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Status of the *Scorpius* Low Cost Launch Services Program*Δ

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Abstract

Scorpius is a Microcosm program to develop an entirely new launch vehicle family with the objective of reducing overall launch system cost by a factor of 10. This paper reports on the progress and problems since the program was publicly introduced at the 9th AIAA/USU Conference.

Substantial technical progress has occurred. The 5,000 lb. thrust engine that was created on the day of last year's presentation was successfully test fired for 200 continuous sec on Nov. 28, 1995, with an estimated 135 sec of additional life on the chamber. The 200 sec burn duration per stage is sufficient to reach orbit for the baseline configurations of both mini-lift (100 kg to LEO for <$1 million) and light lift (1,000 kg to LEO for <$2 million) vehicles as well as low cost stages for existing assets. Some vehicle configurations under consideration use larger engines as well.

In addition, thrust vector control by secondary fluid injection was demonstrated on a later test firing. This demonstrates the use of very low cost approaches to achieving substantial control authority. Videotape of the successful firings will be presented. For each of the engines to date, the recurring, unburdened production cost has been less than $5,000 per engine, which is approximately 2 orders of magnitude less than the cost estimated by traditional costing algorithms.

Contractually, the program has proceeded more slowly than we would have desired. However, five new contracts are now in place that will substantially increase the scope and pace of the program. If funding proceeds, we anticipate being able to substantially reduce total launch costs for small payloads with initial flights in 2.5 to 3 years for new vehicles or in 2 years for existing assets with a new upper stage.

Program Summary

The Scorpius Program for a new family of launch vehicles to dramatically reduce space launch costs was publicly introduced at the 1995 AIAA/USU Conference on Small Satellites [1]. That paper provides the background, baseline configuration, and cost estimates which have not changed. The objectives of the program, drawn from the abstract of that paper, are given in Figure 1. Work has been done on determining the applicability of Scorpius to low cost interplanetary missions [2], as well. Preliminary results for this application are summarized in Figure 2.

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- 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 cost:

SR-S Sounding Rocket	220 lbs to 200 km for $99,000
SR-1 Suborbital Rocket	900 lbs to 200 km for $295,000
Micro Lift	170 lbs to LEO for $750,000
Liberty Light Lift	2,200 lbs to LEO for $1.8 million
Exodus Medium Lift	15,000 lbs to LEO for $8.5 million
Extendable to heavy lift	

- Total non-recurring development cost for all of the above vehicles through medium lift of <$100 million
- Various low cost upper stages for added performance and versatility

Figure 1. *Scorpius* program objectives. Objectives are from the 1995 USU paper [1] and have been adjusted for inflation to FY96$. (assumed inflation factor of 1.08 from FY94 to FY96.)

Vehicle	***Cost (FY95$)***	***LEO (kg)***	***Lunar flyby (kg)***	***Lunar orbit* (kg)***	***Mars Flyby (kg)***	***Mars orbit** (kg)***	***Jupiter flyby (kg)***
Liberty + 2 SPMM† modules	$2.5 million	1000	230	160	180	50	30
Exodus + 2 small stages	$9.6 million	7200	2200	1560	1780	500	310

* 170 km circular lunar orbit ** 340 km circular Mars orbit

† SPAMM = Spacecraft Maneuvering Module

Figure 2. Estimated *Scorpius* payload mass for representative interplanetary missions. (FY96$) Upper stages have been sized to accommodate each mission.

Scorpius remains an R&D program with no guarantee of success. Nonetheless, the program has been ahead of the contract schedule and done more for the money than called for at each stage. Microcosm preestimates have been challenged frequently. However, the program has been through multiple formal reviews and no show stoppers or major cost inconsistencies have been identified. Except for inflation, the recurring and non-recurring cost estimates have not changed in the more than three years that the program has been underway. We are now building and testing major hardware elements at 1/10 to 1/100 the cost predicted by traditional launch system cost models. We anticipate more than a factor of 30 fewer parts than a traditional vehicle with almost no machined or tight tolerance components.

