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Responsive Launch With the Scorpius Family of Low-Cost Expendable Launch Vehicles

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RESPONSIVE LAUNCH WITH THE SCORPIUS® FAMILY OF LOW-COST EXPENDABLE LAUNCH VEHICLES*

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ABSTRACT

Scorpius® is a family of low cost, expendable launch vehicles under development by Microcosm. The first orbital vehicle in the family is the Sprite Small Launch Vehicle (700 lbs to a 100 NMi circular orbit due East from the launch site), currently scheduled for its initial test flight in 2006. One of the top-level requirements on the entire vehicle family is to be able launch within 8 hours of arrival of the payload at the launch site or a formal request for launch for those payloads stored at the site. This paper addresses the economic, technical, regulatory, philosophical, and cultural hurdles to be overcome to achieve this objective and how we are going about getting over (or burrowing under or going around) these to get there.

The most fundamental hurdle is economic, i.e., the launch vehicle itself must be sufficiently low cost to allow it to be built to inventory. The cost of the Sprite vehicle is about $2 million which represents an interest cost for vehicles in inventory of about $15,000 per month per vehicle which we believe would be acceptable in most business models.

The technical hurdle is overcome largely by designing the vehicle from the outset to be moved and launched expeditiously — i.e., stored as an assembled launcher to which the payload is attached and the completed vehicle is then transported to the pad, fueled, and launched.

The most serious difficulties are largely the regulatory, philosophical, and cultural hurdles that dictate that launches in the West simply aren't done in a few hours, even though this has been done in Russia for many years. In the U.S., there needs to be time for approvals, notices to air and ship traffic, and the cultural impediment that says that the payload "must" be checked out on the launch pad. These challenges are perhaps the biggest and must ultimately be addressed jointly by the launch provider, the customer, and the government.

THE SCORPIUS® LAUNCH VEHICLE FAMILY

The Scorpius® family of low cost, expendable launch vehicles is shown in Fig. 1. The two suborbital vehicles on the left, the SR-S and the SR-XM, have been successfully launched from White Sands Missile Range (WSMR) in 1999 and 2001 respectively. The SR-XM is effectively one pod of the Sprite Small Launch Vehicle, which will be the first of the Scorpius® vehicles to go to orbit. The entire family of vehicles and the Scorpius technology on which they are based are described in a companion paper in this conference [Chakroborty, et al., 2003] and by an extensive series of prior papers. (See, for example, Conger, et al [2002], Wertz, et al. [1995, 1996, 1997], and Berry, et al. [1999, 2000].) The purpose of this paper is to focus on the responsive launch aspect of the Scorpius® family.

Two key characteristics of the Scorpius® family that have been a part of the design since it's inception have been dramatically lower cost than traditional vehicles and launch within 8 hours of demand. Thus, Microcosm has been working toward creating a responsive launch system for nearly a decade and has had to face many of the hurdles involved in this process. The two workhorse vehicles in the family are expected to be:

- Sprite Small Launch Vehicle that will put 700 lbs into LEO (100 NMi circular orbit due east from the launch site) for $2.5 million‡
- Exodus Medium Lift Vehicle that will put 15,000 lbs into LEO (again, 100 NMi circular orbit due east from the launch site) for $12.5 million

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‡ All costs quoted in the paper are in FY03$.

Fig. 1. The Scorpius® Family of Launch Vehicles. On the left, are the SR-S and SR-XM suborbitals and the Sprite Small Launch Vehicle. The intermediate-sized vehicles in the center are Antares and Exodus. The Heavy Lift Space Freighter is on the right.

Of these, the Sprite and suboribtal vehicles discussed by Chakroborty, et al. [2003], are expected to be the most used for truly responsive missions because of their low cost. All of the Scorpius® vehicles share a number of features that significantly assist the responsive character:

- Assembled at or near the primary launch site
- Assembled vertically on a reusable launch cradle on which they are also moved about the facility as needed
- Short, fat design for rapid movement and handling
- Transported vertically at the launch site on their cradles on rails or on a flatbed trailers
- No gantry or service tower needed for transportation or launch
- Ground level servicing (vehicles are short enough that the avionics bay and payload compartment can be reached by a cherry picker if required)
- All stages use environmentally friendly LOX/kerosene propellants

The kerosene that is used is Jet-A, available at essentially any airport worldwide. Fig. 2 shows the physical configuration of the Sprite vehicle, and Fig. 3 shows a single Sprite pod (i.e., the SR-XM) just prior to static testing at the Mojave Test Facility in the desert north of Los Angeles. Like most of the Scorpius® orbital vehicles, Sprite uses 7 nearly identical pods and a smaller upper stage. Tables 1 and 2 list the specific operational and vehicle characteristics of the Sprite vehicle.

Because the vehicle is pressure fed, the tanks, which also provide the structure for the vehicle, are sufficiently robust to support themselves and can endure casual handling without problems. The short, fat design makes the vehicle stable during integration, while being transported, and on the pad. The dry weight of Sprite (about 11,000 lbs) is comparable to a small bulldozer, so it can be easily towed by a standard truck cab or nearly any rail-based engine used for moving equipment.

