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SCORPIUS®, A New Generation of Responsive, Low Cost Expendable Launch Vehicle Family*

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ABSTRACT

The Scorpius® vehicle family extends from one and two stage sub-orbital vehicles for target and science applications to small, medium and heavy lift orbital vehicles. These new liquid fueled vehicles have LEO and GTO capabilities. Microcosm, Inc. and the Scorpius Space Launch Company (SSLC) are well into the development of this all-new generation of expendable launch vehicles to support commercial and government missions.

This paper presents the projected performance of the family of vehicles, status of the development program and current projected launch service prices. The paper will discuss the new low cost ablative engines and low cost pressure-fed LOX/Jet-A propulsion systems. Schedules, payload volumes, dispensers, attach fittings, and planned dual manifest capabilities will be presented. The unique configuration of the wide base first stage allows fairings that may extend beyond the current 4-meters. The Scorpius® family is designed to facilitate encapsulated payloads and launch-on-demand. The implications of these new operational procedures will be addressed, including the techniques that will be used to drive down the cost of access to space while improving reliability.

The Scorpius® family of low cost vehicles addresses the full range of payloads from 700 lbs. in the Sprite Mini-Lift to over 50,000 lbs. to LEO in the Heavy-Lift, and over 18,000 lbs. to GTO. Two sub-orbital vehicles have been developed and successfully launched with the latest vehicle (SR-XM) launched in March of 2001 from White Sands Missile Range. Development of the family of vehicles commenced in 1993 under contracts with the Air Force Research Laboratory Space Vehicle Directorate after a number of years of independent studies and system engineering. The Sprite Mini-Lift Small Expendable Launch Vehicle (SELV) that utilizes the SR-XM technologies is planned for an initial launch in mid 2005 with larger, scaled-up vehicles to follow.

BACKGROUND

Microcosm and Scorpius Space Launch Company (SSLC) are developing the technologies to enable the next generation of Expendable Launch Vehicles for both commercial and government missions. Microcosm has created a family of low-cost vehicles to address the need to significantly reduce the cost of access to space as well as a responsive launch-on-demand capability.

The family of vehicles called Scorpius® consists of vehicles starting with sub-orbital, and then small-, medium-, and heavy-lift vehicles with capabilities for LEO and GTO payload deliveries. This new family is based on simple pressure-fed LOX/Jet-A boost and sustainer stages and optional LOX/Jet-A or hydrogen upper stages.

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The Scorpius® family of expendable launch vehicles† has the objective of reducing near-term launch cost by a factor of 5 to 10 compared to the existing operating launch vehicles and the potential for greater cost reduction in the future. The program starts with small sub-orbital vehicles and progresses to the small orbital vehicle to answer the need for the small vehicle market and scales to larger vehicles. The Scorpius® program is based on research done over a 15-year period with government development funding beginning with a Phase I Small Business Innovative Research award in 1993[1–4]. Since that time Microcosm been awarded a total of 18 development contracts with funding from BMDO, the Air Force Research laboratory, NASA, NRO, and Microcosm internal R&D.

The fundamental goal of the program has not changed since its inception—to transform launch to orbit from a dramatically high-cost, high-risk activity requiring vehicle procurement months or years in advance, to one more closely resembling normal commercial transportation systems.

The Scorpius® program began in 1993 with development of the family of concept vehicles after a number of years researching how low-cost vehicles could be developed, and using scalability to develop small sub-orbital vehicles to large orbital vehicles.

Once the concepts were well defined, Microcosm set out to demonstrate the first key ingredient—a truly low-cost ablative engine. With a number of successful engine developments and tests, Microcosm in cooperation with the Air Force Research Laboratory Space Vehicles Directorate (AFRL/VS) and several key subcontractors, have designed and successfully flown two different sub-orbital vehicles. The sub-orbitals serve to validate the launch vehicle technology at much lower cost than is possible with orbital vehicles, and also serve to create a sub-orbital product. This allows far more test flights than would otherwise be done, increases the level of confidence in the technology, and allows the design to mature in response to operational experience.

The test flights increase confidence in the vehicle design, provide increasing amounts of test data under diverse conditions, and validate reliability projections (99% reliability requires hundreds of experiences to validate). The first of the vehicles, the SR-Sa, was successfully launched from White Sands Missile Range (WSMR) in January 1999. Figure 1 shows the vehicle as launched with the 5,000 lb. all ablative engines in a traditional 18-inch diameter vehicle. Figure 2 shows the 42-inch diameter, twin-5000 lb. thrust engine SR-XM, launched from WSMR in March 2001.

