Abstract

While the dominant focus on short response missions has appropriately centered on the launch vehicle and spacecraft, often overlooked or afterthought phases of these missions have been the launch site operations and the activities of launch range organizations. Throughout the history of organized spaceflight, launch ranges have been the bane of flight programs as the source of expense, schedule delays, and seemingly endless requirements. Launch Ranges provide three basic functions: (1) appropriate geographical location to meet orbital or other mission trajectory requirements, (2) project services such as processing facilities, launch complexes, tracking and data services, and expendable products, and (3) safety assurance and property protection to participating personnel and third-parties. The challenge with which launch site authorities continuously struggle is the inherent conflict arising from flight projects whose singular concern is execution of their mission, and the range’s need to support numerous simultaneous customers. So, while tasks carried out by a launch range committed to a single mission pale in comparison to efforts of a launch vehicle or spacecraft provider and could normally be carried out in a matter of weeks, major launch sites have dozens of active projects with dozens of separate sponsoring organizations. Accommodating the numerous tasks associated with each mission, when hardware failures, weather, maintenance requirements, and other factors constantly conspire against the range resource schedulers, make the launch range just as significant an impediment to responsive missions as launch vehicles and their cargo.

The obvious solution to the launch site challenge was implemented years ago when the Department of Defense simply established dedicated infrastructure and personnel to dedicated missions, namely an Inter Continental Ballistic Missile. This however proves to be prohibitively expensive for all but the most
urgent of applications. So the challenge becomes how can a launch site provide acceptably responsive mission services to a particular customer without dedicating extensive resources and while continuing to be cost effective and to serve other projects?

NASA’s Wallops Flight Facility (WFF) is pursuing solutions to meet exactly this challenge. NASA, in partnership with the Virginia Commercial Space Flight Authority, has initiated the Rapid Response Range Operations (R3Ops) Initiative. R3Ops is a multi-phased effort to incrementally establish and demonstrate increasingly responsive launch operations, with an ultimate goal of providing ELV-class services in a maximum of 7-10 days from initial notification. This target will be pursued within the reality of simultaneous concurrent programs, and ideally, largely independent of specialized flight system configurations.

WFF has recently completed Phase 1 of R3Ops that included an in-depth collection (through extensive expert interviews) and limited software modeling of individual launch operations processes by various range disciplines. This modeling is now being used to identify existing inefficiencies in current procedures within each process and to show interdependencies. Existing practices are being tracked to provide a baseline as new procedures are implemented and evaluated. Technology infusion efforts have been identified and are currently underway in the area of space-based range safety and communications.

Phase II of this effort will involve evaluation and implementation of real-time software process flow tools, software integration of processes already defined into an integrated model, and spiral software development of the process flow tools. The technology efforts will begin maturing with flight demonstrations and integration into the operational environment. The completion of Phase II will enable R3Ops efficiencies to meet the requirements of many upcoming commercial and government programs. A critical duty in this phase will be the identification of an effective software tool that meets launch range requirements in a responsive multi-user environment.

Introduction

With the knowledge that today’s range environment does not support the vision and goals of R3Ops, the WFF has taken the initial steps necessary to move toward the desired outcome. The two challenges that the range faces today are the cost of range services, and the lead time to launch. Today’s national ranges are constrained from meeting these challenges by inefficient range and launch processes and procedures and restrictive ground and vehicle communications and safety systems.
This paper will address a range vision focused on R3Ops, along with short- and long-term strategies to meet this vision. This vision identifies key characteristics that the range must possess in order to overcome today’s constraints, and recommends a strategy for meeting this vision. Specific areas addressed include processes and procedures relative to range operations and asset deployment, and the potential to augment automated range assets to streamline range operations and logistics to realize significant cost savings. Included is a discussion of technology advancements and potential infusions that will enhance range efficiency and reduce cost, including low cost launch vehicle transceivers for space-based data communications, use of existing commercial and Government systems for space-based vehicle tracking, and incorporation of autonomous systems for flight control and safety.

**R3Ops Range Vision**

The reality facing the range of today is that it is a large, fixed geographical location. Payloads must come to the range to be launched. Inflexible legacy systems impair integration of new functionality and data interfaces. Range tracking infrastructure dominates both the landscape and the budget. Operations costs are high due to low levels of automation and the need to retain skilled operators even when no launches are scheduled. Safety is viewed as a hurdle to be overcome, and not an enabler of mission success. This reality is not reflective of what is possible and it is not the range envisioned by NASA’s Wallops Flight Facility (WFF). Achievement of the R3Ops concept will require targeted process and technology development.

