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Lessons Learned in Operational Space and Air Traffic Management

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Since the STS-114 mission in August of 2005, the FAA has partnered with NASA to protect aircraft flying in the National Airspace System from the potential hazards associated with a catastrophic failure of a reentering Space Shuttle orbiter, similar to that which occurred during STS-107 in February of 2003. This work has produced a set of procedures and tools for use before and during the reentry to provide FAA air traffic managers and controllers with increased situational awareness. An initial approach was implemented for STS-114 based on the need to maximize the time for the FAA to react to an orbiter failure. This approach has evolved over time through the identification of lessons learned on subsequent flights and the subsequent development of additional requirements to address them. This includes the development of the Shuttle Hazard Area to Aircraft Calculator (SHAAC), a dedicated tool for use in both reentry planning and real-time modes. This paper describes some of those key lessons and the approaches taken to address them. Emphasis is placed on those lessons that resulted from specific air traffic management needs. Many of the lessons learned to date have been captured as requirements for a next-generation FAA tool that will provide similar capabilities during the planning and operational phases of the launches and reentries of future commercial space vehicles. Future commercial space operators and air traffic managers in other organizations may find these lessons useful in the development of future tools to support their space and air traffic safety needs.

I. Introduction

IN the spring of 2005, the Federal Aviation Administration (FAA) began investigating the use of existing air traffic tools to establish Temporary Flight Restrictions (TFRs) for protecting aircraft from the potential hazards of a NASA Space Shuttle orbiter failure during the planned reentry of the "Return to Flight" (STS-114) mission. This work was initiated from a recommendation of the Columbia Accident Investigation Board (CAIB), which highlighted the potential risks to aircraft from the hazards of falling spacecraft debris using data from a study of the Space Shuttle *Columbia* (STS-107) accident[1]. Although a number of procedures for FAA support of Shuttle operations were in existence prior to this accident, these procedures did not take into account the potential hazards to aircraft of falling Shuttle debris during a planned reentry.

In the process of this investigation, several approaches to airspace management were considered. Each approach relied on the same key capabilities in its formulation: the ability to accurately model a Shuttle reentry accident, the ability to identify the potentially affected airspace, and the ability to assess the potential impacts on the air traffic in the National Airspace System (NAS). This paper describes the new tools that were developed and the existing tools that were modified to provide FAA air traffic managers with these capabilities. The method by which these tools were used to identify the ultimate approach and the airspace management plan that has been in place since the STS-114 reentry are also discussed. Further, insight gained in the preparation for STS-114 and the operational experience gained in subsequent missions has yielded a number of lessons learned that have been applied to the FAA's support of subsequent Shuttle flights. Many of these lessons learned will apply to the operations of future commercial launch and reentry vehicles that will transit the NAS on their way to and from space.

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II. Background

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 telemetry data and voice communications 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 communication, navigation, and surveillance (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 management 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 and demand imbalances, increasing air traffic 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 time to respond. 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 FAA Air Route Traffic Control Centers (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 opportunity 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.

In addition to its timeliness, the presentation of information to air traffic controllers and managers must take into account existing standards and expectations. In order to minimize the amount of specialized training required, the processes and tools applied to airspace management of space operations must conform as closely as possible to those applied to more traditional airspace management issues. Efforts to obtain conformance could also help in reducing errors, as commonality can provide the air traffic managers with a sense of familiarity with the response to a situation, regardless of its cause. Most air traffic managers in today's workforce lack significant experience in space mission operations. While this presents some issues, as described below, the careful design of the operational plan to manage airspace around space operations can effectively address these issues.

III. Operational Plan

In order to minimize the impact on normal operations in the NAS, it is necessary to limit the amount of protected airspace required for space vehicle operations. For the reentries of the Space Shuttle, the most effective way to reduce the NAS impact is to allow the airspace below the planned trajectory to remain open for regular operations. Once a de-orbit burn occurs, the orbiter begins to reenter the Earth's atmosphere, and will touch down at its landing site, normally at the Kennedy Space Center, within one hour. During that hour, air traffic proceeds as normal along usual routes, but with the awareness that a Shuttle reentry is taking place provided by advanced notification. The advanced notification provides air traffic managers with the opportunity to identify the extent the airspace that can potentially be affected in the event of vehicle breakup. The air traffic managers will in turn examine the traffic flow during this time period in order to prepare for the potential hazard of falling debris. Since the orbiter does not reenter the NAS (i.e., descend below 60,000 ft) until it reaches the restricted airspace above its landing site within minutes of touchdown, a collision between an aircraft and the orbiter is not a matter of concern for reentry. Rather, air traffic managers and controllers monitor the progress of the reentry and prepare to respond to a debris generating event that could occur in the high altitude airspace, sending debris down into the NAS, below 60,000 feet.

