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Responsive Access to Space – The *Scorpius*® Low-Cost Launch System*

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Abstract

"Responsive space" has substantial benefit in terms of both flexibility to meet real-time needs and assured space access. However, creating responsive space requires a new paradigm for space launch systems, launch operations, and the space systems themselves.

This paper describes the *Scorpius*® family of launch vehicles, being developed by Microcosm and the Scorpius Space Launch Company. The system has been designed from the outset to meet the key requirements of a responsive launch system:

- Sufficiently low cost to allow launch vehicles to be built in advance of need and stored for later use. (For example, the Eagle SLV small launch vehicle designed for the AF/DARPA FALCON program is intended to put 1000 lbs into low Earth orbit at a total launch cost of less than $5 million.)
- Launch within 8 hours of arrival of the payload at the launch site or call up of a payload stored at or near the launch site.
- Mitigation of the need for a large "standing army" of launch personnel.
- Ability to launch from multiple launch sites, with minimal infrastructure required at each site.

As an example of this process, the first suborbital test vehicle for the *Scorpius*® family was developed and built in California and trucked to White Sands, New Mexico, for launch from a bare, flat pad with no infrastructure at the pad. (Full range support was available elsewhere at White Sands.) The vehicle, launch rail, and all ground support equipment were put in place and ready to launch in less than a day.

At the present time, the largest impediments to rapid launch are the regulatory requirements for advance notice and simply the tradition of launches planned long in advance. To the extent that these issues can be resolved, responsive launch systems can become available to meet the changing needs of access to space.

1. Background

Microcosm has been involved in the design and development of low-cost, responsive, pressure-fed expendable launch vehicles[1] for defense and commercial applications for well over 12 years. The family of pressure-fed launch vehicles shown in Fig. 1 include two suborbital vehicles that have been flown successfully and other orbital vehicles in development with capabilities ranging from 700 lbm to 50,000 lbm to Low Earth Orbit (LEO). The critical technologies that are essential for the success of these planned pressure-fed launch vehicles have been either developed or are in the final stages of qualification.

The primary objectives of the pressure-fed launch vehicle program include:

- A factor of 5 to 10 reduction in launch cost
- Low recurring, non-recurring, facility, and operating costs
- Modular and scalable design that allows transition from sub-orbital to progressively larger orbital vehicles
- Launch on demand with weather conditions comparable to commercial airlines

In order to meet the increasing needs for responsive launch for various defense and other related programs, Microcosm has been developing the concept of operations for the *Scorpius*® family of launch vehicles for over ten years. Our focus is to make the flight operations as airline-like as possible. This begins with the system design, where we

