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**Please be advised of the current contact information for Microcosm, Inc.:**


**401 Coral Circle**

**El Segundo, CA 90245-4622**

**Phone: (310) 726-4100**

**FAX: (310) 726-4110**

**website: www.smad.com**

**general e-mail: microcosm@smad.com**

11th Annual AIAA/USU Conference on Small Satellites

# Status of the *Scorpius* Low Cost Launch Services Program* †

**James R. Wertz, Matthew Biggs,**
**Robert E. Conger, Edward L. Keith,**

**Microcosm, Inc.**
**2377 Crenshaw Blvd., Suite 350, Torrance, CA 90501**
**(310) 320-0555, microcosm@smad.com**

## 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 10. This paper reports on progress since the program was publicly introduced at the 9th AIAA/USU Conference.

Technical progress has been slower than desired due to funding delays. Testing of the 5,000 lb thrust engine has continued, with more than a dozen having been built at an average cost of less than $5,000 each for the thrust chamber assembly. Performance and life are appropriate for launch to orbit. Two different scaleable low-cost injectors have been successfully tested and a third injector for larger engines is in development. The design and fabrication of a 20,000 lb thrust engine has started. Other components are in-house or under way.

Construction has begun on two different suborbital vehicles to be flight tested at White Sands Missile Range early in 1998. These will be the first flight tests of *Scorpius* low-cost launch technology. In addition, the rocket engine test facility in Socorro, NM is being upgraded to accommodate testing of engines of up to 100,000 lbs thrust.

### Background

The *Scorpius* family of expendable launch vehicles has the objective of reducing near term launch costs by a factor of 10 and a potential of greater cost reduction in both launch vehicles and spacecraft in the future. The program is based upon research carried out over a 15-year period with government development funding for the last four years in a total of fifteen contracts. An overall summary of the program was provided at the time of its public introduction at the 1995 AIAA/USU Conference on Small Satellites [1]. Additional details have been provided in subsequent reports [2, 3, 4]. The program is



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based on the pioneering work of Ed Keith and in large measure implements the cost reduction strategy defined by John London [5, 6].

In a broad sense, the methods of the *Scorpius* program are similar to those of many of the small low-cost spacecraft builders represented at the USU conference. Specifically, we are trying to move away from the performance-optimized high cost designs characteristic of many existing launch vehicles toward the use of a simple, robust design based on low-cost manufacturing processes to achieve low cost and high reliability at the expense of optimal performance. In our view, the $I_{sp}$ and gross lift-off weight per pound of payload are irrelevant, so long as they meet the design criteria of the system. What matters is simply the overall reliability and cost per pound to orbit.

The single most critical element in this process is obtaining very low-cost propulsion. Microcosm has now built and test fired more than a dozen 5,000 lb thrust engines at an average recurring manufacturing cost of approximately $5,000 each, corresponding to about $1/lb of thrust. This is more than two orders of magnitude less than would be predicted by traditional cost models. Our engines have less than 40 parts (versus an OTA estimated 15,000 parts for a typical liquid propellant rocket engine) and take less than 40 man hours to construct from raw materials. The engines have been test fired for more than 200 sec, which is adequate to achieve orbit. The technical parameters of this engine were defined in last year's summary [2].

The next most expensive element of a launch vehicle is typically the avionics. Here, we are using a commercial off-the-shelf navigation unit developed for other purposes by Rockwell. The flight computer and pod electronics box were designed specifically for the *Scorpius* program by Southwest Research Institute of San Antonio, Texas. Flight units of both the computer and pod electronics have been delivered and cost less than $4,000 each.

Propellant tanks have now been built and burst tested and will meet our low-cost objectives. The turbo pumps and power generation unit are even more economical—they do not exist in the Microcosm design. (The system is pressure fed by a mixing gas generator and propellant feed. Commercial batteries are issued to supply the relatively low power requirements.)

The vehicle configuration is stable and accommodates ground-level servicing such that it can be both transported and launched without using either a gantry or service tower. This and other features provide the potential for extremely low cost facilities and operations. The propellants themselves are LOX and kerosene, the lowest cost propellants in common use.

Design changes have occurred, as they will in any R&D program. Nonetheless, the *Scorpius* program still appears able to meet its formidable cost objective.

## Programmatic Progress

A number of new *Scorpius* contracts and programs have gotten under way in the last year. In December 1996, Microcosm received a Phase II SBIR contract from NASA to develop and build the SR-S one-stage, one-engine suborbital vehicle (see Fig. 1). In April 1997, the contract was extended to fly the SR-S from White Sands Missile Range at the end of the 1997 or early 1998. Work is currently in progress on all elements of the vehicle.

