



TRANSFORMATIONAL SPACEPORT & RANGE TECHNOLOGIES

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“Reducing the cost of sustained operations through technology infusion.”

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ABSTRACT

Today there are 22 spaceports throughout the world and yet, unlike other transportation enterprises, the majority operate independently of one another. Each spaceport and range has its own uniqueness, catering to the vehicle specific designs and Agency or organization specific missions. A lack of an integrated national approach coupled with today's paradigm where ground and launch operations infrastructure (also known as spaceport and range systems) is funded at the implementation phase of vehicle architectures causes the U.S. space access capability to be operations-intensive and extremely expensive. Revolutionary advancements in the reduction of cost and time to access space will not be realized without significant technological breakthroughs in the ground processing, launch operations, and air traffic control/range operation systems. For the only operational reusable launch vehicle (RLV), the Space Shuttle, more than 4 months are spent preparing the vehicle for its mission, which typically is less than two weeks in duration. In addition, costs associated with ground processing and launch operations equate to more than 45% - 60% of the overall life cycle costs for the program. An operational paradigm shift in spaceport and range is required if space access is to ever move more towards airport-like efficiencies. The space transportation system must be designed as a system rather than employing a “patchwork” approach of focusing on one vehicle architecture at a time rather than addressing a “suite” of architectures. Future vehicle architectures are steadily growing more diverse thus requiring a “master plan” for space transportation infrastructure that employs more flexible, responsive ground operations and launch technologies. The infusion of enabling technologies can help reduce the life cycle cost of the program as well as improve

responsiveness. With architectures such as crewed and cargo-only, expendable and reusable, orbital and suborbital using a combination of propellants, a variety of launch locations, in addition to the current programs, these emerging vehicles will drive the need for upgrades to the spaceport and range infrastructure towards more flexible, interoperable, responsive infrastructure.

INTRODUCTION

Today's space launch and launch site operations involve outdated technology and equipment that is expensive and time-consuming to operate and maintain. As a result, 45% - 60% of the total life cycle cost of a space transportation system program is attributed to ground and launch operations¹. In addition, current techniques isolate launch sites from each other and from the national airspace system, forcing duplication of functions and preventing potentially global synergies that could dramatically boost overall flight safety while reducing costs. Advanced spaceport and range technologies are required to transform ground operations to a new vision of a single, integrated national “system” of space transportation systems that enable low-cost, scalable per user requirements, routine, safe access to space for a variety of applications and markets. NASA is looking for improvements in safety and turnaround time, costs reductions, and reduced risk to its workforce. The Department of Defense (DoD) and the Department of Homeland Security needs highly responsive space access operations to support pop-up maneuvers and rapid global surveillance to monitor or react to an evolving crisis or targets of interest. Additionally, commercial space customers need low-cost, routine, safe access to provide products and services pertaining to their business enterprise. These space access customers have common goals of responsive operations, reducing operations costs, and increasing safety and reliability. These national goals

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create the need for enabling spaceport and range technologies and an integrated air and space transportation system that benefits the civil, military, commercial space market sectors as well as ultimately improving the public's quality of life.

CURRENT SPACEPORT & RANGE CHALLENGES

NASA and the aerospace industry have been working the challenge of achieving low-cost, routine, safe access to space for years and have had limited success. There are several factors that contribute to this obstacle at a Macro Space Transportation System perspective:

- Space Access not viewed as a business: NASA and the Air Force have not traditionally had to worry about "cost effectiveness" or "efficiency" from a business perspective. The two agencies have traditionally responded to political mandates or national security and not necessarily driven by market requirements.
- Vehicle-centric rather than Space Transportation System-centric: Traditionally many space programs are centered on the design of the vehicle rather than the payload it is to carry into space or its operability on the ground. Our current space -lift capability was designed for performance using 1970's technology and not designed for operability which leads to extensive ground testing prior to the mission. This results in costs of over \$10,000 per pound to orbit, which proves to be cost-prohibitive for the customer sectors needing space access. When focusing only on the vehicle itself, cost effectiveness and efficiency to the payload customer and ground operators becomes a secondary thought.

