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Status of the *Scorpius* ™ Low Cost Launch Services Program[1, 2]

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Abstract

Scorpius™ is a Microcosm program to develop an entirely new launch vehicle family with the objective of reducing total launch cost by a factor of 5 to 10. This paper reports on progress and problems since the inception of the program in 1993.

System level design has been done for a variety of vehicle sizes, ranging from a small, single engine suborbital, the SR-S, to massive heavy lift vehicles capable of putting 160,000 lb. into low Earth orbit. System development has focused initially on smaller vehicles with the single stage SR-S suborbital successfully launched at White Sands Missile Range on Jan. 27, 1999 and a larger single stage suborbital scheduled for launch in late 1999. Of particular interest to the SmallSat community is the Sprite Mini-Lift vehicle, projected to be able to put 400 lb. into low Earth orbit for $1.7 million (FY99$).

Development of appropriate component technology is ongoing. To date, 25 5,000 lb thrust chambers have been built at an average cost of less than $5,000 each. Achieved performance and lifetime are appropriate for launch to orbit. Avionics are similarly low cost with recurring cost of both the flight computer and the pod electronics substantially less than $5,000 each. In the baseline configuration, valves are the only moving parts in the vehicle, although a low-cost gimbal is also being evaluated. Thus, the cost of turbopumps, actuators, and APU's are particularly low since they aren't present. The design also accommodates very low cost facilities and operations costs, as is necessary to achieve the low total launch cost.

Two test stands have been constructed at the Rocket Propulsion Test Facility at New Mexico Tech, Socorro, NM. The site is currently capable of supporting engine tests of up to 100,000 lb. thrust. To date the ongoing Microcosm engine development program has tested engines of up to 40,000 lb. thrust.

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Background

The Scorpius™ family of expendable launch vehicles[4] has the objective of reducing near-term launch cost by a factor of 5 to 10 and a potential for greater cost reduction in the future. The program is based on research done over a 15-year period with government development funding beginning with a Phase I SBIR award in 1993 [1-6]. Since that time there have been a total of 18 contracts with funding from BMDO, the Air Force, NASA, and Microcosm internal R&D. The program is based on pioneering engineering work by Ed Keith and largely implements the cost reduction strategies defined by John London [7, 8].

- Better than 99% reliability
- Launch within 8 hours of payload arrival at the launch site
- Weather and equipment delays comparable to commercial airlines
- Very low initial recurring vehicle cost

SR-S Suborbital Rocket	100 kg to 200 km for $115,000
SR-M Suborbital Rocket	330 kg to 500 km for $320,000
SR-2 Suborbital Rocket	400 kg to 500 km for $1.2 million
Sprite Mini-Lift	200 kg to LEO for $1.4 million
Antares Medium-light Lift	2,900 kg to LEO for $5.0 million
Exodus Medium Lift	6,800 kg to LEO for $9.5 million
Extendible to heavy lift	

- Various low cost upper stages for added performance and flexibility

Figure 1. Scorpius Program Objectives. Dollar values in FY99$.

As shown in Fig. 1, the fundamental goal of the Scorpius 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 business transportation. Even with a factor of 10 reduction in cost, space will still be expensive at $1,000/kg to low Earth orbit. Nonetheless, we believe that much lower costs, rapid response, and flexible systems oriented toward meeting customer needs will significantly increase the number of missions both designed and flown. This, in turn, will further reduce launch costs and significantly aid in opening the space frontier.

The Scorpius program begins with the development of several suborbital vehicles. This has two principal purposes. First, the suborbitals serve to validate the launch vehicle technology at much lower cost than is possible with orbital vehicles. 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. Second, the suborbitals themselves are commercial products with applications for scientific and microgravity missions as well as low-cost target vehicles. As they become used in this role, they generate initial income, continue to enhance confidence in the vehicle design, and provide increasing amounts of test data under diverse conditions.