Much of the Scorpius technical risk will be eliminated at low cost early in the program. Specifically, a major element of risk has already been eliminated in that extremely low cost engines with acceptable performance and more than sufficient life to get to orbit have been developed and tested. Another major risk reduction step will occur in late 1997 and early 1998 with the anticipated first launch of the SR-S and SR-1 single stage sub-orbital rockets. If funding proceeds, we anticipate being able to reduce total launch costs by a factor of 10 for small payloads within 3 years and for medium payloads within 4 years.

Contract Progress

The Scorpius Program was originally funded under Microcosm internal R&D and multiple contracts with the U.S. Air Force Phillips Laboratory. The result of this work was the verification of the overall Scorpius concept, and the fabrication of prototype hardware, including engines, avionics, and tanks.

Since the last USU conference, an SBIR Phase I contract with NASA Marshall Space Flight Center has been initiated and successfully concluded. This contract called for the design of a small sounding rocket, the SR-S, which could be fabricated within the cost constraints of the SBIR Phase II Program and which would have a vehicle recurring cost of less than $100,000. The design was successfully created in Phase I. (Fig. 3) The Phase II proposal for fabrication is being evaluated by NASA. If funded, this would lead to the potential launch of an SR-S sounding rocket in less than 10 months from contract award.

Funding for the development of a low cost launch vehicle has been slower than what would have been desirable in terms of meeting our previous schedule objectives. Nonetheless, significant progress has been made in recent months. Specifically, five new contracts through the U.S. Air Force Phillips Laboratory are now in place that will increase the pace of the program, lead to the development of specific low cost technologies, and provide the initial funding for the launch of a single stage, three-engine suborbital rocket, the SR-1, in late 1997 or early 1998. (also Fig. 3)

It is still too early to accurately forecast the future of the program. Nevertheless, we believe that the launch of the SR-S and SR-1 sounding rockets have the potential for very dramatically reducing the Scorpius technical risk and proving that the technology is indeed available to reduce launch costs by a factor of 10 in the near term.

Engine Development and Testing

As reported last year, a low cost rocket test facility (RTF) has been established at the Energetic Materials Research Test Center (EMRTC) at New Mexico Tech in Socorro, NM. This location has been the site of all Scorpius engine testing during the last year.