The Macro Space Transportation System, made up of payload, vehicle, spaceport, range, and mission operations elements, must be designed for operability as a whole system. Traditionally, NASA and other federal agencies have provided heavy sustained investment in the launch vehicle element technologies (i.e. propulsion, structures, thermal protection, etc.) and have provided additional sustained investment in payload & mission & flight control elements. However, spaceport and range elements technologies have been ignored. And if there has been some investment it has been sporadic, not sustained, and pointed toward unique or individual launch vehicle architecture. The ground infrastructure and launch technologies tend to be an afterthought of new spacelift programs because the common belief is that the ground infrastructure will accommodate the

vehicle – status quo will do. If the nation is ever to achieve the lofty goals of rapid turnaround rates on the order of hours and costs of around \$10-100 per pound, space access programs must address more than just the launch vehicle, payload, and mission control elements and target significant sustained investment in the spaceport and range elements. If the automobile transportation system applied the same selective technology improvement model that has been ongoing in the space industry we would be driving 150 mph performance sports cars on dirt trails and all the automobile performance and improvements would not be realized. An entire "system" improvement approach must be applied toward the entire space transportation system.

At the spaceport and range perspective, there are also a number of challenges associated with achieving low-cost, routine, safe access to space. Below are just a few examples:

- Lack of interoperability among spaceports and ranges: Current infrastructures at the various spaceports and ranges around the country (and globe when applicable) are often unique, complex, hazardous, and designed around a given vehicle architecture. These characteristics tend to preclude affordable sharing of facilities and infrastructure when a new architecture arises without significant modifications. Facility and infrastructure modifications to accommodate a new architecture tend to take considerable time, on the order of several years, before the spaceport and range system can accommodate a new architecture.
- Inadequate tracking and surveillance coverage: Ground tracking and surveillance assets are costly, difficult to schedule, and provide limited coverage. Surveillance sensors and instruments do not have the required sensitivity and accuracy to detect and positively identify 100% of the objects within the target area of interest. Tracking of the flight vehicle has also posed several challenges such as tracking the vehicle through background clutter, noise, exhaust plume or propellant vapor.
- Frequency spectrum and bandwidth for telemetry is limited: Acquiring telemetry data with insufficient bandwidth capability and uncertain assignment of frequency spectrum presents significant challenges for the range.
- Risk models use conservative parameters: The use of conservative parameters in risk models (e.g. weather prediction, toxic cloud dispersion, etc.) tends to limit the availability of launch windows

because of the confidence of the data used by the models has some uncertainty. This data uncertainty is due to factors such as the breakup characteristics of the vehicle are not well understood, some data sets are not available real-time for decision making purposes, and certain models are inconsistent, inflexible and slow.

- Handling of hazardous commodities: The number of different hazardous fluids used in a space transportation system has a strong correlation to recurring costs (servicing and operation of the system) and hence to the life cycle cost and overall affordability of the transportation system. The relationship is also very strong to the ability to launch on time, the degree of supportability, and the assurance of workforce and public safety. Hazardous operations such as hypergols or cryogenic propellant loading are significant impediments to the overall space transportation system affordability due to the number of “cleared areas” around a system, which in turn prevents other work in the vicinity to continue. Responsiveness and availability of the spaceport systems diminish due to the manpower intensive system verifications required, mostly manual, such as leak checks and interface verifications.
- Intricate and complex assembly operations: Significant time during critical path operations has been spent on previous space programs on transportation, alignment, connection and interface testing of flight hardware elements. These operations expose operations personnel to the hazards of element to element mating and lifting operations as well as are time and labor-intensive due to the precision positioning required.
- Labor-intensive launch operations: Although computer systems control fueling operations and terminal countdown, a large workforce is still required to monitor propellant loading operations and system health. Engineers evaluate ground system performance as well as monitor for hazardous leaks that can propagate into an explosive condition. Transforming data into information for real-time situational awareness & decision support are critical to ensuring safe operations.
- Disjointed data systems: One of the most costly areas of the ground operations is the cost associated with data processing and information management. The efficient management of information is paramount in the operation of the advanced spaceport. The diversity of approaches for procedures and paperwork with varying data

formats and lengthy, numerous, conflicting checklists leads to non-standard, slow, paper based, lengthy review/approval, and labor intensive methods that rely on worker’s craftsmanship for analyzing records for off-nominal conditions, capturing lessons learned, maintaining configuration and requirements satisfaction control, and conducting trend analysis.

