AIR TRAFFIC CONSIDERATIONS FOR FUTURE SPACEPORTS

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ABSTRACT

As the commercial space launch industry continues to grow, plans for new spaceports from which to base launch and reentry operations continue to take shape. Many of these new spaceports will not be located within special use airspace that is routinely cleared of air traffic, creating potential conflicts and impacts in an airspace system that is itself continuing to grow. Processes for designing space vehicle flight corridors that maximize the utility of a proposed spaceport while minimizing the impact on existing air traffic must be developed in order to provide safe and efficient access to all potential users. The Federal Aviation Administration's Office of Commercial Space Transportation is exploring one such process. Used successfully for the Oklahoma Spaceport, this process examines existing air traffic patterns relative to proposed space vehicle requirements to help identify potential air space for space vehicle testing and operations. The FAA intends to construct a tool capable of performing this and other space and air traffic management functions in the near future.

1. INTRODUCTION

Over the past several decades, the U.S. National Airspace System (NAS) has become an increasingly crowded resource, and recent trends of sustained growth and increased air traffic capacity are expected to continue well into the future. By 2016, the FAA projects that domestic flights in the U.S. will increase by 27 percent over the 2005 levels [1]. During this same time frame, the FAA expects an increase in commercial space vehicle launch and reentry operations, and these vehicles must traverse through and over the NAS on their way to and from space.

Many of these operations are planned to take place from spaceports located well inland of the coastal sites that have traditionally supported such activities. A number of sites have been identified, many of them in regions where the air traffic density is considerably higher than that of the oceanic traffic typically observed in the vicinity of a space launch from a coastal site. For example, the FAA's Office of Commercial Space Transportation granted the Oklahoma Space Industry Development Association (OSIDA) a launch operator's license in 2006 to operate the Oklahoma Spaceport near Burns Flat, OK. Situated west of Oklahoma City and north of Dallas/Fort Worth, the spaceport lies within a heavily traversed air traffic region. Beginning this year, this site intends to host a variety of suborbital spacecraft launches.

1.1 Hazards to aircraft from launch and reentry operations

As is the case with any space launch or reentry vehicle, there is a potential for the vehicles utilizing this spaceport to fail in flight in such a way that generates falling debris. An in-flight explosion of the spacecraft or a structural breakup due to higher than anticipated aerodynamic, thermal, or inertial loads could produce debris of various quantities and sizes that would fall to the surface for the next several minutes. The potential for such failures may be relatively high when compared to the potential for a traditional aircraft to fail in a similar manner, especially during the early stages of development of these spacecraft.

In addition to the obvious risks such failures may pose to people on the ground, there could be considerable risk posed to aircraft flying below the failing spacecraft. Aircraft vulnerability standards have been developed based on research that has indicated that a fragment of steel weighing less than one pound and falling at terminal velocity can puncture the cabin or wing of a cruising aircraft, inflicting potentially catastrophic damage [2]. The Space Shuttle *Columbia* accident in 2003 serves as a vivid example of this potential hazard. Some 85,000 pieces of debris were recovered after the accident, a great number of which weighed less than one pound. Given the rough terrain of the recovery area, this likely represented only a fraction of the total amount of debris that fell. Studies have shown that debris capable of inflicting catastrophic damage on an airplane continued to fall for up to 90 minutes after the onset of the accident. The probability of an airplane flying through this area suffering such an impact may have been as high as 1-in-10 [3], orders of magnitude higher than any other risk to aircraft traditionally considered.

1.2 The Space and Air Traffic Management System

To protect aircraft from the hazards associated with such accidents occurring in the future, the FAA has developed a concept of operations for a future Space and Air Traffic Management System (SATMS). This space and air traffic framework calls for the assured separation of spacecraft and aircraft [4]. While the definition of "assured separation" may evolve over time as spacecraft begin to demonstrate higher levels of reliability, its current manifestation requires significant lateral spacing and absolute vertical spacing between aircraft and spacecraft to contain these risks. In other words, spacecraft will operate in and above sterilized airspace as they transition through the NAS on their way to and from space.

