

ICBM Derived Small Lift Vehicles: Past, Present, and Future

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ABSTRACT:

The United States has a rich history of space lift success, most of which is based on the Intercontinental Ballistic Missile (ICBM) heritage. For more than 40 years, the Rocket Systems Launch Program (RSLP) has been executing its charter to store and utilize deactivated ICBM assets. We have had hundreds of successful launches, in multiple launch configurations, from nearly two dozen different launch locations. From spaceports to air launches to all across the Pacific Ocean, RSLP has been the small lift vehicle of choice for the Department of Defense (DoD).

RSLP currently provides affordable space launch test beds for emerging space technologies. We can bridge the gap to the next generation of launch vehicles the community is working towards in the coming decades. Our proven assets and responsive abilities eliminate many of the variables involved in putting small satellites into orbit, which allow space researchers to better focus their resources over the coming years. Research and development efforts should continue, and until future systems come to fruition, the community should look for ways of using assets that are currently available, cost effective, and require no development. This will allow developmental funds to be applied to whatever concept is going to be our next access to space.

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| 6. Launch Vehicle Technology Demonstration Gap | The authors of this paper are all members of the Rocket Systems Launch Program (RSLP) and while this paper does not reflect any official position of RSLP or the government in any way, our direct experience in the launch vehicle community has led us to the conclusions |
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found in this paper. RSLP is located at Kirtland AFB, NM, and has been a custodian of rocket motors from deactivated ICBM systems and other deactivated rocket programs for over 30 years. RSLP has conducted over 650 rocket and missile launches using these surplus motors. The use of surplus motor assets has resulted in great cost savings over the alternative of developing new launch systems to meet various mission requirements. In fact, RSLP has pioneered the use of surplus motor assets to reduce launch costs.

RSLP's contract vehicle for providing spacelift utilizing deactivated ICBM assets is the Orbital Suborbital Program (OSP), which has been awarded to Orbital Sciences Corp (OSC) for the Minotaur family of vehicles. Additionally, with the goal of being able to provide the lowest cost access to space for small satellites, RSLP has recently awarded the Responsive Small Spacelift (RSS) contract to both SpaceX and OSC, for potentially lower cost fully commercial launch vehicles (utilizing no government furnished rocket motors). It is important to note that both of these contract vehicles are Indefinite Delivery Indefinite Quantity (IDIQ) contract, which means that there is no guarantee of any launch vehicle orders from the government. RSLP's business model is based completely on being able to provide launch services on an as needed cost reimbursable basis.

WHERE WE'VE BEEN

In just a few decades, RSLP has amassed an outstanding launch history. The OSP, Sounding Rocket Program (SRP) and Responsive Small Spacelift (RSS) contracting vehicles have been invaluable assets to our success. With our nimble contracting abilities and contract vehicles in place, three successful missions have been accomplished in just the last 18 months under the OSP contract alone.

Under the OSP contract vehicle, we use deactivated ICBM Rocket Motors and flight proven launch vehicle hardware to offer cost effective launch services and test



support for space and ballistic launch missions. XSS-11 was launched using a Minotaur I from Vandenberg AFB in April 2005. The XSS-11 mission demonstrated the ability to use GPB-4 (GPS Position Beacon) to from take-off through final vehicle separation. STP-R1 was then launched in September 2005 from Vandenberg AFB also using the Minotaur I launch vehicle

configuration. The most recent success under the OSP contract was the successful launch of Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) atop a Minotaur I. The COSMIC launch was also able to demonstrate the suitability of NASA's TDRSS system for future orbital and sub-orbital launches, potentially decreasing overall launch costs and allowing for a more flexible launch period. This experiment is explained in more detail later. We currently have three additional Minotaur I launch vehicles on contract; TacSat 2 in November 2006, NFIRE in April 2007, and TacSat 3 in September 2007. We also have a Minotaur IV (3 times the lifting capacity of the Minotaur I) vehicle scheduled for launch in December 2008 for the SBSS mission.



The SRP contract vehicle has also been a great success for RSLP. The SRP contract boasts a short 12-15 month time period from authority to proceed to initial launch capability. To date, we have been 100% successful and on budget, with a 13 mission history and 3 missions currently on contract.

