White Paper

2nd and 3rd Generation Range and Space Traffic Management Concepts and Technologies

The Vision Spaceport Project
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Abstract

Today’s launch ranges rely on a vast network of manual activities to plan missions, schedule launches, configure instrumentation, preserve safety, and support mission analysis. Efforts are underway to replace currently-used 1960’s technology with 1980’s-era systems at the major U.S. launch ranges, but these efforts are insufficient to support the high flight rates and dramatic cost reductions needed by all of the NASA Enterprises requiring space access. Today’s range technology is inadequate to create spaceports that, operating more like airports, could enable revolutionary long-term missions such as space solar power and public space access [1].

A plan to evolve the existing U.S. test ranges toward spaceports that are designed to accommodate routine flights by a variety of vehicle types and mission profiles is proposed. Integrated with the air traffic control system, the evolving spaceport infrastructure would progress through a series of “generations,” eventually supporting space transportation operations to and from the earth’s surface, in earth orbit, and among planetary bodies. Key technical challenges and proposed technological solutions are provided for all range and space traffic control functions. A brief summary of recent studies in the field is also included.

Background

Virtually all U.S. orbital launches occur from one of two coastal “test ranges” in Florida and California. The legacy of these military test ranges and their continued reliance on launch methods designed for experimental missiles and rockets is extensively documented [2]. However, as the reliability and safety of launchers increase, a new era of routine space transportation is dawning. Powerful market forces are the engine of this new phenomenon, so commercial space enterprises are quickly overtaking military applications in terms of launches and economic impact. If this new trend is to grow and flourish, the “test ranges” must be replaced with spaceports that operate more like airports in support of routine commercial space transportation.

For the test ranges, today’s range safety begins with implementation of the procedures spelled out in the Eastern/Western Range standard 127-1 [3]. This 500-page document contains on the order of 10,000 individual documentation, systems, personnel, administrative, and operations requirements that must be met or waived for every launch from these ranges. It is not uncommon
for a team of engineers and technicians to work for up to a year or more on satisfying these requirements prior to a single launch. The team can swell to hundreds of personnel to manually ensure that the thousands of documented procedures and operations occur as planned for range configuration and safety. Range systems must be configured, tested, corrected, adjusted, and re-tested repeatedly for every launch, making turnaround time between missions unbearably long and expensive, particularly between missions involving different types of launch vehicles.

Several efforts are underway to upgrade and modernize the existing test ranges. As the range owners and operators, the U.S. Air Force (USAF) has embarked upon a major two-phase initiative to standardize and automate the two ranges. Called Range Standardization and Automation (RSA), this program has addressed Y2K problems at the range, obsolete communication infrastructure, and is currently working on an automated planning and scheduling system for range facilities as well as automation of certain weather systems. The RSA phase II completion has slipped from 2003 to 2006, largely as a result of internal funding problems [5]. There is widespread belief that the program will eventually deliver technology that is already ten years old or more.

Substantial research has been conducted on replacing or augmenting existing flight tracking radars with on-board GPS units that telemeter position data to ground controllers [6]. Radar equipment is one of the most expensive and time-consuming elements of the existing range, so reducing or eliminating dependence on them should lead to reduced costs and cycle times between flights. In addition, NASA has conducted experiments to show how the Tracking and Data Relay Satellite System (TDRSS) could augment in-flight communications [7, 8]. It is important to note that these efforts, while very promising, have focused on solving isolated issues at the ranges with little consideration paid to how the resulting technology would fit into an overall spaceport or space traffic management architecture.

While the USAF progresses with test range modernization, other groups have initiated efforts to create launch sites at new locations. The most notable of these is perhaps the Kodiak Launch Complex (KLC) in southern Alaska, the only licensed U.S. launch site not co-located on a federal launch range [9]. KLC’s unique situation allowed its developer to create a launch range “from scratch” subject only to requirements imposed by potential users and the Federal Aviation Administration (FAA) as licensing authority. Over $20 million has been invested in creating the new launch facility, which boasts commercial off the shelf control systems and communications. Much remains to be done at KLC, however, as funding shortfalls have so far precluded development of a completely self-contained spaceport.

