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The Sprite Mini-Lift Vehicle: Performance, Cost, and Schedule Projections for the First of the Scorpius™ Low-Cost Launch Vehicles[*, †]

James V. Berry, Robert E. Conger and James R. Wertz

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

Abstract

Scorpius™ is a Microcosm program, under two Phase III Small Business Innovation Research contracts at the Air Force Research Laboratory, Space Vehicles Directorate. The Scorpius™ program is 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 status and substantial progress of the program since our last USU update. Specifically, the Sprite Mini-Lift Vehicle is projected to have a first DT&E flight in the first quarter of 2001 and first production flight in the first quarter of 2002. It has a planned payload capability of 440 lb. to low Earth orbit (due east launch). Total cost to orbit of the system is projected at $2 million (FY99$) after 10 launches.

System development has focused initially on smaller suborbital and orbital vehicles, although system level design has been done for vehicles 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. The first test vehicle, the SR-S suborbital, was successfully launched at White Sands Missile Range on Jan. 27, 1999 and a larger single stage suborbital is scheduled for launch in late 1999.

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Background

The Scorpius™ family of expendable launch vehicles[‡] 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 has 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[1] and largely implements the cost reduction strategies defined by John London[7, 8.]

As shown in Table 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 $800/lb. 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 that will be designed and flown. This, in turn, will further reduce launch costs and significantly aid in opening the space frontier.

The Scorpius program began 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.

Table 1. Scorpius™ Program Objectives. Dollar values in FY99$.

Vehicle	LEO Payload (100 nmi)	SSO Payload (400 nmi)	Vehicle Cost	Total Launch Cost	LEO Price/lb. to Orbit	SSO Price/lb. to Orbit
SR-S Suborbital	200 lb. Suborbital		$115K	N/A	N/A	N/A
SR-M Suborbital	900 lb. Suborbital		$320K	N/A	N/A	N/A
Sprite Mini-Lift	440 lb.	270 lb.	$1.4M	$1.7M	$3,930	$6,300
Independence Small-Lift*	800 lb.	380 lb.	$1.7M	$2.2M	$2,720	$5,790
Liberty Light-Lift*	2,200 lb.	940 lb.	$2.0M	$2.5M	$1,150	$2,660
Antares Intermediate-Lift	6,500 lb.	3,580 lb.	$3.2M	$6.3M	$940	$1,760
Exodus Medium-Lift	15,000 lb.	8,820 lb.	$9.6M	$11.5M	$760	$1,300

*Not in current development schedule

‡ U.S. Patent No. 5,799,902

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, provide increasing amounts of test data under diverse conditions, and validate reliability projections (99% reliability requires hundreds of experiences to validate).

Similarly, the objective in launch to orbit begins with the small Sprite vehicle, and then progresses to the larger Antares and Exodus vehicles for which the market is significantly 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 but 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. The creation of the liquid upper stage to be used as the third stage on Sprite becomes the larger scalable upper stage for the larger Scorpius™ vehicles, as well as other vehicles including reusable launch 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 Figure 1 and a view from the onboard camera in Figure 2. 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.

The Scorpius™ program is intended to use low-cost technology, simplified vehicle design and it provides low-cost responsive operations. The vehicle itself, the Transporter-Erector-Launcher (TEL), and the ground support equipment 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. The kerosene 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 appropriate design changes were implemented based on lessons learned, the operational procedures were changed, and the vehicle was rebuilt. 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.

