

GRAPHICAL COCKPIT-BASED DEPICTIONS OF SPACE VEHICLE OPERATIONS BASED UPON USE OF AERONAUTICAL INFORMATION DATA LINK SERVICES *

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ABSTRACT

To facilitate a more efficient use of domestic and oceanic airspace while maintaining the current level of safety for the public, the Federal Aviation Administration (FAA) is researching new technologies and capabilities that would speed the flow of flight critical information to necessary user recipients. The intent is to increase overall situational awareness for each user segment. To this end, the FAA is developing a Concept of Operations (ConOps) for the graphical cockpit depiction of space vehicle flight operations as part of a proposed addition to the FAA's Next Generation Air Transportation System (NextGen) Integrated Work Plan. The emergence of cockpit-based data link technologies permits the provision and use of data linked aeronautical information services directly to aircraft as well as the sharing of this same information with Air Traffic Control (ATC) and with the airline's operational control (AOC) function. This concept represents an additional means of enabling a framework for seamlessly integrating space vehicles on their way to and from space with more traditional air traffic management functions. By developing a means to provide timely alerts to aircraft, greater airspace access should be maintained from all users, without disruptions to today's global airspace use while, at the same time, fostering the development of this new fledging industry.

1. BACKGROUND

The FAA is developing a Concept of Operations (ConOps) for the graphical cockpit depiction of space vehicle flight operations as part of an overall integrated space and air traffic management concept. This emerging concept of operations represents a framework for seamlessly integrating commercial and government space vehicles on their way to and from space with the more traditional air traffic management functions, and with those airspace users that only operate within the confines of the atmosphere. In doing so, this ConOps calls for "assured separation" between space and terrestrial-based air traffic, and envisions new space and air traffic management tools and enhanced

communications, navigation, and surveillance services, allowing for real time sharing of information among all airspace users, globally.

Up to this point in time, the FAA was planning to rely only upon its traditional Notices to Airmen (NOTAM) system and the complex designation of Special Use Airspace (SUA) to separate space launches and re-entries from other terrestrial air traffic. These NOTAMs were to be issued in conjunction with the space flight operations taking place in the National Airspace System (NAS) and in oceanic/remote airspace. In context, these NOTAMs would serve as a pre-flight briefing tool, but updated/revised NOTAMs would not be structured for rapid communications to flight crews for their in-flight use. However, the emergence of various robust data link technologies now permits the provision and use of data linked aeronautical information services (AIS) direct to the cockpit as well as the sharing of the same information with the air traffic management (ATM) function, with controllers, and with the airline's operational control function (AOC), as shown in Fig. 1 below.

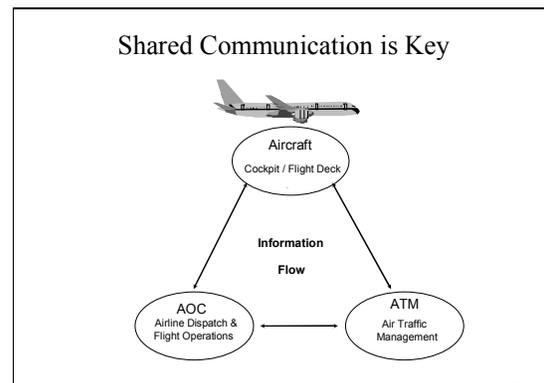


Figure 1. Shared situational Awareness between the Aircraft, the AOC Function, and ATM

Typically, the airspace to be depicted for space vehicle operations is sized for the largest vehicles and the frequency of use for those vehicles that are expected to use them, with fixed boundaries and extended activation

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periods to cover the delays associated with the launch process. This creates a significant impact on air traffic operations, requiring extensive advanced coordination with various air traffic entities, which, in turn, will be difficult to accommodate during launch/landing delays and scrubs.

One critical area, for example, is the North Atlantic Track System during peak travel times. Here, many aircraft are operating in-trail along a limited number of fixed routes, each separated by 10 minutes in-trail based on Mach number technique, and 1,000 feet vertical separation. To complicate matters, other aircraft may be operating nearby along random routes. To stand-down the entire route structure or to delay flight operations throughout this area would result in a major disruption to international air commerce.