Figure 1. Scorpius® SR-Sa launched January 1999.

Figure 2 SR-XM vehicle launched March 2001.

† U.S. Patent No. 5,799,902.

Table 1 shows the Scorpius® program objective in terms of family members and gives their payload delivery and projected total launch cost. As to be expected,the true cost will be what can be achieved once the vehicles are in operation.

Table 1. Scorpius® Program Objectives (FY02$).

Vehicle	LEO Payload (100 nmi)	GTO Payload	Vehicle Price Object	Total Launch Cost-LEO	LEO Price/lb. to Orbit	GTO Price/lb. to Orbit
SR-S Sub-orbital	200 lb Sub-orbital		$125K	N/A	N/A	N/A
SR-M Sub-orbital	2,400 lb Sub-orbital		$340K	N/A	N/A	N/A
Sprite Mini-Lift	700 lb	N/A	$1.6M	$2.0M	$2,836	None
Antares Intermediate-Lift	6,500 lb	2,150 lb.	$5.4M	$6.7M	$1,029	$3,450
Exodus Medium-Lift	15,000 lb.	5,200 lb.	$10.4M	$12.5M	$830	$2,690
Space Freighter Heavy-Lift	50,000 lb.	18,200 lb.	$ TBDM	$ TBDM	Est. $560	Est. $1,710

The objective in launch to orbit begins with the small Sprite vehicle and then progresses to the larger Antares, Exodus (for medium-light and medium), and then the Space Freighter (heavy-lift) vehicles for which there is a larger commercial market potential. Sprite itself will build substantially on the sub-orbital experience. The SR-M sub-orbital becomes a key module in the two-stage SR-2 sub-orbital and Sprite Mini-Lift vehicles.

The SR-M propulsion system is clustered in pods to build the first and second stages based on Microcosm's larger 20,000-lb thrust engines. Therefore, the near-term sub-orbital experience will be directly applicable to the mini-lift to orbit vehicle, which in turn will establish both the technology and operational procedures to be used in the scaled up Antares and Exodus vehicles. Figure 3 shows the Scorpius® family of vehicles.

Figure 3. Scorpius® family starting with the sub-orbital vehicle up through the heavy-lift vehicle.

THE SPRITE MINI-LIFT VEHICLE

The Sprite Mini-Lift vehicle shown in Figure 4 is the first orbital vehicle from the Scorpius® program and addresses the need for the small- and mini-payload markets. Sprite will have a total vehicle price-to-orbit objective of less than $2.0 million (FY02$) and a performance objective of 700-lb to LEO (due east launch) or 330-lb to a 400 nmi circular, polar orbit. The minimum available payload volume is expected to be comparable to the Scout and Orbital's Pegasus vehicle's large fairing, i.e., 38-inch diameter by 63.25 inches long.

Figure 4. Scorpius Sprite mini lift vehicle.

Sprite is designed to accommodate 99 percentile wind levels for the major launch sites with zero visibility, zero ceiling, and moderate precipitation, as are the larger orbital vehicles. Launch operations are hours after arrival of the payload at the launch site, that utilize encapsulated payload-processing methods.

designed to provide for potential launch within 24 The net effects of these design criteria are to provide effective "launch-on-demand" in which payloads can be orbited either as needed or as they become available. The intent is to provide a responsive launch service more characteristic of package delivery services than of the current launch environment.

The Sprite will be a height of 53 feet with a first stage diameter footprint of 11.2 feet. The Sprite pods and center core will be 42 inches in diameter (as are the SR-XM and SR-M), exclusive of the fins. The payload area can be accessed as needed with standard commercial equipment.

Figure 5 shows the performance of Sprite for different inclinations.

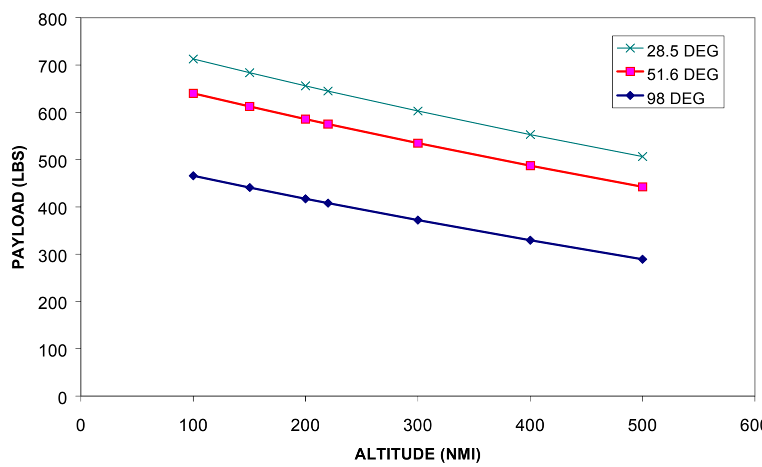

Figure 5. Sprite payload performance to circular orbit at various inclinations. Configuration includes de-orbit of the upper stage.