Alternatively, the potentially affected airspace from a Shuttle reentry trajectory could be preemptively closed to all air traffic. This would close significant portions of the NAS and capacity demands would be strained. As the FAA prepared for the landing of STS-114 in 2005, it conducted a series of air traffic conflict analyses to determine the potential capacity constraints that closures of the airspace below and ahead of a reentering Shuttle orbiter could create[2]. These analyses examined the impacts to instrument flight rule (IFR) traffic over the continental United States as well as the en-route oceanic traffic over the Pacific Ocean and Gulf of Mexico using recorded air traffic loads. A conflict was recorded for each aircraft within the closed airspace at the time it was closed, as well as each aircraft that was planned or scheduled to enter the closed airspace during the closed periods. Only primary conflicts were identified; aircraft not scheduled to fly through a corridor that would be delayed or rerouted as a result of other aircraft directly affected by an airspace closure were not counted.

In these analyses, the airspace closures were modeled as static TFRs. TFRs are one of several tools available for air traffic managers to use to close airspace. For the case of a Shuttle reentry, beginning at some point prior to the landing, a corridor of airspace spanning in range from the Shuttle's current position to the landing site and in altitude from the Shuttle's current altitude to the surface could be closed until the notification arrived of a successful landing or an accident. An example 25-mile wide corridor, plotted over the boundaries of the NAS air traffic control sectors, is shown in Figure 1.

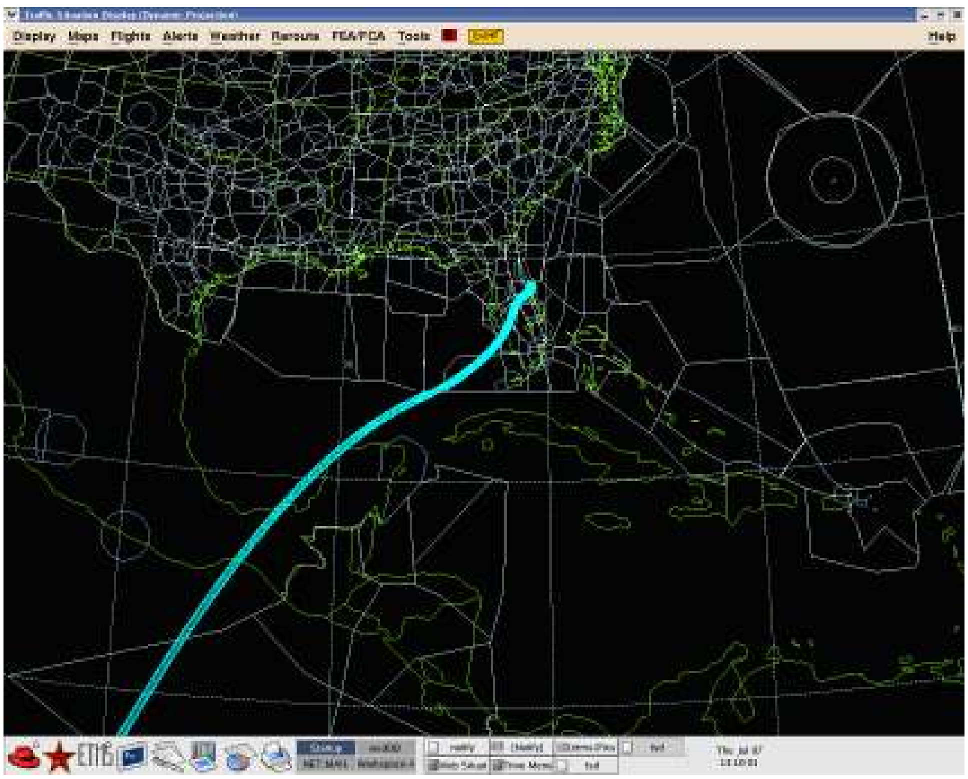

Figure 1. Example Shuttle Reentry Airspace Corridor.

The minimum amount of time that the airspace would need to remain closed would depend upon the amount of time required for the Shuttle to traverse the length of this corridor and any additional time prior to the Shuttle's arrival required to clear the corridor of ambient traffic.