Spaceports in other areas of the U.S. have also been proposed. Many of these were initiated in response to the proposed VentureStar™ program from Lockheed-Martin; most are now sufficiently advanced to recognize that many other potential spaceport users could make their enterprise successful. State-sponsored spaceports in Florida, California, and Virginia are now open for business in cooperation with the respective federal launch facilities in those states. Existing and proposed spaceports outside of the U.S. follow some of the same patterns; operational sites in Russia and South America [10] compete with the U.S. test ranges for commercial launch business; proposed spaceports in Brazil, South Africa, Australia, and elsewhere are at various stages of development.
Additionally, the picture remains cloudy for truly commercial spaceports as the FAA grapples with the tremendously complex problem of identifying the EWR 127-1 requirements that apply to non-federal property. The FAA has taken a substantial first step in defining a draft concept of operations for space launch activities integrated with the National Airspace System [11].

This paper identifies several potential components of the National Airspace System (NAS) that the FAA believes is needed to support future commercial space transportation operations. An integrated Spaceport-NAS infrastructure might include dynamic airspace reconfiguration, enhanced weather prediction, trajectory modeling, simulation, information exchange tools, cockpit displays, and decision support systems. These components are discussed in the technology section below.

In response to the progress of the spaceport industry, both NASA and the FAA have recognized there will soon be a need to routinely accommodate space flight vehicles in and through the NAS. NASA has initiated research into the tools that will be required to integrate launch vehicles, including reusable vehicles that will return to earth from orbit, into the nation’s air traffic control system [12]. This research has yielded a prototype architecture for integrating RLV mission planning with flight operations. The FAA draft concept of operations proposes a space and air traffic management system that will address the unique characteristics of vehicles moving between the earth’s surface and orbit. This work has led to considerable research into how air traffic control methods and airline/airport operations could be applied to future space transportation operations. This research is emerging as one of the key technological and regulatory challenges facing the space transportation industry. Some of these challenges are described later in this paper.

Recent Relevant Studies

After 50 years of safely supporting the nation’s space launch needs, the national test ranges are confronting a challenge to rapidly change to accommodate the growing commercial launch industry or face obsolescence. This challenge has led to the commission of several studies in the past two years to investigate how the ranges have evolved and what they can do to strengthen the U.S. space industry without risking their strong safety record or core military mission. Several of these studies capture the problem from differing perspectives; taken collectively, they offer substantial insight into the complexity and enormity of the challenge:

Earlier this year, a National Research Council committee on space launch range safety supported the re-evaluation of the 50-year legacy of the ranges in light of new technologies, lessons-learned, and the growing demand for commercial launch services. Over 100 individuals participated in public proceedings of the committee, and the final report notes the 15 recently completed or on-going studies examining space launch activities. The committee explored the need for new telemetry and tracking technologies in particular [3].

Also this year, a federal interagency working group headed by the White House Office of Science and Technology Policy and the National Research Council completed a study dealing with future management and use of the national launch ranges. Their final report succinctly captured the need for launch range technology development:
“While the Air Force is pursuing substantial range upgrades through the range standardization and automation program, currently no focused, funded effort exists within the federal government to develop and demonstrate long-term next-generation technologies for range capabilities. Next generation range technologies will be essential to improve safety and reduce costs by orders of magnitude to enable high launch rate operations using next-generation highly reusable space transportation systems.” [13]

The Air Force released a new report in July 2000 calling for definition of a “national space launch range vision” and enabling federal legislation to meet anticipated demands on the U.S. range infrastructure. The report summarizes several on-going modernization efforts and opportunities for several new technology applications [5].