The Scorpius® vehicles LEO versions have modest mass fraction, three stages, and robust margins. The vehicles are designed to be truly expendable low-cost transportation systems. The Scorpius® technologies and vehicle designs are developed with scalability as a key design requirement to allow the incremental development of the large vehicles.

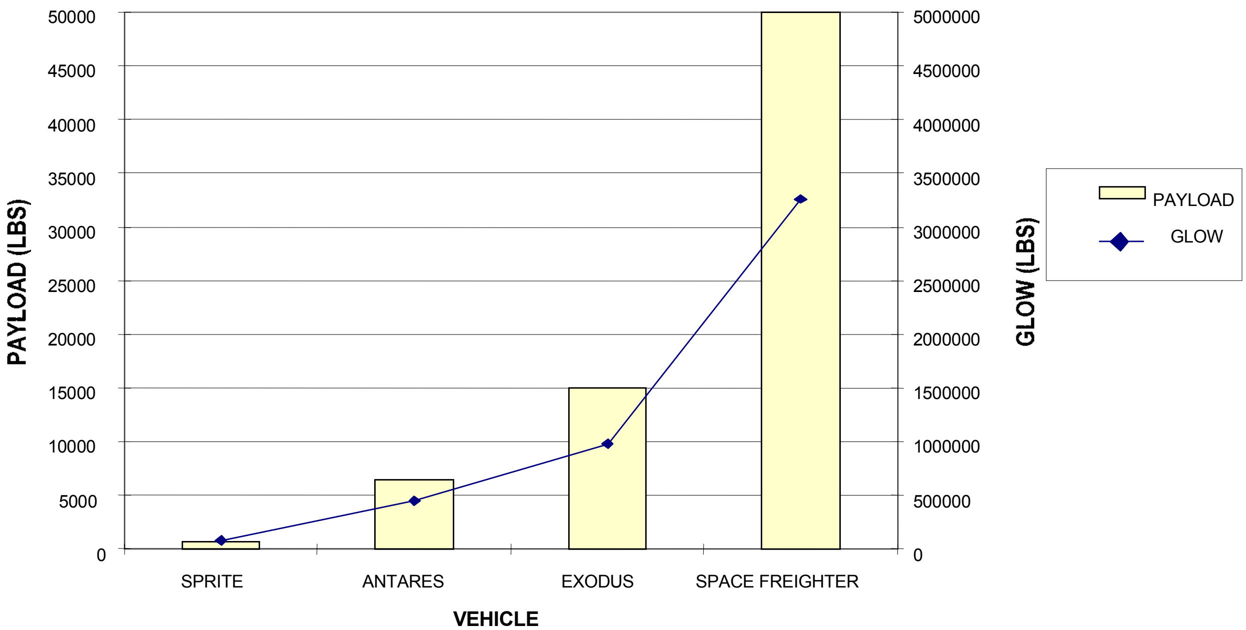

Figure 6. Performance of Scorpius® family.

VEHICLE PERFORMANCE

The Sprite Mini-Lift vehicle is the first orbital vehicle in the Scorpius® program. The scalable technology and design heritage will allow the development of increasingly larger vehicles such as the Exodus, Antares, and the Space Freighter. The performance results of our conceptual design efforts for these vehicles are shown in Figure 6.

Exodus, Sprite, and Space Freighter were constrained to have Stage 1 mass equal to six times the Stage 2 mass. Using six identical pods for Stage 1 and a single pod as the second stage incorporates this design feature. Antares uses only two of the six pods of Stage 1 of the Exodus vehicle with relatively larger engines. The performance results shown in Figure 6 were based on mass ratio optimization of Stage 2 relative to Stage 3. While our Sprite vehicle has achieved a high degree of design maturity, more thorough sizing and optimization efforts are in progress for the larger vehicles.

PRIMARY DESIGN ELEMENTS

The Scorpius® vehicles are an all-new generation of vehicles based on state-of-the-practice low-cost technologies, and simplified vehicle design for manufacturing and low-cost responsive operations. The primary subsystems, engines, tanks pressurization systems, and avionics are new and the vehicles are from a "clean-sheet" design.