Similarly, the objective in launch to orbit is to begin with the small Sprite vehicle, and then progress to the larger Antares and Exodus vehicles for which the market is

[4] US Patent No. 5,799,902

substantially larger. Sprite itself will build substantially on the suborbital experience. Thus, the SR-XM suborbital, currently scheduled for launch in late 1999 or early 2000, is in effect the central core of the SR-2 suborbital and Sprite Mini-Lift vehicles. The side pods of each of these vehicles will also be nearly the same as the SR-XM with Microcosm's larger 20,000 lb. thrust engines. Therefore, the near-term suborbital 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.

Recent Developments

Very substantial progress has occurred in the program over the last year, culminating in the successful launch of the SR-S suborbital on Jan. 27, 1999, at the White Sands Missile Range, NM. The launch is shown in Fig. 2 and a view from the onboard camera in Fig. 3. Because there was no destruct system on board, propellant was offloaded and the launch elevation was adjusted to ensure that the vehicle would not leave the range in spite of significant winds aloft.

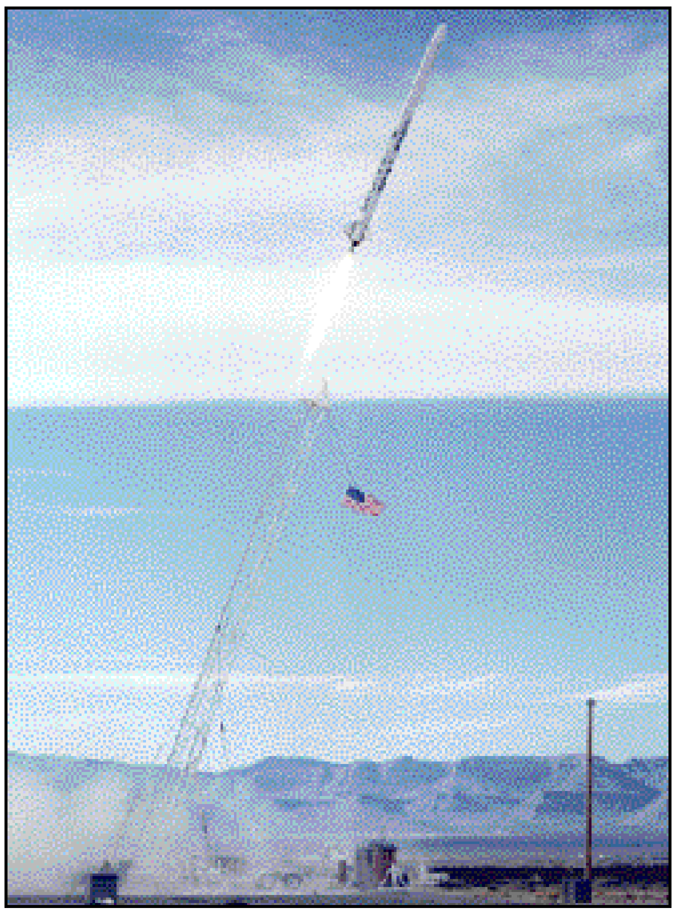

Figure 2. Scorpius SR-S launch from White Sands Missile Range, NM, Jan. 27, 1999. The vehicle was ready for launch within 8 hours of its arrival at the launch site.

Figure 3. View from the SR-S Onboard Camera. The onboard camera provided real-time visual confirmation of the telemetry data, including the vehicle attitude motion. Onboard status information and GPS data were also telemetered back to verify the flight profile determined by the White Sands tracking network.

The Scorpius program is intended to use low-cost technology and provide low-cost responsive operations. The vehicle itself, the Transporter-Erector-Launcher (TEL), and the ground support electronics were all developed, assembled, and tested at the Microcosm facility in Torrance, CA. They were then shipped via truck to the White Sands facility. Although, several days were allowed in the schedule for launch site assembly, check-out, and problem resolution, the vehicle was actually ready for launch in less than 8 hours after it arrived at the launch site. While the SR-S is a simple suborbital vehicle, this operational performance on the first flight serves to validate much of the Scorpius approach to responsive quick turn-around operations.

