

# A Tool for Integrating Commercial Space Operations Into The National Airspace System

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**Potential growth in the commercial space transportation industry, coupled with an expected doubling of air traffic operations over the next 10 years, could place additional safety and capacity demands on the National Airspace System (NAS). The Space and Air Traffic Management System (SATMS) is a proposed framework of operations designed to accommodate future commercial space operations within the NAS and to provide for the additional safety considerations associated with space vehicles operating in close proximity to air traffic. This paper discusses how the FAA plans to implement this strategy by developing a new decision support tool (DST) that will help air traffic controllers to manage a diverse mix of aircraft and space vehicles operating in shared airspace.**

## I. Introduction

**I**N the fall of 2004, the Scaled Composites Team captured the \$10 million Ansari X Prize with two historic flights of *SpaceShipOne*. At the same time that this remarkable vehicle was earning its pilots the nation's first commercial astronaut wings, it was also laying the foundation for new markets and opportunities in the commercial space flight industry. Based on the success of *SpaceShipOne*, Paul Allen, co-founder of Microsoft, Burt Rutan, founder of Scaled Composites, and Richard Branson, founder of Virgin Atlantic Airways, recently announced a partnership to operate the world's first suborbital commercial space tourism flights in 2008. At the same time, a number of new prizes and incentives are being offered to entice further development within the industry. These include an annual X-Prize Cup, the America's Space Prize, offering a \$100 million award for the first commercial orbital reusable launch vehicle (RLV), and NASA's Centennial Challenges, created to foster the development of space exploration technologies. In addition, current government space initiatives will continue to progress as embodied in NASA's space exploration agenda and the nation's expanding national defense capabilities for responsive access to space.

This increase in space operations, coupled with an expected doubling of air traffic operations over the next 10 years, could place unprecedented demands on the National Airspace System (NAS) and the nation's Air Traffic Control (ATC) system. In preparation for these activities, the FAA has developed a concept of operations for a future Space and Air Traffic Management System (SATMS). This proposed framework for seamlessly integrating space vehicles on their way to and from space with traditional air traffic operations will require new space and air traffic management tools and enhanced communications, navigation, and surveillance (CNS) services. The FAA plans to incorporate these capabilities into a SATMS decision support tool (DST) that will assist the nation's air traffic controllers in maintaining the high level of safety that the air traveling public has come to expect.

## II. Hazards to Aircraft from Space Operations

The next generation of space vehicles will most likely pass through the NAS relatively quickly, in the same manner as today's space vehicles, to maximize performance and payload capacity. Thus they will most likely spend little time flying through the denser regions of the atmosphere below 60,000 ft, an altitude generally associated with the upper bound of the NAS. As such, these operations would affect a relatively small region of airspace for a short period of time, minimizing the risk of a collision with an aircraft.

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Space vehicle over-flights between the upper limits of the NAS and the threshold of space, however, could pose far greater hazards to aircraft if they should fail in a manner that generates falling debris. For example, a catastrophic failure of a vehicle reentering from orbit, such as the Space Shuttle *Columbia* accident in 2003, can produce a large cloud of falling debris, the majority of which would be capable of severely damaging or even destroying any aircraft it impacts. A debris fragment too small to cause a serious injury by striking a person could still be capable of causing a hazard by striking an aircraft. Models currently in use by the Federal launch ranges assume that a piece of spacecraft debris weighing much less than one pound can puncture the wing or cabin of a cruising aircraft, inflicting catastrophic damage.

While the reliability of future space vehicles is challenging to predict, it is generally agreed that, at least in their early stages of development and test, these vehicles will be far less reliable than today's aircraft. That being the case, hazards from spacecraft operations have the potential to pose a far greater risk to aircraft than any other aircraft hazard traditionally considered, including mechanical failure, severe weather, pilot error, or collision with another aircraft. Accordingly, approaches to the management of the risks these vehicles pose to aircraft based on containment, including the use of airspace restrictions at all altitudes below and around the launch and reentry operations, have been successfully implemented in the past and will most likely continue to be used in some fashion until a greater level of launch and reentry vehicle reliability is achieved.