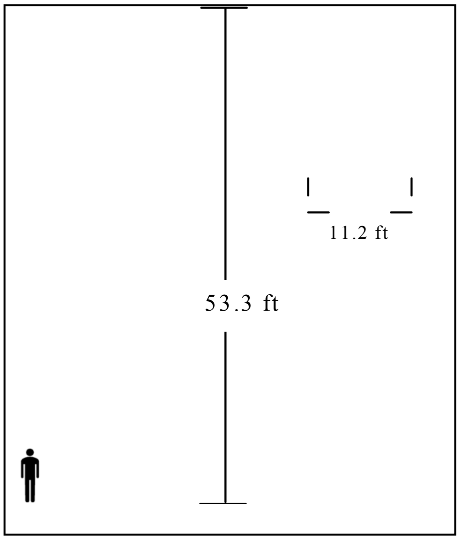

Fig. 2. Sprite Vehicle Configuration.

Fig. 3. Sprite Pod Static Testing.

Table 1. Sprite Small Launch Vehicle Physical Characteristics.

Payload volume		38" dia X 63" long		
Gross payload to 51.6 deg., 220 X 220 n.mi. (with stage 3 de-orbit)		575 lbm		
Launch response		Within 8 hours of demand		
Launch weather		Zero ceiling, Zero visibility, Moderate precipitation		
Launch winds		99.5% KSC, Wallops, or VAFB		
Stage 1/2/3 main propellant		Jet fuel and LOX		
Liftoff Configuration	GLOW	79,980 lbm		
	Empty WT	10,859 lbm		
	Dimensions	47.3 ft X 11.2 ft dia.		
Stage 1	Gross WT	66,040 lbm	Lbs Propellant	
	Empty WT	8,878 lbm	LOX	40,159
	Thrust (SL)	6 X 17,330 lbf	Fuel	16,733
	Dimensions	38.1 ft X 11.2 ft dia.	Press.	270
Stage 2	Gross WT	11,090 lbm		
	Empty WT	1,580 lbm	LOX	6681
	Thrust (Vac)	22,600 lbf	Fuel	2784
	Dimensions	33.2 ft X 3.5 ft dia.	Press.	45
Stage 3	Gross WT	2,850 lbm		
	Empty WT	401 lbm	LOX	1723
	Thrust (Vac)	2,530 lbf	Fuel	1718
	Dimensions	14.1 ft X 3.5 ft dia.	Press.	8

Table 2. Sprite Operational Characteristics.

Air and Road Transportable Launch Systems
- Entire rocket shipped in two standard truck trailers
- Easily-erected pods weigh less than one ton each

Less than 20 Person Launch Crew

Designed for 99.5% Weather
- High structural margins

Self-aligning GPS/INS Guidance and Navigation

Simple Launch Pad with Fly-off Interfaces
- Ground-level servicing. No gantry
- Flat concrete pad with stool and thrust deflectors
- Enables multiple sites, multiple pads per site

No Hypergolics or Explosive Devices

Thrust Termination based FTS with GPS Tracking

Fig. 4. SR-S Launched January 1999.

Fig. 5. SR-XM Launched March 2001.

Two Scorpius® suborbital test vehicles have been successfully launched to date. The SR-S was launched from White Sands Missile Range (WSMR) on Jan. 27, 1999 (Fig. 4), and the SR-XM was also launched from WSMR in March, 2001 (Fig. 5). The WSMR site used for both launches consists of a bare concrete pad and empty blockhouse with no equipment, cables, or even windows. The vehicles themselves, the transporter-erector-launcher, all of the ground support equipment and propellant loading equipment, and all of the cabling and launch operations computers and electronics were assembled and tested in Los Angeles and trucked to WSMR. For the SR-S flight, the equipment arrived at about noon on Saturday and the vehicle was ready for launch by the end of the day. The SR-S was much simpler than the orbital vehicles will be and, in some respects, required less processing. Nonetheless, it was also being prepared for the first launch at a site with no advance facility preparation. This experience demonstrates that 8 hours from demand to launch in a prepared facility is a reasonable and achievable objective. (The SR-XM did not fare as well. There was a short in the cable running from the launch pad to the blockhouse that required a new cable to be sent from LA to WSMR. Thus, it was 3 days before the system was ready to launch.)

THE ECONOMICS OF RESPONSIVENESS

The first requirement for a responsive launch vehicle is that it be sufficiently economical to be built to inventory. The cost of inventory is not only the maintenance cost of the vehicles in storage but, most importantly, the cost of the money required to build them, i.e., the capital that is tied up in a vehicle waiting to be launched. (Of course, the cost of launch operations is not paid until the vehicle is actually launched.) A rough estimate of the inventory cost is on the order of 0.75% of the vehicle build cost per month that it is stored. This implies that a Sprite vehicle in inventory (with a vehicle cost of about $2 million) would cost approximately $15,000 per month to be held in inventory. The situation is significantly different for larger, more traditional launch vehicles. For example, a launch vehicle that costs $65 million to build would cost about $500,000 per month to keep in inventory. Thus, it is most economical to hold in inventory vehicles that are low cost and have a high turnover rate. For inherently more expensive vehicles that have a low turnover rate it is much more difficult to make a case for a responsive launch capability. The lower cost vehicles should also have the highest turnover rate, that is, more launches per year and more unscheduled launches per year. Thus, there is two-fold advantage to low-cost vehicles in terms of being economically viable to build to inventory.