All of these challenges can be overcome by planning a cohesive vision for interoperable systems for spaceport and ranges and developing the necessary technologies to enable efficient, timely, and safe operations.

FUTURE CAPABILITY DESCRIPTION

Spaceports and ranges must be transformed towards a national network capable of supporting multiple vehicles architectures concurrently. The long-term vision for space transportation is to have airport-like operations that will accommodate high flight rates and multiple vehicle architectures without significant infrastructure reconfiguration after each mission.² The transition of a space vehicle through the National Airspace System will be seamlessly integrated causing minimal disruption in the current air traffic control system. To achieve this vision, the development of a national master plan for space transportation infrastructure to include standardization and new technologies is critical.

- Range: 80-90% of range systems on space-based platforms that can be seamlessly augmented when and where needed, with mobile or deployable assets, and modernized ground assets at departure and recovery locations. High accuracy weather prediction models to expand the probable launch window and DoD quick response and advanced decision-making models are essential to enhanced situational awareness and enable real-time, high-fidelity risk assessment.
- Spaceport: Advances in ground processing and launch technologies and infrastructure modernization are needed to improve processing safety and reduce turnaround times and operations costs. Turnaround times will be on the order of hours with intelligent inspection technologies, rapid handling and assembly techniques, and advanced fluid servicing technologies. Specific operational capabilities enabled by these technologies include coordination among a network of spaceports, on-demand propellant loading, autonomous, reconfigurable ground systems, and automated inspections all working towards ensuring flight safety and sustaining multiple flights per day.

- **Standards:** Spaceports and ranges will become interoperable by employing standardized interfaces to reduce expensive dedicated infrastructure. This capability will enable future operations concepts for space flight vehicles that, like today's commercial and military aircraft, are not limited to operations at particular spaceports. Standards provide flexibility to accommodate various types of space flight vehicles by adapting to new vehicles and payloads with minimal reconfiguration expense and time as well as provide evolvability to adapt to next-generation flight vehicle architectures.

CAPABILITY BENEFITS

Future scenarios requiring responsive spaceport and range technologies include all NASA missions (Expendable Launch Vehicle Program, Space Shuttle Program and the new Exploration Initiative), DoD missions and commercial partners to obtain cost effective, rapid processed and safe access to space. Table 1 lists a subset of key technology areas and anticipated benefits identified in the national spaceport and range technology roadmaps

Technology Area	Benefits
Inspection & System Verification <ul style="list-style-type: none"> • Non-Intrusive Inspection Techniques (i.e. structural, wiring, TPS, etc.) and Ground Systems Self-Diagnostics 	<ul style="list-style-type: none"> • Eliminates disassembly operations of vehicle/payload systems and ground support equipment to assure mission readiness
Transportation / Handling / Assembly <ul style="list-style-type: none"> • Precision alignment & positioning control technologies • Standardized Flight-to-Ground Interfaces with self-verifying connections and self-latching mechanisms • Payload containerization 	<ul style="list-style-type: none"> • Simplifies and expedites intricate positioning, rotating and handling operations of flight hardware thus reducing time, workforce and specialized equipment needs • Eliminates workmanship error during interface verification & checkout.
Launch Operations <ul style="list-style-type: none"> • Autonomous fueling systems with self-sealing quick disconnects, non-intrusive hazardous leak detection network, low-maintenance cryogenic insulation • Intelligent Command & Control Systems with advanced decision support tools 	<ul style="list-style-type: none"> • Protects the workforce from hazardous operations (e.g. propellant loading) • Reduces boil-off loss of cryogenic/volatile propellants • Rapid and accurate transformation of system data into information for real-time situational awareness and enhanced decision support • Reduction in the workforce required during critical loading operations
Supply Chain Management <ul style="list-style-type: none"> • Standardized Procedures and Work Authorization System • Autonomous, adaptive self-training scheduling systems for spaceport and range assets 	<ul style="list-style-type: none"> • Real-time configuration management, requirements tracking, and improved documentation processes • Automatic scheduling of spaceport and range assets on a national level • Timely and accurate analysis of artifact parameters
Tracking & Surveillance <ul style="list-style-type: none"> • Space-based and mobile platforms (i.e. satellites, UAVs, HAAs, etc) with sensitive detection instruments 	<ul style="list-style-type: none"> • Enhanced tracking and surveillance coverage for the entire geographical area of interest with improved detection and object recognition
Telemetry <ul style="list-style-type: none"> • Advanced signal processing for data compression and error correction 	<ul style="list-style-type: none"> • Increased frequency spectrum and bandwidth for telemetry enabling use of unregulated, unassigned, or unused frequency spectrum
Weather Prediction & Decision-Making Models <ul style="list-style-type: none"> • Integrated Land-Sea-Air Weather Prediction Models 	<ul style="list-style-type: none"> • Weather forecasting and risk models will use more accurate (less conservative) parameters to increase the availability of the launch windows
Communication Architecture <ul style="list-style-type: none"> • Distributed integration of high-rate voice, video, data 	<ul style="list-style-type: none"> • Improved quality of service with high data rate and bandwidth and enhanced bit error detection • Global interoperability between multiple spaceports and ranges