### **III. Current Space and Air Traffic Management Strategies**

Over the years, the FAA has developed separation standards for aircraft. These standards describe minimum altitudes and lateral distances for separating one aircraft from another in flight to avoid collisions and hazardous conditions like wake turbulence. A present lack of experience in spacecraft methods of operation has prevented similar separation standards between spacecraft or between aircraft and spacecraft from being developed. In the meantime, the procedure for ensuring aircraft is safely distanced from spacecraft during a launch or reentry involves the use of Special Use Airspace (SUA) and Temporary Flight Restrictions (TFRs).

Types of SUA utilized for space launch and reentry activities include Restricted Airspace and Warning Areas. These areas are generally quite large, sized for the largest vehicles that may use them, with fixed boundaries. They are typically activated for extended periods of time to accommodate military operations and space launches and reentries. For instance, the launches of commercial and government expendable launch vehicles (ELVs) from the Federal ranges, including the coastal sites of Cape Canaveral, Florida and Vandenberg Air Force Base, California, take place within Restricted Airspace over the launch areas themselves and Warning Areas that extend a distance downrange over the ocean.

When a launch or reentry activity takes place, the FAA issues Notices To Airmen (NOTAMs) to alert the air traffic community, including air traffic controllers, airlines, and general aviation pilots, of the times of these operations and boundaries of the required airspace. Flight service stations provide these notices to pilots and they are also made publicly available on the Internet. Once NOTAMs are issued, flight plans and paths are adjusted accordingly so that aircraft that would normally fly through this airspace take a longer, alternate route to their destination. Radar and visual surveillance of these areas prior to the launch activity ensures that they are clear.

Although there are a limited number of examples, the launches and recoveries of reusable launch vehicles (RLVs) have been handled successfully in a similar fashion. For example, the flights of *SpaceShipOne* took place from Mojave Airport, in Mojave, California, within the Restricted Airspace north of Edwards Air Force Base. Future spaceports lying within existing SUA boundaries may be the exception rather than the rule, due to the level of coordination required with current SUA users and the potential for scheduling conflicts. Further, the development of a new SUA involves an extensive airspace design process, making it unlikely that the majority of future space vehicle flights will take place within SUA boundaries.

Currently, a small number of launches do take place from locations that lie outside of existing SUA boundaries, such as the Kodiak Launch Complex near Kodiak, Alaska. These launches require the issuance of TFRs to ensure that the surrounding airspace is sterilized. TFRs are short-term restrictions issued via NOTAMs and advisories, often on short notice, that keep all aircraft at designated altitudes from entering a specified area. Due to its relatively remote location and the infrequency with which launches have taken place, large TFRs can be issued over and around the Kodiak Launch Complex with manageable impact to air traffic.

TFRs have proven effective in their application to space launch activities and they will most likely continue to be utilized to implement airspace restrictions at future launch and reentry locations that lie outside of SUA boundaries, including the proposed Oklahoma Spaceport near Burns Flat, Oklahoma. However, in regions such as this one, where air traffic loads are already quite high and launch activity is predicted to take place on a near daily basis, a more efficient method of implementation will be required to minimize the impact to air traffic while maintaining

safety. A major goal of SATMS will be to identify methods and procedures to reduce the amount of airspace that is restricted for each launch and the amount of time that the restriction needs to be in effect, and to schedule the restriction so as to accommodate conventional air traffic while still achieving the space mission and safety objectives.

#### **IV. Future Space and Air Traffic Management Strategies**

The concept of operations for future control of space and air traffic calls for the use of space transition corridors (STCs) to safely segregate traffic. STCs would be defined by strategically sized airspace restrictions that would be dynamically issued and withdrawn, as necessary, to maximize safety while minimizing the impact to air traffic. For example, the trajectory of a suborbital space flight originating and ending at the proposed Oklahoma Spaceport could be entirely contained within an STC that would be sufficiently large to contain any debris from a potential failure during the flight. The vertical extent of the STC would span all altitudes, while the lateral sizing would be determined using specific characteristics of the space vehicle and the way in which it is to be operated, combined with predicted weather conditions.

Although advisories and planning documents would be issued further in advance, the STC would be established shortly before the flight was to take place and withdrawn once it had been completed. During the flight, air traffic controllers would monitor its progress against actual weather and air traffic conditions, standing at the ready to respond to an accident by quickly identifying the extent of the affected airspace and maintaining its closure until it was free of hazardous debris. Airspace within the STC that was no longer at risk from the vehicle or its debris could be released.