An example of this interplay between cost and responsiveness is the use of low-cost launch vehicles for either experiments or university payloads. University payloads, such as the University of New Hampshire CATSAT, or small scientific test satellites, such as ST-5 from Goddard Space Flight Center, are nearly unable to find a launch because of the high cost. However, to be useful, they should be launched relatively soon after they are built. It would be highly desirable to launch university payloads while the student is still a student, or at least while he or she is still in astronautics. The experimental nature of the satellites themselves and the high probability of last minute glitches or items in need of fixing suggest that a launch schedule fixed years in advance is not practical. These payloads don’t have the $20 million or more required to secure a dedicated launch in today’s market. Low cost launch-on-demand is an ideal solution for payloads of this type. These payloads do not have the high national priority of either military systems or launch in response to an emergency on the ISS. Nonetheless, they can provide a strong market that can ultimately make low-cost, responsive launch economically successful. It is also the economic return that makes the market sustainable without an ongoing "contribution" from the federal budget.

Launch vehicles in inventory can be held in multiple ways in a financial sense. They can be purchased in advance by the end user and stored for later use. This would be the economic model used for cruise missiles, ICBMs, or most munitions. In this case, the actual launch operations would probably be conducted by the end user. Alternatively, the vehicles could be built and stored in anticipation of future need by the manufacturer or a third party launch provider. This is comparable to the way new cars are sold, or in the case of a third party provider, similar to the car rental approach. The inventory cost is simply added to the price of the vehicle. If we assume that the average small launch vehicle sits in inventory for 6 months prior to use, this would add $75,000 to $100,000 to the price of a Sprite launch, which seems like an acceptable price for having low cost launch-on-demand.

A third alternative might make the most sense for a specialized, low-turnover business such as launch. The end customer, such as a constellation owner wanting ground-based spares, could pay the launch manufacturer or provider a monthly fee to have a launch vehicle ready either at all times, or within so many days of notification of a potential need. The launch provider then adjusts the build rate to ensure that the contractual conditions are met. This is a compromise solution in which the launch provider is still providing the vehicle and the launch service, while the end customer is concerned primarily with the payload and the services or data which it is providing.

There is another fundamental financial problem that must be solved to enable low-cost responsive launch. Sprite, for example, can be launched in a day with a launch crew of less than 20 people. This makes launch operations much lower cost than for traditional systems, <u>if the launch crew has something else to do when they aren't launching spacecraft</u>. If there is a dedicated launch crew, then we have a "standing army," which implies a cost of launch operations inversely proportional to the launch rate. When launch rates are low, as they will be initially, launch operations costs will be high, which will in turn tend to keep launch rates low. We need to break this cycle in order to enable responsive, low-cost launch. For Microcosm and the Scorpius Space Launch Company that will build and launch the Scorpius® vehicles, we believe the fundamental solution to this problem is to assemble the vehicles at or near the primary launch site. In particular, the physically largest components are the tanks and the assembled pods. The tanks are wound composites requiring equipment that can be readily installed in nearly any industrial or warehouse facility. Building pods and assembling them vertically into a launch vehicle requires a high bay of approximately 50 ft ceiling height for Sprite and 70 ft ceiling height for Exodus. While higher than many warehouses, this is not an unreasonable or unusual height for commercial construction.

The major advantage of this build-and-fly at one location approach is that most of the launch crew will spend most of their time building other vehicles. This mitigates the "standing army" problem and allows low-cost launch operations to be just that. However, there are a number of secondary advantages as well. Tanks and assembled pods are relatively large and, therefore, cumbersome to ship. While they are small enough to transport to remote sites, the most economical approach is to create the tanks and pods at the primary launch sites. In addition, the launch crew is now extremely knowledgeable about how the vehicle is built and, therefore, about how it can and should be handled and what constitutes potential problems. All of the tools and equipment used to construct the tanks and vehicle are automatically available at the launch site. This means the right tool to fix a problem is more likely to be available and reduces the capital cost of multiple sets of equipment. If a problem occurs on the pad, the vehicle can be changed out immediately, and the problem vehicle can be "returned to the factory" within about an hour for repair, refurbishment, or replacement of damaged components. It is also more personnel-friendly in that there is much less travel to remote launch sites to resolve problems or to wait for a launch to occur. This approach serves to maximize responsiveness while minimizing personnel, facilities, operations, and equipment costs.

Note that manufacturing at the launch site will be done for reasons of economics or a need for responsiveness. It is not a technical necessity. Pods or vehicles can be transported from wherever they are built to either the primary or secondary locations. This will certainly be the case for the first few test and operational launches. The transition to launch site manufacturing can be done as dictated by business factors. One approach is to have experimental and test vehicles manufactured at the Microcosm facility until the design has fully matured. At that point, manufacture and launch transitions to a Scorpius Space Launch Company facility in the vicinity of the launch site, and Microcosm takes on the task of building next generation vehicles or otherwise upgrading the design. This leaves Microcosm personnel with the continuing task of creating and testing new vehicles or vehicle upgrades and gives the Scorpius Space Launch

Company the task of building and launching mature vehicles.

SPRITE LAUNCH FACILITIES AND OPERATIONS

The Sprite facility requirements are sufficiently straightforward, that we expect to use existing facilities for many activities. Therefore, in order to minimize facilities cost, we anticipate taking advantage of whatever facilities may be available at or near the selected primary launch site.

Thus, the ultimate facilities configuration will depend on the primary launch location, which has not yet been selected. (Discussions with a number of possible sites are in progress.) What we describe here is a generic launch site facility layout that provides a good perspective on the needs and flexibility of the Scorpius® system.

