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“SPACE DATA INTEGRATOR (SDI) AND SPACE PROGRAM INTEGRATED DATA AND ESTIMATED RISK (SPIDER) PROOF-OF-CONCEPT (POC) SOFTWARE SOLUTION FOR INTEGRATING LAUNCH AND REENTRY VEHICLES INTO THE NATIONAL AIRSPACE SYSTEM (NAS)”

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Abstract

The Space Data Integrator (SDI) Project is the initial step to satisfy the Federal Aviation Administration (FAA) strategic initiative to integrate commercial space launch and reentry vehicles into the National Airspace System. The project addresses the needs for greater situational awareness and monitoring, and increased response capability during non-nominal and catastrophic incidents during space operations.

The initial phase of this project leverages current FAA systems, and provide an initial demonstration of capability that will provide for state data from a commercial reentry vehicle to be ingested into a the FAA Traffic Flow Management System, and displayed on Traffic Situation Displays. Space vehicle data will be received at the William J. Hughes Technical Center, and transmitted to the Event Management Center at the Air Traffic Control System Command Center.

The second phase, called the Space Program Integrated Data and Estimated Risk system, will be built upon the initial SDI Demo phase, and deliver a Proof-of-Concept system that will provide added capability and situational awareness displays similar to current systems utilized at the major federal and commercial ranges.

I. Introduction

In order to meet the Federal Aviation Administration (FAA) Strategic Measure for the National Airspace System (NAS), the FAA formulated a Strategic Initiative to “safely and efficiently integrate new types of operations, such as commercial space and unmanned aircraft, into the NAS and enable the benefits these operations will provide” (FY2015 ATO Business Plan, p. 27). The FAA Office of the Associate Administrator for Commercial Space Transportation (AST) and Air Traffic Organization (ATO) work collaboratively in order to meet this initiative.

AST’s mission is “to ensure the protection of the public, property, and the national security and foreign policy interests of the United States (US) during commercial launch and reentry activities and to encourage, facilitate, and promote US commercial space transportation” (n.d.). ATO is responsible for ensuring the safety, efficiency, and security of air traffic operations across the entire NAS.

AST commissioned Millennium Engineering and Integration Company (Millennium) to develop prototype systems with the capabilities to perform a technical demonstration and proof of concept that would meet their stated mission as well as the strategic initiative for the FAA.

II. FAA Current Approach

The collaborative approach to commercial space operations by AST and ATO, has resulted in various management strategies, according to Murray (2013). As not every launch or reentry operation is the same, these strategies have been tailored for each individual operation, and mission need.

Strategies include limiting the impact to existing airspace operators, by placing hazard areas for a minimum duration, and scheduling operations for times when air traffic may be less impacted. Some of these strategies may be limited by vehicle trajectory or orbital intercept needs. For instance, the National Aeronautics and Space Administration’s (NASA) Commercial Resupply Services (CRS) program flights, conducted by SpaceX and Orbital ATK, travelling to the International Space Station (ISS) require launches at specific times to ensure proper intercept with the ISS for docking.

Regardless of the mission, the FAA has a need to ensure minimal impact to the NAS, and airspace users. This necessity has led to the FAA’s responsive approach of monitor and response strategies for operations. These current methods include generating a Hazard Area in response to a non-nominal event. This requires manual, deliberate actions be taken by members of the Joint Space Operations Group (JSpOG), and communication with Air Traffic Control (ATC) operators for manual insertion of the Hazard Area into the NAS. This approach has been successfully employed by the FAA for all reentries of the NASA Space Shuttle following the Columbia accident (Murray & Mitchell, 2010) as well as reentry operations of all SpaceX Dragon spacecraft (Murray, 2013).

Monitoring of the vehicle is performed with negotiated communication with the vehicle operator, typically consisting of simple position coordinates being transmitted to the FAA for use in Hazard Area generation. While effective, this limits the real-time situational awareness of the FAA traffic managers and safety analysts, and can take several minutes before the Hazard Area is entered into the Traffic Flow Management System (TFMS) Traffic Situational Displays (TSD). The FAA must rely on the vehicle operator for position information, and there is no map display to show the position in an easy-to-read manner. Additionally, there is no exposure to vehicle state or status of the flight, such as the list of expected events.

To improve operational effectiveness, Murray (2013) states, “the FAA must work to automate receiving, processing, and disseminating data and information in real-time” (p. 8) and transition “to an approach that operates for success through limited airspace restrictions, increased mission monitoring capabilities, and the ability to effectively respond to contingencies” (p. 8).

III. Millennium Solution

Millennium’s Product Development Center was contracted by AST, to create a solution that would automate the manual processes used to accommodate commercial space launch and reentry operations. To this end, there are three functions that AST and the JSpOG require of the solution during operations, which in term serve to meet their stated mission. These functions are:

1. Automated display for Situational Awareness during the launch or reentry operation.
2. The ability to monitor the progress of the launch or reentry vehicle’s transition through the NAS.
3. Notice and responsive support to non-nominal flights, events, and/or conditions.