We have over 1,700 Minuteman and Peacekeeper deactivated rocket motors and 28,000 supporting components in storage ready for future launches. Our capability to store, age and monitor these assets allows us to offer deactivated weapons grade motors and components as some of the most reliable launch vehicles currently available. RSLP maintains the ability to launch from Kodiak AK, Poker Flats AK, Vandenberg AFB CA, Barking Sands HI, Wake Island, Kwajalein Atoll, Green River UT, Ft Wingate NM, White Sands NM, Wallops VA and Cape Canaveral FL. We also offer an air launch solution giving us the capability to achieve almost any orbital inclination. With several future launches already scheduled, RSLP is capable and stands ready to take on a multitude of additional missions.

OPERATIONALLY RESPONSIVE SPACE (ORS) BACKGROUND

The National Space Transportation Policy 40-1, signed 21 Dec 04, states, "Before 2010, the United States shall demonstrate an initial capability for operationally responsive access to and use of space to support national security requirements." In concert with this Presidential direction, the definition of Operationally Responsive Space (ORS), as provided by the Air Force

Requirements Oversight Council-approved ORS Initial Capabilities Documents, is as follows: “ORS will provide an affordable capability to promptly, accurately, and decisively deliver, position, and operate national and military assets in and through space and near space, fully integrated and interoperable with current and future architectures, and provide space services and effects to warfighters and other users. ORS is a vision for transforming future space and near space operations, integration and acquisition, all at a lower cost.” Additionally, General James E. Cartwright, Commander, USSTRATCOM, defines ORS as “directly benefiting the warfighter with an agile, responsive, commander-oriented space capability focused primarily at the tactical and operational levels of war.” Essentially, ORS provides an affordable, rapid reaction combination of responsive payloads, responsive space launch, responsive launch traffic control (ranges), and responsive near-space optimized to provide on-demand theater support, surge, reconstitution, augmentation, and prompt global strike.

RESPONSIVE VS. LOW-COST SPACE LAUNCH

Currently, the near to mid-term goal to have responsive access to space at a lower cost is only feasible if we make the assumption that there will be a continuous and significant increase in the annual number of launches. This is a very dangerous assumption, as numerous times in the history of launch vehicles the promise of a booming launch market has failed to materialize. In fact, numerous recent studies indicate that through the foreseeable future, at least until 2020, the rate of space launches will remain fairly stable at the current levels, unless there is the breakthrough of the as-of-yet unrealized “killer app.”

Could ORS provide the killer app that has thus far eluded the space industry? In reality, ORS would be utilized primarily in brief surge operations requiring extensive infrastructure to react to such scenarios. The ORS infrastructure would also require peacetime training exercises, which would meet the current forecasted launch requirement. It is doubtful that maintaining such a standby war reserve will significantly reduce the cost per launch during peacetime, as the system will be operated at a fraction of its designed capability. Whereas in a war scenario, the cost per launch will be significantly less than it is currently due to the system operating at its designed state of efficiency. Meanwhile, as the ORS concept searches to demonstrate its effectiveness in the near term through demonstrations like the TacSat missions, the emphasis is on the lowest cost launch at a responsiveness that matches the spacecraft development timeframe (~12 months). However, these near term

demonstrations show no significant increase in the rate of annual launches, making it difficult to justify the investment needed to lower launch costs. Finally, there are no plans for use of a common launch vehicle architecture between NASA and DoD, which will continue to dilute the limited launch market. Further evidence is that the lowest cost launch systems like the Dnepr have not seen dramatically increased launch rates since their introduction into the market. Based on all of this evidence, we can not use the assume that dramatically higher launch rates will justify significant investment in a new launch system to ultimately provide lower recurring launch cost.

REVOLUTIONARY VS. EVOLUTIONARY LAUNCH VEHICLE DEVELOPMENT

There is a continual hope that brand new “revolutionary” launch systems will somehow solve all of the problems of current launch systems and succeed in dramatically reducing the cost of launch. New launch vehicles put forward the promise of low cost launches because they have no track record that proves otherwise. They have no history of known issues that have to be continuously monitored and tracked, which is a significant cost for current launch systems. They also get to assume that their reduction in launch cost will dramatically increase the rate of launches, which as we have discussed previously is overly optimistic. The difficult question that has to be asked is if technology is available to provide a significant leap in launch vehicle technology, ultimately resulting in dramatic cost savings to justify increased launch rates. While there is always the promise of new technology to solve the problems of the past, that technology always comes with new problems that will overwhelm a program if it hasn’t been thoroughly demonstrated before utilization in an operational system.