Additionally, in the event of a space vehicle malfunction during flight over or through the NAS, or within oceanic/remote airspace, debris could fall on any aircraft below. Research has shown that a small piece of steel weighing as little as one gram can produce catastrophic damage to an aircraft in flight, jeopardizing the safety of all onboard. To mitigate this hazard, the FAA is developing predictive tools that will estimate the extent of the airspace that may contain debris hazardous to aircraft in the event of a space vehicle malfunction. This information can be developed well in advance of a space vehicle operation and can be used to alert controllers and airspace users of the potential hazards so that they can take whatever precautions they find appropriate. In addition, in the event of a space vehicle accident, the FAA will be able to estimate the extent of the airspace containing falling debris and the amount of time that nearby aircraft will need to remain clear of the affected airspace. Alternatively, identification of the impacted area could allow aircraft to fly through the predicated debris field, while accepting the associated risks. In some instances, it may take as long as 90 minutes for all of the hazardous debris to fall to earth.

The timing and urgency for this paper is significant. Within the next ten years, the number of air traffic operations in the NAS is expected to double while space operations, in the form of research and development flights, space tourism flights, prize attempts, commercial International Space Station (ISS) re-supply missions, and military operational responsive space missions is expected to steadily increase. Vehicles will be launched and recovered from as many as 10 different spaceports in the U.S., many of which will lie well inland of the coastal sites that have traditional hosted such operations. This may result in a major impact to passenger and cargo flight operations unless adjustive strategies are developed and implemented. For example, Fig. 2 shows an artist's rendering of a concept

vehicle unveiled recently that is planned to begin suborbital flights from Mojave, CA in 2010. Upwards of two flights per day are planned, with proposed operations requiring large tracts of airspace to be NOTAMed as "off limits." Since space vehicle operations will initially be conducted from launch sites in California and New Mexico, it is expected that a significant number of commercial and general aviation flights operating in the southwestern U.S. will be adversely affected unless appropriate procedures and mitigations are developed, validated, and implemented.



Figure 2: XCOR Lynx Reusable Suborbital Rocket (courtesy XCOR Aerospace)

Additionally, by 2015, NASA plans to introduce a new space vehicle (named Orion) that could impact commercial flight operations in domestic as well as oceanic airspace. This includes the vehicle's launch phase which could influence commercial flight operations over the North Atlantic. Fig. 3 shows an example ascent trajectory to the ISS, plotted in blue over an example set of air traffic North Atlantic Tracks, plotted in red. A malfunction during launch could cause the vehicle or its debris to fall through this airspace.



Figure 3: Example Ascent Trajectory of the Planned NASA Orion Space Vehicle

To further complicate matters, unlike the Space Shuttle, the new NASA space vehicle will make use of oceanic recovery, with nominal splashdown expected to occur off the coast of San Diego, California. A malfunction during re-entry could cause these vehicles to land far inland, posing a significant albeit short-term hazard to both air carrier and general aviation flight operations.

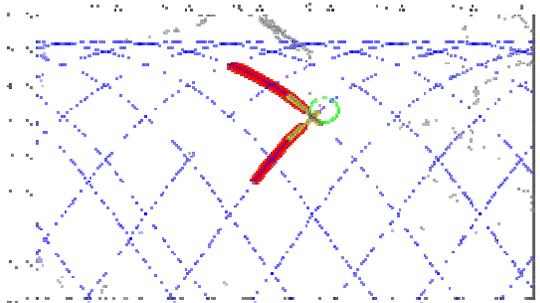


Figure 4: NASA's Planned Space Vehicle Recovery Process (courtesy NASA)

By developing a means to provide timely information and alerts to pilots, greater airspace access could be maintained, without disruptions to today's global airspace use, while at the same time fostering development of the new fledging space industry, and maintaining a high degree of safety.

Initially, the number and type of space operations will be limited in terms of their geographical locations. As such, there may be a tendency for the associated NOTAM information to produce confusion among untrained flight crews because of the relatively low frequency of NOTAM issuance as compared to other events. This may be especially prevalent in the early implementation phases, when the potential for misinformation may be high. Because of this, procedures defining communication and coordination between those responsible for these space vehicles, flight crews and air traffic control will need to be carefully defined. System safety analyses will need to identify and eliminate, control, or accept each of the operational hazards identified. Flight crew notification of the existence of a hazard would be a most helpful first step in mitigating the hazards. The FAA anticipates that as space launch and reentry operations increase, the response to anomalies associated with these operations will need to be incorporated into routine flight procedures.