A difficulty exists then in establishing new spaceports given the potential for the extent of the airspace required to conduct these operations safely to impact air traffic operations. While spacecraft proposing operations from areas near or within existing special use airspace may be able to take advantage of the extent of that airspace to protect aircraft and minimize impacts, other locations will have to rely on the use of temporary airspace closures to prevent aircraft from entering potentially hazarded airspace. The airspace would be strategically sized to maximize safety and the closure would be dynamically issued and withdrawn to minimize impacts. For example, the trajectory of a suborbital space flight originating and ending at the proposed Oklahoma Spaceport could be entirely contained within a corridor of airspace that would be sufficiently large to contain the entire trajectory of the vehicle and any debris from a potential failure during the flight. The vertical extent of this space transition 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 designated airspace 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 the area was free of hazardous debris.

2. THE BASIC PROCESS

The FAA has continued to formulate a structured process to support these planning activities. This process consists of five steps, beginning with a simple survey of maps to facilitate initial designs and culminating in an agreement between the potential spaceport operator and the FAA to conduct space launch and reentry activities from the proposed site. This process is described in detail below.

2.1 Map survey

As with traditional airports, the locations of obstacles, uneven terrain, and the direction of prevailing winds will determine key aspects of a successful spaceport design, including the location and orientation of runways or launch and landing pads. Factors influencing public safety will also play key roles, including the density of surrounding populations and the prevalence of overflying air traffic. Therefore, a successful spaceport design process often begins with a simple map survey. A combination of traditional maps and aeronautical charts can be used to identify areas of dense ground population and dense regions of air traffic, such as those near airways, airports, heliports, and navigation aids. Special consideration may be required for heliports hosting emergency medical flights, such as those located at or near hospitals, to prevent the obstruction of those flights.

A potential operator should carefully consider locating its spaceport within or near airspace assigned for military or special use, such as military operations areas, restricted airspace, and air traffic control assigned airspace. While these areas offer the benefit of being routinely cleared of air traffic to support special operations, their use may require coordination with multiple entities, presenting a potential for scheduling conflicts. The locations of military training routes also should be considered.

On a related note, a number of potential spaceport operators are looking to co-locate their sites with existing airports or former military installations to reduce costs. In addition to the existing infrastructure, such as runways, hangars, and communications and weather observation equipment, these sites often have existing documentation on record that can be used to reduce the level of effort required to perform the required assessment of environmental impacts. While these aspects certainly provide advantages to potential spaceport operators, they often have the disadvantage of being located in areas with significant population buildup and overflying air traffic.

2.2 Spacecraft trajectory design

Next, designers would develop initial trajectories using the characteristics of the vehicles and their concepts of operation, including the method of takeoff and landing (horizontal/vertical), maximum expected range from site, and crossrange capability relative to the locations of potential abort landing sites. Other considerations may include gliding return-to-base capability for ferried launch vehicles in the event of a misfire of the rocket engine and the avoidance of hazardous terrain, such as mountain ranges, over which bailouts and search and rescue operations may be especially treacherous. The resulting trajectories can then be overlaid on the maps described above to identify other potential issues. Flight azimuths can be manipulated to place potential trajectories over sparsely populated areas lying between more densely populated areas or between existing airways and airports. For ferried launch vehicles or launch vehicles capable of flying under jet power, these trajectories may include some amount of outbound flight to a point at which the rocket engine can be ignited over sparsely or unpopulated areas and away from air traffic.

While these trajectories are often overlaid on an existing map as thin lines, it is important to consider an associated corridor for each trajectory – a finite distance surrounding the trajectory capable of containing the flight path of the vehicle and any debris during off-nominal conditions. Depending upon the design of the proposed launch vehicle and its concept of operations, factors such as winds, propulsion system performance, and guidance, navigation, and control dispersions may affect the vehicle's ability to follow the nominal trajectory. Human factors may make this especially important for manually piloted vehicles (as opposed to computer guided or autopiloted vehicles). In an effort to maintain assured separation from aircraft, the results of launch vehicle failures also will require consideration. The resulting catalog of debris from a vehicle explosion or breakup in flight also should be contained within a corridor.

In the early stages of spaceport design, it is often difficult to characterize the performance of a proposed launch or reentry vehicle or the extent of the area it may hazard in the event of an accident. While a small number of launch vehicles may have flight histories and associated analyses from which to obtain dispersion information and debris catalogs, the majority of vehicles initially intended to be hosted by these sites will be experimental in nature with limited or no flight history and supporting analyses. In these cases, a potential spaceport designer may have to make preliminary estimates of these parameters using data from similar vehicles, analytical models, or best estimates.