A prior, aborted attempt to launch the SR-S occurred in Sept., 1998. At that time, a LOX valve failed to open due to a pressure leak and kerosene was released onto the launch pad which subsequently caught fire and burned much of the lower portions of the vehicle. The vehicle was returned to the Microcosm facility in Torrance for detailed evaluation and refurbishment. The leak was repaired, operational procedures changed, and the vehicle was rebuilt with substantial changes in detail based on the lessons learned. The vehicle itself was ready to be flown again in less than 3 months, although an additional 6 weeks was needed for launch site rescheduling.

This aborted attempt was described in some reports as a "devastating setback" to the program. While that potentially could have been the case, we believe that, in fact, it demonstrates the high value of low-cost, flexible programs that are capable of responding promptly and efficiently to emergencies, anomalies, or changing requirements. In an R&D environment, it is virtually impossible to have a program free of failures. What is critical is that the technology is both sufficiently low cost and sufficiently robust to overcome failures that will inevitably occur.

Substantial progress has been made on components for larger vehicles as well. A 5,000 lb. thrust engine test stand has been operational and in nearly continuous use for Scorpius engine testing since 1995 at the Energetic Materials Research Test Center in Socorro, NM. As shown in Fig. 4, a 100,000 lb. thrust test stand was completed in 1998. In August, 1998, this stand was used for initial testing of a 40,000 lb. thrust engine. (See Fig. 5.) These tests were intended to characterize a new pintle injector being developed for the Scorpius program by TRW.

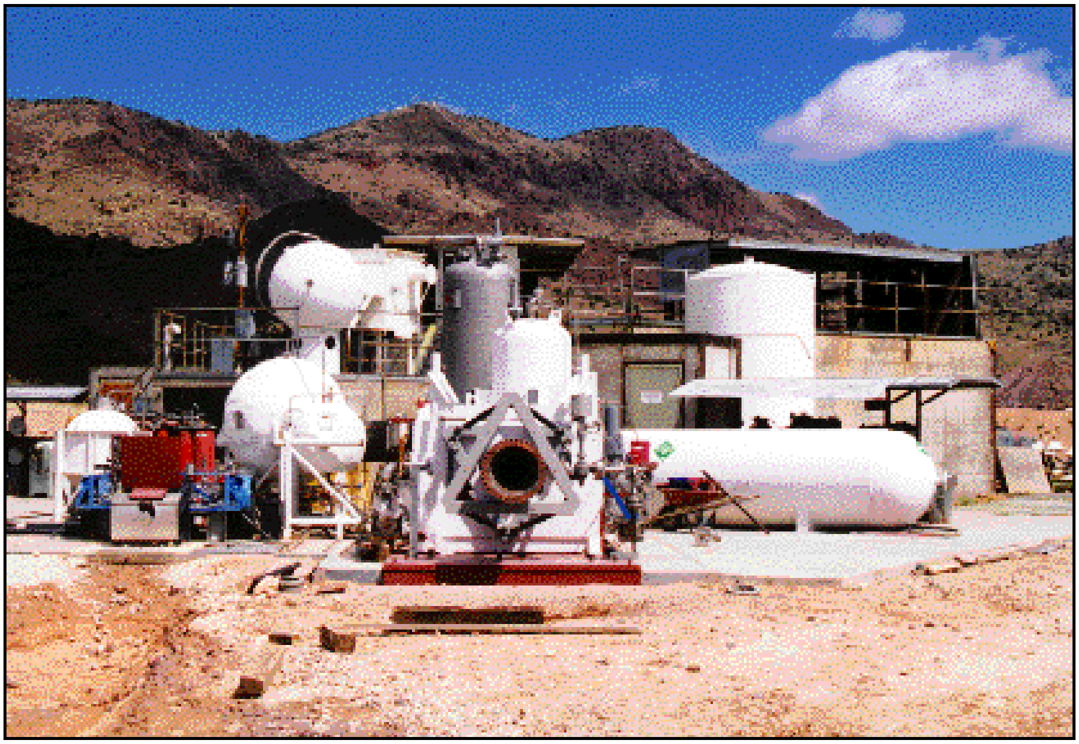

Figure 4. 100,000 lb. Thrust Engine Test Stand at the Energetic Materials Research Test Center (EMRTC) Rocket Test Site at Socorro, NM. In addition to testing of 5,000 lb. engines on a smaller test stand at the site, tests will be done using this stand on engines currently being developed with 20,000 lb., 40,000 lb., and 80,000 lb.. of thrust.