Several other studies have been conducted in the past two years to probe the economic, political, and technological issues at the national launch ranges. In 1998, the U.S. Air Force Space Command initiated a “Range IPT” to address range turnaround times, scheduling systems, modernization programs, and other issues of concern to the space launch industry. Conclusions of the IPT stressed the importance of range modernization [2].

A Commercial Space Transportation Advisory Committee (COMSTAC) working group recently prepared a report addressing high priority issues related to spaceports. The committee makes several recommendations, including improvements to the range reconfiguration process with available technology and procedures and initiation of an independent assessment to determine specific modernization needs to satisfy evolving commercial space launch infrastructure needs [14].

**Description of Concept**

The future evolution of space launch ranges is intertwined with air traffic management. Routine space flight operations will take place at spaceports outside the “test ranges,” thereby requiring safety oversight from systems not currently associated with the USAF. One scenario begins with turning over a portion of an existing test range to non-military spaceport operators. With this approach, one of the existing test ranges would be divided into two geographical areas: one dedicated to military and experimental launches that remain under the control of the USAF and subject to existing safety standards for test launches, and the second under the control of a spaceport operator subject to the FAA regulation associated with their launch site operators license. Operations and technology needed for the non-military spaceports will initially be similar to that used at the test ranges, but will evolve toward streamlined operations suitable for proven and certified launch vehicles. As the evolution unfolds, the range/spaceport systems and the air/space traffic control concept will converge, replacing the legacy range systems, procedures, and regulations with an aerospace traffic control and management systems. Once complete, orbital traffic management and eventually interplanetary traffic management will be added.

The vision of test ranges partially transforming to spaceports, then converging with air traffic management and expanding to in-space traffic sets the stage for designating “second generation” and “third generation” spaceports. “First generation” spaceports are existing facilities that operate under EWR 127-1. A second generation spaceport would operate under FAA license
rather than EWR 127-1. Some of the facilities, systems, and procedures would resemble those of first generation spaceports such as vehicle-specific systems and instrumentation largely dedicated to space operations. A global spaceport infrastructure will be required to link second generation spaceports, laying the groundwork for the aerospace traffic management system.

Launch, reentry, landing, and abort operations will eventually occur on a regular, daily basis from several Spaceports throughout the United States. New, reusable launch vehicles (RLVs) will fly through the lower atmosphere and into orbit via space transition corridors (STCs) while other aircraft proceed on their routes in neighboring airspace. A national spaceport infrastructure, integrated with the NAS, will require all the necessary capabilities for supporting launch, orbit and ascent operations, as well as fueling, payload processing, and maintenance while maintaining required levels of safety, capacity, and efficiency.

A third generation commercial spaceport would also operate under FAA license, but the operations would be completely integrated into a comprehensive air and space traffic control system with minimal instrumentation and systems unique to space flight operations (i.e., the infrastructure would be shared with airliner operations where feasible).

A possible third generation spaceport or mission scenario within the NAS domain would begin with an electronic filing of a flight plan. The flight plan contains the vehicle description, proposed flight, orbit, and trajectory data to be processed at the FAA Air Traffic Control System Command Center (ATCSCC). The mission profile will be checked for conflicts, weather, and other possible constraints in a fast-time simulation, which is part of the launch, reentry, landing, and abort approval process. Once the flight is scheduled into the local and national daily operations, the automated command and control system issues clearances and uploads mission data directly to the vehicle operator, spaceport operator, the International Space Flight Organization (ISFO), the RLV’s flight management system, and appropriate Airline Operations Centers (AOCs). During flight, the range and tracking systems will monitor progress and disseminates flight status data to the ATCSCC and other system operators and users. For the final phase of flight, the orbiting or hypersonic vehicle receives a reentry clearance and returns to land at a spaceport where it is prepared for its next launch.