To examine the sensitivity to duration of a closure, the number of conflicts was counted over 35, 45, and 60-minute intervals. Analyses were conducted for several landing opportunities at each of the three potential landing sites at different times of day and different days of the week. For each scenario, a corridor of closed airspace was established along the nominal trajectory. The width of a corridor, measured as the perpendicular distance from the centerline to either edge, was kept constant for each scenario, but was varied from scenario to scenario. The results of an example analysis, corresponding to an 11:00 AM local time landing at KSC are listed in Table 1.

Table 1. Traffic Conflicts for Hazard Corridor for Mid-Day KSC Landing.

Duration (min)	Corridor Width (nmi)		
	20	40	50
35	105	126	142
45	121	146	158
60	159	184	195

The results of this analysis show that significant amount of traffic would be affected. Similar analyses conducted for Edwards Air Force Base and White Sands Space Harbor showed similar results. Airspace closures, particularly those of the size and duration depicted above, are potentially complex and costly activities, requiring a level of coordination between air traffic managers and airspace customers that can take days to plan and establish. In addition to incurring delays, rerouting of flights sometimes requires particular flights to carry additional fuel, or, for flights that are already fuel-optimized, such as trans-Pacific flights, to be diverted to an alternate airport. In this regard, airspace closures can have a cascading effect across the NAS. Accordingly, the FAA determined that the airspace below a reentering Shuttle should remain open for normal air traffic operations, provided that an operational plan was in place to notify airspace users in advance and provide air traffic controllers with the necessary information to appropriately address a potential accident.

To provide the airspace-using community with the awareness that an operation is taking place, the Air Traffic Control System Command Center (ATCSCC) issues Notices to Airmen (NOTAMs). These notices are created prior to all proposed landing operations once NASA provides the FAA with trajectory data describing each opportunity, which generally occurs 48 hours in advance of the first landing opportunity. The ATCSCC uses the trajectory data to specify a series of latitude/longitude coordinates that identify the airspace under Advisory. For reentries of the Shuttle, the NOTAM is called a "Space Shuttle Landing Operations Advisory". An example is shown in Figure 2 below.

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FDC 9/1945 (A0856/09) - ...SPACE SHUTTLE LANDING OPERATIONS ADVISORY...
   EFFECTIVE 0911271848 UTC UNTIL 0911271923 UTC SPACE SHUTTLE
LANDING OPERATIONS 25 NM EITHER SIDE OF THE LINE BETWEEN
2743S/17214W 0411N/16214W 2925N/13455W 3440N/11828W 3457N/11745W
FROM SURFACE TO UNLIMITED. WIE UNTIL UFN. CREATED: 25 NOV 21:11 2009
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Figure 2. Example Shuttle NOTAM.

These NOTAMs notify airspace users that the specific area 25 nautical miles to either side of the nominal reentry trajectory is potentially vulnerable to debris, but the airspace is not closed. These advisories provide users the opportunity to plan according to the available information, but they do not prevent the airspace from normal operations, which would create a major impact to the NAS. When several landing opportunities may be considered, all of the applicable NOTAMs are created 48 hours prior to the first opportunity. The ATCSCC transmits the applicable NOTAM upon the completion of de-orbit burn, which is consequently cancelled in the minutes following a successful touchdown. Space vehicle debris advisory NOTAMs are currently created manually, but their creation should be automated through the system along with future developments to enable accurate space vehicle tracking, debris hazard area calculations and emergency movement protocols.

Maximizing the response time if a debris event occurs will allow controllers to clear the affected airspace and implement other necessary traffic management initiatives, such as increased separation of adjacent traffic and ground stops at underlying airports. Predictions of the locations and extent of the airspace that could be hazarded provide air traffic managers and controllers with opportunities to plan and practice their response. Real time calculations, providing the best estimate of the extent of a debris event, must provide results to managers and controllers within a matter of seconds, in order to clear the affected airspace prior to collision opportunities. Additional procedures include the ability to quickly and efficiently shift support between alternative landing sites that are situated across the continent. Coordinating with the ARTCCs across the NAS requires immediate action, including the input and display of new trajectories and predicted debris hazard areas, NOTAM activation, and time zone considerations. It is standard practice to keep traffic managers from these centers on an open teleconference line during a Shuttle reentry for contingency planning. Direct communications with NASA's Mission Control Center are advantageous for air traffic coordination, for direct notification of contingency plans, landing waive-offs, and off-nominal events.

As the first indication of a debris-producing event could be the loss of communications with the orbiter, air traffic controllers should also be made aware of any potential loss of signal or degraded signal periods during the reentry. Knowing these communication losses in advance will prevent air traffic from assuming a vehicle breakup has occurred, and initiating traffic management initiatives. Additionally, the real time calculations change to take these losses into account, as described in the following section, since the location of a vehicle loss cannot be pinpointed during that blackout period. The resulting airspace closure would be larger, necessitating the movement of more aircraft, and additional work for the controller, which should be identified immediately.