Scorpius® vehicles are designed utilizing a variety of innovative concepts. These include both horizontal and vertical staging, pressure-fed propulsion, low-cost ablative engines, all-composite fuel and cryogenic tanks, high performance pressurization system, and low-cost GPS/INS based guidance and navigation.

The Scorpius® architecture employs multiple, nearly identical pods for the first and second stages. The first two Sprite stages include 6 booster pods and a single sustainer pod, respectively. Instead of building one large booster and a different smaller sustainer stage, 7 nearly identical pods are built. This reduces the number of unique part types by half and increases the total number of similar parts produced. Repeatability and reliability of the production units are improved by building enough parts to optimize the production line, without resorting to high cost "aerospace quality" approaches. Further, reliability is improved since the parts are used multiple times, increasing by almost an order of magnitude their flight experience and associated confidence. This same technique is used with the larger vehicles.

Simple pressure-fed engines use LOX and jet fuel propellants to power all stages of the Scorpius® vehicles to LEO. A LOX/hydrogen upper stage is planned to be utilized for the GTO configuration, still using the similar pressure fed, but higher performance ablative engine. The technology for the ablative cooled engines is to provide good performance at substantially reduced cost of traditional expendable engines. Scorpius® vehicles give up some performance to achieve the cost and reliability objectives of the program. Hot fire testing and launch have confirmed their performance. Figure 7 shows the new 20,000 lb. Engine in test and the 20,000 lb. (vac) ablative engine in development. The engine is scaled up from the successful 5,000 lb. engines.

The all-composite fuel tank shown in Figure 8 allows the use of pressure-fed systems for orbital performance without the cost and complexity of turbo-machinery. A non-autoclave tank was flown in the SR-XM vehicle. The enabling high-pressure all-composite cryogenic tank technology development continues and has been initially flight demonstrated with smaller tanks. An all-composite LOX tank is shown in Figure 9 during cryogenic pressure development testing. The processes being developed to build these tanks are optimized for very low recurring cost without the need for autoclave curing. Low-cost feed and pressurization systems are also incorporated in the Scorpius® development.

GPS/INS based guidance and navigation and smart

Figure 7. Typical Scorpius® hardware, 20,000 lb. Engine firing and chamber.

Figure 8. All-composite fuel tank.

Figure 9. All-Composite LOX tank during development testing.

controller bring robustness and lower cost to the system. COTS industrial grade components and low cost orbital-capable avionics are used to increase reliability and reduce cost. Flight termination is based on "Thrust Termination" that shuts down the vehicle propulsion systems allowing the flight to be terminated without the use of extensive explosives on board. This allows for safer ground operations prior to launch and lowers cost. While we have used cold helium gas as the pressurant for the propellant pressurization system of the suborbital vehicles launched to this date, we have in the process of developing a high performance pressurization system (HPPS) based on a Tridyne system. Our analytical and laboratory test demonstration indicates almost 50% reduction of weight of the pressurization system with the HPPS compared to the cold helium system.

The development of the liquid upper stage to be used as the third stage on Sprite scales directly to the larger upper stage for the larger Scorpius® vehicles, as well as others expendable and reusable launch vehicles. Our conceptual design for the upper stage of all the Scorpius vehicles will allow the payload deployment in a 100 nmi LEO (due east launch) orbit. The same design will allow payload insertion to other orbits, i.e., 400 nmi circular, polar orbit. The upper stage design incorporates restart capability for multiple burns required for orbit circularization and deorbit of the spent stage.

The LEO capable upper stages are based on LOX/ Jet-A to maintain the lower cost objectives. However, LOX/LH2 are planned for the high and GTO orbits. Table 1 shows the performance objective of the vehicles with these higher energy stages. The same pressure-fed propulsion will be utilized. As the development continues, the higher performance upper stage engines will be produced, as well as larger 80,000 lb to 100,000 lb booster engines.

The payload volumes will be increased and a complementary set of fairings is planned as the vehicles achieve further maturity. In addition to increased volume, dispensers, attachment fittings for secondary payloads, and dual manifest capabilities will be designed. The larger vehicle is designed to allow for larger fairings beyond the current 4-meter size. The compact first and second stage of the vehicles provide a wide diameter, that will accommodated much larger fairing diameters without the undue bending moment stresses that impact most traditional vehicle designs.

With a low vehicle production cost the need for lower operations and range costs gains importance. The simplified operations and range interfaces being developed for Sprite to reduce operations complexity is being developed based on launch operations of the sub-orbital vehicles. These include a "clean pad to clean pad" launch that utilizes encapsulated payload processes and a small launch crew of less than ten individuals.

