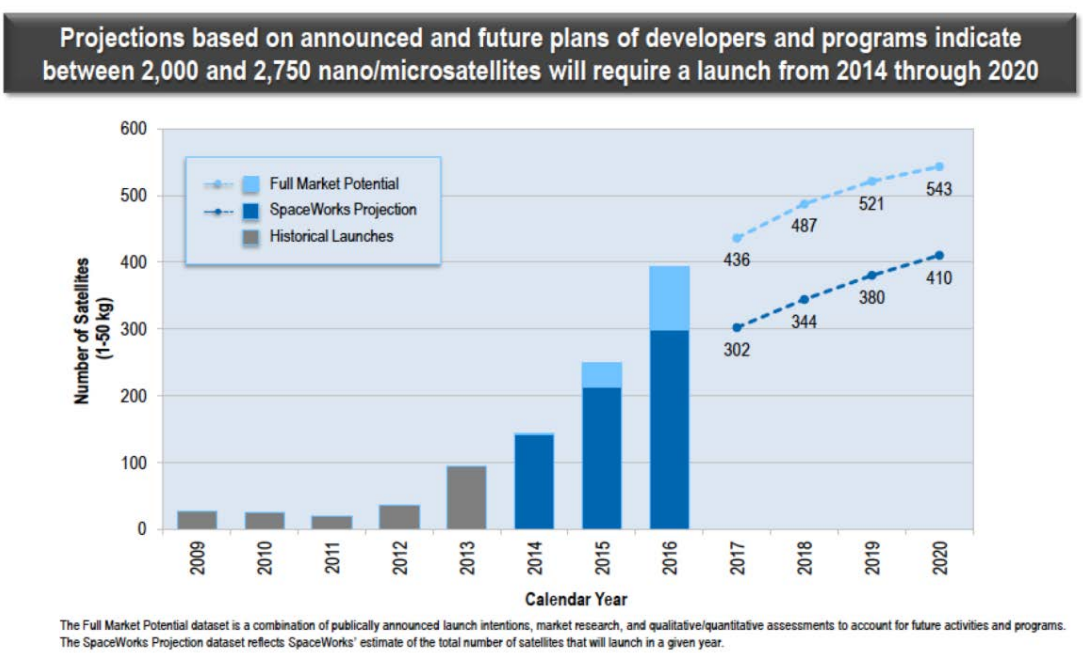

Figure 16. SpaceWorks Assessment of the Nano/Microsatellite Launch Demand. Reproduced from Buchen and DePasquale,[9] with Permision.

of developers and programs indicate that between 2,000 and 2,750 nano/microsatellites will require a launch during the period from 2014 through 2020 (compared to 92 in 2013 alone). According to SpaceWorks, the nano/microsatellite industry continues to thrive, with an estimate of roughly 140 satellites requiring launch during 2014. Additionally, the commercial sector contributed 64% of 2014 nano/microsatellites, and the civil sector contributed ~25%; future launches suggest that this trend will continue. Finally, 91% of the nano/microsatellites launched in 2014 were used for either Earth observation/remote sensing or technology demonstration.

The 2nd source of information used by Microcosm is the DoD Space Experiments Review Board (SERB) list, which was evaluated by Microcosm in 2010.[10] The SERB list contains 62 payloads or spacecraft, 59 of which with sufficient definition to compute an equivalent mass to LEO for launch vehicle sizing. The analysis consisted in determining how many SERB payloads could be launched by specific Scorpius® launch vehicles. The result is shown in Fig. 17 and also summarized below:

- 41 (70%) could be launched by Demi-Sprite
- 50 (85%) could be launched by Sprite
- 9 (15%) vehicles would require Liberty

As the figure shows, currently the knee of the demand curve falls generally near the Demi-Sprite launch capability.

The 3rd relevant source used by Microcosm for its market analysis is a Futron Study conducted in 2006 for AFRL, and presented at the 2008 USU SmallSat Conference.[11] The study identified over 30 markets in 4 principal areas: military (the largest market), civil/commercial remote sensing, civil/commercial communications, and other. The total addressable market for small satellites (which were defined in the study as having a mass between 100 kg and 200 kg) resulted to be 39 to 76 satellites per year. This projection showed that the SmallSat market is very robust and growing, and that there are many non-traditional customers. According to the SpaceWorks 2014 study, this market has increased by more than a factor of 10 since the time of the Futron study; many more non-traditional customers could come from selling complete systems to traditionally non-satellite users (e.g., oil pipeline protection in Mexico, U.S. border security, and worldwide emergency response).