Table 1. Spaceport and Range technologies areas and benefits associated with implementation³

TECHNOLOGY BENEFIT ANALYSIS

Since all federal agencies are currently in times of limited budgets, it is imperative to be stewards of the taxpayer’s money and verify that monies being spent are going towards a high-value project. A quick-look return on investment analysis demonstrates the cost economies are attainable: Preliminary results suggest opportunities to decrease sustained ground and launch operations costs by 25% - 40% are common. Six technology areas were identified and selected to perform a quick-look return on investment (ROI) analysis because of their potential for substantially reducing costs in multiple ways. The six target areas of interest are:

- Telemetry, Tracking and Control (TT&C)
- Spaceport Command, Control and Checkout Systems (C2)
- Integrated Health Management System (IHMS)
- Decision Support Systems
- Planning and Scheduling Systems
- Automated Propellant Servicing

Analysis shows that Telemetry, Tracking, and Control, Command, Control and Checkout Systems, Decision Support Systems, and Planning & Scheduling Systems provide a large return on investment with significant annual savings as shown in Table 2.

	TT&C	C2	Decision Support	Planning & Sched.
Investment (millions)	\$87	\$57	\$36	\$48
Annual Savings	27%	30-40%	40%	30%
ROI (in 25 years)	13:1	12:1	19:1	17:1

Table 2. Return on Investment Indicators⁴

The quick-look ROIs for C2, Decision Support, and Planning & Scheduling examined the likely costs and potential benefits of one representative enhancement to the space transportation infrastructure – specifically, replacing manpower-intensive, manual decision, planning and scheduling processes for launch and ground operations with automated decision support techniques and automated planning, scheduling and modeling systems. The results of the study illustrate that a modest investment in technologies largely already available would significantly cut launch processing time and

manpower while improving both safety and reliability of the overall launch system.

The TT&C study examined the likely costs and potential benefits of one representative enhancement to the space transportation infrastructure – specifically, replacing conventional range tracking, telemetry and commanding assets with space-based assets augmented with unmanned aerial vehicles. By applying this new technology, the study found that downrange telemetry, tracking and commanding infrastructure could be eliminated, leading to operations and maintenance savings of over \$50 million per year, with a total net savings of over \$1 billion in 25 years, or thirteen times the amount of the original investment.

However, the other 2 areas of interest did not fair so well based on return on investment as shown in Table 3. Investments in Integrated Health Management Systems and propellant management only prove to be valuable when measuring against responsiveness, system reliability and availability, and safety. The study was performed assuming a flight rate of eight per year. IHMS and propellant management technologies would improve, but the most compelling business case is made with a higher launch rate.

	IHMS	Propellant Servicing
Investment (millions)	\$86	\$40
Annual Savings	28%	16%
ROI (in 25 years)	4:1	3.6:1

Table 3. Return on Investment Indicators³

TECHNOLOGY DEMONSTRATIONS

To realize these savings in life cycle costs, the technologies 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 fear 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. There is a “Technology Readiness Level (TRL) Gap” created because of this situation. What is needed to remedy this “gap” is a test and evaluation capability that can increase the maturity of emerging technologies by testing them in a relevant environment until confidence is increased prior to eventual implementation into a program. Both ground demonstration and flight demonstrations are needed to increase the TRL such that Program Managers will have the needed confidence in implementing new technologies.