Figure 6 shows a schematic representation of the launch site facility layout. The production, assembly, storage, and administration facilities are located at a safe distance from the launch pad, typically a minimum of 3 miles. A wide road or rail bed goes in both directions (shown schematically as a loop) so that a vehicle can be moved from storage to the launch site at the same time hat a vehicle is being returned to the assembly area in case of a problem requiring that the vehicle be changed out.

The administration and production facility houses the usual engineering, manufacturing, management, clerical, and safety personnel. Components and material are received here and some amount of manufacturing is done. Specifically, large tanks and nose cones are wound here because it is much lower cost to ship the raw materials than to ship the finished tanks, and the facility requirements for winding the tanks are modest. Thrust chambers could be built either here or elsewhere, depending on economic or business issues. A schematic of the production and administration facility is shown in Fig. 7. A ceiling height of 20 to 25 ft is adequate for this activity. Photographs of the current production and pod integration facility at Microcosm are shown in Fig. 8.

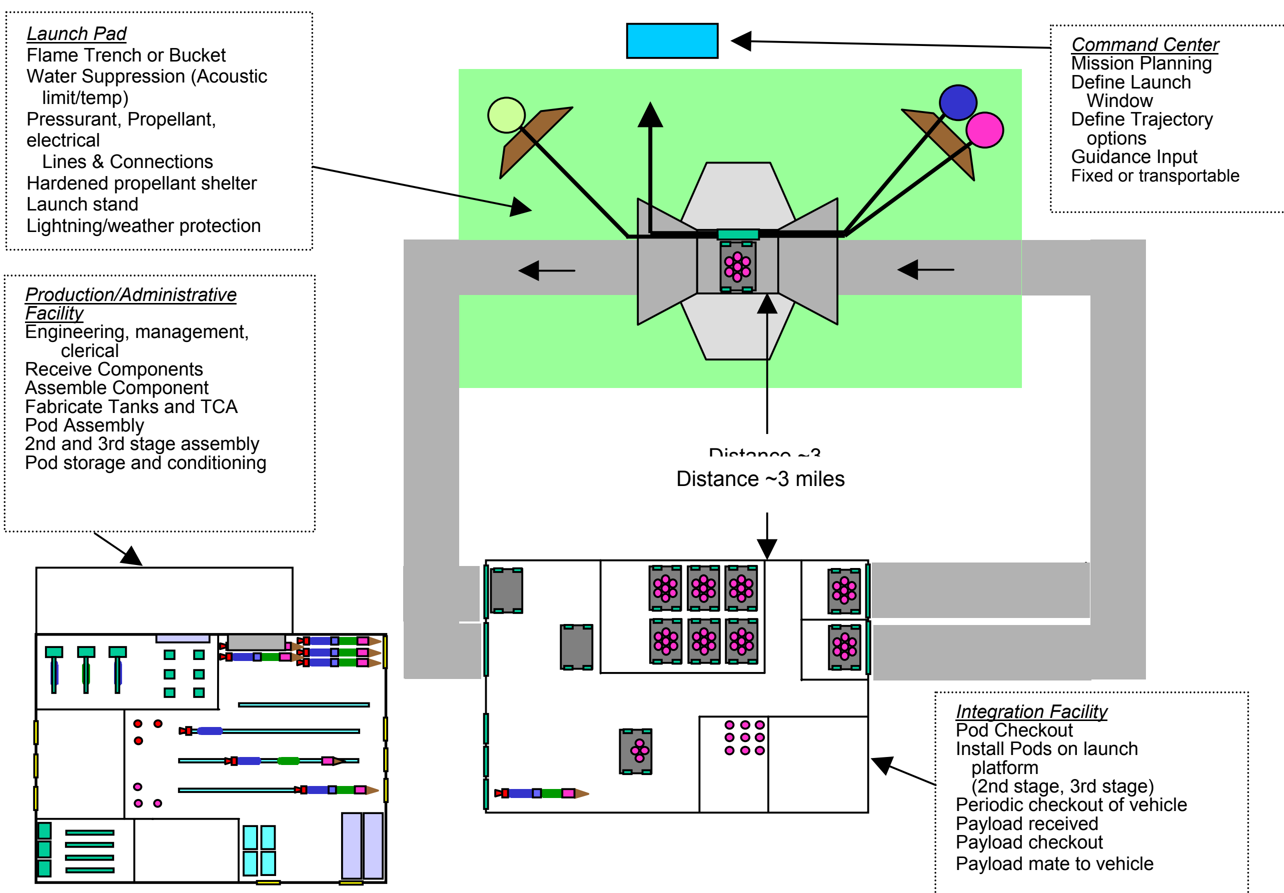

Fig. 6. Scorpius® Launch Site Schematic Representation.