Mission planning and mission operations are two major space access activities that impact NAS operations. Vehicle performance, mission profile, traffic volume, safety and environmental considerations, and economics are the primary variables or factors that affect these activities. The planning process will require: initial mission profile information (analogous to an aircraft flight plan); a graphic depiction of the NAS configuration; a graphic depiction of user-preferred trajectories (both aircraft and space vehicle); resource demand under current, future, and alternative traffic situations; relevant environmental information; and 4-D trajectory modeling (X, Y, altitude, and time) and fast-time simulation capabilities. Upon completing the planning process, the ATCSCC spaceport operations coordination system disseminates the mission profile via the NAS-wide area information system (NAS-WIS) to notify airmen, mariners, and the military of the impending mission.

During a mission, flight status information will be continually updated and disseminated in real-time to the NAS users. This information will also be displayed on ATC-system and cockpit situational displays for tactical purposes. STCs and airspace sectors will be dynamically allocated and monitored to accommodate the mission and air traffic system demands. This
integrated NAS/Spaceport infrastructure will provide all the necessary services and capabilities to accommodate space and air traffic operations.

A “fourth generation” spaceport might be proposed to address orbital and interplanetary traffic management, extending the space traffic management system to in-space vehicles, debris, and natural objects. Such a system might be hosted on an in-orbit space station and implemented entirely through space-based assets, freeing the earth environment from related transportation infrastructure.

Technology Improvement

Within this framework, technology challenges can be identified for each “generation” of spaceport. This arrangement directly leads to time-wise investment priorities and a comprehensive technology roadmap as suggested later. From a functional perspective, several range functions present serious technology challenges to achieving second generation status. For the sake of completeness, current range functions are listed below:

- Mission Planning
- Scheduling
- Flight Tracking
- Flight Monitoring
- Flight Safety
- Range Surveillance
- Weather monitoring and prediction
- Telemetry and Communications
- Emergency Response
- Mission Analysis

Taken together, these functions make up the range infrastructure in place today. Other functions that will be required to realize next generation spaceports include:

- RLV support (launch and landing)
- Flight control
- Flight testing
- Multi-spaceport/airport infrastructure

As mentioned earlier, technology work for first generation spaceports is already underway. This work is focused largely on advanced flight tracking techniques and development of commercial off the shelf products to support the listed functions. In general, the goal of this work is to reduce the range infrastructure and its associated maintenance cost. One of the goals of creating a second generation spaceport is to eliminate as much of the existing range infrastructure as possible. New technology is required to achieve this goal; key technology challenges and suggested research areas are listed below.

Mission Planning
The flight planning process will transform mission objectives into standard flight plans. A wide range of technology and techniques will be required to automate this complex process that must accommodate many types of vehicles, missions, and operations.

- Advanced planning systems compatible with commercial computer platforms, closely integrated with launch and mission control
- Trajectory modeling and simulation for various launch sites given mission parameters
- Multi aircraft/spacecraft simulations that predict time and location of potential congestion
- Automated flight planning
- Orbital transfer simulation
- Automated conjunction on launch assessment (COLA) models, integrated with existing orbital debris databases (NORAD) and automated rendezvous maneuvers
- 6 degree of freedom models
- 3D visual representations of mission trajectories with visual cues for altitude, heading, and predicted conflicts
- Integrated E_c analysis with flight safety planning
- Advanced planning and scheduling systems
- Integration of spaceport data into the NAS-wide area information system (NAS-WIS)
- Integrated launch and range safety systems
- Remote configuration of range and vehicle assets
- Interactive simulation for training and validation
- Multi-vehicle and multi-fleet mission planning techniques
- Collaborative environments for building joint flight plans among vehicle, payload, and spaceport operators
- Real-time flight plan updates to accommodate constantly changing orbital debris and weather databases
- Automated flight plan submission
- Integration of satellite imagery with mission modeling
- Area and regional notification plans (marine, air, land)

Scheduling

- Automated planning and scheduling techniques to allocated ground assets in a multi-mission or multi-flow environment
- Synchronization of flight profiles with mission objectives (e.g., “launch window” scheduling for nominal and abort profiles)