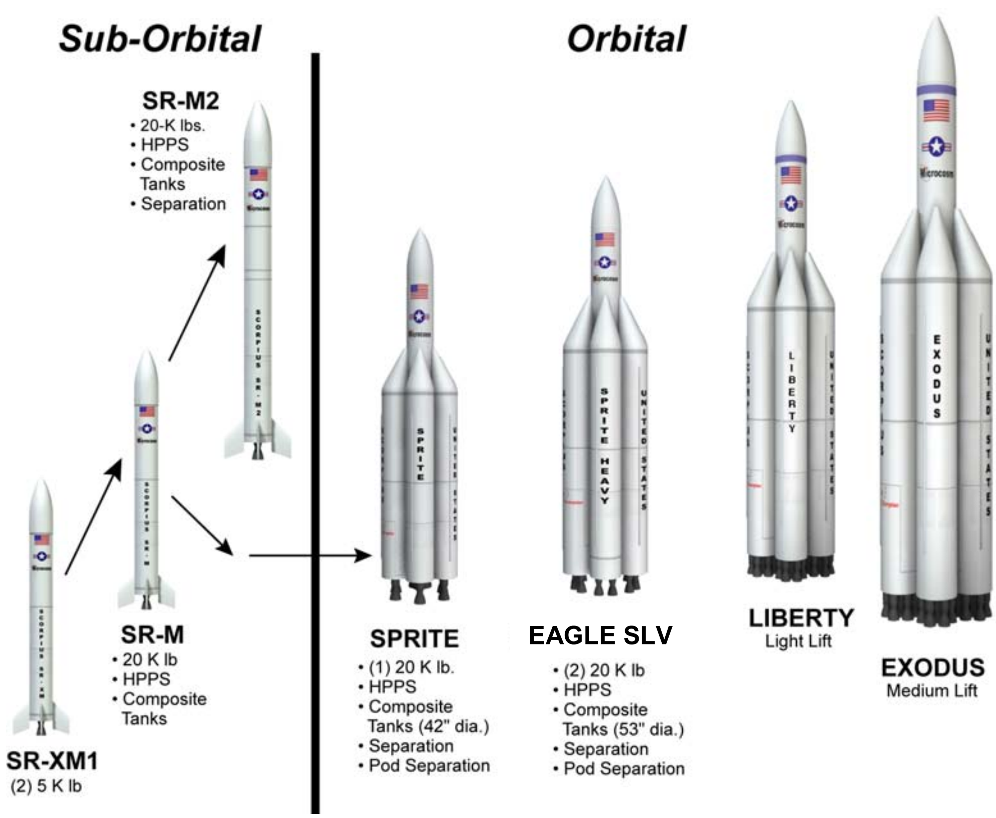

Fig. 1. Microcosm's Family of Low-cost, Pressure-fed Launch Vehicles.

emphasize simple, robust designs, minimal parts counts, maximum commonality between stage hardware designs, and operability. This approach enhances reliability, minimizes manufacturing and integration times, allows for quick and easy repair of any hardware failures, and allows for fast, efficient flight and ground operations.

The substantial cost reduction provided by these launchers stems from the non-traditional design. The launchers are designed as expendable rockets for low cost and simplicity rather than high performance or reuse. While many new rocket designs use two-stage to Low Earth Orbit configurations driven by high performance pump-fed engines, Microcosm rockets employ a three-stage configuration using simple, very low cost, pressure-fed engines. The vehicle configurations are modular and built around scalable components and technologies. Consequently, the vehicles can be scaled up easily to accommodate larger payloads.

Some of the positive features of the *Scorpius*® program that allow us to reduce cost with increased reliability and operability include:

- Improved reliability due to low number of parts, extensive use of identical parts, few precision parts and more robust production margins
- A demonstrated factor of 5 to 10 reduction in cost from existing and heritage vehicles
- Scalable size to balance cost vs. payload mass and destination
- Simple and robust design for low complexity, improved reliability, and low cost
- Simple LOX/Jet-A, pressure-fed system without turbopumps
- Low cost avionics with GPS/INS and integrated self test (much of the avionics have already flown on prior missions)
- Incremental development and flight qualification
- Low complexity production
- Innovative manufacturing process with minimal touch labor
- Efficient operations infrastructure
- Final pod integration on launch cradle by an integration team who also perform most of the final test, payload integration, and launch
- Ability to launch from a simple flat pad virtually anywhere in the world for vehicles up to the Eagle SLV.

In general, our pressure-fed launchers are simple, reliable, and robust. They are easy to operate, have good specific impulse, and are low in cost. The largest drawback of pressure-fed systems is their higher weight. However with a moderate staging arrangement of 3 stages to LEO, the much lower developmental and recurring costs of the pressure-fed systems more than offset the somewhat higher gross weights of the pressure-fed vehicles. That the weights are only moderately higher[2] for the lower stages of the pressure-fed vehicle is enabled by the composite tanks and a high performance pressurization system. A benefit of the higher gross weight of the pressure-fed system is that the vehicles are robust during manufacturing, transportation, and ground handling when, of course, they are empty of propellants. Further, the thicker tank walls yield stronger structures with more margin for flight through maximum dynamic pressure and winds aloft.