Evolving the current set of launch vehicles allows you to start with a known mature system; removing the risk of problems with cutting edge technologies and integration of the entire system. Integration of multiple new unproven systems will always be a high risk process. Instead we need to design launch vehicles with the ability to evolve over time and to become more cost effective and responsive in order to meet ORS requirements.

One of the most interesting recent developments is the desire for new launch systems to try to operate outside of the existing Eastern and Western Ranges. It’s as if new launch vehicle providers feel the problem with affordable launch is the costly and antiquated processes associated with the current ranges. While demonstration missions can be performed from austere

launch locations, they have their own additional costs and will eventually experience the same problems as traditional launch systems. Instead, we need a focus on reducing the life cycle costs for both the ranges and the launch vehicles. For instance, Air Force Space Command has been working to implement GPS metric tracking (GPS/MT) for all vehicles operating out of the Eastern and Western Ranges in order to reduce the need for costly radar vehicle tracking. The implementation of GPS/MT has suffered greatly from a lack of incentive for the launch vehicles to incorporate such technologies; it only shifts risk to them with no cost savings from the range. Rather than reinventing the ranges elsewhere, we need to truly focus on developing the proper incentives to lower overall life cycle costs for the ranges and launch vehicles.

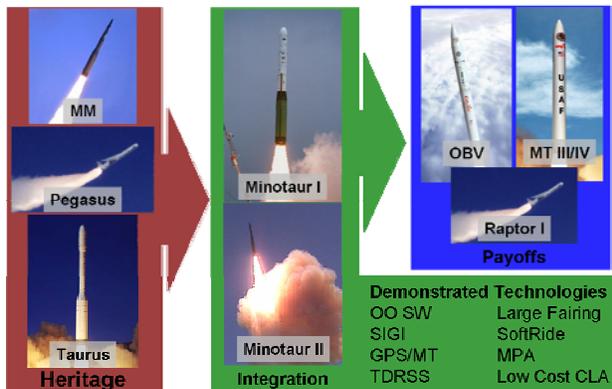


Figure 1: The evolution of launch vehicles and ongoing demonstration of technologies has proved highly successful.

LAUNCH VEHICLE TECHNOLOGY DEMONSTRATION GAP

To create an ORS capability, the technologies required must be infused into an operational environment. The capability of testing, evaluating, and integrating these emerging technologies becomes just as critical as developing the individual technologies themselves. It has been demonstrated in many aerospace programs that overall program costs are greatly affected by the application, or lack thereof, of advanced technology development and testing during the formulation period of a program. Program managers tend to shy away from implementing emerging technologies into their programs because of the fear that it may affect mission success. In turn, technology developers cannot increase the reliability of their emerging technologies because no program wants to risk mission failure by implementing unproven technologies. What is needed to correct this gap in technology readiness levels (TRL's), are regular technology demonstration that can increase the maturity of emerging technologies by

testing them in a relevant environment until confidence is increased in the technology. Both ground and flight demonstrations are needed to increase the TRL's such that program managers will have the needed confidence in implementing new technologies.

The space launch industry suffers from the inability to readily insert and demonstrate new technologies that could provide significant increases in responsiveness and cost savings. The nature of the current launch market is so risk adverse that any modifications to the proven configuration are seriously discouraged. The problem of demonstrating new launch vehicle technologies and giving them the opportunity to mature, before utilizing them as critical launch systems is significant. In almost every other industry, the cost to demonstrate a new technology is minimal compared to that of the LV industry. While technologies such as new propulsion systems and structures can't be easily demonstrated in parallel with ongoing launches, many of the technologies required for ORS can be. Advanced avionics, processes, and other tools that will be essential to ORS could be demonstrated today on current launches if there was any support to do so. Instead, the focus is on implementing these technologies on completely new systems that don't have a demonstrated capability.