Figure 10 shows the Exodus medium-lift vehicle on its launch cradle over a flame bucket on a flat launch pad. The low height of the vehicle allows for the elimination of launch towers and gantries. The operation allows for rapid transport of the vehicle to the pad and with remote ground servicing, rapid launch after the encapsulated payload is installed, and quick pre-flight checks completed.

Figures 11 and 12 show the fairing and auxiliary payload structure for the Sprite Vehicle. Secondary, auxiliary, and dual manifest provisions are being developed to maximize the payload launch opportunities. Standardized interfaces are in development allowing for any unused primary payload mass to be allocated to other payloads.

In addition to the technical progress, substantial business progress has occurred. The Scorpius Space Launch Company (SSLC) was created with the objective of commercializing the Scorpius® low-cost launch vehicles (both sub-orbital and orbital) as well as subsystem products. SSLC will concentrate on the manufacturing and launch services aspects of low-cost launch. Microcosm will continue to concentrate on R&D and vehicle development.

COST AND SCHEDULE

The use of common pods allows the first and second stages to be manufactured in a production assembly line mode. Significantly reduced parts count of the pressure-fed system allows for significant reduction in touch labor. The price of each vehicle will decrease as production volumes increase.

The Sprite Mini-Lift vehicle is projected to have a first DT&E flight in 2005 and first production flight nine months thereafter. With Scorpius® low infrastructure cost and simplified operations, multiple launch sites are planned. Continued improvements in production and proven successful launches are expected to allow prices to be reduced from our initial objectives. Variations of our upper stages are planned to add flexibility and cost reductions for the higher energy orbits.

Figure 10. The Scorpius Exodus on the Launch Pad

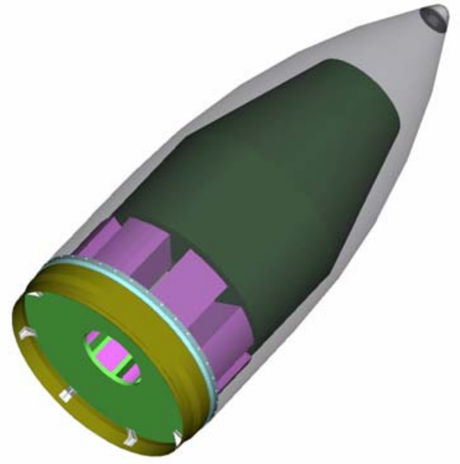

Figure 11. Sprite upper stage auxiliary payload configuration

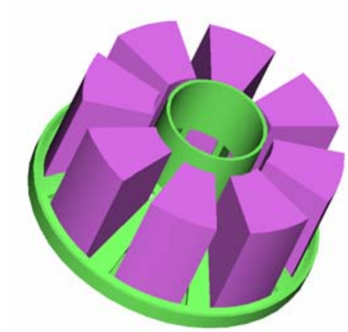

Figure 12. Auxiliary payload interface to payload adapter

CONCLUSION

There is a demand for lower cost access to space for LEO and GTO. The Sprite vehicles from the Scorpius® low-cost launch vehicle program have been designed from the outset to achieve this by manufacturability, ease of operation, and low infrastructure cost. A great deal of engineering development remains to be done. Nonetheless, Scorpius® experience gained to date (i.e., component development, testing, and the launch of the SR-Sa and SR-XM sub-orbital vehicles) shows that our cost and operability goals, though challenging, are achievable.

The Scorpius® propulsion systems utilize ablative engines, composite tanks, and a high performance pressurization system to reduce mass and cost. As has always been a driving factor within the Scorpius® program, improved reliability, responsive launch, and reduced cost are the primary objectives.

These factors must include not only the vehicle-specific items, but also the entire operational aspects. System development has focused initially on smaller sub-orbital and the small orbital vehicles to validate the technologies, though designs have been developed for vehicles in the medium and heavy class. Our modular approach based on scalable technologies allows us to transition to increasingly larger launch vehicles.

ACKNOWLEDGMENTS

The Scorpius® development takes a substantial team effort to put together a successful rocket program, ranging from funding and administrative efforts, through innovative design, development, fabrication, integration, and test, to the launch campaign itself. Though a small team, many people have worked hard to make Scorpius® come alive. We could not have progressed this far without their assistance, perseverance, and continuing effort to make the program succeed and drive down cost.

We would like to particularly acknowledge the technical contributions of the Air Force Program Manager, Ken Hampsten, at the Air Force Research Laboratory Space Vehicle Directorate, the staff at the White Sands Missile Range, Schafer Corporation, Polaris, and the entire Microcosm development team.

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