2. Operational Concept

Our operational concept is built around maximizing responsiveness of our launch vehicles while minimizing the cost of launch operations which is traditionally a significant part of the total cost per launch.[3]

Two factors drive the responsiveness of the launch system: the ability to put vehicles on the launch pad when needed (vehicle availability) and the readiness of those vehicles to fly their missions (flight worthiness.) The key to satisfying the vehicle availability requirement is having flight-ready vehicles in storage for rapid call-up. Our vehicles are well suited to this task. Its pressure-fed propulsion, off-the-shelf avionics hardware, and robust structure easily accommodate long-term storage in a ready state. Our analyses indicate that the only components which may need periodic replacement in stored vehicles are the batteries. The systems in the pods and the core are nearly identical, allowing for rapid assembly and economies of scale.

During normal launch operations, the vehicle's larger components (e.g., the all-composite propellant tanks) are fabricated at a manufacturing/integration facility located near the primary launch site, while smaller components may be fabricated elsewhere and shipped to the manufacturing/integration facility. Fig. 2 shows the Microcosm facility for tank fabrication and pod assembly. The manufacturing/integration facility assembles the vehicle systems into flight elements of pods, cores, and upper stages. These flight elements are transported to an adjacent Integration and Checkout Facility, where they are assembled into complete vehicles and checked to ensure flight readiness. The short, stout launch vehicles are integrated atop portable launch platforms, which are transported with the vehicle to the launch pad on vehicle call-up. The robust structure of our vehicles allows vertical towing at higher speeds and over rougher surfaces than is common for launchers.

Fig. 2. Tank Production and Pod Integration Equipment.

The portable launch platforms include structure to support the fully-loaded vehicles during launch, launch hold-down/release hardware, propellant and pressurant manifolds, and structural attachment hardware to mate to the launch pad or stool. The flight ready vehicle is put into storage at the Integration Facility. The manufacturing and the integration facilities are expected to be located 3–5 miles from the launch pads to ensure safety while minimizing transport time and costs.

Fig. 3 shows a simplified diagram of the assembly and launch facilities. Our launch vehicles are designed to minimize pad operations. We will shift as many vehicle assembly and checkout operations to the Integration Facility as possible and will have several flight-ready vehicles in storage.