Prior to the flight, measures could be taken to minimize impacts and further reduce the risks. Existing traffic patterns in the surrounding area could be identified and analyzed to determine the times of day and days of week in which the ambient air traffic is lighter, reducing the impact to other airspace users while further minimizing their exposure to any hazards. Reroutes of regularly scheduled air traffic could be preplanned to maximize efficiency. In addition, space launch operators could also use this information to assist in the design of their trajectories, utilizing corridors of airspace that are typically less traveled by aircraft.

Such operations and analyses will require tools and processes to communicate with and track the spacecraft, to identify the potentially affected airspace in both a planning and an operational mode, and to plan and identify the most efficient air traffic reroutes. The SATMS DST is currently being designed to fill this need.

#### **V. The SATMS Decision Support Tool**

The SATMS DST is a software and computing system currently being designed to assist air traffic controllers in managing airspace restrictions and the risk to aircraft from space operations with improved situational awareness. To accomplish this, the tool would be used in two modes: planning and realtime. In the planning mode, it would identify the airspace restriction requirements, potential impacts to other NAS users, and options for mitigation of those impacts. In the realtime mode, it would display the space vehicle's trajectory and estimates of the potentially hazarded airspace against current air traffic data, and assist air traffic controllers in maintaining a safe separation in the event of an accident.

The size and duration of a launch or reentry airspace restriction would be based, in part, on quantitative risk analyses using complex vehicle debris models, similar to the analyses currently performed for range safety prior to space vehicle launches at the Federal launch ranges. Characteristics of the vehicle and its intended operations, including its likelihood of failure, the modes through which it could fail, and catalogs of the resulting debris would be input to the DST to probabilistically compute volumes of potentially hazarded airspace at a series of failure times. Conservatism would be applied to such calculations, to account for uncertainties such as vehicle performance and the velocity and direction of prevailing winds, in a manner consistent with assumptions about the vehicle's failure modes and resulting debris.

In the planning mode, air traffic management (ATM) tools could then receive the output debris volumes and compare them to existing air traffic patterns to size the airspace restrictions and plan optimized air traffic routes around them. Air traffic managers, space vehicle operators, and spaceport operators could also use this information to collaboratively make adjustments to the space vehicle's proposed trajectory and launch or reentry time that optimize safety and minimize impacts to the rest of the operations in the NAS. Ultimately, the SATMS DST would allow decision makers to make informed risk reduction decisions.

In its realtime mode, the tool would be used to predict the extent of any potentially hazarded airspace from input data describing the space vehicle's current position and the current environmental conditions. Depictions of this airspace would be cyclically constructed and displayed on an air traffic controller's display of the current air traffic

conditions as CNS data from the vehicle was received. In the event of a space vehicle failure, the debris volume prediction would freeze in position over the best estimate of the affected airspace, based on the vehicle's last known position and the current environmental conditions. ATM functionality within the tool would then provide conflict advisories and recommended air traffic reroutes to assist the controller in maintaining the required airspace closure until all of the debris had impacted the surface.

The aircraft trajectory model and conflict analysis algorithms needed to accomplish these tasks could be quite similar to those used in current ATM tools. In a sense, the DST could treat a debris hazard like an area of severe weather occurring at all altitudes, providing recommended reroutes while identifying potential airport and airspace demand/capacity imbalances. As a result, the proposed DST would not require the development of new ATM models and algorithms. Rather, it would integrate existing aircraft ATM and spacecraft range safety capabilities.

However, a number of challenges must be overcome to bring this tool to fruition -- challenges no less daunting than those encountered while preparing any new tool to provide safety critical functionality in a highly proceduralized operational environment. The detailed requirements currently being developed must be validated. Extensive verification testing will be required throughout the development and implementation process. In addition, the tool must be flexible enough to receive CNS data from a variety of vehicle types and operators. It may be required to interface with a number of air traffic tools, including the Enhanced Traffic Management System (ETMS) and the Display System Replacement (DSR), depending upon the facility at which it is being operated. Although the SATMS DST is envisioned to be primarily an FAA tool, it may be required to provide output to a number of external entities, including the space vehicle operators, other NAS users such as airline operators, the military, and NASA, as well as future spaceport and range operators, all of whom will likely use its outputs to make collaborative decisions that allow fair and safe access to the NAS for all users.