In April 1997, we received a follow-on contract from Phillips Laboratory (with funding from the Ballistic Missile Defense Organization) to build the first SR-1 (also shown in Fig. 1) single-stage, three-engine suborbital vehicle. Supplemental funding will be required for launch which is expected to occur in the spring of 1998. CDR's for both the SR-S and SR-1 will be combined and are expected to be held in October.

**Fig. 1. SR-S, SR-1, and SR-2 Suborbital Vehicles.** The SR-S and SR-1 will be launched from White Sands Missile Range in late 1997/early 1998.

The SR-1 contract also calls for building and test firing of a low-cost 20,000 lb thrust engine and the preliminary design for both 80,000 lb and 320,000 lb engines based on the same low cost technology. Thus, by next year's USU conference we hope to have made substantial progress in developing significantly larger, ultra low-cost engines, appropriate to larger members of the *Scorpius* launch vehicle family.

In March 1997, Microcosm received an SBIR Phase I contract for the preliminary design of a "mini-lift-to-orbit" vehicle. That design has now been completed (Fig. 2). Unfortunately, this vehicle was not successful in the recent NASA competition for a low-cost mini-lift development.

During the last year, Microcosm has also completed a design for the Ballistic Missile Defense Organization (BMDO) for a very low-cost, heavy lift launch vehicle. Thus, as shown in Fig. 3, the potential *Scorpius* family has grown substantially over the last year with the first two suborbital flights scheduled to occur within the next year.

## Facilities

Two major facility improvements have taken place in the last year. In June 1997, Microcosm opened the *Scorpius* Integration Facility in Torrance, CA to integrate both the SR-S and SR-1 (Fig. 4). With work on both the SR-S and SR-1 proceeding simultaneously, the existing facility was simply inadequate for the larger task.

Similarly, the Rocket Engine Test Facility at the Energetic Materials Research Test Center (EMRTC) at Socorro, New Mexico is able to test only the 5,000 lb thrust engine. The other side of the test facility is being renovated and appropriate equipment added to provide test capability for LOX/kerosene engines of up to 100,000 lbs thrust (Fig. 5). A CDR has been held on the larger test stand and construction has begun. Overall, EMRTC has provided an excellent, low-cost engine test facility and has been a substantial asset to the *Scorpius* program.


**Fig. 2. The Sprite Mini-lift Launch Vehicle.** Sprite was intended to put 330 lbs into low Earth orbit at a recurring cost of $1.5 million by the middle of calendar year 2000.


**Fig. 3. The New *Scorpius* Vehicle Family.** Suborbital vehicles in the foreground. Background from left: Heavy Lift, Liberty Light Lift, Sprite Mini-lift, Super Heavy Lift, Exodus Medium Lift.

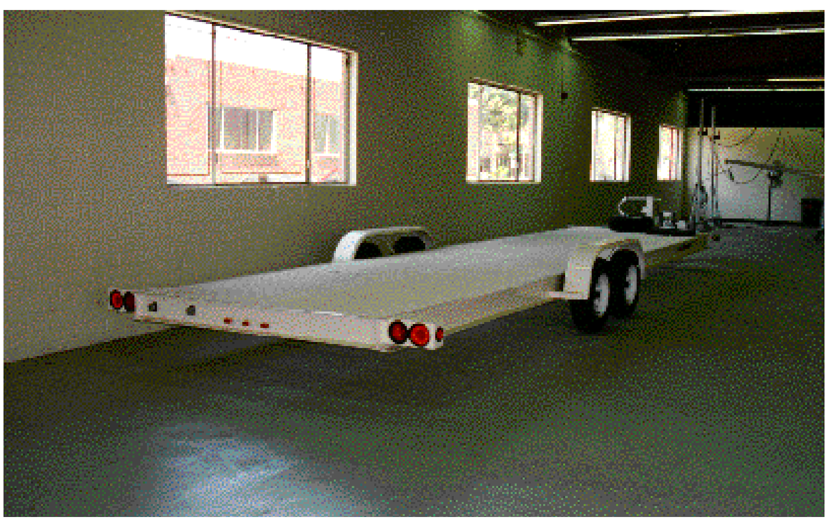

**Fig. 4. The *Scorpius* Integration Facility.** Showing the transport trailer for both the SR-S and SR-1 suborbital vehicles. Vehicle specific adapters (not shown) will allow either vehicle to be transported and erected.