Knowledge of the vehicle's material properties, anticipated operating envelope, design limitations, and structural weak points can provide insight into the contents of a debris catalog. Although several alternate catalogs of debris can be constructed, based on the anticipated outcomes of multiple potential failure scenarios, it may be most helpful to begin with an assumed worst case. For many proposed vehicles, this case would consist of a high altitude explosion of the vehicle. Velocities imparted on the debris, combined with the low atmospheric density at altitude, have the tendency to disperse debris great distances in such circumstances.

Analysts typically begin to assemble a debris catalog using a list of the vehicle's components, focusing on attachment points and points of transition between component geometries to identify potential fracture locations. Analytical techniques such as finite element analyses, test results including the static and dynamic failure strengths of load-bearing components, and historical data from previous failures can be examined relative to the anticipated flight envelope to produce the contents of a catalog.

Alternatively, the spaceport designer could size a corridor by maximizing its length and width up to point of conflict with an existing constraint, such as a population center, airway, airport, or other potential risk driver. For example, in Fig. 1, a hypothetical corridor originating from Spaceport A could be designed to maximize the area lying between Victor airway 123 (V123) and V456 to the north and south and jet route 1 (J1) and J2 to the east and west. Such a corridor could support outbound trajectories to the north and inbound trajectories to the south, as indicated by the dashed line.

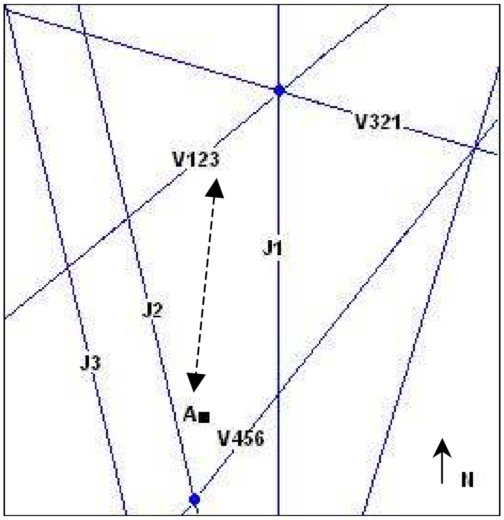

Figure 1. Potential corridor between airways

In such cases, a prospective vehicle operator wishing to operate within the corridor would have to verify preflight that the hazards associated with its vehicle could be contained in the corridor. If not, alternative corridors would have to be developed or another site chosen.

Taking all of these factors into consideration, the key to successful airspace design lies in the ability to balance the extent of a flight corridor to contain potential hazards of the vehicle against the impact such a corridor would have on air traffic operations. Air traffic analyses can be conducted to quantify this impact.

2.3 Air traffic analysis

In Figure 1, Spaceport A could benefit largely from an increase in it proposed corridor that would allow spacecraft trajectories to overfly J1, shifting the corridor boundary out to V321. Doing so would open up a larger corridor for outbound trajectories to the northeast and inbound trajectories to the southwest, as depicted by the dashed line in Fig. 2.

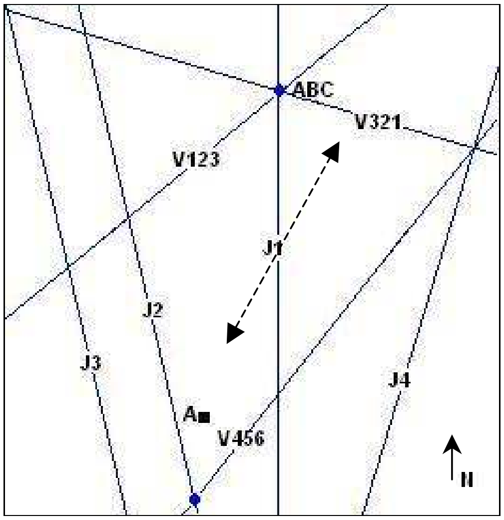

Figure 2. Potential Corridor Across J1

However, air traffic management initiatives such as reroutes or increased separation (miles-in-trail) restrictions may be required to support such trajectories. One potential solution is to temporarily close J1 to southbound traffic south of VORTAC ABC and reroute northbound traffic along J4. Depending upon the volume of traffic along J1 and J4, these actions could have significant impacts on the traffic flow in the region. Fortunately, FAA air traffic flow managers at the Air Route Traffic Control Centers (ARTCCs) and other facilities have a variety of tools available, such as the Sector Design and Analysis Tool (SDAT) or the Performance Data Analysis and Reporting System (PDARS), to assess these types of impacts.