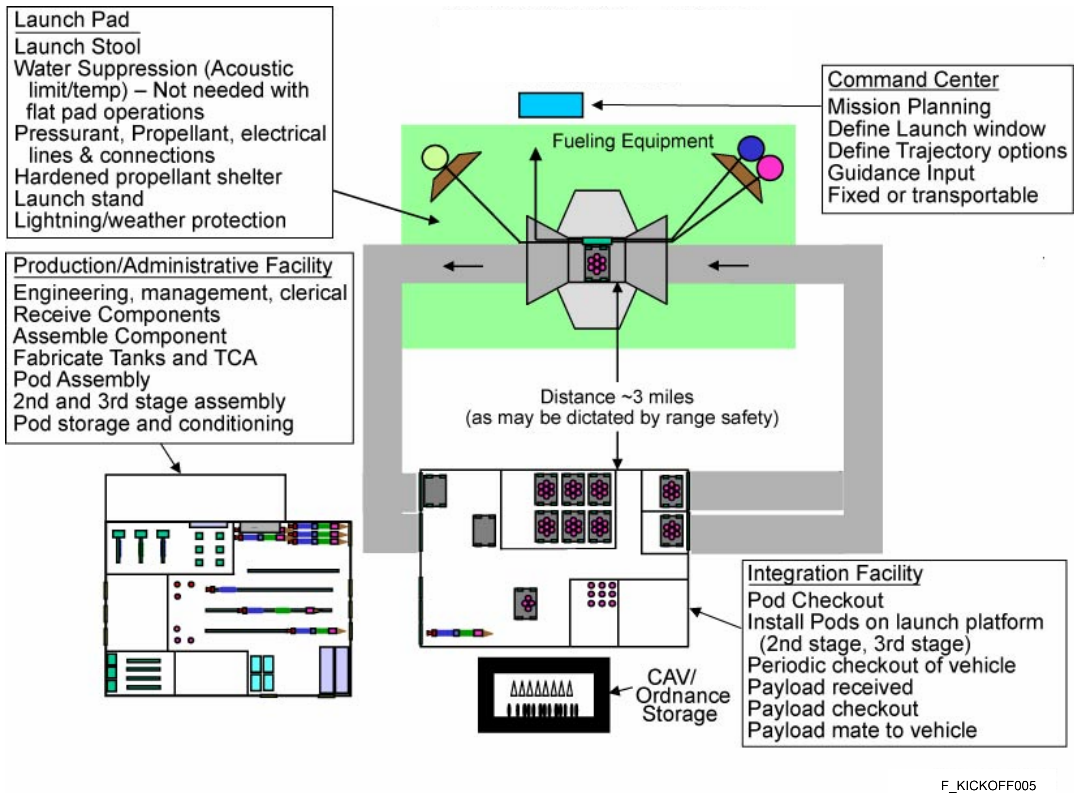

Fig. 3. Overview of Operational Features.

When a mission is initiated, the appropriate payload is selected and integrated onto the top of the third stage. The vehicle, integrated payload, and launch platform are transported to the launch site aboard the vehicle transporter as shown in Fig. 4.

Launch operations are planned and performed at the launch control trailer or launch control room at the Integration and Checkout Facility. All interconnections utilize an Internet protocol for high speed information exchange and secure broadcast of vehicle status and health information. This trailer includes all ground control equipment, telemetry hardware, and flight simulation software needed to plan and execute a mission. Vehicle tracking is performed via onboard, GPS-based downlink to the ground with a range-certified independent system.

Mission planning will rely on a set of "canned" launch profiles tailored for each launch site and payload class. This allows thorough testing and verification of the generic flight plans well before launch. These canned missions will be adjusted for the specific mission parameters once they are known and tested in the flight simulation programs to ensure their viability. These mission planning capabilities are already being utilized at Microcosm.

Our launch vehicles are designed for operability. Our operational approach allows us to launch from a flat pad anywhere in the world within 8 hours of call up. No gantry or service tower is required. So long as the onboard GPS is allowed for range safety, the only requirements for a remote launch site are a bare concrete pad and supplies of LOX and Jet-A. LOX can be manufactured at the site using commercial equipment, if needed. A key benefit of our launch system is that the vehicle is inert and lightweight until filled with propellants, thus allowing easy, safe transport