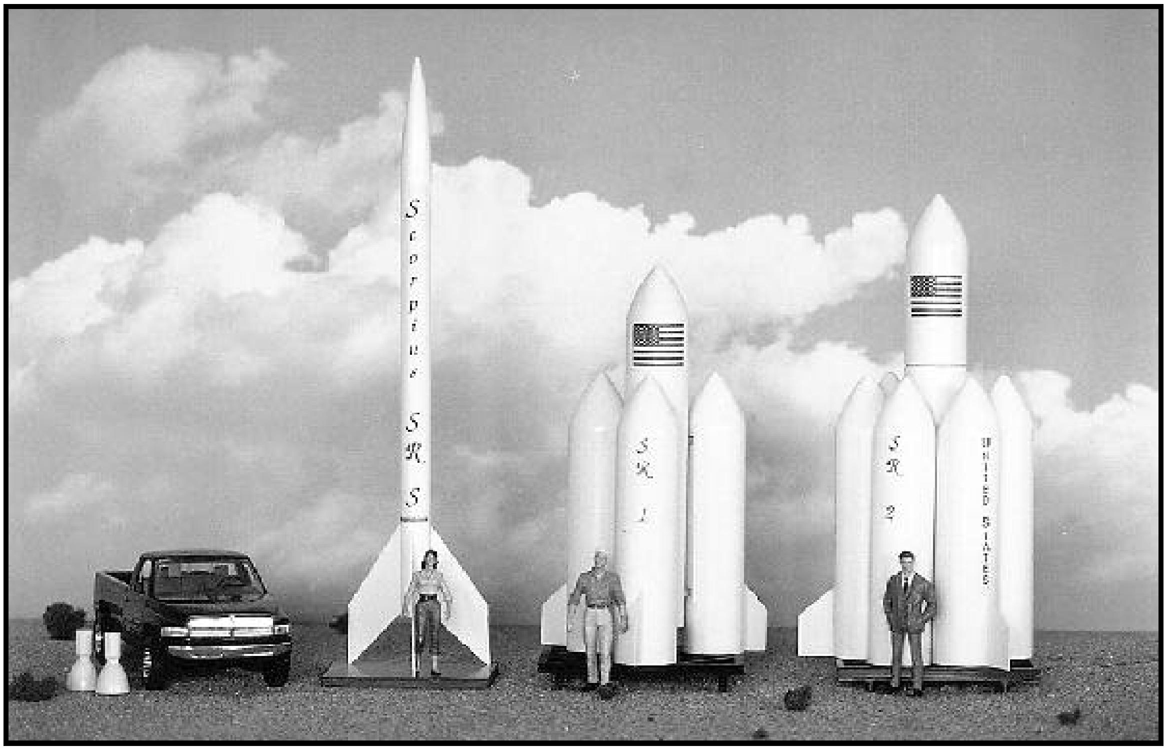

Figure 3. The *Scorpius* Suborbital Rocket Family. From left the vehicles are the SR-S single-stage rocket, the SR-1, 3-engine, single-stage vehicle, and the SR-2, two-stage vehicle**.**

Our sixth 5,000 lb vacuum thrust test engine was constructed on the day of the Scorpius presentation at last year's USU conference. That engine was subsequently test fired at the RTF in a single continuous firing of 200 sec duration on November 18, 1995 as shown in Figure 4. The performance of the engine was consistent with both the original program objectives and the goal of launch to orbit. The 200 sec firing was longer than the engine burn time required to achieve orbit. In addition, the engine had relatively little erosion and it was apparent that there was at least an additional 135 sec of life on the engine. This test established both the performance and life necessary to achieve orbit using extremely low cost engines.

The importance of this engine test is that it establishes the credibility of using dramatically lower cost manufacturing processes to create engines fully capable of meeting the demands of launch to orbit. The Scorpius engine which achieved full performance had a total of 31 parts including fasteners. It had no precision or high tolerance components and was assembled from raw material in less than 40 hours of labor, even though it was a prototype, one-of-a-kind engine rather than an assembly line product. The cost of this engine was a factor of 10 to 100 or more less than comparable engines built using more traditional processes. As intended, the Scorpius engine is not a new breakthrough in performance for liquid propulsion systems, but rather a major breakthrough in price, as illustrated in Figure 5.

Figure 4. 200 sec *Scorpius* engine test at RTF on Nov. 18, 1995. All performance parameters were nominal. Achieved engine life exceeded requirements for launch to orbit with substantial life left on the engine.

Manufacturer	Rocketdyne	Microcosm	Aeroject
Engine	Atlas Vernier	Liberty	AJ-10-118K
Type	Liquid, Pressure-fed	Liquid, Pressure-fed	Liquid, Pressure -fed
Thrust[1]	1000 lbs	4250 lbs	9645 lbs
Weight	20 lbs	50 lbs	160 lbs
Thrust/Weight	50:1	85:1	60:1
Propellant	LOX/RP-1	LOX/RP-1	A50[2]/NTO
Lifetime	indefinite	>300 sec	600 sec
Specific Impulse	187 sec (sea level)	245 sec (sea level)	320 sec (vac)
Price	$60K[3]	$12K[4]	$2500K
Price/Thrust	$60/lb	$2.8/lb	$260/lb

[1] Sea level thrust for Atlas and Liberty engines; Vacuum thrust for AJ-10-118K, which is qualified only for vacuum operation; would be ~ 8200 lbs at sea level

[2]A50 = Aerozine 50 = hydrazine + UDMH

[3] Not sold separately. Atlas Vernier engine is one component of the control system.