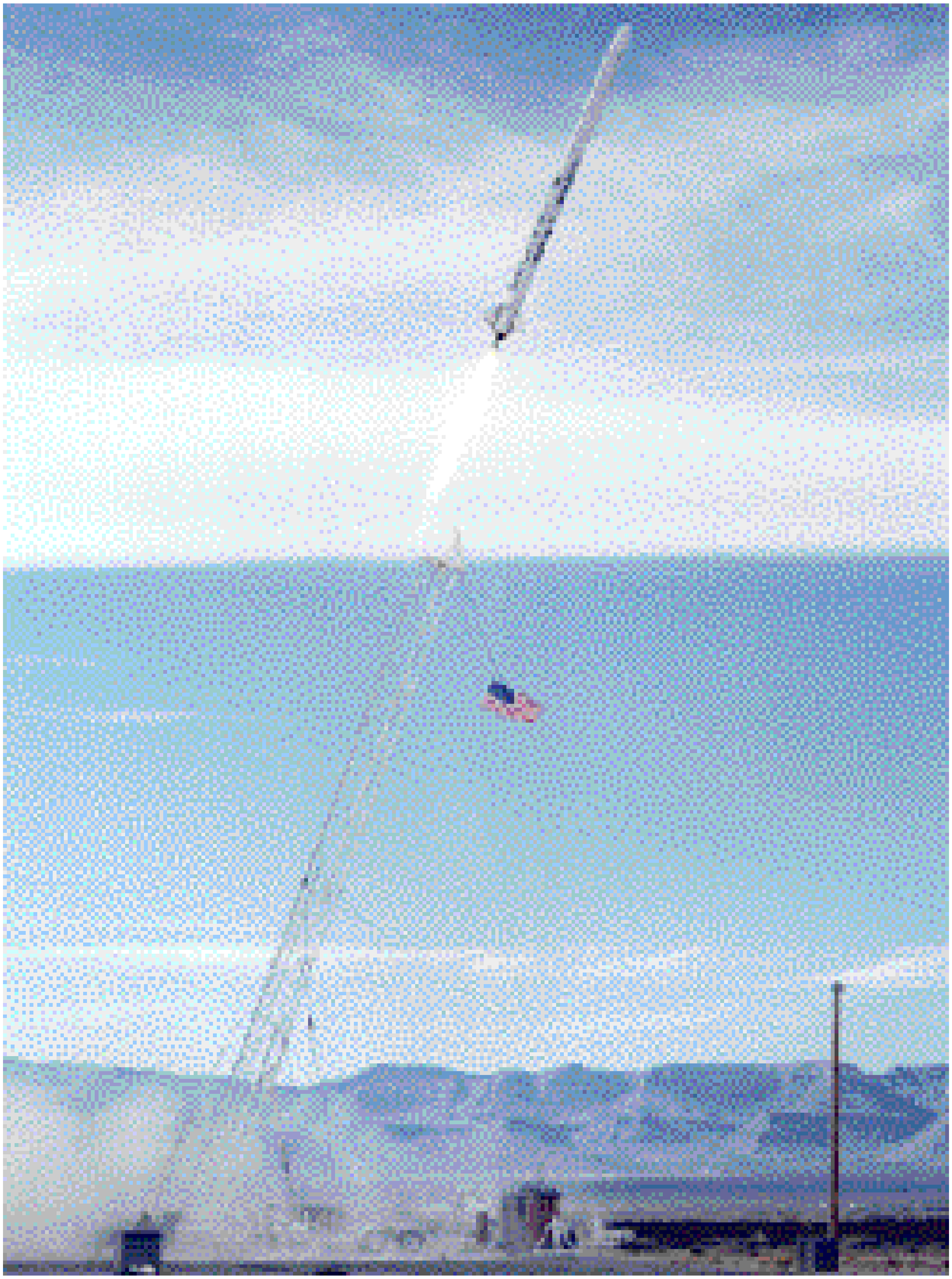

Figure 1. Scorpius™ SR-S launch from White Sands Missile Range, NM, Jan. 27, 1999. The vehicle was ready for launch within 8 hours of its arrival at the launch site.

Figure 2. 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.

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 Figure 3, a 40,000-lb. thrust test stand was completed in 1998 and recently upgraded to 80,000-lb. capability. In August 1998, this stand was used for initial testing of a 40,000-lb. thrust engine, shown in Figure 4. These tests were intended to characterize a new pintle injector being developed for the Scorpius™ program by TRW.

Microcosm in cooperation with AFRL and Schafer Corporation are 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. More than 25 of the 5,000-lb. chambers have been built at an average cost of less than $5,000 each and a small number of R&D injectors have been built at under $9,500 each. Many of the engines have been run in excess of 200 seconds, the maximum firing time needed to reach orbit in the baseline launch configuration. Testing on the 20,000-lb. engines began during July of 1999. Microcosm's low-cost engine design is intended to be expendable, thus significantly lowering both the non-recurring and recurring cost which is a substantial portion of all space launch vehicles.

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, 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, and launch services aspects of low-cost launch. Microcosm will continue to concentrate on R&D and vehicle development.

Figure 3. 80,000-lb. Thrust Engine Test Stand at the Energetic Materials Research Test Center (EMRTC) Rocket Test Site at Socorro, NM. The facility will be used to test the Microcosm 5,000-lb., 20,000-lb., 40,000-lb., and 80,000-lb. thrust engines.