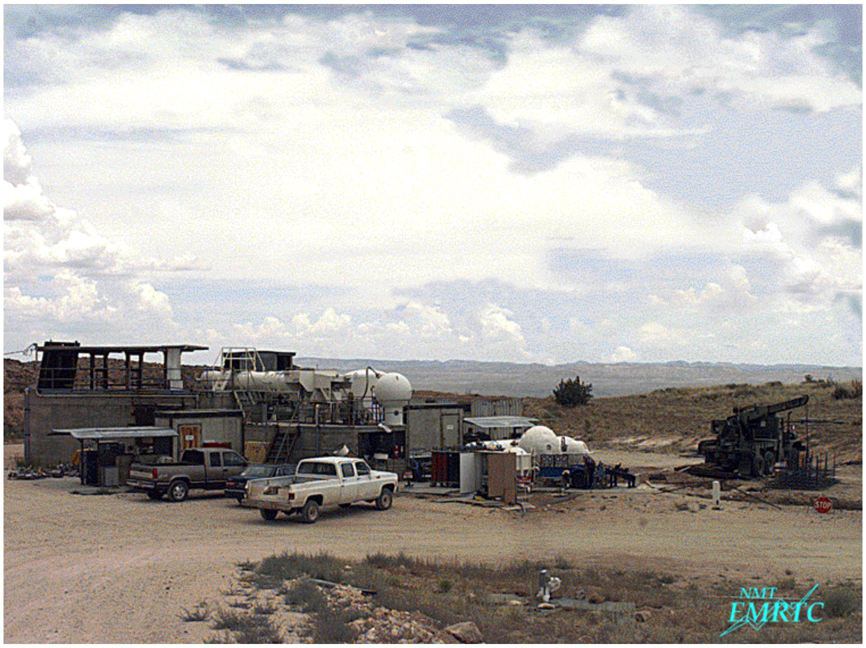


**Fig. 5. The Microcosm Rocket Engine Test Facility at EMRTC at Socorro, New Mexico** is being expanded to provide test capability for engines up to 100,000 lb thrust.

## Technical Progress

As mentioned above, preliminary designs have been completed for both a mini-lift and heavy lift vehicle. The key technical conclusion is that the *Scorpius* design is applicable over an extremely wide range. While there are clearly differences (e.g., combustion stability becomes more important for larger vehicles and throat erosion less so), the general technical approach and much of the design can be scaled over a large range of vehicle sizes. Interestingly, we believe that the cost per pound will reach a minimum with the medium lift vehicles. Very small launch vehicles are simply unable to carry sufficient payload to be dramatically economical on a cost per pound basis. At the other extreme, the very large launch vehicles require substantial handling equipment, expensive transportation, and unique parts. Perhaps most important, they won't achieve the economy of scale possible with smaller vehicles due to low of demand. Consequently, while they will be far more economical than current vehicles, heavy lift vehicles are unlikely to be able to drive the cost per pound down to below what can be achieved with very low-cost medium lift vehicles.

Most of the *Scorpius* vehicles have undergone minor revisions in design. The SR-1 was redesigned to provide better aerodynamic performance and be aerodynamically stable through the full flight regime. Overall, the design changes have been subtle and well within what would be expected in an R&D activity.

In terms of components, substantial progress has been made on the propellant tanks. Twelve inch diameter subscale tanks were successfully burst tested. The *Scorpius* tanks are intended for a working pressure of 500 psi and designed to a pressure of 1,000 psi. With derating of the fibers and margin, they are expected to burst at approximately 1,400 psi. In fact, both tanks built to this requirement burst at almost exactly 1,400 psi during testing. While the development of the propellant tanks was not expected to be a major issue, the tank testing has provided strong validation for the cost, weight, and performance estimates for the tanks. This, in turn, is important in establishing the design parameters for the vehicle as a whole.

We have now built and tested over a dozen low-cost engines. In addition, two different low cost injectors have been designed and built, both of which are scaleable to 20,000 lbs. In addition, a third design for the 20,000 lb injector, which will be scaleable to much larger sizes, is also being built. As an example of the benefits of low-cost technology in the development process, one of the long duration test burns recently experienced a burn-through which was subsequently traced to one of the low-cost injectors. That injector is now being reworked to resolve the identified problem and a retest program will begin shortly. Having low-cost components such that we can learn from the test program, rather than simply verify results, represents a new way of doing business in the launch vehicle area. It is often cheaper and faster for us to build and test a low-cost design to see how it performs, than to analyze paper designs for many months to estimate and analytically verify what the performance might be. We believe this is an extremely important aspect that has the potential for driving down the non-recurring development cost and schedule, as well as the recurring cost of all launch vehicles.

The principal issue for recent engine testing has been thrust vector control, using secondary fluid injection. Using kerosene as the injection fluid has not been as successful as we would have liked on small engines with very short nozzles. We do not yet have a good understanding of the multi-port injector physics; however, work will continue in this area. In the meantime, a design change has been made to use a low-cost gimbal on the SR-S and SR-1 to prevent launch delays.

Three flight sets of navigation units, flight computers, and pod electronics boxes have now been delivered to Microcosm. The avionics bay intended for environmental testing at Marshall Space Flight Center is now nearing completion (Fig. 6).