The launches and reentries of future commercial space vehicles will incur similar, complicating issues as those described for Shuttle reentries. These vehicles may utilize multiple, geographically separated landing sites. They may also be subject to similarly tight weather and operational constraints. Preliminary estimates of the capacity impact for these vehicles are of similar magnitude to those of the Shuttle described above. Accordingly, large scaled preemptive airspace closures for future commercial space operations are similarly undesirable. While these space vehicles may present a safety risk within the NAS, it has been demonstrated with the Shuttle that normal operations can continue in the airspace, with the proper data sharing, communication and planning to enable educated decision making.

IV. Shuttle Hazard Area to Aircraft Calculator

The need to accurately model a Shuttle reentry accident and the ability to identify the potentially affected airspace prompted the FAA to develop a dedicated tool to support Shuttle reentries. The Shuttle Hazard Area to Aircraft Calculator (SHAAC) tool works in both a planning mode and a realtime mode to predict the extent of the airspace that could contain falling debris hazardous to aircraft in the event of a Shuttle breakup during reentry. The requirements for this tool were based on a similar tool developed by NASA's Johnson Space Center Shuttle Descent Analysis Group[3]. The NASA tool uses a simplified Shuttle debris catalog and input wind characteristics to predict the size and location of a "footprint" that would contain the debris of the Shuttle if it were to break apart along a given trajectory at a given time.

SHAAC performs the same operation as the NASA tool, but it is tailored for airspace management use. Similar to the NASA tool, SHAAC outputs an aircraft hazard area, or debris footprint, for each Shuttle state vector it receives. This hazard area depicts the extent of the airspace that could contain falling debris hazardous to aircraft if the Shuttle were to break apart at the time, position, and velocity associated with the input state vector. The hazard area computation can be conducted repeatedly in a planning mode, producing a file of hazard areas based on an input file of state vectors, or in a "realtime" mode, producing a single hazard area for a single state vector. The detailed methodology for these computations is described in reference 4.

In addition to a Shuttle trajectory file, SHAAC imports forecasted wind data from the National Oceanic and Atmospheric Administration (NOAA) via a downloaded file. The use of forecasted wind data provides an accurate assessment of the additional airspace that could be affected by falling debris entrained in the prevailing winds. As there is a degree of uncertainty in the wind forecast, which increases with increasing time from the actual landing time, SHAAC applies an uncertainty factor to the length and width of the computed hazard areas. The extent of this factor also accounts for the debris to potentially generate lift as it falls.

SHAAC outputs a set of four latitude/longitude coordinate pairs for each hazard area. These coordinates form a box that surrounds the airspace containing the hazardous debris. Four coordinates represent the ideal number of coordinates needed to represent this airspace on an air traffic control display, as described in the following section. The FAA uses SHAAC's planning mode to develop a preliminary set of aircraft hazard areas that are distributed to the potentially affected air traffic facilities. This preliminary set consists of a series of fifteen hazard areas for each potential landing trajectory. The air traffic managers at the ARTCCs use the planning mode results to obtain a preliminary look at the extent of the potentially affected airspace and the times at which the airspace may be affected. This information allows them to anticipate the potential air traffic load and plan their staffing of the reentry. In realtime mode, SHAAC outputs a best estimate of the single hazard area that describes the affected airspace.

For ease of use, SHAAC was designed to minimize the number of inputs required to produce the necessary outputs. This is essential in realtime mode, where a solution must be computed as quickly as possible (15 seconds or less per requirement) in order to maximize the time to respond. At the same time, the inputs were simplified in order to adapt the tool for use by air traffic managers. As discussed in more detail below, typical air traffic managers, while highly skilled in airspace management, generally lack space mission operations expertise. In an effort to minimize the amount of training required to run the tool, including any insight into the mathematics and physics which underlie the computation, the number of inputs was kept at a minimum. Specifically, the debris characteristics of the Shuttle, specified in terms of ballistic coefficient, were removed from the list of potential inputs and provided as default values for the tool. Default values were also provided for the uncertainty parameters associated with the wind and lift characteristics of the debris. Figure 3 shows the user input for the planning mode.