[4] Not a commercial product. Estimated price if sold as stand alone production item in moderate quantity.

Figure 5. Comparison of *Scorpius* engine with other liquid propulsion engines of comparable size. Engines are built for specific purposes so an exact comparison is not possible. Nonetheless, the approximate magnitude of the cost reduction becomes apparent.

Subsequent to the 200 second test firing, a new engine test stand was created to measure side forces to allow testing of vehicle control by secondary fluid injection. Modifications were completed, and testing was resumed in December 1995. In February 1996, tests were conducted that validated the control performance achieved with this technique. Together, the two sets of engine tests demonstrate long life, reasonable performance engines, with full control characteristics appropriate for both sounding rocket and launch-to-orbit applications at dramatically lower prices than traditional techniques.

Following the first thrust vector control tests, the contract ended and engine testing stopped. However, with the new round of contracts now underway, engine testing at RTF resumed in August 1996, and substantial additional testing of the 5,000 lb thrust engine will be undertaken throughout the fall.

In addition to the engine life and thrust vector control tests, a new injector design has been completed and initial testing performed. The new injector is expected to be significantly lower cost than the low cost injector designed on the preceding contract. Both injectors have now been successfully used in test firings at RTF. Consequently, we now have two alternative low cost injectors, both capable of full performance for launch to orbit.

Tank Development and Testing

A significant Scorpius design challenge was the development of the metal tank liner for the graphite-epoxy tank for both kerosene and cryogenic fluids, principally LOX. After several unsuccessful attempts at liner generation, a successful approach has now been developed and a number of test tanks with liners have been manufactured as shown in Figure 6. Tank testing will get underway shortly to verify the performance of these tanks with cryogenic fluids.

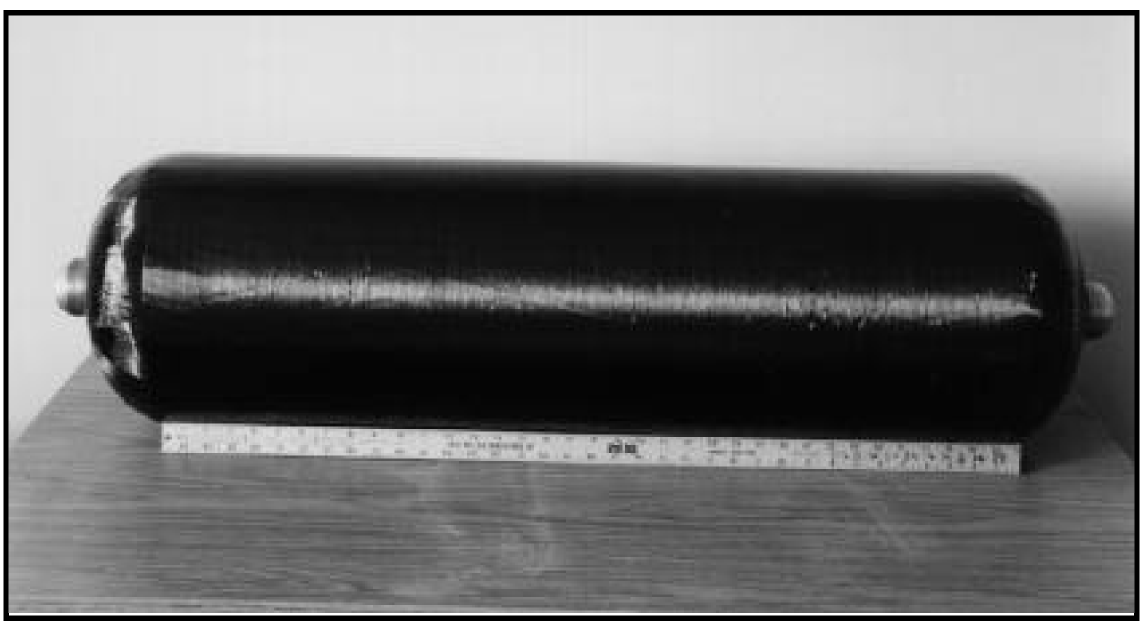

Figure 6. ***Scorpius*** **test tanks.** The tanks have a metallic liner and will be tested shortly for performance in holding LOX and kerosene.