To meet these functions, Millennium developed the Space Data Integrator (SDI) system. SDI was developed to be used during technology demonstrations, and to further identify and refine requirements for the next phase system; the Space Program Integrated Data and Estimated Risk (SPIDER) Proof-of-Concept (POC) system.

Space Data Integrator (SDI)

SDI began with an aggressive schedule of eight months from the completion of the initial systems engineering study, to installation and on-site testing-, culminating in an operational shadow and demonstration of the system’s capabilities during the reentry of a commercial spacecraft from the ISS.

SDI Objectives

In order to develop SDI, initial requirements were defined for the system with the assistance of AST and ATO. These requirements were limited to high-level goals in order to execute within the project schedule, while providing the greatest opportunity for success.

The four high-level requirements for the SDI system are as follows:

1. Automatically generate a TFMS message of the vehicle position for integration into the NAS.
2. Automate manual development of a data file to be used for generation of Hazard Areas.
3. Display vehicle state vector and Vacuum Impact Point (VIP) on a two-dimensional (2D) map for situational awareness of the operator.
4. Display vehicle staging events with individual countdown timers for situational awareness of the operator.

Communication Architecture

Millennium met with members of AST, ATO, and other key FAA personnel to determine the system and communications architectures for the project. The architecture placed special consideration on the use of existing administrative and Research and Development networks and systems. This was done in order to satisfy the project requirement that FAA operational systems would not be impacted by the development and integration of the SDI system. While this, understandably, placed certain restrictions on the system, the team was able to overcome the limitations, and rapidly respond to changes in the communications design that occurred due to unforeseen circumstances.

For ingestion of vehicle data, the FAA coordinated with a single vehicle operator, SpaceX, and together they coordinated the development of a message format to provide required data elements to the SDI System. These data elements include vehicle state vector, important vehicle mark event information, message time, as well as other critical elements. Due to the sensitive nature of the information, secure communications were setup for this data.

SDI was designed in a distributed architecture, with a server unit processing received data, commutating data into new formats, and generating displays. This unit was placed at the William J Hughes Technical Center (WJHTC) in Atlantic City, NJ. A workstation unit, located at the Air Traffic Control System Command Center (ATCSCC) in Warrenton, VA, was developed to act as the interface to the SDI Server, and display the Graphical User Interface to a JSpOG operator.

SDI System Development

The primary goal of integrating a vehicle into the NAS presented unique challenges to the project as space vehicle data was not in a valid TFMS format; -furthermore, no current TFMS message format exists for a space vehicle. The FAA determined that the best course would be to use a TFMS message format used for international flights, and that the space vehicle would present itself as such to traffic managers on the TSD. This required the SDI Server to process the received vehicle data and generate the correct message for the TFMS to recognize and accept it. To accomplish this, advanced coordinate transformations needed to be applied to the vehicle state vector information. Additionally, other critical information either needed to

be processed from the incoming data or defined by the system user during pre-operation configuration.

Hazard Area file generations were performed in the same manner as the TFMS Message generation, with the added step of the processed data being placed into a file. The format of this file was determined by the tool currently used by the JSpOG, at the ATCSCC, to calculate the Hazard Area polygon and ultimately generate the file containing this polygon for ingestion into the NAS.

As part of the SDI, an Enhanced Space Data Display (ESDD) was designed to serve as the primary data display, and to provide the situational awareness and monitoring capabilities of the demonstration system. This display satisfied the final two goals of the SDI phase of the project.

The most prevalent portion of the ESDD is the Map Display, containing a 2D global map with the ability to zoom into the region of focus. This map contains markers for vehicle Present Position (PP), PP History Trace, VIP, VIP History Trace, Nominal Trajectory, and Launch Site or Splashdown marker. Additionally, pre-defined Air Route Traffic Control Center (ARTCC) Boundaries appear on the map to provide the operator the ability to determine sector control of the vehicle at any given point along the nominal trajectory and/or vehicle PP.

The ESDD also contains a list of vehicle events for the operation. For Reentry missions, events such as Deorbit Burn Start, Drogue Chute Deployment, and Splashdown are included. For Launch operations, there are events such as Liftoff/Ignition, Main Engine Cutoff (MECO), Staging/Hardware Jettison, as well as others.

The display also offers a chart depicting the nominal trajectory with respect to the vehicle's altitude relative to the distance (range) from the trajectory's end. This "Altitude versus Range" chart also displays the vehicle's PP marker and history trace. A separate portion of the display provides status lights representing the vehicle data link (the link from the Dragon or Falcon 9 vehicle to SpaceX) and ground station source link (link from SpaceX to the WJHTC). Lastly, the ESDD contains a readout of Hazard Area generation status. This represents the ability to generate a Hazard Area, given the vehicle's current position, if a catastrophic event were to occur.

Demonstration of SDI

SDI was completed significantly ahead of schedule, allowing the FAA and Millennium to conduct rigorous testing of the system.