Certainly the most exciting activity is that the development of the first suborbital vehicle is now beginning. Over the next several months, we will see the CDR, flight vehicle integration, and ultimately the test launch of the first member of the *Scorpius* launch family. While this will be a relatively modest launch, contained entirely within the White Sands Missile Range, it will be an important milestone in the development of low-cost launch systems.

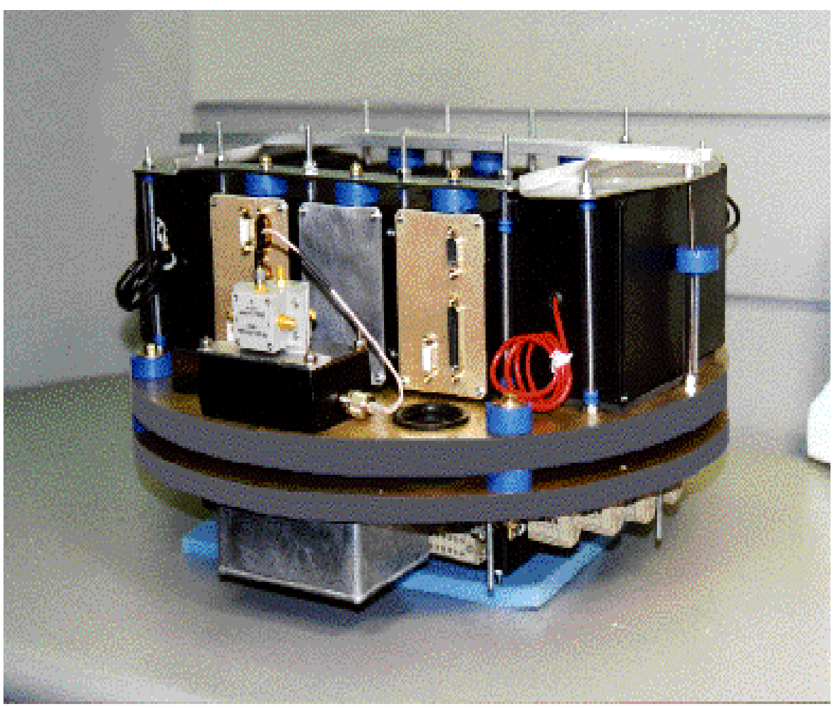

**Fig. 6. Avionics bay being prepared for vibration testing.**

## Summary of Future Prospects

Substantial progress has been made in the last year. New contracts have been put in place to further expand the *Scorpius* low-cost launch vehicle activity. Technical progress has been made, although not as rapidly as we would have liked. Nonetheless, we anticipate that within the next year the first launch will occur of both the SR-S and SR-1 suborbital vehicles. In addition, we have developed preliminary designs for a broader range of low-cost vehicles and made good progress on low-cost components.

Nonetheless, rapid progress on reducing the cost of launch for small payloads remains elusive. Changing the paradigm by which launch vehicles are built has proven to be exceptionally challenging. It is now clear to those of us working on the *Scorpius* program that the technology and processes are in hand to reduce launch costs by about a factor of 10. However, it is not yet clear whether the opportunity will exist to fully put these into practice.

## Acknowledgements

We would like to acknowledge the substantial technical contributions of the government program manager, Ken Hampsten, at the Air Force Phillips Laboratory to this effort. In addition, engine testing has been undertaken in Socorro, NM, throughout the year under the very capable direction of Ken Mason.

## References

1. James R. Wertz and Edward L. Keith, "The *Scorpius* Low Cost Launch System," presented at the 9th Annual AIAA/USU Conference on Small Satellites, Sept. 18-21, 1995.
2. James R. Wertz, Thomas P. Bauer, Robert E. Conger, Edward L. Keith, "Status of the *Scorpius* Low Cost Launch Services Program," presented at the 10th Annual AIAA/USU Conference on Small Satellites, Sept. 16-20, 1996.
3. James R. Wertz, Thomas P. Bauer, and Edward L. Keith, "Getting There at Very Low Cost," No. IAA-L-0702, presented at the 2nd IAA International Conference on Low Cost Planetary Missions, April 16-19, 1996.
4. Thomas P. Bauer, "Low Cost GN&C System for Launch Vehicles," paper No. 38, presented at the First Conference on Next Generation Launch Systems, STAIF-96, Albuquerque, NM, Jan. 7-11, 1996).
5. John R. London III, *LEO on the Cheap--Methods for Achieving Drastic Reductions in Space Launch Costs* (Maxwell AFB, AL: Air University Press, Oct. 1994)
6. John R. London III, "Reducing the Cost of Space Launch," Chap. 4 in, *Reducing Space Mission Cost*, ed. by J. R. Wertz and W. J. Larson, Microcosm Press and Kluwer Academic Publishers, 1996.