SDAT is the primary airspace analysis tool for en route airspace development. PDARS is the primary traffic management tool for the collection, analysis, and reporting of performance-related data from the NAS. Together, these tools provide snapshots of air traffic patterns in the NAS using archived flight plans and aircraft tracks relative to airspace elements like sector boundaries and airways. Returning to the example employed above, an air traffic manager could use these tools to determine whether the traffic along J1 and J4 is potentially light enough to allow for the temporary rerouting described. Potential problems with this plan could manifest themselves in the form of traffic imbalances. A solution that causes one region of the NAS to become overloaded at the expense of another could pose potential safety issues and should be avoided. In addition, ingress and egress routes for Class A airspace could be impacted. Municipal, county, and private airports lying within the corridor could see disruptions in their operations.

Given the limited insight that a typical spaceport designer might have into potential air traffic impacts such as these, it may be in their best interest to identify several corridors for analysis. A limited series of analyses similar to the one described above could then be used to down-select between options.

2.4 Investigation of mitigating factors

Impacts to air traffic may depend as much on the time at which a potential corridor is intended to be activated as the extent of the airspace it may occupy or overly. Surveys of existing air traffic patterns, using the tools described above, could reveal times of day and days of week that minimize impacts to existing routes and airports. For example, traffic over the continental U.S. is generally lighter on Saturdays than on Mondays or Fridays. Accordingly, a spaceport operator could schedule the majority of the activities it intends to host on weekends to avoid air traffic conflicts. In addition, launches and reentries conducted in the central U.S. could benefit from the time difference with the coasts. Early morning air traffic heading west from locations such as New York or Miami may not arrive over the central or western parts of the country until an hour or more after sunrise, providing spaceport operators in that area with the opportunity to host launch and reentry operations with minimal impacts.

Again, the identification of multiple potential corridors may be beneficial. Retaining the option to fly an east-west trajectory when a north-south trajectory may impose a significant impact, or vice versa, would provide all parties involved with additional flexibility. Multiple corridors will provide the additional benefit of more flight opportunities when factors such as weather become an issue. For example, higher than allowable winds out of the north may force the cancellation of launches along east-west trajectories if the wind could push potential debris beyond the edge of a corridor. However launches conducted within north-south corridors may still be feasible under such conditions.

Another mitigating factor that may be available is the potential to close and release airspace incrementally. Since many of the potential spacecraft operators plan to conduct envelope expansion test flights of their vehicles, a spaceport operator could define a corridor to be composed of a small number of segments, such that only the number of segments required to contain the current flight would be cleared. For instance, a corridor could be defined such that a single segment over the spaceport itself could accommodate the extent of airspace needed to perform touch-and-go or low altitude vertical launch operations. When these operations were being conducted, additional segments that make up the rest of the corridor could remain open to air traffic.

2.5 Letter of agreement

Once one or more potential corridors have been identified, a spaceport operator would seek to establish a formal agreement with the FAA for their use. FAA regulations require a spaceport operator to enter into an agreement with the Air Traffic office having jurisdiction over the airspace containing the corridor [5]. The purpose of the agreement is to define the responsibilities of the spaceport operator and the FAA with regard to planning and executing safe air and space traffic operations. In doing so, it must establish procedures for the issuance of Notices to Airmen (NOTAMs) prior to a scheduled launch operation and for the closing of air routes during the launch window. The agreement also should define procedures for the spaceport operator to provide sufficient notification of the FAA of scheduled activities and cancellations, and the timeline by which the FAA receives notification and issues notices of temporary flight restrictions. Operational requirements, such as communications and tracking requirements, weather constraints, and emergency procedures also may be defined in the agreement.