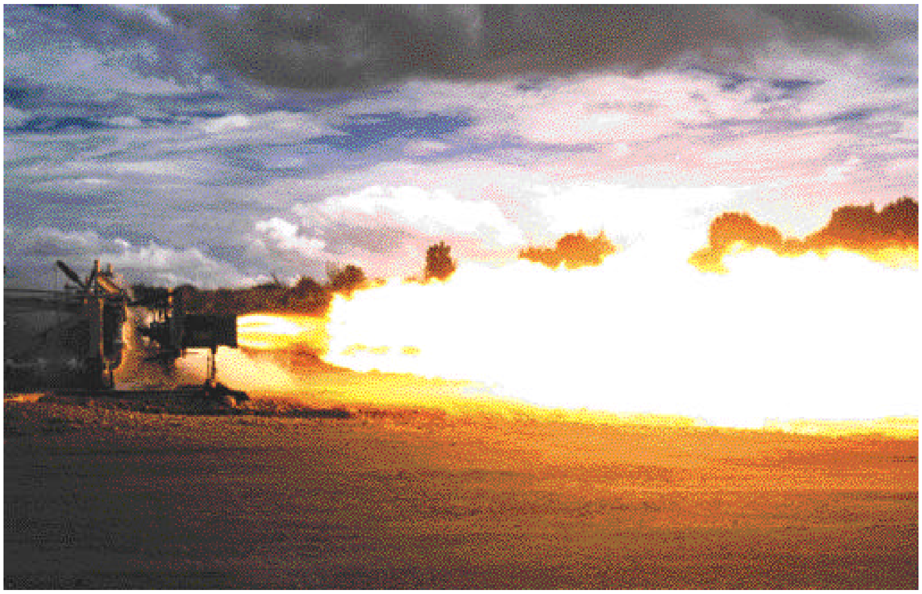

Figure 4. Testing of 40,000-lb. Thrust Engine at the Rocket Propulsion Test Facility. These tests were used to characterize a 40,000-lb. thrust injector modified by TRW for the Scorpius™ program.

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 will also be used with multiple manifesting. This is also the size range at which economies of scale can begin to significantly drive down the cost per pound to orbit. The Antares and Exodus vehicles in the Scorpius™ family will address this market.

Nonetheless, there is significant interest in a low-cost launch vehicle with very small to small payloads (200 to 2,000-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 relatively high, but the total cost of a dedicated Sprite 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, the Sprite Mini-Lift vehicle, shown on the right in Figure 5, will address this need. Sprite has a total cost-to-orbit objective of less than $2 million (FY99$) and a performance objective of 440-lb. to LEO (due east launch) or 330-lb. to a 150 mi 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.

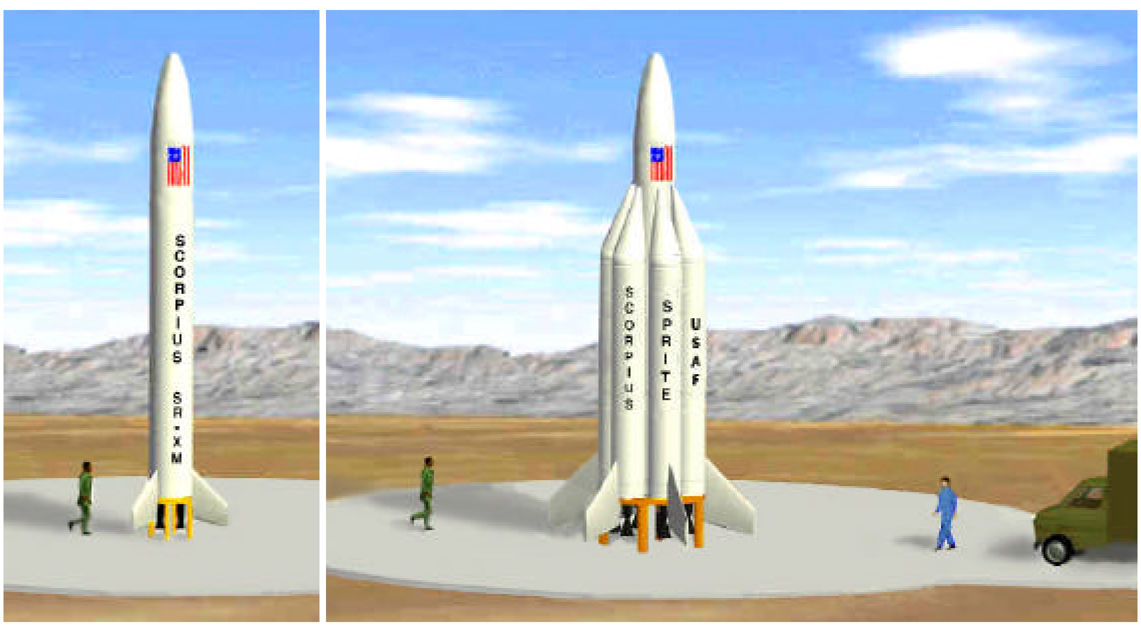

Figure 5. SR-XM Suborbital Vehicle and Sprite Mini-Lift Launch Vehicle. Sprite is intended to put 440-lb. into LEO at a price of less than $2 million (FY99$).