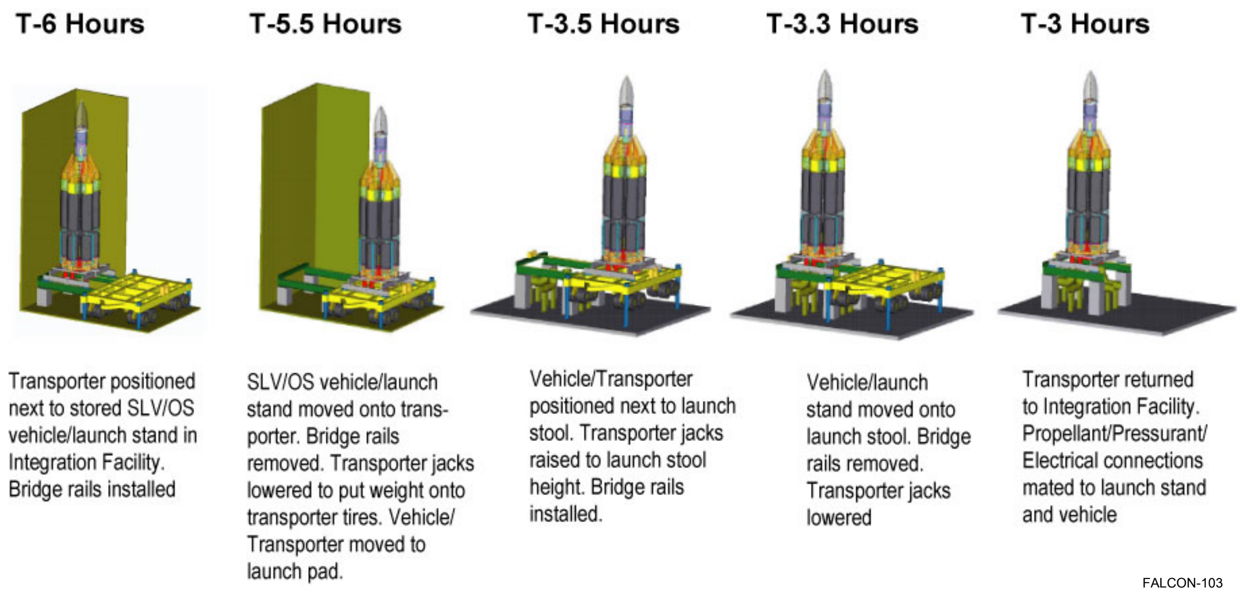

Fig. 4. Sequence of Launch Preparations

wherever needed. The low inventory cost, ease of operations and responsive launch of our vehicles facilitate the mission need for surge operations and affordability.

We have successfully applied this approach on our launches of the SR-S and SR-XM-1 vehicles in 1999 and 2001, where we demonstrated our ability to build flight hardware that requires minimal crew to setup and fly in a short period of time from White Sands Missile Range. In both cases, we started with a bare concrete launch pad and were ready to fly within eight hours of arrival of the vehicle using a crew of under fifteen, even as a development flight test vehicle.

3. Cost Objectives

One of our primary objectives is to provide low cost access to space. Our innovative design approach is built around modular and scalable, pressure-fed propulsion tech-nologies. In addition, our efficient and low-cost launch operations enable us to provide launch services at an order-of-magnitude lower cost compared to launch vehicles currently available. Table 1 shows our

Vehicle	LEO Payload (100 nmi)	SSO Payload (400 nmi)	GTO Payload	Vehicle Cost	Total Launch Cost	LEO $/lb to Orbit	SSO $/lb to Orbit
SR-S Suborbital	440 lbs suborbital			$155K	N/A	N/A	N/A
SR-M Suborbital	2,400 lbs suborbital			$432K	N/A	N/A	N/A
Sprite Mini-Lift	700 lbs	330 lbs	None	$2.3M	$2.9M	$4,190	$8,887
Eagle SLV	1,470 lbs	720 lbs	None	$3.7M	$4.7M	$3,192	$6,517
Antares Intermediate-Lift	5,900 lbs	3,240 lbs	1,950 lbs	$7.3M	$8.8M	$1,494	$2,721
Exodus Medium-Lift	14,800 lbs	8,730 lbs	5,130 lbs	$13.4M	$15.9M	$1,071	$1,816

Table 1. Cost Objectives for Various *Scorpius*® Orbital Launch Vehicles ($FY04).

projected costs of a number of vehicles in the *Scorpius*® family.

The Exodus medium-lift launcher provides a good example of the cost objectives of the *Scorpius*® launchers. At 15,000 lbm to Low Earth Orbit (LEO), Exodus has slightly more payload capability than Delta II launcher at a projected cost of just \$16 M. This cost of approximately \$1100 per pound of payload is more than 5 times lower the Delta. It is clear that this low cost option would enable new space missions that are currently not affordable. Similarly, the Eagle vehicle will deliver small payloads to orbit for less than \$3,400 per pound. The current price of a small payload launch on America's only small launcher, Pegasus, is currently about \$20,000 per pound. Following Eagle, larger *Scorpius*® vehicles will be developed to drive down costs for both Government and commercial customers. Fig. 5 shows the cost and specific costs (\$/lbm to space) of four of our vehicles that are an order-of-magnitude lower costs compared to corresponding conventional solid and turbo-pump based launch vehicles with the same payload capability.