For spaceports proposing operations within or above special use airspace, additional agreements with the primary users of that airspace may be necessary.

3. THE OKLAHOMA SPACEPORT

Perhaps the best way to illustrate this process is to cite a recent example of its application. The Oklahoma Space Industry Development Authority (OSIDA) received a license from the FAA to operate a spaceport from the Clinton-Sherman Industrial Airpark (airport identifier: KCSM), roughly two miles west of Burns Flat, OK. The airpark is a former military installation that is still used occasionally by nearby Air Force bases for training operations. It has a 13,500 ft runway, a control tower, and a number of hangers and industrial facilities. The spaceport does not lie within or below any special use airspace.

In meeting the requirements for this license, OSIDA entered into discussions with the Fort Worth ARTCC (ZFW), the FAA Air Traffic office with jurisdiction over the airspace above and around the airpark. This resulted in a letter of agreement describing the resulting corridor and the terms of its use. Although the final corridor extended beyond the ZFW boundary into the Kansas City (ZKC) and Albuquerque (ZAB) ARTCC airspace, ZFW assumed the role of FAA Air Traffic point of contact for the spaceport during both the design of the corridor and the operations within it.

3.1 Map survey

Although corridors could be designed to extend in any direction from the spaceport, the orientation of the primary runway and the direction of prevailing winds benefit operations that will depart to and arrive from the north. The surrounding terrain contains mostly sparsely populated farmland separating a number of small towns with populations of a few thousand people. Elk City, 12 miles to the northwest, is the largest town in the vicinity of the spaceport, with a population of about 10,000 people.

A number of potential air traffic constraints were identified from a survey of aeronautical charts of the area. For example, eight military operations areas (MOAs) and some 36 military training routes used by nearby Vance, Sheppard, and Altus Air Force Bases lie within a roughly 100-mile radius of KCSM. Within that same area, as many as 16 jet routes and 23 Victor airways crisscross, indicating a potential for a high volume of cross-country air traffic. Further, this area is home to some 230 airports, heliports, and landing strips. The locations and potential for use of all of these items were factored into the trajectory design.

3.2 Trajectory design

Several prospective launch vehicle operators have been identified for the Oklahoma Spaceport. One particular operator provided initial trajectory requirements based on its vehicle's characteristics and its mission objectives. The proposed vehicle is a winged, horizontally launched and landed concept that proposes to conduct flights to 100 km altitude. Configured with both jet engines for atmospheric flight and a rocket engine for the climb to maximum altitude, the operator proposed flights consisting of an outbound leg from the spaceport under jet power, followed by a turn onto an inbound heading back to the spaceport at roughly 100 miles downrange from the spaceport. Once the turn had been completed, the jet engines would be powered down and the rocket engine ignited, propelling the vehicle toward its maximum altitude. After the rocket engine had exhausted its supply of propellant, the vehicle would coast to maximum altitude and begin a gliding descent that culminated in an unpowered landing back at the spaceport, as depicted in Fig. 3.

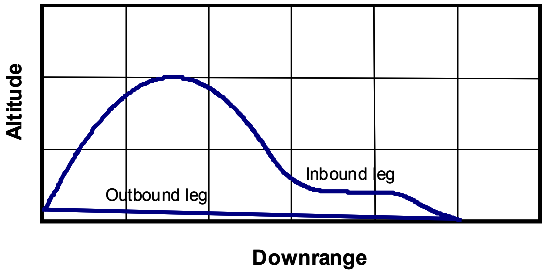

Figure 3. Representative suborbital trajectory

Although the vehicle operator had provided some initial trajectories, estimates of the potential guidance and performance dispersions and debris model were unavailable at the time. Without this data, OSIDA and ZFW sought to maximize the size of a corridor in terms of both length and width while minimizing the impact to airways.