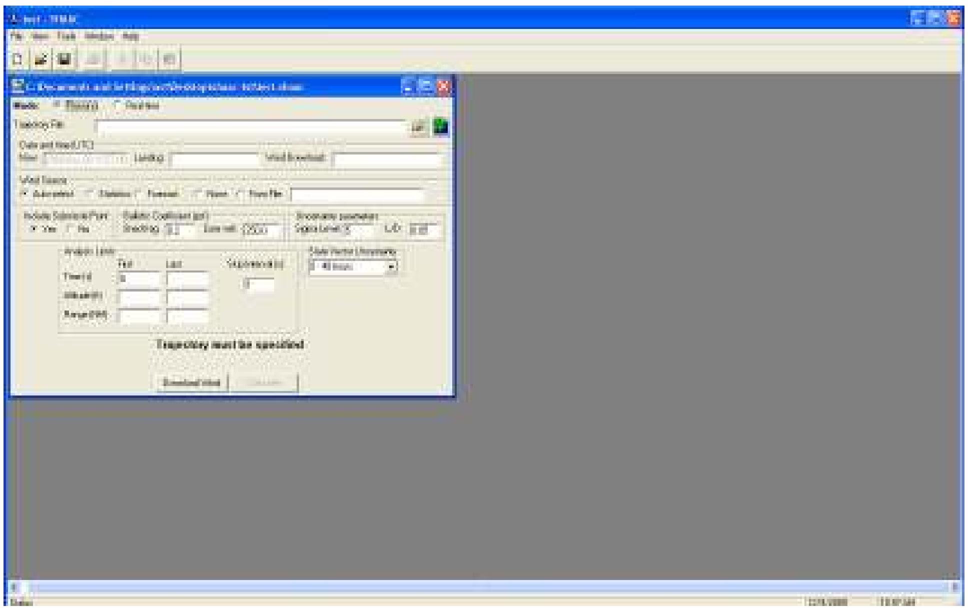

Figure 3. SHAAC User Interface.

Since its initial application, SHAAC has received two major enhancements. These enhancements incorporated the capability to characterize the uncertainty in the predicted Shuttle nominal trajectories received from NASA and the means to model the flight of the Shuttle during periods in which it loses contact with Mission Control. Both of these enhancements are described below.

The actual Shuttle flight during a nominal reentry can vary from NASA's trajectory prediction by such an amount that the computed hazard area could misrepresent the airspace at risk. Figure 4 below shows an example from a previous mission. In this case, the difference between the planned trajectory and the actual trajectory was large enough to offset the Shuttle's actual position (shown as a red line) outside the predicted hazard areas (shown as colored boxes).

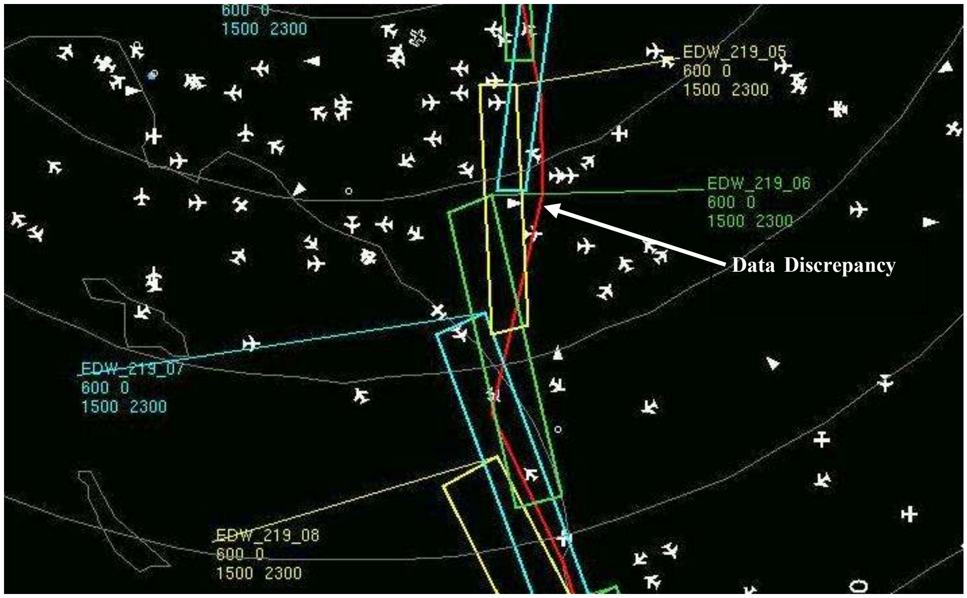

Figure 4. STS-117 Traffic Situational Display of Data Discrepancy.