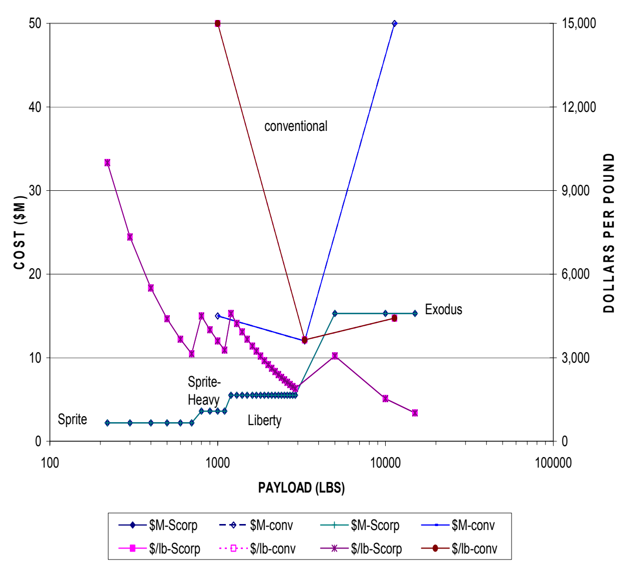

Fig. 5 Scorpius® Life-Cycle Costs Compared to Conventional Launchers.

4. Development Status

Microcosm has successfully flown two of its suborbital vehicles from the White Sands Missile Range (WSMR). Since then, we have matured a number of critical technologies such as the all-composite LOX tank, a Tridyne-based high performance pressurization system, and low-cost simple propulsion technologies built around low-cost ablative engines.[4] Most of these technologies, shown in Figs. 6 and 7 are in the final stages of qualification. We plan to demonstrate these technologies with the flight of our SR-M suborbital vehicle which is the high-performance derivative of the SR-XM-1 vehicle flown in March 2001 and is identical to a single pod of our Mini-lift orbital vehicle, Sprite. Our current plan includes the flight of the Sprite and/or its larger version, the Eagle SLV vehicle in the 3rd quarter of 2007.

Fig. 6. All-Composite LOX Tank (top) in Cryogenic Testing and Flight-Proven Fuel Tank.

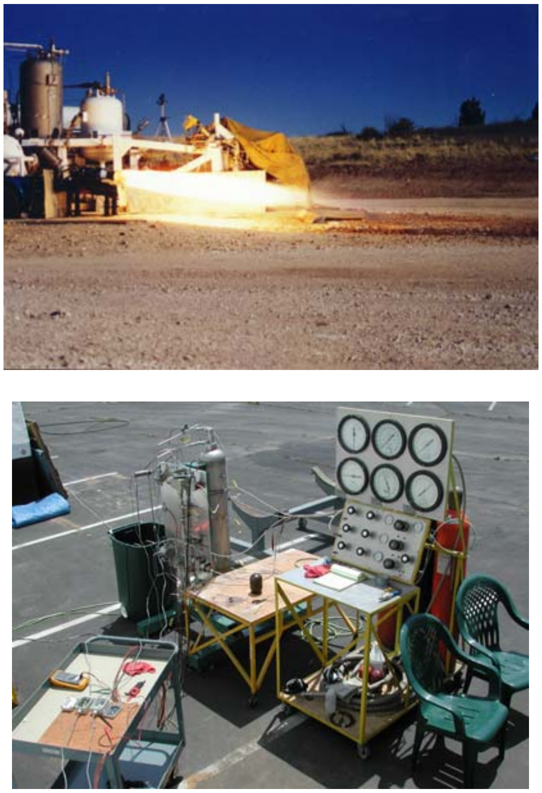

Fig. 7. 20-klbf Engine in Testing (top) and Tridyne-based HPPS Test Rig (bottom).

5. Conclusion

This paper describes Microcosm's approach to developing low-cost, responsive launch vehicles to meet the evolving needs for responsive, low-cost access to space. Our efforts continue to build on the innovative design features built around modularity and scalability, low-cost manufacturing processes that minimizes touch labor and expensive tooling, simple operations procedures that minimize launch cost while maximizing operability and responsiveness, and the maturity of the enabling technologies. Launch on demand at a cost that is an order-of-magnitude lower than currently available launch services is within reach and will create a new paradigm to revolutionize space transportation.

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