Appropriate range process and technology development requires a long term vision of what the range should be at some point in the future. The range vision supporting R3Ops will be described by two key characteristic capabilities or vision elements.

The first characteristic is that the range will be largely infrastructure-less with respect to tracking and data services. Current tracking and data systems used in support of most launch missions are ground based radar, telemetry, and command destruct systems. Such systems are notoriously large, expensive to maintain and operate, and time consuming to configure. An infrastructure-less range is not dependent on the existence of such ground-based assets. In an infrastructure-less paradigm, launch vehicle tracking will be accomplished through the elimination of radar tracking and the implementation of the combination of on-board autonomous GPS/INS tracking and safety systems and space-based communications systems. Telemetry systems will be replaced by spaced-based systems. Command destruct range safety systems will be accomplished initially by space-based systems and later by on-board autonomous destruct systems.
An infrastructure-less range is essential to the R3Ops range vision because it will provide a level of launch responsiveness not envisioned from similar launch systems in the past. The space-based systems require little configuration and will eliminate a significant portion of the mobile range transportation cost for mobile operations. It is clear that the ability of current ground-based systems to support R3Ops is severely limited. An added benefit is also the reduction in operational cost. By purchasing data and communications capability as needed, the cost of the ground infrastructure is dramatically reduced or eliminated as data services become purchased per launch rather than requiring a perpetually funded standing range operations team. An infrastructure-less range will therefore reduce cost and increase the responsiveness and deployment capabilities of the range.

The second key characteristic of the R3Ops range vision is that the range will be highly automated. Range operations are among the least automated of all operational processes. This is true across the ranges in existence today. The R3Ops vision is a range whose setup and operations are computer-based and controlled by user friendly software in which users will select services they desire. Once range services are selected, the software will configure the range and provide the user with projected costs. This will allow the user to investigate support scenarios to optimize cost and mission support.

Beginning in control center and payload support functions, automation must, by the long term, be required as a fixture in all range safety and launch management functions. Automation is typically achieved through the development or integration of software tools. This will require capture, management, and engineering of the processes and knowledge to support ongoing range activities. These tools are currently being developed at NASA’s Wallops Flight Facility. This knowledge and process engineering activity will enable the development of both automation systems as well as mission and range management tools supportive of the range vision. So the automated range is one in which routine functions of data management, distribution, archival, and post flight analysis is highly automated. Mission managers will need to plan missions through the use of knowledge-based tools that anticipate mistakes and problem areas and assist in the planning, testing, and launch activities if the responsiveness and launch frequency needs are to be met.

The opportunities are many for range operations responsiveness improvements in this area. However the opportunities for range operations cost savings are also significant. The combined result will be a more efficient, less costly range that is more available than ever anticipated in the past.

These range vision characteristics and capabilities will provide the framework for the R3Ops development efforts. At the current time and even throughout the near term, the nation’s launch ranges meet virtually none of the goals set forth in the characteristics above. However, a reasonable evolution from the current
state of each range vision element to the desired future state is not difficult to describe. The following section describes the technologies and tools required to meet the R3Ops vision.

**R3Ops Technologies and Tools**

The following discussion describes the strategy to overcome the constraints of today’s range, and meet the vision of the future. The discussion will address the evolution which is necessary in range process and procedures, and technology developments which are necessary to achieve rapid response for launch and operations.

The two primary areas of focus to realize the R3Ops vision are space-based range capabilities and automated processes and tools.

The space-based range technology is an essential element in providing an Infrastructure-less Range. Ground-based command destruct systems located at both the launch site and downrange will be eliminated, and replaced by the on-board system. Downrange tracking assets will also be eliminated, with position data transmitted through space assets. Since this technology is vehicle-based, it provides flight termination, communication, and/or tracking from virtually anywhere. This technology provides the functional capability only while the mission is underway, as opposed to ground-based systems, which are permanent or semi-permanent. All of these features provide for a more cost effective, highly available range. Space-based range initiatives include:

- Autonomous flight safety systems.
- Efficient low cost launch vehicle space-based communications systems.
- Automated wind profile measurement systems for range safety and mission assurance.