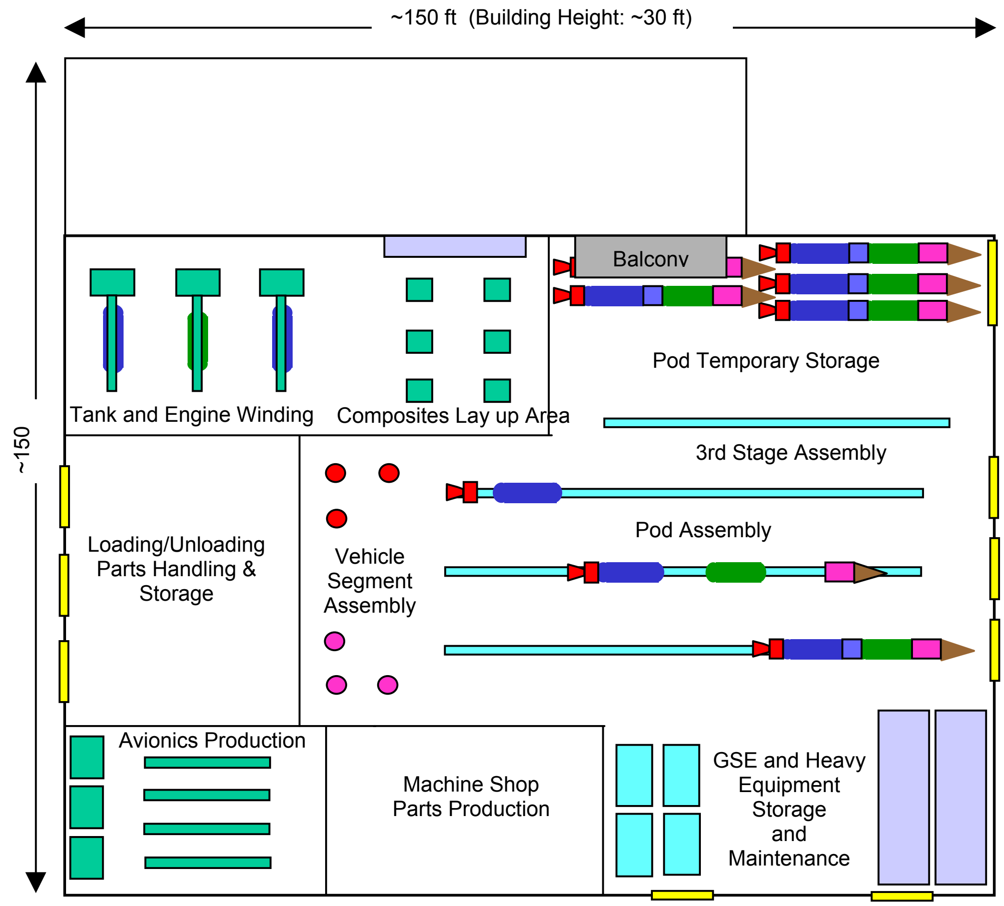

Fig. 7. Schematic Layout of the Production and Administration Facility.

The vehicle assembly and storage facilities, shown schematically in Fig. 9, require a significantly higher ceiling height than the manufacturing area. For Sprite a height of about 50 ft is required to accommodate the vehicle without payload and a height of about 75 ft is needed in a small area where the payload will be integrated just prior to movement to the launch pad. The vehicles are assembled on a reusable launch cradle and stored vertically until they are needed. As described below, when launch is imminent, the vehicles will be moved out of storage, mated with the payload, and transported vertically by either road or rail from the assembly area to the launch site.

As discussed above, Scorpius® vehicles do not require a gantry or service tower. Thus, as illustrated in Fig. 10, the launch site itself can consist largely of a bare concrete pad with a flame bucket or, alternatively, a launch stool and flame deflectors. A supply of LOX, kerosene, pressurant, and electric power would be required. A water deluge system would also be needed for fire safety and acoustic noise suppression during launch. Recall that the vehicle is brought to the launch pad vertically via truck or rail and is already on its reusable launch cradle. The cradle itself is on removable wheels and can be pulled over the flame bucket by a winch.

Launch vehicles will be stored nearly fully integrated in the assembly and storage facility near the launch site. They will not have propellants, batteries, or pyrotechnics on board and will undergo automated testing on a regular basis to ensure that all systems are ready to go. As much preparation as possible will be done in advance of the launch.

Table 3 summarizes the launch operations timeline for the 8 hours preceding launch. At the time that a decision to launch is made, parallel activity is initiated in three areas — mission planning, vehicle and pad preparation, and payload integration. Additional details of the vehicle preparation timeline and the payload integration timeline are given in Tables 4 and 5. The mission planning element can, in principle, be made more responsive by a high level of automation. However, this element also includes the various approval and notification cycles. Therefore, as discussed in the next section, this portion may represent the largest impediment to responsive launch. In addition, the responsiveness of the range itself may depend on the willingness to accept telemetered GPS tracking or to modernize and upgrade existing tracking facilities.

Fig. 8. Current Scorpius® Manufacturing and Pod Assembly Facility in El Segundo, CA.