At a low level of involvement, the FAA is currently exercising the above capabilities during each of remaining NASA Space Shuttle reentries. Following the Shuttle *Columbia* accident of 2003, the FAA and NASA agreed to share data and develop procedures to protect aircraft in the event of a similar accident. Prior

to a Shuttle reentry, the FAA uses its Shuttle Hazard Area to Aircraft Calculator (SHAAC) tool to predict the size and locations of potential hazard areas along the Shuttle's planned reentry trajectory. These hazard areas are then graphically depicted and distributed to the impacted air traffic facilities for display on air traffic tools, such as a Traffic Situational Display (TSD) shown in Fig. 5.



Figure 5: Traffic Situational Display Depicting Shuttle Reentry Trajectory and Traditional Air Traffic

In Fig. 5, each box represents a discrete hazard area corresponding to a Shuttle failure at a particular point along its predicted reentry trajectory. In the event of an accident, the FAA intends to use its SHAAC tool to compute a real time estimate of what would be the affected airspace. This estimate would then be distributed on a priority basis among the appropriate air traffic facilities, who, in turn, could implement appropriate traffic management initiatives such as establishing Temporary Flight Restrictions (TFRs), rerouting aircraft within or approaching the affected areas, and implementing ground stops at underlying airports. The technical metrics to quickly identify the affected airspace and develop, approve, publish, and disseminate such NOTAMs are still being developed. Such NOTAMs are called "stressing" as they establish severe technical performance requirements regarding the collection, processing, dissemination, receipt, and display of information on the flight deck (air carrier) or in the cockpit (general aviation).

Assuming that performance metrics can be established with the appropriate level of integrity, continuity, and availability of service, this paper proceeds to identify architectures and candidate message set elements for the provision of data link services direct to flight crews. (Another paper in preparation will expand this same thinking to the provision of real-time air-to-air surveillance services utilizing emerging data link technology.) The following are the three safety centric space vehicle data link options being considered:

1. Providing data link messages that would enable graphical cockpit depictions of planned space vehicle trajectories during all normal space vehicle launch and reentry operations. This includes the timely notification of the space vehicle's position and trajectory intent transmitted to nearby aircraft while overcoming the latency issues associated with delayed air-to-ground-to-air transmission of alerts or warnings.
2. Graphical cockpit depictions of predicted space vehicle debris hazard areas that result from a failed launch or reentry. Additionally, these depictions would also address those instances where the space vehicle was anticipated not to land in its originally designated area, but would land short, long, or at an alternate site. These depictions may take the form of routine ground-to-air graphical AIS NOTAM products based upon predictions, telemetry, or other data. Data would be sent in a timely manner to suitably equipped aircraft, both air carrier and general aviation.
3. A graphical cockpit depiction of the estimated space debris hazard area in the event of a launch or reentry incident and / or accident. This application would take the form of a priority ground-to-air graphical AIS data linked NOTAM product estimating the extent and duration of the affected airspace should an event occur

2. APPLICATION OF THE PROVISION OF AERONAUTICAL INFORMATION SERVICES (AIS) DATA LINK

From a flight safety perspective, space operations should not impact any more airspace than is absolutely necessary, and the airspace impacted should not be impacted for any longer than necessary. To facilitate a more efficient use of airspace while maintaining the current level of safety for the public, the FAA is researching new technologies and capabilities that would speed the flow of critical information to the necessary recipients and increase situational awareness. Two technical options are proposed here for further consideration:

- The transmission of real-time crosslinked space vehicle flight data via a suitable data link. (This topic is outside the scope of this paper.) Using such a crosslinked, exchanged message, critical data could be transmitted directly to the cockpit of all

aircraft at risk. The exchanged (broadcast) message would describe the trajectory and hazards associated with nominal and off-nominal space launch and reentry operations.

- The uplink of data from which to create a graphical aeronautical information services (AIS) NOTAM with a message format and content similar to what may be provided to flight crews for other aeronautical information purposes (e.g., the depiction of closed runways and/or taxiways on an airport electronic moving map depiction, the existence of temporary restricted / segregated airspace). Such an application would be used to increase situational awareness during space vehicle operations.

It is this latter means that provides flight crews with time perishable space hazard data that is suggested in this paper, assuming that appropriate procedures can be developed, validated, and globally accepted and implemented.

To expedite the flow of information and increase the available flight crew time to react, aeronautical information would be transmitted to and received onboard each suitably equipped aircraft. Data from which to create text and graphical information displays describing the planned route of the space vehicle over and through the NAS and oceanic/remote airspace would be transmitted. Representation of this information could be similar to the example shown in Fig. 6 below, consisting of the planned route and the corresponding predicted possible debris hazard areas overlaid on an electronic moving map with own-ship position depicted should an incident / accident be imminent.