Following successful completion of this testing, with no significant defects identified, the system was prepared for its formal demonstration with the planned reentry of the SpaceX CRS-7 mission. CRS-7 would culminate with the reentry of a Dragon spacecraft returning from the ISS. In preparation for the event, communication flow tests had been accomplished between the FAA and SpaceX, and live data was scheduled to be sent to the FAA during the reentry. Unfortunately, a non-nominal event occurred during the launch of CRS-7, resulting in a loss of

the vehicle in flight. As a result of this, the demonstration of SDI was placed on hold until a suitable reentry event is scheduled to occur.

Space Program Integrated Data & Estimated Risk (SPIDER) Proof-of-Concept (POC)

While SDI was developed to complete a demonstration of capability, the SPIDER POC system is being designed to provide enhanced capabilities that were not considered in the original schedule for SDI. SPIDER POC will further prove the validity of conceptual designs for a system to improve their current methodologies, while providing the FAA with a concept system to assist operations in recognizing off-nominal scenarios, and the capability to react to them.

SPIDER POC Objectives

The objectives of the SPIDER POC effort are to leverage the existing development of SDI, and to enhance the overall capability of the system by providing the FAA with a more robust system that will assist in the identification of requirements for the development of an operational system. To this end, Millennium identified requirements for SPIDER POC that were focused on these capabilities.

SPIDER POC System Development

While SPIDER POC is currently in development, there will be several key enhancements that are a significant improvement over SDI. One such improvement is the inclusion of customizable tolerance values for each of the predicted times of staging events for reentry and launch missions. This provides the FAA with the ability to see if an event occurs outside of a specific range, as this behavior may be indicative of a non-nominal scenario. For instance, if a launch vehicle is having thrust performance issues, then the actual times of staging events, such as MECO, may occur significantly later than predicted. This information will provide the JSpOG operator with greater situational awareness and, depending on the specifics of the scenario, may allow the JSpOG to inquire with the vehicle operator for status of the vehicle, continue to observe and monitor more closely, or begin taking action in preparation to respond to the non-nominal condition(s).

Another example would be the expected time of signal reacquisition for a reentry vehicle. As the vehicle reenters the Earth's atmosphere, a loss of signal is expected to occur for the period of time the vehicle is transitioning from space. Following this communication blackout, the signal is expected to be reacquired by a specific time. If the signal is not reacquired, this may indicate a non-nominal or catastrophic event has occurred. In this example, it is easy to see the benefit that notification by the system that the expected time for reacquisition of signal has passed. This will also provide the user with the ability to be proactive, rather than passively wait for information from the operator.

The inclusion of capability to select a three-dimensional (3D) representation of the map display is another addition to the system. This enhancement affords the user the freedom to change views of the vehicle, and its associated trajectory, with pan, tilt, and zoom controls. This display

also includes the addition of vehicle flight data, speed and altitude, directly on the screen, and in a manner consistent with current FAA systems used by ATO. As an added benefit, the system will also be capable of ingesting the same Hazard Area files currently generated for the TSD, and place the resulting polygon on the map display of SPIDER POC.

For added situational awareness of the vehicle, SPIDER POC uses an Instantaneous Impact Point (IIP) instead of a VIP. The IIP is calculated with a user-selected drag coefficient value from a pre-defined list of objects. This list includes objects of varying size, weight, and aerodynamics, and allows the operator to customize how they wish to represent the IIP of a vehicle based on the mission specifics. As a POC, SPIDER is limited to this list of values, but an operational system could provide users with the increased capability of ingesting additional data elements, thereby providing a more complete debris analysis and impact prediction.

SPIDER POC includes several other features focused on providing the user a system with greater control as well as the flexibility to handle a multitude of launch and reentry missions, and their scenarios. To accomplish this, a major modification to the system will allow the user to define the format of data ingested. As SDI is currently limited to SpaceX as a vehicle operator, and the FAA-coordinated format for SpaceX vehicles, SPIDER POC will allow other vehicle operators to send data to the system as well. These additional operators will be able to define their own format, with some minor limitations, and will not require the overhead of extensive pre-processing of vehicle telemetry data.

Demonstration of SPIDER POC

The SPIDER POC system is currently ahead of schedule, with estimated completion and installation in the winter of 2015. Adhering to the architecture of the SDI system, Millennium will install a SPIDER POC server at the WJHTC, and a workstation at the ATCSCC.

Given the launch mishap on CRS-7, the launch of CRS-8 is currently anticipated to occur after SPIDER POC has been placed at FAA facilities. This will enable the FAA to present a formal demonstration of the capabilities with the more robust SPIDER POC.

IV. Conclusion

Millennium's rapid development of the SDI and SPIDER POC systems has, and will give to the FAA, the ability to meet their strategic initiative of integrating launch and reentry vehicles in the NAS. SPIDER POC meets the FAA approach mentioned by Murray (2013) to only place Hazard Areas when required, increase capabilities for monitoring of commercial space missions, and response to contingencies. The development of an operational SPIDER system will further these goals, provide the FAA with even greater capabilities, and aide in the advancement of the Commercial Space Industry.

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