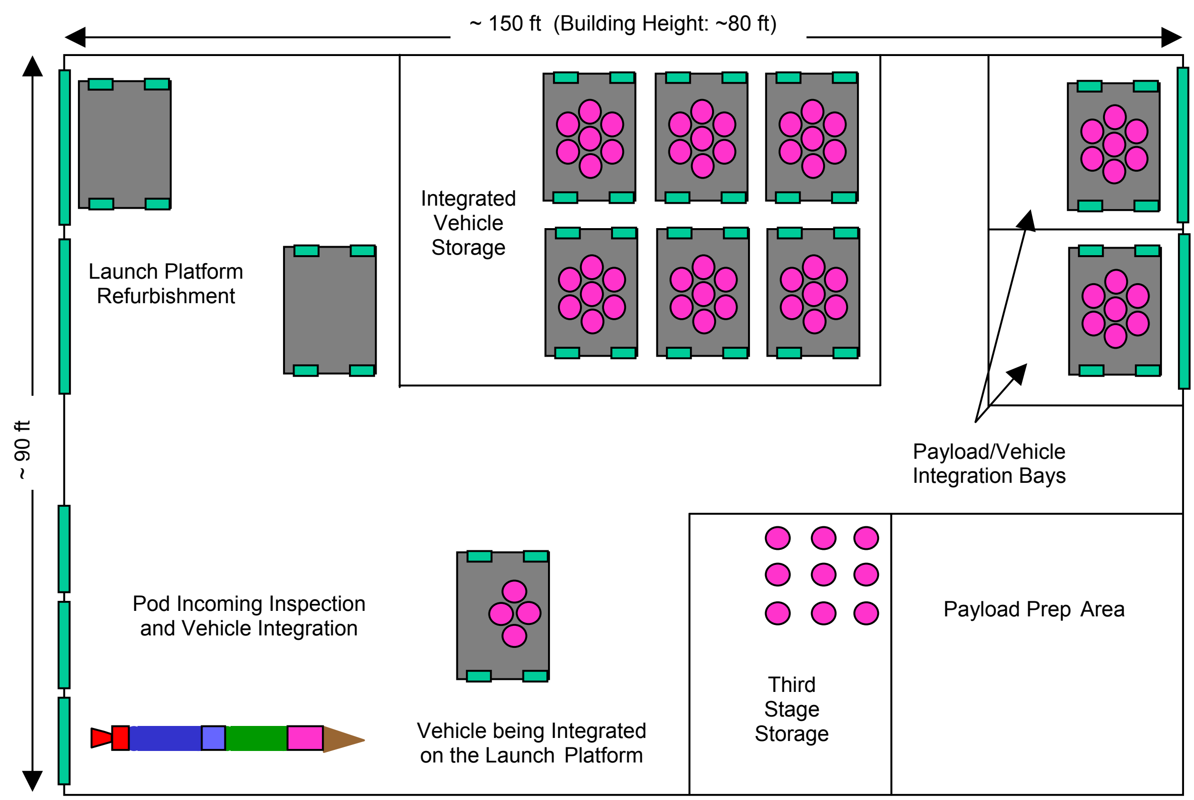

Fig. 9. Vehicle Assembly and Storage Facility Layout.

Fig. 10. Scorpius Launch Pad. Exodus pad is illustrated. Sprite could be launched from the same pad or a smaller one of comparable design.

Table 3. Launch Operations Timeline.

