Safely Integrating Space Operations Into The National Airspace System

by Daniel P. Murray and Richard VanSuetendael

In 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 $50 million award for the first commercial orbital reusable launch vehicle, 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 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 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.

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 though 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.

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. A major goal of SATMS will be to identify methods and procedures to reduce the amount of airspace that is restricted for each launch or reentry, to reduce 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.

This concept of operations calls for the use of space transition corridors to safely segregate space and air traffic. These corridors 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 Oklahoma Spaceport in western Oklahoma could be entirely contained within a space transition corridor that would be sufficiently large to contain any debris from a potential failure during the flight. The vertical extent of the corridor 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 corridor 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 space transition corridor 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. The DST is a software and computing system that will 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 tool would base the size and duration of a launch or reentry airspace restriction, 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 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 a 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 communications, navigation, and surveillance 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. Air traffic management 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 SATMS DST is envisioned to be primarily an FAA tool, used by Traffic Flow Management Coordinators at Air Route Traffic Control Centers and Terminal Radar Approach Control facilities, with centralized command and oversight located at the Air Traffic Control System Command Center. It may be required to interface with a number of air traffic tools, including the Enhanced Traffic Management System and the Display System Replacement, depending upon the facility at which it is being operated. 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.

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 mission (STS-114) in July 2005 and has continued to utilize this plan for subsequent missions. This experience provides valuable lessons-learned for future space and air traffic operations, including several design implications for the SATMS DST.

Shuttle landings pose 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 data from the Shuttle orbiter 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 may incur losses of data for the same reasons as the Shuttle. 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 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 potential 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 conducted sensitivity analyses for several Shuttle reentry scenarios, counting the number of air traffic conflicts due to airspace restrictions of various sizes and durations. Using previously recorded air traffic data to simulate NAS loading, a conflict was recorded for each aircraft within a potential hazard area, as well as each aircraft that was planned or scheduled to enter the area during the modeling periods. 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. Accordingly, the scenarios tallied conflicts numbering from as few as 20 aircraft for an early morning landing at Kennedy Space Center, Florida, to as many as 250 for a mid-afternoon landing at Edwards Air Force Base, California.

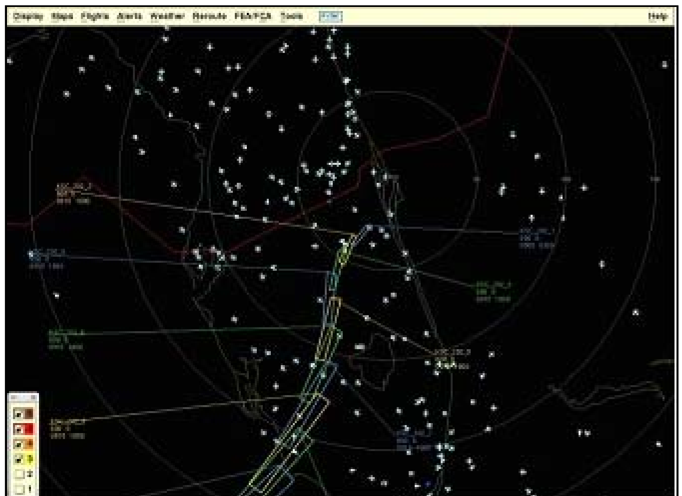

Figure 1: Traffic Situational Display of Miami Center airspace during STS-121 landing, courtesy FAA

Without the benefit of a SATMS DST to assist the controllers in the dynamic management of this airspace, the FAA has taken a number of steps to tailor its strategy for Shuttle reentries in an effort to safely minimize these potential impacts. First, air traffic flow evaluation areas are used to identify the potentially affected airspace and establish air traffic advisories. A flow evaluation area 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. The boundaries of these areas are set to the boundaries of debris footprints provided by NASA that describe the potentially affected airspace associated with a Shuttle accident at various points along each reentry trajectory. The areas are depicted as rectangles on a Traffic Situational Display, as shown in Figure 1, and provide additional situational awareness to air traffic controllers. Each series of flow evaluation areas defines a corridor, centered on a nominal Shuttle trajectory, at all altitudes along the portions of that trajectory that over-fly the NAS. Notices To Airmen listing the coordinates of the boundaries of these corridors are distributed to the NAS user community in advance of a landing to alert them of the potentially affected airspace.

Figure 2: STS-121 Recovery Support at the Air Traffic Control System Command Center, courtesy FAA

During a nominal Shuttle reentry, air traffic is allowed to proceed through these flow evaluation areas along normal routes. Traffic managers at the FAA's Command Center and field centers monitor this traffic relative to information received regarding the Shuttle's progress over a dedicated line of communications between the FAA centers and NASA's Mission Control Center, as shown in Figure 2. In the event of an accident, NASA will notify the FAA of the Shuttle's last known position over this line. The FAA will then identify the particular flow evaluation areas that bound the hazardous area and implement traffic management initiatives, including reroutes, ground stops, and temporary flight restrictions, as necessary, to clear them of traffic and keep them clear until the hazards no longer exist.

n preparation for each Shuttle landing, the FAA and NASA conduct several realtime exercises. Each application of this plan presents new challenges and lessons learned. 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 situational awareness aids, and the analyze impacts of Shuttle reentries and other space operations. Accordingly, the DST is being designed to consolidate the necessary analysis, planning, and implementation tools and automate tasks where practical.

As enthusiasm for space tourism and investment in other commercial space ventures increases, the SATMS DST will play in an increasingly pivotal role in providing safe access to the NAS for all of its users. In preparation for these events, the FAA will continue to develop, refine, and optimize traffic management strategies and tools to maximize the safety and efficiency with which these operations are conducted.

The FAA plans to take on the role of integrating air and space traffic into an aerospace traffic control architecture. The Space and Air Traffic Management System lays out the concept of operations for this new paradigm and the Decision Support Tool is the first step in making that process operational. But there is still plenty of work to do. To begin accommodating the generation of space and air traffic, the FAA will have to develop requirements for communications, navigation, and surveillance data for spacecraft operators as well as separation between aircraft and operational spacecraft. The Shuttle is one example of how the FAA will have to work across agencies to accomplish this task. Collaboration with the Air Force, Navy, and Missile Defense will also be required.

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