Traffic Flow Management Coordinators (TMCs) at Air Route Traffic Control Centers (ARTCCs) and Terminal Radar Approach Control (TRACON) facilities are expected to be the primary users of the SATMS DST, with centralized command and oversight located at the Air Traffic Control System Command Center (ATCSCC). Based on the number of potential users, another challenge of developing the SATMS tool will be to determine how the information should be presented to controllers. Significant research will be needed to design the displays and to develop the corresponding air traffic procedures.

## **VI. In the Meantime: Space Shuttle Experience**

While a number of commercial space vehicle operators are busy developing their vehicles, there is currently one vehicle continuing to operate in and above the NAS that can be used to validate DST requirements and provide scenarios for initial testing: NASA's Space Shuttle. Although the FAA had air traffic procedures for supporting Space Shuttle operations prior to the *Columbia* accident, those procedures did not take into account the potential debris hazard to aircraft during a Shuttle reentry. As a result, the FAA developed a plan to address that issue in preparation for the return-to-flight of *Discovery* (STS-114) in July 2005. That experience provided valuable lessons-learned for future space and air traffic operations, including several design implications for the SATMS DST.

STS-114 posed several operational challenges to protecting aircraft from the potential debris hazard, many of which will be common to any commercial space vehicle operation. First, it may be difficult to ascertain when a hazardous condition exists. An unexpected loss of CNS data would most likely be NASA's first and perhaps only indication that there may be a problem, as was the case with *Columbia*. However, during a typical Shuttle reentry, the orbiter can periodically lose contact with Mission Control for several minutes at a time due to reentry plasma interference, antenna geometry, and other less predictable phenomena like telemetry and tracking system failures.

Future commercial space vehicles returning from orbit may incur losses of CNS data for the same reasons as the Shuttle. Although not as susceptible to reentry plasma effects due to their lower velocities, suborbital vehicles can also suffer from antenna pointing errors and tracking system failures. While periods of data loss can be predicted to some extent based on trajectory design and link analyses, this is not always the case, and air traffic actions taken in response to false indications of an accident can be just as risky as those taken during actual accident scenarios. Traffic reroutes of any nature can create airspace and airport capacity/demand imbalances and increase controller workload. Further, the false declaration of an accident could cause previously restricted airspace to be released prematurely, increasing the risk of a collision between the spacecraft and aircraft.

At the same time, the difficulty in determining an accident has taken place can limit the FAA's response time. Based on NASA estimates, debris from a Shuttle failure on reentry could begin impacting the Earth's surface in as little as three to four minutes after the failure occurs. Depending upon the altitude of the failure, debris capable of damaging or destroying an aircraft could continue to fall for the next 90 minutes. In addition, the Shuttle is capable

of landing at multiple, geographically dispersed sites, each requiring overflight of multiple ARTCCs and hundreds of miles of the NAS. Preparation time could also be limited, given that weather conditions at a landing site can delay the selection of a particular landing scenario until as late as just one hour prior to the scheduled touchdown. Most commercial vehicles returning from orbit are anticipated to pose the same types of operational challenges.

Considerations such as these prompted the FAA to study the impacts on the NAS based on procedures for isolating aircraft from the potential hazards. To that end, engineers at the FAA's William J. Hughes Technical Center (WJHTC) conducted sensitivity analyses for several Shuttle reentry scenarios, counting the number of air traffic conflicts due to airspace restrictions of various sizes and durations. Hypothetical corridors were constructed to surround each Shuttle nominal reentry trajectory for the portion of that trajectory that passed over or through the NAS. Using previously recorded air traffic data to simulate NAS loading, a conflict was recorded for each aircraft within a corridor at the time that it was activated, as well as each aircraft that was planned or scheduled to enter the corridor during the modeling periods. Only primary conflicts for IFR traffic were identified; all VFR traffic and any IFR aircraft not scheduled to fly through a corridor that were delayed or rerouted as a result of other aircraft directly affected by a corridor were not counted. A number of factors influenced the results, including variations in the width and geographical location of the corridor, the time of day of the landing, and the duration of the restriction. As a result, the scenarios tallied conflicts numbering from as few as 20 aircraft for an early morning landing at Kennedy Space Center, FL, to as many as 250 for a mid-afternoon landing at Edwards Air Force Base, CA.