The causes of these discrepancies vary. In some cases, NASA may change the runway being targeted as the orbiter approaches (switching the approach to the opposite end) based on prevailing weather. In other cases, the Shuttle's onboard guidance may make fine adjustments based on the conditions it encounters during the reentry. These adjustments can cause it to make energy management maneuvers earlier or later than predicted, as was the case in the divergence shown in Figure 4. Statistics based on predicted versus actual trajectories have been collected for many of the Shuttle flights since STS-114 and used to incorporate a guidance and performance trajectory uncertainty into the size of the hazard areas computed in the SHAAC planning mode, making them slightly larger. The extent of the uncertainty is based on the difference between the time at which the planned trajectory (provided by NASA 24 to 48 hours in advance) is constructed and the time of the actual reentry. SHAAC allows the user to apply trajectory uncertainty modeling or not (the default value applies uncertainty). Accordingly, any hazard areas computed using this capability will include more area (individual hazard areas will be both longer and wider) than those computed without it.

As mentioned above, during a nominal reentry the orbiter sometimes passes through brief periods in which both voice and telemetry communications with Mission Control are lost. The timing and duration of these loss-of-signal (LOS) periods are typically known in advance. An LOS is often experienced when the orbiter is in a turn and a wing rises up to the point where it blocks the line of sight of the antenna on the top of the orbiter with the Tracking and Data Relay Satellites. Should the orbiter suffer a breakup during one of these LOS periods, the lack of reestablished communications with the orbiter at the predicted acquisition of signal (AOS) time might be NASA's only indication. In that case, a hazard area computed based on the last received state vector values (corresponding to the time at which LOS occurred) may not adequately characterize the area at risk, as the orbiter may have been capable of continuing to fly for some amount of time beyond the LOS point before suffering a breakup. Therefore, in the realtime mode, SHAAC computes a larger hazard area assuming that the orbiter could have continued flying in any direction for an input LOS duration, which could be based either on the time that the LOS condition was scheduled to end or the time at which NASA receives some other indication that a breakup has occurred. SHAAC computes the larger hazard area by modeling the lift acceleration that could act on the orbiter during the LOS period in all possible directions of flight.

The requirements for both of these enhancements were identified through experience gained in supporting Shuttle landings since the return to flight mission. This underscores the importance of developing space operations expertise in the air traffic managers who became the users of this tool, a point which is elaborated on further in the following section.

V. Air Traffic Controller Considerations

Space traffic control is a term that is frequently misused to describe a type of air traffic control of space vehicles. One of the main elements of contention with this term involves the physics of space vehicle performance, which limits their maneuverability and the duration of their operations in the NAS. Alternatively, airspace management around space operations is the optimal means of integrating space vehicles into the NAS. The challenges presented by space vehicles operating in the NAS require a delicate balance of air traffic management, which takes into account the current operational procedures while reducing preemptive and reactive approaches to handling air traffic conflicts. Seamlessly integrating regular space vehicle operations into the NAS will require new approaches to data sharing that will conform to air traffic controller and airspace user needs and expectations.

One of the foremost concerns for data sharing between space operations and the current air traffic management systems is the presentation of data on an air traffic controller's display. Whether data is imported through automated systems or manually, it should be reduced to a concise data set required to indicate the location and extent of the affected airspace. As discussed, this is currently accomplished by creating conservatively sized rectangular debris hazard areas. Emergency protocols might require the verbal transmission and manual input of data, and therefore fewer coordinate pairs and simple shapes are required. In planning mode, the debris hazard areas should overlap. A slight overlap eliminates gaps in the potentially affected airspace, allowing air traffic managers to use a subset of the rectangles to initially overestimate a hazarded area in the event of an accident, until refined calculations can produce a best estimate of the area. In the interest of preventing confusion on behalf of the air traffic controller, the trajectory information shared on the air traffic display should be sufficient to accurately characterize the trajectory without cluttering the screen. To maintain an accurate depiction of the operations, overlap of the hazard areas should be optimized, especially in the turning portions of the trajectories, and areas that completely contain smaller fields should be eliminated. Figure 5 shows a typically configured Traffic Situational Display (TSD) with hazard flow evaluation areas.