GN&C Developments

Substantial progress has also been made during the year in GN&C system development. The previous three degree of freedom guidance simulation has now been expanded to include a full six degrees of freedom in order to allow high fidelity simulations of Scorpius ascent profiles. A large number of verification runs have been made for a variety of Scorpius configurations as reported by Bauer [3].

The very low cost flight computer and pod electronics box had been developed prior to last year's Small Satellite conference and were on display at that conference. These units have undergone ground testing throughout the year and a new set of electronic units for flight test are now being built. Software for the GN&C system is under development. The Scorpius GN&C system is currently scheduled for flight testing as a payload on a suborbital rocket flight currently scheduled for February, 1997. Similar to the Scorpius engine and tanks, the GN&C system achieves moderate performance at dramatically lower cost than has previously been the case. For sounding rocket applications, the vehicle attitude determination can be achieved with relatively low cost gyros. For launch-to-orbit or more complex suborbital profiles, a commercial GPS/INS navigation package will be used in conjunction with the low cost Scorpius avionics and pod electronics. This combination will provide a broadly capable, very low cost GN&C system for both sounding rocket and launch-to-orbit applications.

Summary
Forthcoming Flight Tests

The Scorpius Program has made substantial technical progress over the last year in terms of both reducing risk and validating the cost achievable in very low cost launch systems. As would be expected in any R&D program, engineering difficulties have arisen and minor design changes have been made. We believe it is indicative of the very robust Scorpius design that alternatives for all major elements are available and that those problems which have arisen have been overcome within the time and cost constraints of the small development contracts currently in place. Consequently, our estimates of both the total cost for non-recurring development and the recurring price for each launch vehicle have not changed, except for inflation to current year dollars. There is still substantial design margin in all key elements of the system.

While we are still early in the R&D activity, the design remains very robust and major risk elements have been either eliminated or substantially reduced.

The next critical phase of the program will be the launch of the SR-S and SR-1 single stage sounding rockets. Both vehicles will verify significant elements of the Scorpius technology and, perhaps most importantly, will validate the development of low cost approaches for all elements of the vehicle, including integration and test and operations procedures. While the sub-orbital vehicles are not as large or as complex as full launch-to-orbit vehicles, they serve to validate a major part of the *Scorpius* technology and to ensure skeptics that nothing has been "left out" of the vehicle design. The full verification of low cost launch-to-orbit remains several years away, with the actual launch of a very low cost expendable rocket. Nonetheless, we believe that the first suborbital flights will be a major milestone and an important validation of Scorpius technology. Indeed, the fundamental philosophy of the Scorpius program is to develop and test all components at the lowest possible cost. This is a key reason for beginning launch vehicle development with the flight of suborbital test vehicles that can serve to validate performance, as well as providing valuable and useful products.

References

1. James R. Wertz and Edward L. Keith "The Scorpius Low Cost Launch System" (Paper presented at the 9th Annual AIAA/USU Conference on Small Satellites, Sept. 18-21, 1995).

2. James R. Wertz, Thomas P. Bauer, and Edward L. Keith, "Getting There at Very Low Cost" (Paper presented at the 2nd IAA International Conference on Low Cost Planetary Missions, April 16-19, 1996).

3. Thomas P. Bauer, "Low Cost GN&C System for Launch Vehicles" (Paper presented at the First Conference on Next Generation Launch Systems, STAIF-96, Albuquerque, NM, Jan. 7-11, 1996).