Automated processes and tools are critical for realizing the goals and vision of R3Ops. These initiatives will provide tools that define, improve, and implement the specific range architecture; the processes, procedures, reviews and approvals; and, hardware configurations, setup, and tests required to support a rapid response capability. This is an essential element in providing a highly automated range. Mission managers can operate remotely through the use of these tools, providing for highly responsive range operations, while reducing costs. Automated processes and tools initiatives include:

- Automated range operations process workflow tools.
- Advanced range simulation and performance verification systems.
In the sections below, initiatives, technologies, and range capability enhancements that directly benefit the R3Ops vision will be discussed in detail.

**Autonomous Flight Safety System**

One of the most onerous requirements imposed on launch operators is that of ensuring flight safety through multiple methods of vehicle tracking and a highly reliable, redundant Flight Termination System (FTS). Because of the reliability and redundancy requirements, ensuring range safety is not inexpensive. Getting an FTS evaluated and certified for flight is timely and expensive for a program. Deployment of multiple ground based tracking and command systems takes time and adds to the cost. Launch operators must maintain agreements and pay for services that are required to maintain safe communications with the vehicle throughout its powered flight regime. This requires ground tracking and command assets to be deployed around the world to maintain this communications coverage to ensure vehicle performance parameters are monitored and destruct actions can be initiated in the event of an anomalous flight situation.

WFF has embarked on an effort to develop a new way of providing this service reliably without the need for ground tracking assets outside the launch head coverage area.

The Autonomous Flight Safety System (AFSS) project seeks to develop an autonomous on-board system that can augment or replace the function of the traditional ground commanded Range Safety system. The motivation for this project is to decrease range operations costs by negating the need for ground-based command systems that are required at the launch site and along the downrange trajectory, to provide global coverage for mission operations thus enabling safe launch environments where no range may exist, and to increase responsiveness for launch operations by decreasing vehicle range safety certification timelines and reducing the risk of ground system failures that can create launch delays and cancellations.

The AFSS will use redundant on-board navigation sensors and flight processors to monitor the progress of the launch vehicle with respect to multiple flight termination criteria and if necessary, terminate the flight. The feasibility of automating the flight safety decision process was verified with the successful completion of AFSS Phase I begun under the WFF managed Advanced Range Technology Initiative (ARTI) in January 2001. Phase II was undertaken as a joint effort between Kennedy Space Center (KSC) and WFF. Lockheed Martin Space Systems Company, Huntsville, AL was selected as the prime contractor to develop and refine the flight algorithms and demonstrate a Government furnished flight prototype system based on GPS receivers and flight processors. The program is now in Phase III of the development effort under a WFF managed effort with KSC as a development partner. Phase III of the project will result in an
autonomous flight termination system demonstrated by both simulations and actual flights. It has been proposed to use the DARPA FALCON Small Launch Vehicle (SLV) as a test bed to focus the technical and environmental subsystem performance requirements.

**Low Cost TDRSS Transceiver (LCT2)**

Space-based communications is essential to meet the responsiveness goal of the R3Ops vision. There are several space-based communications initiatives underway. The LCT2 is an effort currently underway to make Tracking and Data Relay Satellite System (TDRSS) communications flight hardware more economical and less intrusive for flight vehicles with low weight and power margins. In the long term, the LCT2, coupled with the AFSS, will provide a complete space based Range Safety and flight communications system, providing global coverage and unparalleled responsiveness for mission operations. While the AFSS will provide onboard flight termination, the LCT2 is essential in providing range safety data and telemetry to the ground. This information is critical for failure analysis of a mission. The LCT2 will provide data through a TDRSS spacecraft throughout the entire launch phase.

By utilizing space-based communications assets for range tracking activities, the LCT2 will lower launch operations costs by eliminating launch head and downrange telemetry asset requirements; provide increased range availability and operational response time by reducing the possibilities of launch holds/cancellations due to range instrumentation issues; and enable remote/austere launch operations by providing truly world-wide telemetry transmission capability to any launch control location. The LCT2 project will provide a product that can be transferred to industry to enable future range operations cost savings and enable rapid response range operations which are essential for the realization of the R3Ops vision.