Figure 6: Predicted Shuttle Reentry Hazard Areas

This information could be potentially displayed on the same cockpit multifunction displays and electronic flight bags (EFBs) in use today to depict navigation, traffic, and weather information, thus consolidating the entire pilot's needed situational awareness information in one location. The same information could also be supplemented with the addition of a Vertical Situational

Awareness Display (VSAD) depicting the planned space vehicle trajectory in the vertical plane (i.e., altitude versus range). VSAD displays are currently making their way into the cockpit as part of new multifunction displays and EFB systems.

Then, during the actual space vehicle flight, tracking or telemetry data, perhaps based upon air-to-ground Automatic Dependent Surveillance-Broadcast (ADS-B) data received from the space vehicle, would be used to describe its actual vehicle path along with its planned path in the form of projected trajectory change points (i.e., programmed and actual trajectory waypoints). If a hazardous situation should occur involving the space vehicle, its last known position and the corresponding estimate of the affected airspace that may contain debris hazardous to aircraft could be uplinked to all aircraft in the vicinity. An example is shown in the following figure.



Figure 7: One Possible Graphical Cockpit Display Presentation of a Space Debris Field

3. COCKPIT-BASED PROCEDURES

Upon receipt of an AIS message indicating an imminent safety hazard, pilots of aircraft at risk could consider taking evasive action by executing predefined procedures for evacuating or avoiding the area consistent with approved FAA and company policies. Obviously, such contingency procedures would need to be developed for both visual flight rule (VFR) and instrument flight rule (IFR) operations. The approach suggested is similar in principle to that used by aircraft flying in areas where today's flight operations may encounter unforecast volcanic ash or severe icing, requiring an immediate change in routing, altitude or both. For example, the following excerpt is taken from the flight operations manual of a major U.S. airline. It instructs their flight crews to take certain action upon encountering a region of severe icing or receiving a severe icing alert, as follows:

“En Route Icing -- Policy: Aircraft are prohibited from operating into areas of known or forecasted severe

icing. If severe icing is unavoidably encountered, the pilot should change altitude, course or proceed to a suitable airport and land.”

As envisioned, if an aircraft were to be alerted to a hazardous area along its flight path that required the aircraft to make an immediate deviation, the pilot (if operating under VFR) might simply alter course to circumvent the hazard in the most efficient perceived way. If the aircraft found itself within the affected area, the pilot (again, if operating under VFR) could immediately alter the route of flight to egress the affected area in the minimum time possible.

If the aircraft was flying domestically on an instrument flight plan and had communications with air traffic, compliance with an amended ATC clearance would be the appropriate course of action. Occasionally, even though effective communications may exist, ATC may be unable to approve an immediate deviation due to conflicting traffic or proximity to nearby warning areas, etc. However, just like in the case of severe weather, deviation procedures might be developed for instances where an immediate routing change may be required. Likewise, in the event of an immediate space debris hazard, if a clearance was not available, the pilot could exercise his or her pilot-in-command prerogatives and execute an approved contingency procedure to exit the hazardous area to maintain safe flight.

For flight operations in oceanic or remote area airspace (where timely and reliable communications may be not be available), similar contingency procedures will need to be developed, validated, and implemented. For example, flight operations along the busy North Atlantic Track System whereby aircraft are spaced 10 minutes in-trail based on Mach number technique, and spaced 1,000 feet apart vertically, will require careful analysis and discussion before suitable procedures can be developed for a “mass turn back” procedure. What the authors envision is that in those instances when no ATC clearances or instructions are readily available, contingency procedures would permit crews to immediately exit (or delay their entry) into the hazardous area to maintain safe flight. Other aircraft in-trail along the same route and in the same geographical area would also need to execute appropriate contingency procedures to avoid loss of separation. Alternatively, if the hazard assessment showed a negligible risk, perhaps an appropriate procedure may just be to instruct all crews and passengers to proceed on course with “due regard” to the hazard.

4. POTENTIAL BENEFITS

Potential benefits include a reduction in latency (i.e., the time required to send a message to alert the crew) compared to the time required to receive similar information through air traffic control and/or other traditional communication services (such as monitoring “Guard” frequency on 121.5 MHz., receipt of an aircraft communication addressing and reporting system (ACARS) message, etc). Reduced message latency should manifest itself as increased flight crew time to react. In addition, this proposal assumes that flight crews would prefer to receive space activity NOTAMs as a graphical depiction rather than receiving the same information via verbal communications, then having to plot the data, thereby increasing overall situational awareness. Presented on a multifunction display or EFB, graphical depictions are assumed to provide increased situational awareness and help facilitate enhanced pilot decision making.