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 times 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 Figure 5 above, the overall Sprite design is relatively short and squat, as are the other Scorpius™ launch vehicles. The launch operations do not require a gantry nor service tower. The total vehicle height is 48 ft. with a circumferential pod height of less than 34 ft. Consequently, the payload area can be accessed as needed with standard 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-XM and 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 built. 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. Likewise reliability is improved since the parts are used multiple times, increasing by almost an order of magnitude their flight experience and associated confidence.

Cost Performance and Lessons Learned

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. The R&D injectors are less than $10K with unit cost dropping in production.
- Commercial GPS/INS unit sells for $25K. The price of the unit is planned to decrease as production volumes increase.
- Flight computers built for Microcosm at $4K/unit. (Upgrade to a more powerful processor may be needed.)
- Pod electronics built for Microcosm at $4K/unit.

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.

The SR-S which was launched and the current development and fabrication of the SR-XM yield considerable insight into recurring cost and the ability to scale suborbital to orbital Scorpius™ vehicles. Even without being able to fully determine final production cost, it is clear from the SR-S development 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[9] is that our cost model remains intact, i.e.,

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

Though the next SR-XM vehicle launches will continue to be launched at WSMR, the very energetic SR-2 and Sprite vehicles will move to coastal ranges. We anticipate launching the initial DT&E flights from Space Systems International (California Spaceport at Vandenberg AFB), and launch operations processes are currently underway. The objective is to perform the initial DT&E flights in March of 2001 and achieve the first commercial launch in the first quarter of 2002.

For a number of missions easterly launches are desired, and with Sprite's low infrastructure cost and simplified operations, easterly range operations and additional polar sites are expected to be available in late 2001. As Sprite transitions into full production, a recurring launch price, with payload delivered on orbit, is projected to be less than $1.7 million. Continued improvements in production and proven successful launches are expected to allow prices to be reduced to below $1.5 million, and the overall vehicle capability to improve to at least 500-lb. to LEO.

The Scorpius™ family of vehicles already incorporate the use of GPS/INS for guidance, navigation, and control, thus as the launch ranges utilize GPS for range safety, continued cost reductions in launch are anticipated. Microcosm is already working with the various ranges to achieve range cost reductions. Further, the Scorpius™ family of vehicles incorporates a new Flight Termination System (FTS) which allows for improved ground and flight safety operations.

As has always been a driving factor within the Scorpius™ program, improved reliability and reduced cost are the primary objectives. These factors must include not only the vehicle specific items, but also the entire operational aspects.

The combination of system engineering, detail design, fabrication, and launch of a first vehicle generate untold opportunities for success and failure. Coupled with very tight funding, aggressive schedules, and a requirement to include a wide cross section of engineering disciplines further strains the development and launch teams. However, time is money. Cost and schedule constraints increase risk but force decisions to be made. Errors will be made both in technical aspects as well as in omission. But, with a focused goal for both near-term and long-term program objectives, significant accomplishments can be made in a non-traditional sense.

The Scorpius™ Program has been founded on reasonable engineering (a very subjective term), and early test (Murphy is a terrific teacher). Thus far this formula has proven very valuable and successful. Some test failures have occurred, costs have exceeded estimates, and schedules have slipped, but the program has achieved results for a small fraction of the traditional space vehicle development cost.

Norm Augustines' Law XV states, "The last ten percent of performance generates one-third of the cost and two-thirds of the problems."

In line with this rule, the Scorpius™ Vehicles are designed to be as simple as possible and modest in performance. We will accept ten percent less performance to achieve higher reliability and simple operation. The vehicles are heavier with modest mass fraction, three stages, short and squat. They are designed to be truly expendable low-cost transportation systems.

Conclusion

The Scorpius™ low-cost launch vehicle program has been 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 higher reliability and low cost objectives. 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 eager 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, fabrication, 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 Space Vehicle Directorate, 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 Propulsion Test Site at the Energetic Materials Research Test Center (EMRTC) of New Mexico Tech directed by Dr. Jose Cortez. The Microcosm propulsion development program is directed by Dr. Shyama Chakroborty. Ken Hampsten of the AFRL and Tedi Ohanian of the Schafer Corporation have played a key role in development of the engine thrust chamber and injector, respectively. 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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