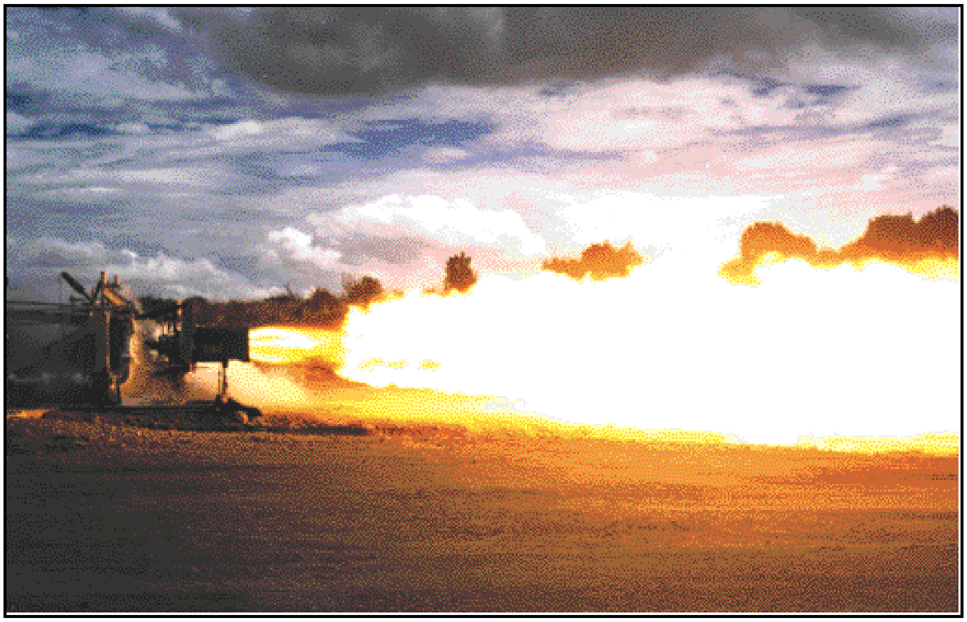

Figure 5. Testing of 40,000 lb. Thrust Engine at Socorro Test Site. These tests were used to characterize a 40,000 lb. thrust injector developed by TRW for the Scorpius program.

Microcosm is now developing both the chamber and injector for a 20,000 lb. thrust engine. This is a scaled up version of the extremely successful 5,000 lb. engine. Over 25 of the 5,000 lb. chambers have been built at an average cost of less than $5,000 each. Many of the engines have been run for 200 seconds or more, the maximum firing time needed to reach orbit in the baseline launch configuration. Testing on these engines 20,000 lb. will begin during the second quarter of 1999.

Scorpius rockets employ simple pressure-fed engines rather than the complex and costly pump-fed engines used in conventional boosters. We use higher pressure propellant tanks to eliminate expensive engine components such as turbopumps, preburners, gas generators, and heat exchangers. Microcosm is currently taking advantage of recent advances in composite materials to develop the technology for producing light-weight, low-cost high pressure tanks. This emerging technology is one of the elements enabling our low-cost, pressure-fed approach.

In addition to the technical progress, substantial business progress is being made as well. The Scorpius Space Launch Company, Inc. (SSLC) has been created with the objective of commercializing the Scorpius low cost launch products (both suborbital and orbital). SSLC will concentrate on the manufacturing, operational, and business aspects of low-cost launch. Microcosm will continue to concentrate on R&D and vehicle development.