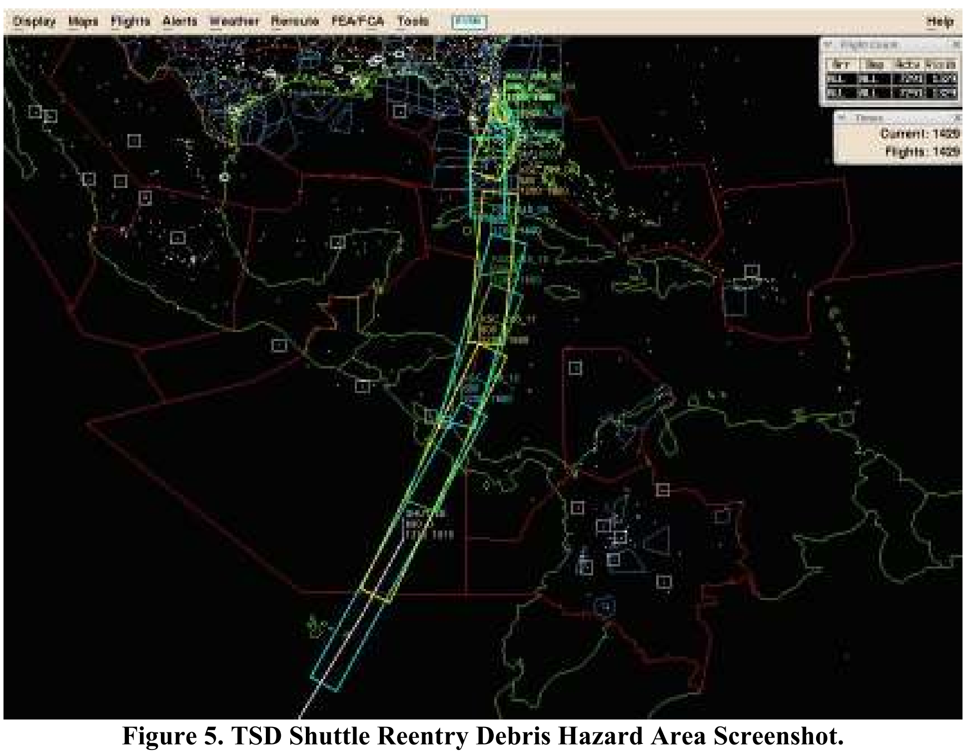

Figure 5. TSD Shuttle Reentry Debris Hazard Area Screenshot.

In the interest of minimizing the impact on the NAS, air traffic controllers may be working sectors with regular traffic while at the same time monitoring the air traffic flow in and around potential debris fields denoted for a reentry trajectory. In the case of nominal reentry operations, an air traffic controller may prefer the ability to hide the field display on their screen, until the vehicle actually overflies the airspace of interest. Enabling these types of options on the air traffic display will support more seamless airspace management around the space operations, and enhance an air traffic controller's ability to focus on the imminent traffic needs as necessary. Sharing additional data, such as the tracking of a vehicle's position in regard to the debris hazard areas, at a real time rate will also enhance air traffic manager and controller judgment and decision making in the event of off-nominal operations requiring air traffic rerouting. Having access to real time streaming data is also necessary to enhance traffic management awareness. The TSD is currently updated manually to reflect the Shuttle's current position relative to the predicted debris hazard areas via flowing information from NASA for Shuttle operations, and latitude and longitude points are relayed on a digital display with verbal confirmation. All commercial space vehicles will need to provide this data at a minimum, and direct vehicle communication will allow for verbal updates on the vehicle health status, weather constraints, and event notification.

Tools such as SHAAC will eventually be integrated into the Traffic Flow Management System (TFMS), allowing for minimal controller specialization with respect to space vehicle operations. While these tools are in development and vehicle launches are not commonplace, a dedicated group of traffic managers and controllers will provide expertise on these operations. Immediate obstacles that will need to be overcome include gathering devoted staff with sufficient levels of awareness and experience with the tools, who can comfortably support these missions. Dedicated controllers could work at all hours of the day, covering different shifts according to mission needs. Mission pre-planning would be similar to flight planning for typical airline operations, except earlier in the schedule. The schedule for the mission, predicted trajectories and hazard area computation would be required in advance of the launch or reentry day. Depending upon the tools that may be integrated into the TFMS, data will need to be transferred, and potentially modified for numerous uses.

As mentioned previously, the majority of air traffic managers and controllers lack significant experience in space mission operations. Tools and processes are tailored accordingly to accommodate their needs, as described above. However, a general knowledge of space mission operations is also useful to provide context and perspective. Such knowledge can better facilitate the airspace management operations by providing controllers and managers with a better understanding of the rationale behind a space vehicle operator's decisions and the constraints that can frame these decisions. These constraints are important as they can affect the timing of events. For example, weather constraints, expressed in terms of wind speeds and directions, precipitation amounts, and visibility, may prompt a space vehicle operator to choose one landing opportunity over another. In addition, for piloted vehicles, crew considerations may become a factor, as increasing fatigue from living and working in space for extended durations may prompt an operator to choose a daylight landing opportunity, which is generally less taxing, over a night landing opportunity.