Space Integrated GPS INS (SIGI) Navigator



| Experiment | Demonstration | Operational |
|---|---|---|
| <p>QRLV-1 TLV-1</p> <p>SIGI flew as a secondary experiment</p> | <p>QRLV-2</p> <p>SIGI flew as primary nav on low fidelity mission</p> | <p>All Orbital LVs (TLV-4)</p> <p>SIGI is now a highly capable low risk navigator</p> |

Figure 2: The SIGI is an example where demonstration of a critical technology evolved over a series of missions.

CURRENT TECHNOLOGY DEMONSTRATIONS

RSLP has been able to demonstrate and integrate a variety of new technologies, in addition to accomplishing its launch vehicle mission, because there are no other cost effective options available. Our partnerships with the Air Force Research Laboratory (AFRL) and NASA have made available a variety of new cost effective technologies that could solve the

problems we currently face. Additionally, the launch contractors that support RSLP have integrated these technologies into the vehicles in the most cost effective manner without providing significant risk to the mission. Finally, the RSLP mission assurance process does not discourage the inclusion of new technologies as long as the risk to the overall mission is limited. The following are some of the technologies that we have been working to demonstrate and utilize:

SoftRide for Small Satellites (SRSS) was a Small Business Innovative Research (SBIR) AFRL contract with CSA Engineering to develop a passive spacecraft isolation system. The program was in Phase 2 when it was realized that the SoftRide could cost effectively solve a spacecraft loads problem on one of the early Taurus launches. This success led to further implementation of SoftRide for a number of other missions and demonstrated the technology for use in other applications.

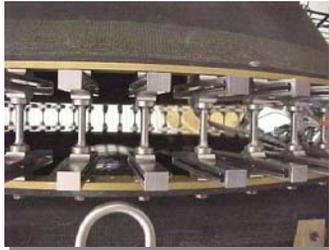


Figure 3: SoftRide could have remained just another undemonstrated technology if the right partners hadn't had the foresight to utilize it.

GPS metric tracking evolved out of the need to operate out of austere launch locations without vehicle tracking radars available (primarily Kodiak) and the need for high precision position, velocity, and time data for Missile Defense Agency (MDA) applications. OSC developed and demonstrated this on a series of recent launches of continuously improving GPS Position Beacons (GPB) to meet this requirement.



Figure 4: GPB-4, OSC's latest iteration of implementing GPS Position Beacons (GPB) meets new range standards for less than \$1M in development costs.

The 20W transmitter portion of the NASA Wallops Low Cost TDRSS Transceiver (LCT2) was just demonstrated on the COSMIC mission while all other downrange telemetry collection assets were cost prohibitive. The inclusion of this technology as an experiment on the COSMIC mission is an example of an innovative solution that we need more of. While the complete LCT2 system is still in development, this demonstration provided a valuable data point and solved a significant problem for the mission.



Figure 5: LCT2 was developed by NASA Wallops and successfully flown on the recent COSMIC Launch.

The AFRL-developed Minotaur I Large Fairing provided an enabling technology to support the Near Field Infrared Experiment (NFIRE) satellite program. The use of this innovative technology was made possible with AFRL's support and because we were able to involve the integrating contractor early in the program to help guide the technology, ensuring the final product could meet mission requirements.



Figure 6: The AFRL Minotaur I Large Fairing will first be flown from the Wallops Flight Facility

Finally, RSLP is supporting a number of other SBIR's with AFRL for Multi-Payload Adapters (MPA) and Rapid Software development tools. In addition to supporting the SBIR directly, we have also worked to enable our launch contractors to be directly involved in the development of these technologies as mentioned above.