Examples of potential ground demonstrations include testing of autonomous umbilicals, rapid propellant loading techniques, launch exhaust management validation, launch environment vibro-acoustic evaluation, as well as smaller subsystem designs such as advanced hazardous gas and leak detection methods.

In addition, range technology demonstrations should be at the forefront of the test and evaluation effort. Space-based, mobile, and deployable range systems technologies & demos should be aggressively pursued. Integration of command, tracking, & surveillance technologies should be demonstrated during launch events in “shadow” mode with long duration High Altitude Airships (HAA’s) and with long duration Unmanned aerial vehicles (UAV’s). These systems should also be instrumented with advanced weather sensor systems to better model/track weather systems and effects. Other areas of focus for test and evaluation of transformational spaceport and range technologies should include:

- Self healing (situational awareness) & interoperable range system technologies & demos
- Advanced Command & Control Networks & Architectures
- Autonomous, adaptive self-training, planning, & schedule systems for flight vehicle, ground facilities, & support infrastructure
- Advanced Virtual modeling and simulations
- Autonomous safing/reconfiguration after landing technologies
- Advanced cryogenic systems for on-demand propellant loading operations
- On-board Launch Vehicle autonomy technologies
- Self-diagnosis and autonomous repair technologies

INTEGRATION READINESS LEVEL – SYSTEM DEMONSTRATION

There is another challenge associated with technology development and its eventual application into the system and it is called the Integration Readiness Level, or IRL. A new technology could be considered mature at the TRL 7 or 8 on the bench however when infused into an integrated system, the Integration Readiness Level (IRL) is at 1 or 2. There is a strong need to infuse the technologies into a system testbed to workout the integration “bugs” as well as gain a better understanding of the operation of the fully integrated system.

In the system integration arena, Kennedy Space Center is currently engaging in designing a highly flexible and capable testbed for a broad scope of technology evaluation activities ranging from individual component development and test to large-scale system integration and test. The Advanced Technology Development Center, or ATDC, will concentrate on proving new operations technologies critical to the next generation spacelift in a relevant environment that will reduce the operations cost of launch processing activities. The benefits of having a test and evaluation capability such as ATDC is a program can perform operational certification of critical operations technologies without actually building the full scale vehicle architecture. The reduction of program risk achieved by testing emerging technologies provides the program manager the opportunity to control technical and total program cost risk.

SUMMARY

Vehicle architectures are growing steadily more diverse thus requiring more flexible, responsive ground operations and launch technologies. With architectures such as crewed and cargo-only, expendable and reusable, orbital and suborbital using a combination of propellants, a variety of launch locations, these emerging vehicles will drive the need for upgrades to the infrastructure of spaceports and ranges. Traditionally, much of the technology funding budgeted towards a spacelift capability is focused on technologies for the flight vehicle to improve its performance rather than its operability even though 45%-60% of the total life cycle cost of a space transportation system program is attributed to the ground and launch operations. The ground and launch operations infrastructure design has been a “patchwork approach”; limited funding and generally directed to support a particular architecture rather than

a “suite” of architectures. This paradigm prevents the transformation of the entire space launch infrastructure along a path toward an integrated national vision that allows interoperable, flexible, and evolvable spaceports and ranges. Developing technologies and designing ground systems to meet multiple space transportation architectures will allow recurring costs to be optimized and contained through spiral development of the ground systems as launch vehicle architectures evolve. Initial return on investment (ROI) indicators show that developing and fielding key operations technologies could cut sustained operations costs by as much as 25% - 40% for exploration missions. Other benefits realized are infrastructure modification investments are less due to system re-use and increased capacity at the launch site. The alternative would be a growing mountain of sustained costs to operate launch equipment that has been modified or designed to support additional specific missions and architectures. If spaceport and range architectures are not aligned with this integrated interagency vision, U.S. commercial space launch competitiveness, national security, and flight safety could be compromised. Key recommendations for a robust space transportation system that can be utilized by all parties would include identifying and implementing standardized infrastructure to accommodate multiple architectures and developing and infusing spaceport and range technologies to provide for safe, efficient/responsive operations.

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