Without the benefit of a SATMS DST to assist the controllers in the dynamic management of this airspace, the FAA took a number of steps to tailor its strategy for Shuttle reentries in an effort to safely minimize impacts. First, flow evaluation areas (FEAs) were used to identify the potentially affected airspace. An FEA is a three-dimensional volume of airspace used to identify aircraft associated with a condition that has the potential to cause demand to exceed the capacity of any NAS resource. While the boundaries of the FEAs were set to the boundaries that would have described the potentially affected airspace associated with each reentry trajectory, the FEA established an air traffic advisory instead of an airspace restriction. NOTAMS listing the coordinates of these boundaries were distributed to the NAS user community to alert them of the potentially affected airspace, and allow them to plan for the reentry and to take any additional measures they felt were necessary. TFRs were then sized to match the FEAs and prepared for issue and activation in the event of an accident.

The FAA also developed visualization aids for the predicted reentry trajectories to provide additional situational awareness to air traffic controllers. Overlays depicting each of the potential Shuttle reentry trajectories received from NASA were constructed at the WJHTC on ETMS Traffic Situational Displays (TSDs). These adaptations were then shipped to the ATCSCC. The ATCSCC plotted FEAs, sized using results of a series of debris analyses conducted by NASA, on top of these trajectories. This series of FEAs defined a corridor, centered on a nominal Shuttle trajectory, at all altitudes along the portions of that trajectory that over-flew the NAS, identifying the potentially affected airspace. The adaptations and corresponding FEAs were then distributed to each of the potentially affected ARTCCs.

In addition, a dedicated line of communication was established between the ATCSCC, each potentially affected ARTCC, and NASA's Mission Control Center, providing a means for verbal notification of an accident to be quickly broadcasted. Finally, a planning document describing this strategy was prepared and distributed to NAS users and each potentially affected Center. With this plan and its supporting elements in place, FAA personnel supported the Shuttle reentry operations on August 8<sup>th</sup> and 9<sup>th</sup>. STS-114 had a nominal reentry and landing at Edwards Air Force Base, CA, at 5:11 AM PDT, on August 9, 2005.

As this process demonstrates, until an operational version of the SATMS DST is available, a number of tools at various facilities will be required to construct traffic management plans, prepare visualization aids, and analyze impacts of Shuttle reentries and other space operations. Accordingly, the tool is being designed to consolidate the necessary analysis, planning, and implementation tools and automate tasks where practical to alleviate this labor and coordination-intensive process. Since STS-114, the FAA has conducted several exercises involving air traffic managers and NASA landing support officers. Each application of this plan presents new challenges and lessons learned for future air and space vehicle operations and the SATMS tools that will support them.

## **VII. Conclusions**

The FAA is developing traffic management strategies and a decision support tool to safely and efficiently accommodate an anticipated increase in space and air traffic operations while minimizing impacts. The proposed fusion of existing technologies will create a tool capable of identifying airspace restriction requirements and mitigation options for potential impacts while providing increased situational awareness during nominal operations and accident scenarios. To that end, experience gained in support of Space Shuttle reentries has helped the FAA to

identify a number of challenges associated with these operations and refine its tool requirements and implementation strategies. Enthusiasm for space tourism and investment in other commercial space ventures will continue to increase, and with it, the challenges of accommodating its operations safely. As the rate of space operations increases, the SATMS DST will play in an increasingly pivotal role in providing safe access to the NAS for all of its users.

### **Acknowledgments**

The authors would like to acknowledge the assistance of Mr. Douglas Baart, Mr. Robert Fietkiewicz, Mr. John Hensyl, and Mr. Charles Milk of the FAA's William J. Hughes Technical Center (WJHTC) and Ms. Shelia Helton-Ingram of the FAA's Office of Commercial Space Transportation (AST) for the work that they have performed in support of the FAA's air traffic management efforts during Space Shuttle reentry operations and the corresponding contributions to this paper

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