Flight Tracking

New cost-effective and highly reliable techniques for determining the position of launch vehicles are essential to reducing the existing range infrastructure. Current operations rely heavily on fixed radar sites, aircraft, and optical tracking devices. This area appears to be ideally suited to space-based deployment and standardization. New techniques include, but are not limited to:

- GPS tracking (eliminates specialized ground infrastructure)
- Laser tracking (reduces specialized ground infrastructure)
- Landing/re-entry tracking
- Multiple vehicle tracking (in all phases: ascent, on-orbit, re-entry)
Advanced display techniques

Other technical challenges in flight tracking include:

- Rotating body tracking
- Elimination of dedicated downrange tracking instrumentation
- All weather tracking

Flight Monitoring

Cost-effective and highly reliable techniques are also required for determining the performance and status of space vehicles during flight. During a mission, flight status information will be continually updated and disseminated in real-time. This information will also be displayed on ATC-system and cockpit situational displays for tactical purposes. STCs and airspace sectors will be dynamically allocated and monitored to accommodate the mission and air traffic system demands. This integrated NAS/Spaceport infrastructure will provide all the necessary services and capabilities to accommodate space and air traffic operations. This area is closely related to telemetry and communications. Potential techniques in this area include:

- Dynamic airspace reconfiguration
- Satellite Communications (early proof of concept using TDRSS has been demonstrated)
- IVHM techniques that link on-board health monitors to spaceport systems
- Advanced display techniques
- Payload monitoring and information distribution to customers

Flight Safety

For expendable vehicles, flight safety is currently culminates in the flight termination decision. Other range functions, particularly flight tracking and surveillance, are support functions to this decision making process. A second generation spaceport must support transportation systems that have multiple abort profiles for reusable vehicles rather than termination devices, making the flight safety function much more complex than a single flight termination decision. Decision support tools and methods for reducing the size of ground and flight crews are needed to make this transition while avoiding increased costs. Specific technology needs include:

- Flight safety analysis
- Orbit, re-entry, and landing modeling
- Airspace modeling and prediction of flight hazards presented by orbital debris and spacecraft, and flight through commercial air corridors
- Real-time position and impact prediction calculations throughout all flight phases on standard equipment with human-centered computing techniques to improve the user interface
- Intelligent systems: tools for intelligently collecting, representing, sharing, and re-applying highly specialized flight safety knowledge to reduce the size of ground crews
- Intelligent systems: research to determine the optimal architecture, knowledge representation techniques, and human/computer interaction methods for implementing decision support tools
- Multi-vehicle and multi-fleet flight safety
- Integrated $E_c$ analysis for potential failure on ascent, re-entry, or landing
- Multiple $E_c$ algorithms
- Methods for calculating risk to ground traffic and shipping in the flight and re-entry corridor
- Automated landing support and landing aids

Range Surveillance

- Area and regional notification (marine, air, land)
- Automated sea surveillance and situational awareness
- Advanced display techniques

Weather monitoring and prediction

- Integrated weather monitoring, forecasting, and visualization
- Advanced local area/short term weather prediction techniques
- Integrated local, national, and global information
- Upper atmosphere monitoring
- Lightning protection

Telemetry and Communications

- Multi-vehicle and multi-fleet communications
- Next generation internet
- Satellite Communications (early proof of concept using TDRSS has been demonstrated)
- High bandwidth video and audio
- Data security
- Advanced timing techniques
- Data archive and playback

Emergency Response

- Drift pattern prediction for toxic vapor clouds
- Vehicle debris impact prediction and response
- Sonic boom considerations

Mission Analysis

- Automated performance analysis of the launch vehicle and air space model

RLV support (launch and landing)

Existing range infrastructure does not accommodate the proposed new generation of reusable launch vehicles. Increased vehicle autonomy, flight crews and passengers, multiple re-entry, landing, and abort scenarios all present challenges for existing range systems. Key technology needs include:

- RLV processing and simulation
- Integrated command and control for pre-flight, flight, and re-entry operations
- Planning tools that accommodate RLV flight profiles including ascent and re-entry/abort scenarios
Real-time abort site selection and modeling for all phases of ascent and re-entry
Launch vehicle models that include engine and thrust modeling, moment of inertia matrices, aerodynamic coefficients, and related parameters

Flight Control

Better integration of the flight control function with the range/spaceport control function is required to support routine operations at future spaceports. Today, “launch” control is typically handled by crews, systems, and procedures from the vehicle manufacturer, while the USAF provides range control. This separation of authority will likely be maintained in second and third generation spaceports, as public safety should be in the hands of an organization with no economic interest in the flight. However, the coordination between launch/flight control and range/spaceport control must be improved to reduce the vehicle-unique infrastructure and costly manual activities that pervade today’s range operations. Technologies to be investigated in this area include:

- Simultaneous operation at multiple pads, with different types of vehicles
- Rapid/automated instrumentation reconfiguration
- Interface standardization

Flight testing

An aggressive flight test program using suborbital and LEO launches is needed to validate new range/spaceport technologies and provide performance data. Using experimental launch vehicles to also test spaceport technology makes integration and analysis difficult. A flight test program using proven flight articles would allow a controlled stepwise approach to spaceport range technology demonstration. Such a program is also required to test flight and space-based elements of spaceport technology.

- Space-based range techniques, including GPS tracking and satellite-based TT&C
- IVHM system flight testing
- Spaceport Testbed products
- Range Technology Testbed

Global Spaceport Infrastructure

The proposed global spaceport network would link spaceports together to enable coordinated operations and reduce duplicity. Information exchange standards are essential to the growth of a commercial spaceport industry that supports “launch & land anywhere,” global mission tracking, and cargo/vehicle/spaceport coordination.

Several enabling technologies in the command and control arena will be needed to develop a national Spaceport infrastructure. The NAS Architecture document identifies future air traffic systems in the 2008 to 2015 time frame. Some new systems or concepts yet to be determined, will be required for specialized Spaceport operations. Based on the anticipated evolution of the NAS and the spaceport concepts being explored by NASA and the commercial space industry, for future spaceport design, this section presents an initial set of candidate technologies that could support the above concept.
Communications

- NAS-wide Data Link (air/ground & air/air)
- NAS-wide Information Network (inter-facility)
- Emergency Backup Communications

Navigation

- Integrated Satellite/Inertial Navigation System (airborne)
- Wide Area & Local Area Augmentation (GPS ground stations)
- Precision Landing System

Surveillance

- Ground-based and Airborne Radar
- Automated Dependent Surveillance
- Advanced Weather and Wake Vortex Sensing
- Strategic and Tactical Collision Avoidance
- Space-based Range

Displays

- Lowvisibility enhanced reality HUDs
- Synthetic Vision
- Integrated glass avionics

Flight/Mission Management

- Automated Flight Plan Processing & Approval
- Flight Assessment Fast-time Simulation Tools
- Integrated Flight Management/ground Control System
- Trajectory Analysis Conflict Probe
- Schedule and Decision Support Tools
- Automated Range Safety and Data Acquisition System
- Data Archiving and Incident Reporting System

Technology Roadmap

A “NextRange” concept has been proposed that provides a long term strategy for migrating existing test ranges to commercial spaceports and products [16]. The NextRange concept applies the principles of NASA’s Advanced Space Transportation Plan (ASTP) to spaceport technology. One of the key facets in the approach to a second generation spaceport is the strategic technology roadmap. The roadmap is based on four complementary research and technology elements that span TRL 2 to 9; proposed NRA-level work comprises the first element culminating in TRL 4 laboratory validation demonstrations. Subsequent elements include directed research (TRL 4-5) to refine the second generation launch range concept with an emphasis on defining system and component requirements for intelligent systems technology and decision support tools. The third
element is a technology demonstration (TRL 6-7), and the fourth element is operations
demonstration and commercialization. Details of this concept will be presented at the Space

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