Operational constraints may also affect the geographical area in which the operations take place. For example, vehicles in orbit pass over a particular landing site on the Earth's surface multiple times per day, providing a number of opportunities to de-orbit and land, depending upon the vehicle's crossrange capability. However, some of these opportunities take place on what are called ascending orbits and others take place on descending orbits. Ascending orbits are those in which the vehicle crosses the equator from south to north as it approaches its landing site. Descending orbits move from north to south as they approach the site. For landings at U.S. sites, ascending orbits provide the advantage of minimizing the amount of land that is overflown during the reentry, as approaches from the south overfly the Pacific Ocean or Gulf of Mexico. The ability of air traffic managers to approach the airspace management of space operations in light of the orbital dynamics and vehicle performance constraints of an operator could facilitate greater understanding and more efficient planning.

VI. Implications for the Future

Ultimately, the long term goal for air traffic will be to treat airspace management around space operations in the same manner as any other typical operational problem. Airspace management currently overcomes issues such as severe dynamic weather, VIP movements, military exercises, and system capacity demands. To ensure the seamless integration of space vehicles into the NAS, high data rate processing, flight planning and real time data communication will be required. Due to the speeds of these vehicles, high rate surveillance and tracking data must be accepted and processed by the system and tools, while being filtered and displayed alongside standard aircraft traffic data. Flight planning for launch and reentry vehicles will be required in advance of missions, and much earlier than traditional aviation flight plans. These plans will allow air traffic controllers to manage the mission needs and impacts to the NAS, while adapting to the off-nominal events through planning and prediction tools. Tool adaptation and flexible support for numerous vehicles will permit real time debris hazard area calculations for minimizing risk and enhancing the safety of the NAS. Likewise, the capability to instantaneously transmit NOTAM and warning information through digital data systems straight into the cockpit will improve response time and increase situational awareness in the airspace[5]. Data sharing in the cockpit will necessitate precise implementation procedures for airspace clearance and re-routing on behalf of air traffic managers. The procedures for responding to a vehicle failure should be user-friendly and produce solutions with minimal tool-specific training, to avoid unnecessary burden on pilots, dispatchers and controllers. Ensuring safe means for airspace adaptation and responsive maneuvers will facilitate space vehicle integration into the world's safest aviation system.

VII. Conclusion

As the current air traffic control systems merge into the FAA's Next Generation Air Transportation (NextGen) system, airspace management around space operations will be as commonplace as traditional air traffic control. As demonstrated with the support of the Space Shuttle reentries, the ability to maintain regular operations in the NAS without interruption during space vehicle events is a reality. Space operations will not be special events that require case-by-case management procedures, but rather, exercises of the truly flexible and reliable capabilities of the NextGen system. The development of dependable tools and procedures, controller training and vehicle equipage will be critical to the overall growth and success of the air traffic system. Through continued data sharing, lessons learned and industry effort, the FAA can develop the requirements necessary to build adaptable systems and respond to commercial space transportation needs. The FAA will continue to successfully manage the NAS and provide the world's safest and most reliable aviation system for both aircraft and spacecraft users.

References

[1] Carbon, S., Larson, E., "Modeling of Risk to Aircraft from Space Vehicle Debris", Proceedings of the 2005 AIAA Atmospheric Flight Mechanics Conference and Exhibit, AIAA-2005-6506, August 2005

[2] VanSuetendael, R., Baart, D., et al., "Final Report: FAA Airspace Analyses for Space Shuttle Return to Flight (STS-114) Recovery", Federal Aviation Administration, September, 2005 (unpublished)

[3] Mendeck, G., Graybeal, S., "Probabilistic Debris Impact Modeling for Public Risk Analyses", Proceedings of the 2005 AIAA Atmospheric Flight Mechanics Conference and Exhibit, AIAA-2005-6320, August 2005

[4] Larson, E. and Carbon, S., "Automated Calculation of Aircraft Hazard Areas from Space Vehicle Accidents: Application to the Shuttle", Proceedings of the 2008 AIAA Atmospheric Flight Mechanics Conference and Exhibit, AIAA-2008-6889, August, 2008

[5] Murray, D., Livack, G., "Graphical Cockpit-Based Depictions of Space Vehicle Operations Based Upon Use of Aeronautical Information Data Link Services", Proceedings of the 3rd International Association for the Advancement of Space Safety, October 2008