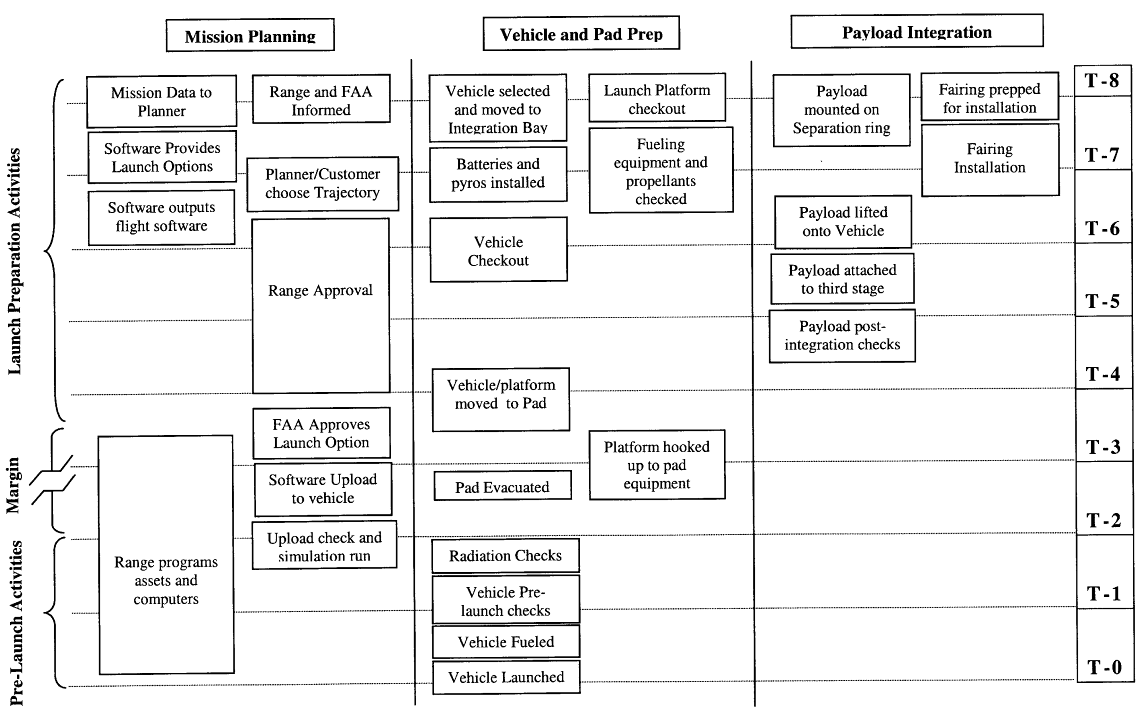

Table 4. Vehicle Preparation Timeline

Task	Duration	Timeline	# People	Notes
Vehicle is selected for this flight from pre-assembled stored vehicles	10 min	T-8 hrs	1	Many tasks can be concurrent, but increases personnel needed
Launch platform checkout	30 min	T-8 hrs	1	
If not already in one, vehicle is moved to an integration bay	20 min	T-7.5 hrs	1	
Floors lowered over third stage of the vehicle for payload integration	10 min	T-7.3 hrs	2	
Batteries installed, or shorts removed, and pyros are installed	1 hr	T-7 hrs	2	
Vehicle electrically connected to vehicle checkout equipment, and automated checks conducted	1 hr	T-6.5 hrs	2	Mostly leak checks
When payload integration and vehicle checks are complete, automated mover hauls launch platform out to the launch pad	1 hr	T-5.5 hrs	1	
Fueling equipment and water system checked and prepped for use	45 min	T-7 hrs	2	Really only 1 person needed, but 2 required for all hazardous ops
Propellant, pressurant, water checked	10 min	T-6.8 hrs	1	
Platform connected to fueling equipment, ignition system, umbilicals, and other systems	20 min	T-4.5 hrs	2	
Pad evacuated	20 min	T-3 hrs	0	
Radiation checks (remote)	10 min	T-2 hrs	2	
Vehicle pre-launch checks (remote)	20 min	T-1.5 hrs	2	
Vehicle fueled remotely	30 min	T-1 hr	2	
Vehicle launched		T-0	2	

Table 5. Payload Integration Timeline.

Task	Duration	Timeline	# People
Payload unpacked (if packaged)*	30 min		2
Payload pre-integration checkout and fueling*	4 hrs		4
Fairing prepared for installation*	20 min	T-8 hrs	1
Payload weighed and balanced*	30 min	T- 7 hrs	3
Payload mounted on Separation ring*	30 min	T- 7.5 hrs	4
Fairing installation*	1 hr	T-7.5 hrs	3
Third stage cover removed	10 min	T-7.3 hrs	1
Payload lifted onto vehicle	10 min	T-6.8 hrs	4
Payload adapter attached to third stage	20 min	T-6.5 hrs	2
Payload electrically connected to vehicle	10 min	T-6.3 hrs	2
Payload post-integration checkout	30 min	T-6 hrs	1
Customer to command center		T-5 hrs	1

Notes: *Not applicable for encapsulated payloads.

The launch vehicle remains in a vertical orientation throughout storage, final integration, transportation to the pad, and launch. The actual launch sequence is straightforward. The selected payload and launch vehicle are checked out, covers are removed, and the flight batteries and pyrotechnics are installed. The payload is installed on the launch vehicle and the entire assembly is transported vertically to the launch pad on its launch cradle on a flatbed truck or rail car. On the pad, final radiation checks and pre-launch checks are done and fluid lines are attached. Personnel then leave the pad and the vehicle is fueled and launched remotely.

In case of an abort that will require scrubbing the launch, the propellants are recovered via the fill lines and the vehicle is recycled to a wait state. Whether it remains on the pad or returns to the storage and assembly area will depend on the conditions of the abort. If the abort occurs after the fuel lines have been disconnected, then the LOX is dumped into the flame bucket and allowed to evaporate. The system is then safe for personnel to return to reconnect the fuel line so that the kerosene can be recovered and not dumped into the environment.

During launch of the Scorpius® SR-XM at WSMR an unintended test of the abort procedures occurred. Approximately 15 sec before launch a small anomaly occurred on the vehicle and, nearly simultaneously, an airplane crossed into the edge of the restricted air space. This set off alarms in the closed blockhouse and caused an automatic abort. The launch crew climbed down from the ceiling, safed the vehicle, recycled all appropriate valves and electronics, and reinitiated the countdown at the appropriate time in the cycle. The SR-XM was then successfully launched with approximately a 7 minute delay.

REGULATORY, PHILOSOPHICAL, AND CULTURAL HURDLES

The most difficult issues facing responsive launch are the regulatory, philosophical, and cultural hurdles that have been created over time. These are summarized in Table 6. It is important to recognize that nearly all of these barriers were put in place over time in response to real problems. Notices to ships and aircraft are required to ensure the safety of everyone involved in the launch and those who simply happen to be in the vicinity. While we attempt to modernize or streamline the approaches we also need to keep in mind the essential functions that created them in the first place and ensure that these functions are fulfilled. In addition, the significant changes in launch site and range operations that may be required to achieve a responsive launch capability may not be appreciated by the ranges themselves, particularly if an attempt is made to dictate changes. We believe that the strongest approach is to work with the ranges to try to bring about changes in both cost and schedule. Our experience to date has been that the ranges themselves are very responsive to trying to meet these evolving needs.

Table 6. Regulatory, Philosophical, and Cultural Hurdles to Responsive Space.

Issue	Comments
Existing Range Issues	
Scheduling	Typically required months in advance
Obsolete range equipment	Long programming time
GPS-based tracking	Not currently accepted at existing ranges (some discussion in progress)
Flight safety requirements	Assessment required for each flight — often slow
Ancillary services (payload processing)	Specific vendors often required and typically slow
Creating a New Range	
Range certification and licensing	Can be both expensive and time consuming
FAA Requirement	
Approval required for each flight	Often slow response time
NOTAMs and other notification requirements	Existing process is slow
User Community	
Payload requirements	Mission specific interfaces and handling is currently standard
TRADITION	"LAUNCH IT TODAY" ISN'T THE WAY WE DO BUSINESS IN SPACE

A good example of the above process is the existing range tracking system which is needed to ensure downrange safety and provide data on which to base a flight termination decision during powered flight. We believe that this function can be satisfied by using GPS-based on-board tracking. Both Scorpius® sub-orbital test launches have included GPS/INS on board and have telemetered the data to the ground. This process has not yet been approved for flight termination by WSMR, but we will continue data collection and discussion with all potential ranges in an attempt to look for more economical and responsive means of fulfilling the range tracking function, satisfying the flight termination requirement, and ensuring safety.