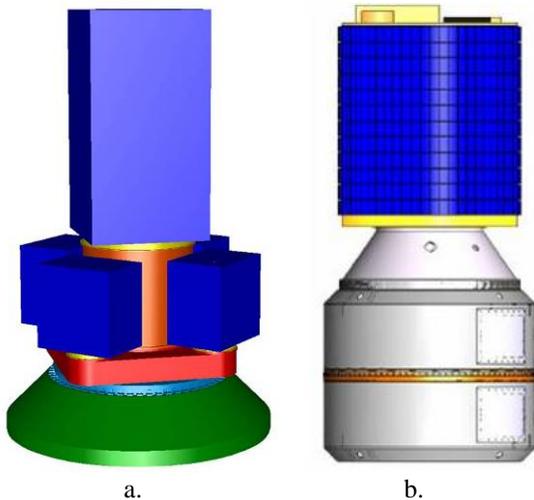


Figure 7: Multi-Payload Adapters are an example of some of the technologies that will payoff in the future. (a) ATA Minotaur IV MPA (b) CSA CASPAR Minotaur IV MPA

OPPORTUNITIES TO REDUCE COST AND IMPROVE RESPONSIVENESS

In the near term it is necessary to continue to strive to lower the cost of access to space by introducing new tools and processes that will also increase responsiveness. One of the key components to make this a reality is to work toward decreasing the total manpower required for a space launch, while not adversely impacting mission success. There are currently plans to demonstrate a reusable first stage for a hybrid launch vehicle and while this may provide a uniquely responsive capability there are many tools that this system will require that could be demonstrated at lower risk on an existing mature launch vehicle. Primarily the challenge of integrating both new hardware and new automated responsive tools and processes will prove to be very difficult while maintaining schedule and budget. New hardware alone will not reduce the current cost of space launch, and until new hardware becomes mature, will almost definitely increase the cost of space launch. The key to both reducing cost and increasing responsiveness is to build tools and processes that will automate currently labor intensive segments of developing a space launch vehicle. The following are just a few of the technologies that should be looked at:

Rapid Safety Analysis - Currently the process to tailor range safety requirements and to perform trajectory risk analysis is a labor intensive and lengthy process. The range safety analysis activities need to become faster and more automated if we are to support responsive space. Primarily a launch vehicle provider needs an automated tool that will automatically generate the data needed to satisfy range safety requirements and range safety needs to accredit that tool, so that the data it generates is automatically accepted.

Automated Flight Software/GN&C - The building and testing of flight software is another labor intensive process that with the proper investment could become much more efficient. Right now every space launch requires a new build of flight software that is specifically designed for that mission. While developing the flight software has become more efficient over the years, it still is not automatic and requires extensive testing.

Automated Built in Test and GSE - Testing of actual flight hardware with flight software is one of the most important steps to ensuring mission success, but it is also takes extensive time to perform. With automated ground support equipment (GSE) and built in tests this checkout could occur much faster and with less labor required. The use of line replaceable units (LRU's) would dramatically support this capability since they could simply be swapped out on the launch pad if a problem was discovered.

Automated Coupled Loads Analysis (CLA) -

Analyzing spacecraft to launch vehicle induced environments is another labor intensive process that requires several iterations to ensure mission success. A validated simulation tool that could automatically generate a CLA for a spacecraft designer would be a significant step towards increasing responsiveness and lowering the cost per launch.

All of these tools need to be evolved and demonstrated appropriately over time, on missions where the current, more labor intensive methods are still the primary process.

Another approach to increase responsiveness and decrease cost is to rely heavily on agreed upon standards in order to significantly reduce the amount of analysis and planning for a specific mission. It's important to note that these standards will have to be significantly more restricting than just a standard mechanical and electrical interface between spacecraft and launch vehicle. For instance, a standard will have to be as specific as fairing access door location and set limits for the spacecraft frequency, mass, and volume. Standards will also need to cover a specific set of predefined orbits that will have flight software already built, tested, and approved by range safety. These standards will be very difficult to establish in the near term as there is little consensus throughout the spacecraft community. One of the most promising areas that could benefit from application of stricter standards is the EELV Secondary Payload Adapter (ESPA), which the Space Test Program (STP) is currently working on making a reality through their Launch on Schedule (LOS) initiative.

DEMONSTRATING A SPACE-BASED LAUNCH RANGE

In addition, to developing new launch vehicle technologies it is also important to develop and demonstrate new range technologies, to both increase responsiveness and reduce cost. There are three basic requirements to launch a rocket; track it, communicate with it, and be able to command destruct it. Tracking the launch vehicle means being able to determine the launch vehicle's position in space to a required level of accuracy. Currently, tracking is accomplished using ground-based radars near the range. However, GPS has evolved to the point that it can reliably fix a projectile's position, as long as the vehicle has the capability to see the GPS satellites. The launch vehicle can determine its position and send the data back to the ground through the telemetry stream. There are several attempts now to get range approval for GPS-based tracking units, most notably the GPB system mentioned above.