The Sprite Mini-Lift Vehicle

The dominant emerging market for low-cost launch to orbit is expected to be in the range of 6,000 to 15,000 lb. to LEO, although larger vehicles are also used with multiple manifesting. This is also the size range at which economies of scale can begin to significantly drive down the cost per lb. to orbit. This market will be addressed by the Antares and Exodus vehicles in the Scorpius family.

Nonetheless, there is significant interest in a low-cost launch vehicle with very small to small payloads (200 to 2000 lb. to LEO) and a total launch cost below $3 million. Like the suborbitals, this vehicle serves two purposes:

- Test and validate the technology appropriate to larger vehicles
- Serve the mission needs of the SmallSat community, including
  - University payloads
  - Mini and microsatellites
  - Microgravity experiments
  - On-orbit servicing, refueling, or parts replacement
  - Low cost missions that need a dedicated launch or a unique orbit

For these vehicles, the cost per lb. will still be high, but the total cost of a dedicated launch will be a factor of 5 to 10 below that of current alternatives. We anticipate that Sprite will be the lowest cost orbital launch vehicle ever built.

For the Scorpius program, this need will be addressed by the Sprite Mini-Lift vehicle, shown in Fig. 6. Sprite has a total cost-to-orbit objective of less than $2 million (FY99$) and a performance objective of 200 kg to LEO (due east launch) or 150 kg to a

250 km circular, polar orbit. The minimum available payload volume is expected to be comparable to the Scout vehicle large fairing, i.e., 38 inch diameter by 63.25 inches long.

Figure 6. The Sprite Mini-Lift Launch Vehicle. Sprite is intended to put 200 kg into LEO at a price of less than $2 million (FY99$).

Sprite is designed to accommodate 95% wind levels for the major launch sites with zero visibility, zero ceiling, and moderate precipitation. Launch operations are designed to provide for the potential of launch within 8 hours after arrival of the payload at the launch site, although in practice astrodynamic considerations will ordinarily require longer delays while waiting for a specific launch window. The net effect of these design criteria is to provide effectively "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.

As illustrated in Fig. 6 above, the overall Sprite design is relatively short and squat, as are the other Scorpius launch vehicles. This allows the fully assembled vehicle to be moved as needed without requiring a gantry or service tower. The total vehicle is 48 ft tall with a circumferential pod height of less than 34 ft. Consequently, the payload area can be accessed as needed with simple commercial equipment. The vehicle itself is designed for complete ground-level servicing. The Sprite pods and center core will be 42 inches in diameter (as will the SR-M), with an overall vehicle diameter of 11.2 ft, exclusive of the fins.

The pod configuration of the Scorpius architecture employs multiple, nearly identical pods for all but the final stage. The first two Sprite stages include 6 booster pods and a single sustainer pod. Instead of building 1 large booster and 1 small sustainer stage, 7 nearly identical pods are build. This halves the number of unique part types and increases the total number of similar parts produced. The production of larger quantities of smaller parts reduces the cost of part production due to increased efficiency. Subcontractors are more interested in reducing cost due to the larger quantity involved. Production repeatability and reliability are also improved by building enough parts to "tune" the production line, without resorting to high cost "aerospace quality" approaches.

Cost Performance

It is clear that launch vehicles with the basic Scorpius design can be built and that the cost objectives represent a dramatic improvement over existing systems. The fundamental question for the Scorpius program is whether our cost projections are real. Fortunately, the costs for some of the traditionally more expensive components are now reasonably established or constrained based on the SR-S and other test experience:

- 5,000 lb thrust chamber assemblies (without injector) cost about $5K.
- Commercial GPS/INS unit sells for $25K. The unit was planned to drop in price as production volumes increased, but the specific unit used on the SR-S may go out of production.
- Flight computer was built for Microcosm at $4K/unit. (Upgrade to a more powerful processor may be needed.)
- Pod electronics was built for Microcosm at $4K/unit.
- Turbopumps and associated power units are not used.

Note that these are unburdened costs. The sell price would be several times these values. Nonetheless, they are indicative of the price performance that is being achieved.