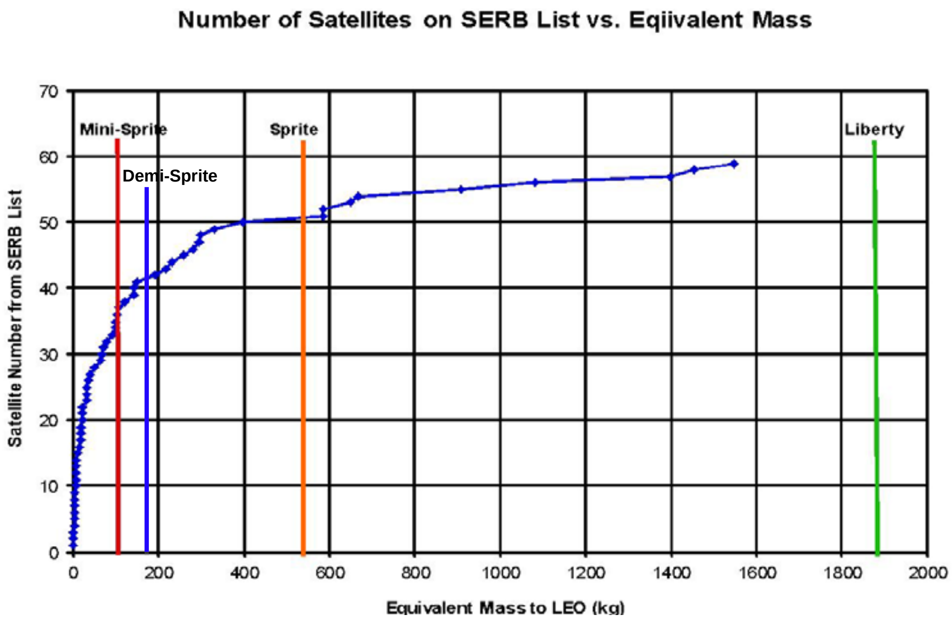

Figure 17. Distribution of Required Scorpius® Launch Vehicle Size for DoD SERB List.
(Mini-Sprite has now been replaced by Demi-Sprite in the launch manifest.)

8. CONCLUSIONS

The Scorpius® family of low-cost launch vehicles developed by Microcosm and its sister company, Scorpius Space Launch Company (SSLC), can greatly reduce the cost of access to space. The Scorpius® technology is scalable to different sizes and enables a wide range of missions based on the size of the vehicle. All Scorpius® orbital vehicles use the same vehicle configuration: 3-stage expendable, 6 outer pods constituting the first stage, a nearly identical inner pod constituting the second stage, and a smaller restartable third stage. (A fourth stage may be added for some missions.) All vehicles use the same key technology elements: a pressure-fed propulsion system based on LOX/Jet A, ablatively-cooled engines, all-composite cryogenic propellant tanks, and a high performance pressurization system based on Tridyne. By having 7 virtually identical pods in each vehicle, even if only a few vehicles are produced per year, a small assembly line can be created, which further reduces cost due to the economies of scale. The unique vehicle architecture offers a very low parts count, virtually no secondary structure, high structural stiffness, large performance margins, low thermal effects sensitivity, high shock and vibration tolerance, and a high controllability launch environment.

This design also has a compounding impact on logistics and operational costs. The smaller vehicles are easy to transport in a standard cargo container; they are also easy to move thanks to their robustness and compact dimensions. They do not need a flame bucket for launch but just a flame deflector, and therefore can launch from virtually anywhere. They are all characterized by a squat configuration, which lowers the moments of inertia and enables greater steering control. They can launch through 100 kt ground winds and 99.9% of winds aloft, thanks to their better controllability and strong structure.

The design for manufacturability is a key aspect of the Scorpius® launch vehicle technology. The Scorpius® manufacturing process consists in setting up, maintaining, and using a low-cost launch vehicle manufacturing environment, with build-to-inventory and launch-on-demand. Manufacturability, low cost, and assured availability are preferred over the traditional space industry's emphasis on performance optimization. A throughput orientation and an industrial production mentality are adopted, versus a traditional mission assurance orientation that is anchored in large systems and manned flight requirements. This approach does not trade away quality or reliability – it trades accommodations to manufacturability (cost) against performance optimization. Additionally, significant cost reductions are achieved by robust design, large margins, modularization, and standardization. Microcosm and SSLC are breaking the chain of perpetual performance optimization.

The Sprite small launch vehicle can deliver up to 480 kg to LEO for less than $6.0M. It is clear that a substantial market for small satellite launches exists, and will almost certainly grow significantly over time as small spacecraft become increasingly competent. The Sprite launch vehicle is expected to fulfill the need of potential customers to launch small satellites by providing access to various orbits and enabling numerous missions. The vehicle greatly reduces the cost of access to space and is very responsive thanks to its capability for launch-on-demand within 8 hours of payload arrival at the launch site. Sprite is expected to introduce a breakthrough, disruptive capability in the launch vehicle market.

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