The next requirement is to communicate with the launch vehicle. Typically this includes the ability to receive the telemetry data the vehicle is sending, however it also applies to the flight termination system, which will be discussed later. The range uses a variety of ground-based receivers to capture launch vehicle telemetry. However, these radars are expensive and there are limitations once the vehicle has gone over the horizon. In many cases, mobile telemetry receivers are used along the vehicle flight path to capture the data. The costs of gathering data in this way can be extremely costly and unresponsive. There are satellite systems currently in orbit that allow data to be sent to them and relayed to the ground. One example of this is the Telemetry Data Relay Satellite System (TDRSS). An experiment was flown on the COSMIC mission that took a low-cost, low-weight, transmitter and successfully transmitted data from the vehicle directly to the satellite. There was a limitation in bandwidth however, which is leading to another experiment to upgrade the transmitter to the Ku-band, allowing for much higher data rates. The transmitter will also be upgraded to a transceiver, allowing for communication from the ground to the vehicle for things like heading changes, commanding, and destructing the vehicle.

Finally, one must be sure of the ability to command destruct the vehicle. The range initiates flight termination by sending a command at a certain frequency to initiate destruction. Since FTS remains a requirement well downrange, it makes requires extensive infrastructure support. Utilizing GPS to track the vehicle, a destruct command can be sent through a satellite-based system to command the vehicle to destruct. There are also automated methods being considered such as the Autonomous Flight Safety System (AFSS). This system utilizes GPS tracking with pre-programmed flight corridors. If the vehicle passes over one of these destruct lines, flight termination is automatically initiated.

Using all these technologies in concert, one could still utilize the range, but be less dependent on its infrastructure. GPS would control fixing the position of the vehicle and this data would be passed to the ground controllers via TDRSS along with all the other data typically transmitted from the launch vehicle. If the vehicle went off course and needed to be destructed, the controller would initiate the destruct command and transmit it through TDRSS to the vehicle receiver. If the vehicle lost link with the satellite or the transceiver failed, the AFSS would act as a backup to destroy the vehicle if it became necessary. Another advantage of this system vs other automated systems is that they have been designed that if the link is lost, the vehicle

would automatically destruct. Just because an antenna failed, the ground controllers would not necessarily want to blow up the vehicle. The AFSS would only initiate destruction if the vehicle went out of control and passed over one of the pre-programmed destruct lines.

One of the big advantages of a space-based range system is the ability to launch from anywhere on the planet, without the fixed-range infrastructure, and have all the same capabilities of the range. As long as there is an uplink capability and internet, any location can be made into a launch control center. The satellites that would be used are in place at all times.

Another advantage is the responsiveness of a space-based system. Often the range is not available on short notice due to reprogramming of the radars and FTS systems. This causes delays and increases cost. GPS transmits all the time and TDRSS, while not sitting idle, can be scheduled for quick turn-around. Finally, if launch locations and trajectories are preprogrammed, destruct programming for the AFSS or similar system can be quickly uploaded.

SUMMARY/CONCLUSION

Significantly increasing the responsiveness while lowering the cost of launch vehicles is a challenge that today's vehicles can meet, with the proper investment in new technologies. Can we afford to bet the future of responsive space on future launch systems that are currently only concepts, especially when they will need many of the same technologies that we could be demonstrating on launch vehicles available today? It is important that we not assume a significant decrease in launch cost from dramatically higher launch rates, costs must be lowered even at the current launch rate. There are many possible solutions to the responsive launch vehicle issue, but the one with the highest probability of success at the lowest investment cost is to demonstrate and integrate the appropriate technologies into today's small launch vehicles. A program of regularly scheduled small launch vehicles to support the demonstration of responsive spacecraft; that is also funded to demonstrate new responsive launch vehicle technologies is needed to make responsive space a reality. Once the utility of responsive space is demonstrated and demanded, we will have a requirement for the next generation of launch vehicles, but there are several technologies those systems will need that can be demonstrated today.

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