For aircraft flying in remote or in oceanic areas, or for those aircraft not normally in continuous ATC contact (i.e., aircraft operating VFR), use of a viable data link is essential to expedite the timely flow of flight critical information. In these instances, verbal communication is slow and sometimes not readily available. For IFR operations, ATC data may travel through multiple systems, networks, and entities to span the distance between the controller and the flight crew. The ability to uplink data from which to create textual as well as graphical information in the cockpit and the ability to receive data linked surveillance information directly from the space vehicle could provide an alternate and more effective means of communicating time-critical information to aircraft.

For general aviation (GA) pilots who may not be in constant, direct contact with ATC, provision of uplinked AIS textual and graphical information might provide the only means of alerting this class of users to a potentially hazardous situation in near real-time. Currently, NOTAMs received during the pilot’s preflight process

in advance of planned space activities represent the only information that GA pilots may receive with regard to the potential that a hazardous space reentry situation may occur. Once airborne, these pilots typically do not receive warnings or other advisories unless they monitor 121.5 Mhz. and there is a transmission on “guard” frequency, or upon request from a Flight Service Station. Receipt of direct AIS data linked information would allow GA pilots to identify and respond to events in almost real-time, similar to and in the same manner as their fellow pilots who are in continuous, direct contact with ATC.

Additionally, as a separate, discrete application, there are low-key technical discussions underway within the community as to whether downlinked and/or crosslinked ADS-B flight data can be transmitted from space vehicles to nearby aircraft and to air traffic ground stations, and the potential benefits that could accrue for having such a real time surveillance data link. It is noteworthy that the current ACSS electronic flight bag implementation being installed on UPS Boeing 757 and 767 aircraft includes a vehicle type data field for “SPCVs” (i.e., for space and trans-atmospheric vehicles). Additional on-condition message sets could be added to indicate the planned and actual “intent” space vehicle trajectory. While such additional message set elements may be feasible, to do so would require a significant revision to RTCA’s DO-242A and DO-260A documents.

5. TEXTUAL AND GRAPHICAL MESSAGE DEPICTION EXAMPLES

In Fig. 8, below, a sample textual AIS NOTAM is presented. This textual NOTAM describes the planned reentry path of a Space Shuttle. The same message (formatted in XML mark-up language) could be used to construct a corresponding graphical depiction. Both public as well as private sector data links could be used to provide the data to the aircraft.

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FDC 8/5274 (A0060/08) - ...SPACE SHUTTLE LANDING OPERATIONS ADVISORY...  
EFFECTIVE 0802201330 UTC UNTIL 0802201407 UTC SPACE SHUTTLE  
LANDING OPERATIONS 25 NM EITHER SIDE OF THE LINE BETWEEN  
450513S/1420228W 173242S/1065143W 135208N/0880546W 275631N/0810126W  
283054N/803744W FROM SURFACE TO UNLIMITED. WIE UNTIL UFN. CREATED: 18 FEB  
19:33  
2008
```

Figure 8: Sample AIS NOTAM (Textual Format version)

In this example, textual geo-spatial latitude and longitude coordinates are provided that describe the geographical area at risk, along with the corresponding times and altitudes. Issued in conjunction with a graphical depiction, the information displayed could be used to greatly increase a pilot's situational awareness and facilitate enhanced risk-based decision making.

the SPR analysis. The authors are currently working with RTCA SC-206 / EUROCAE WG-76 to ensure that their AIS data link services consider the unique "stressing" requirements needed to support this application in all airspace domains and for all airspace users.

Fig. 9 below, is a graphical depiction of the same AIS text NOTAM as in Fig. 8, with the hazard area graphically depicted and shaded in yellow. This notional graphical depiction could be used as the basis for developing an acceptable human factors-centric depiction suitable for flight deck implementation.



Figure 9: Sample AIS Space Vehicle Hazard NOTAM (Graphical Depiction)

6. CONCLUSIONS AND SUGGESTED WAY FORWARD

Considerable work is needed to mature this preliminary effort into a viable and acceptable concept of operations. With support, the authors' intent would be to morph this paper into a mature application using the Operational Services and Environment Description (OSED) format and methodology in RTCA's DO-264, and then perform a Safety, Performance and Requirements (SPR) analysis using the same safety risk methodology that is outlined in D0-264. Initially, such an analysis would be link agnostic; however, at some point one or more data links would need to be selected to complete the interoperability (INTEROP) portion of