Table 1 shows the component prices for the principal components that went into the SR-S vehicle that was launched from White Sands. The SR-S was intended to sell for $115K (FY99$) without the GPS/INS[5], range transponder, or camera payload and be ready within 1 day of arrival at the launch site. For the first SR-S, the component cost alone was $90K. However, nearly all of the components were individually built test articles, not manufactured goods. The total cost of the avionics was $63K including the GPS/INS and range transponder and $28K with these items excluded.

[5] The GPS/INS unit was not required for the SR-S. It was flown to provide a demonstration of GPS-based tracking and to evaluate hardware and software for future GPS/INS-guided Scorpius vehicles.

Component	***Cost***	***Notes***
Fluids	$600	LOX, kerosene, helium (largest cost)
Thrust chamber *	$4,400	Scorpius low-cost engine
Injector *	$9,700	Lower cost injector in work
Valves	$5,200	Investigating lower cost units
Tubing and fittings	$3,000	Individually fitted
Gimbal *	$1,300	May not use on later flights
Tanks (3) *	$13,000	LOX, kerosene, helium
Other structure *	$21,000	Nose cone, avionics bay, tank interconnects
C-MIGITS II	# $25,000	Commercial GPS/INS unit (price going down)
Flight computer *	$3,500	Scorpius avionics product
Operating sys. software	$900	Commercial operating system
Flight electronics box *	$3,500	Scorpius avionics product
Telemetry equipment	$9,000	Includes transmitter
Transponder	# $10,000	Range required equipment
Roll control system	$4,000	Not used on larger vehicles
Power & signal cond'ing	$10,000	Estimate only; internally built
Misc. avionics	$1,000	Highly variable in test vehicles
Onboard camera	# $2,750	Flown as payload; not required
TOTAL	$127,850	Component cost only; $90,100 without # items

Table 1. Principal Component Costs for the SR-S First Flight (built as a single prototype vehicle). Note that all non-commercial components are individual test articles, not production units. Items marked with a "*" were designed and manufactured for the Scorpius program. Those marked with a "#" are not required for SR-S production units.

Obviously, production rockets must include substantial overhead, I&T cost, and profit. This first flight unit did not meet the cost goals for production units, but was never intended to. Even without being able to fully determine final production cost, it is clear from the table that dramatic reductions in component cost with respect to traditional vehicles are indeed achievable. The first flight unit was ready to go less than a day after arrival at White Sands. This implies significant operations cost savings relative to existing units. Therefore, our fundamental conclusion is that our cost model remains intact, i.e.,

Based on our first flight, Scorpius cost goals appear challenging, but achievable.

Conclusion

The Scorpius™ low-cost launch vehicle program is designed from the outset for manufacturability, ease of operations, and low infrastructure cost. It does not require technological miracles to achieve success. However, partially because we are not relying on major breakthroughs in technology, we do need to continuously monitor each step of the design process closely and to be both aggressive and relentless in pursuing our low cost objective. There remains a great deal of engineering development to be done. Nonetheless, based on the Scorpius experience to date, including component development, extensive testing, and the launch of the first suborbital vehicle, we believe that our cost and operability goals are challenging, but achievable. We are anxious to bring this capability to the space community.

Acknowledgments

It takes a substantial team effort to put together a successful rocket program, ranging from funding and administrative efforts, through innovative design, development, build, integration, and test to the launch campaign itself. A great 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 substantial technical contributions of the government program manager, Ken Hampsten, at the Air Force Research Laboratory and the exceptionally capable launch assistance provided by Maj. Steve Buckley (SMC/TE) and the entire staff at the White Sands Missile Range. Extensive engine testing has been successfully performed at the Rocket Test Site at the Energetic Materials Research Test Center (EMRTC) of New Mexico Tech. EMRTC is directed by Dr. Jose Cortez and the Microcosm engine test program is directed by Ken Mason and Dr. Shyama Chakroborty. Finally, but certainly not least, we would like to acknowledge the substantial effort and professional performance of the Scorpius launch crew, led by Dave Crisalli.

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