Range scheduling is also a potentially major issue for responsive launch. Currently, ranges are scheduled anywhere from 8 months to 2 years in advance. Short notice activities can be scheduled between major events, but are likely be bumped in the event of schedule slips in the major programs. The Scorpius® vehicles themselves would be on the pad for only a short period. However, if they were sharing a launch pad with a vehicle that was being integrated or tested on the pad, the system could be unavailable for an extended period.

The most likely solution for a truly responsive launch capability would be a launch pad dedicated to that purpose. While this adds non-recurring cost, it is less of a cost burden than for many traditional systems because of the simplicity of the pad itself, as described above. This simplicity also provides a high level of flexibility. Thus, Scorpius® vehicles could be launched from many existing launch pads, if desired. A dedicated pad could be built at low cost or the smaller vehicles could be launched from a low-cost stool with flame deflectors. Both primary and secondary launch sites could be created, if desired for security, back-up, orbit insertion needs, or the need for multiple sites to overcome possible weather delays.

Perhaps the biggest difficulty to be overcome is simply tradition and the mindset of the user and regulatory community. Dedicated, specialized launch vehicle interfaces are currently the normal practice. Extensive final payload testing is often done on the pad prior to final close-out. While the FAA has become the regulator of the launch industry, it has not yet approached the problem using the model of commercial airlines, which would allow scheduling on short notice.

Once again, the solution is to find ways to satisfy the need, but in a more responsive fashion. Much as in the computer industry, standard interfaces will need to be used that are sufficiently flexible to accommodate a wide variety of payloads. Testing on the pad prior to launch should be done to ensure that all systems remain functional after the trip from the assembly area. However, these tests can be automated and should be run via either telemetry broadcast through the fairing or a hard line running down the launch vehicle.

BREAKING THE BARRIERS — HOW DO WE GET TO RESPONSIVE SPACE?

The technical and financial barriers to responsive launch are challenging, but can be overcome. The Russians, and the Soviets before them, have been doing this successfully for many years. If we can overcome the mindset that a "standing army" launch crew is required, then a truly responsive launch can also significantly reduce launch operations costs. We believe that both the analysis and experience to date show that is reasonable to conduct a launch within 8 hours of demand with a launch crew of less than 20 people. Of course, to make the system low cost as well as responsive, that crew must have some other useful work during the months between launches.

There are two principal technical and financial criteria that must be met to achieve responsive launch. The system must be designed from the outset for responsive operations by maximizing the work that is done in advance and minimizing the work that must be done as a part of launch operations. From the financial perspective, the vehicle must be sufficiently low cost that it can be built to inventory and that it will have a reasonable turnover rate.

The recent Columbia tragedy and failures in the unmanned program will continue to remind us that safety and reliability will remain critical issues. After 40 years of launch experience, our industry remains at a 90% to 95% reliability. Launch to orbit is a business in which technical margins are slim and the consequences of minor flaws can be major disasters. This implies that launch procedures must remain well controlled, personnel in the immediate vicinity of the launch must be severely restricted, and down range debris will continue to be an issue that must be carefully watched. All of these are issues that must concern everyone, but they can be worked. To be successful, responsive launch must also reduce cost and improve reliability.

The government holds most of the keys to making responsive launch real. If, in practice, getting government approval for a launch requires a month, then no company will build a launch-in-a-day capability, irrespective of whether it's technically feasible. The launch ranges must accept GPS-based tracking, modernize and streamline range operations, or preferably both. Scheduling and all approval and notification cycles must be made much faster.

Perhaps the most challenging barriers are culture and tradition. The customer must be willing to accept standard interfaces, such that the next vehicle in line can be used and an entire vehicle can be changed out if needed. The customer must also be willing to give up last minute tests on the launch pad, or, more likely, be able to run these tests remotely and largely automatically. Industry must accept the need for responsiveness as real and respond appropriately. One of the larger problems at Microcosm is convincing ourselves that the need is real and that it is worth the effort (i.e., money) to design the system to be responsive.

In the words of the famous Pogo cartoon, "We have met the enemy and he is us." Nonetheless, if the need is real, the barriers to responsive space can be broken.

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From a technical perspective, much of the original Scorpius design is from work done over a decade by Ed Keith. On the vehicle side, the technical team has been led by Jim Berry and, more recently, by Dr. Shyama Chakroborty. Operations concepts were refined and put into practice by Dave Crisalli of Polaris Engineering who led the launch support for the SR-S and Anne Chinnery who undertook this task for the SR-XM. Both did exceptional jobs. Much of the results and proposed processes were first documented by Anne. Their activity was watched with great care by Maj. Gen. (ret) Jack Kulpa who served as the launch director for over 50 launches for the NRO, and is currently serving as President of the Scorpius Space Launch Company, co-author on this paper, and a very interested reviewer of all launch operations activities. Finally, the technical support of all of the Scorpius® team is much appreciated and gratefully acknowledged.

As usual, any residual errors should be blamed on the authors. We would appreciate any corrections or comments being sent to us at microcosm@smad.com. We would be delighted to hear from anyone interested in this topic.

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