**Wind Profiling**

Wind profiling is necessary for ELV operations to assure that the launch vehicle will not encounter winds that will cause a structural breakup or ones that may cause a loss of launch vehicle guidance control. Wind profile measurements from 60,000 to 80,000 feet are required in order to perform the pre-launch analysis to determine the degree of risk. Current range systems used to obtain the wind profiles include radar measurements of wind balloons and wind profilers. These instruments are suitable for operations at fixed sites, but become timely and expensive for mobile or remote operations because their physical size makes transportation costly and they require staff of approximately six to operate.
Technology development initiatives are currently underway at NASA’s Wallops Flight Facility to eliminate the need for radar tracking. One of these initiatives is to develop a GPS Sonde system that communicates to ground processing systems using space based communications systems such as Iridium and GlobalStar.

The goal of the WFF initiative is to provide the range with a means of obtaining cost effective and timely wind profile measurements anywhere a launch site is established. WFF plans to achieve this goal further by integrating the GPS Wind Sonde system into a processing system that will provide the wind profile necessary for the range.

Automated Range Operations

Automated range operations are one of the key deficiencies of our national ranges. Development of tools is essential to realizing the vision of the range. These tools are necessary to realize the lead time to launch objectives of R3Ops.

NASA Wallops Flight Facility’s automated range operations initiative is an effort to incrementally establish and demonstrate quantifiably responsive launch operations. This objective will be pursued within the reality of simultaneous concurrent programs and largely independent of specialized vehicle, payload, and launch site configurations.

Specifically, the objectives are as follows and will be pursued sequentially:

- Document current range operations processes and identify the critical path.
- Develop a mechanism for creating, updating, and reviewing range operations procedures.
- Develop and/or integrate software automation tools that expedite and enhance range operations processes.
- Develop tools, principles, and recommended best practices to optimize routine missions.
- Develop the interfaces between the tools and range users to enhance the automation processes.

Automated range operations will include the development of a collection of process definitions, optimizations, and enabling tools. This will require the capture, management, and engineering of the processes and knowledge that are required to support ongoing range activities. This knowledge and process engineering activity will enable the development of the automation systems as well as mission and range management tools supportive of the future FALCON
range. Thus, the automated range is one in which routine functions of data management, distribution, archival, and post flight analysis is highly automated. Mission managers will need to plan missions through the use of knowledge-based tools that anticipate mistakes and problem areas and assist in the planning, testing, and launch activities if the responsiveness and launch frequency needs are to be met.

**Advanced Range Integrated Simulation Environment (ARISE)**

Vehicle and ground subsystems required to support a successful launch operation are myriad, complex, and in many cases tightly coupled. Opportunities for testing, validation and certification in an all-up integrated configuration have historically been limited, and in some cases simply not feasible. The inability to "test-as-fly" has contributed to several in-flight failures of critical range subsystems. The impact of such failures is compounded during mobile launch operations since for such missions the range will typically deploy only the minimum required complement of instrumentation. This factor has also made the insertion of modernized subsystems and advanced concepts into the range instrumentation complement exceedingly difficult resulting in an inordinately long lag time between the ready availability of new technologies and their operational deployment in any single range subsystem.

ARISE was initiated to develop a simulator capable of emulating, through both hardware and software in an integrated manner, the full spectrum of systems involved in launch operations. This includes systems that emulate the launch vehicle, the range, and external participating elements such as GPS and satellite data relay constellations. ARISE will offer a unique national capability that will serve multiple purposes, including a test bed in which new range or vehicle technologies (hardware, software, or processes) can be integrated for validation and demonstration without requiring active range systems that are difficult to schedule, and expensive test flights. The type of tests supported by ARISE will span the spectrum from the conduct of the checkout of an individual range subsystem to the execution of a full-blown end-to-end range verification test. Ideal uses include the validation of eventual autonomous flight termination systems space-based transceivers. ARISE will also offer a valuable training resource for new range personnel. In all cases the article under test will be exposed to high fidelity simulations of any systems that cannot feasibly be exercised such as the launch vehicle and certain vehicle subsystems.

The development of ARISE is critical for realizing the goals and vision of the range. ARISE is an essential element in providing a Highly Automated Range. The development of this simulation environment will provide for highly responsive Range Operations, especially during crucial Test and Evaluation, while reducing costs and increasing Range Safety.
**Summary**

Today’s national ranges impose many constraints on the goals and objectives of the R3Ops vision. This outline of the next generation range and its defining characteristics provide a vision of the future range and one that meets the challenges. The development of the technology and tools presented are crucial in order to realize this vision and to provide a cost effective, highly available range.

The R3Ops objectives are achievable, but only through a continuing process of incremental implementation of new technology and process adaptation at the systems level, and a commitment by the Government to enable and support the endeavor.