3.3 Air traffic analysis

Based on the trajectory data, two potential corridors originating at the spaceport and spanning over 100 miles to the northeast and northwest were proposed. Archived air traffic data was surveyed to identify gaps between existing airways and periods of low volume along those airways that would support the use of one or both of the corridors. Based on a combination of the air traffic data and a desire to avoid scheduling conflicts associated with the Vance Air Force Base MOAs to the northeast, a northwest corridor was selected. The roughly 130-nautical mile long corridor originates at the spaceport and is bounded by J231 to the north, J168 to the west, J78 to the south, and a line connecting the Liberal, Kansas VORTAC (identifier: LBL) to the intersection of J52 and J78 to the east. The width of the corridor increases in the direction of the rocket powered flight, from 20 nautical miles at the north end to 45 nautical miles at the south end. The corridor is depicted in Fig. 4 relative to the ARTCC and MOA boundaries in the local area and the jet routes listed above.

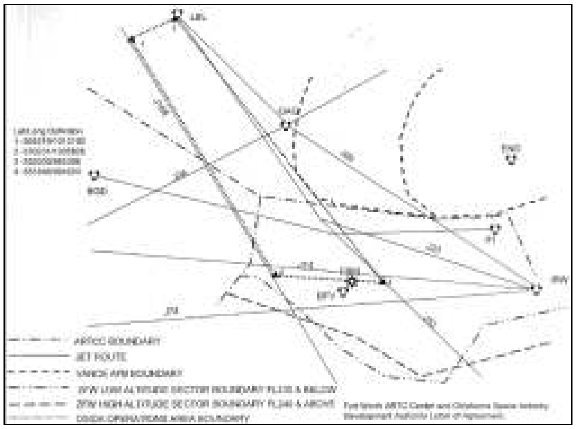

Figure 4. Oklahoma Spaceport corridor

3.4 Investigation of mitigating factors

Fig. 4 shows that, in addition to the jet routes that bound the corridor, portions of J8, J20, J26, and J52 lie within it. To lessen the extent of the impacts to traffic on these airways, ZFW identified several mitigating factors based on air traffic patterns in the area. First, they noted that, because of its location in the Central time zone, early morning launch operations within the corridor could be conducted after sunrise but before the cross-country traffic from both coasts began to build. Further, traffic in this region is generally lighter on Wednesdays and Saturdays, further minimizing the impact.

Based on these trends, a plan was assembled to activate the corridor to accommodate morning launches, requiring the airspace to be reopened to air traffic by 10:00 AM. In addition, the plan required restricting the activation of the proposed corridor to two primary days per week, on Wednesdays and Saturdays, with an additional 24-hour window available following both days to accommodate launch scrubs. Once this original schedule comes into use and lessons learned are accumulated, plans call for the expansion of scheduling to accommodate more frequent operations and an additional corridor to the southwest.

Because the original corridor was located and sized without the use of vehicle guidance and performance or debris data, the prospective vehicle operator, or any other future vehicle operator desiring to use this corridor, would have to verify that the hazards associated with their vehicle could be contained to the corridor. This would be a requirement to obtain an FAA license or permit to operate the vehicle at the spaceport.

3.5 Letter of agreement

A letter of agreement was drafted between OSIDA and ZFW that defined this corridor and included these mitigating factors as terms of its use. Within the agreement, OSIDA was assigned the responsibility of coordinating with the spaceport users and ensuring that all necessary information is provided to ZFW in a timely manner. In return, ZFW agreed to be responsible for the safe and orderly flow of known aircraft relative to the corridor and the dissemination of pertinent information to the aviation community. The agreement also outlined procedures for the scheduling of operations, notification of affected parties, and the issuance of NOTAMs were also provided.

4. OTHER CONSIDERATIONS

While the process described above worked well for this particular scenario, the FAA anticipates a need to integrate, automate, and standardize these and other space and air traffic management processes as space operations become more common in the future. The FAA's Space and Air Traffic Management System Decision Support Tool (DST), a proposed space and air traffic management software technology, is envisioned to support this process [6]. This tool is intended to operate in both a planning and realtime mode. In the planning mode, the DST will identify potential space transition corridors and assess their potential for creating air traffic impacts. In the realtime mode, the DST will receive data indicating the present position and velocity of the spacecraft relative to the corridor boundaries. This will increase the situational awareness of air traffic controllers and provide opportunities to institute more effective traffic management initiatives, as necessary, in the event of an accident. The integration of these capabilities will provide the FAA with the ability to more effectively plan and monitor spacecraft launches and reentries, allowing for more responsive space operations while minimizing impacts to air traffic operations. While the DST is envisioned to be an FAA tool, there is a potential for it to serve in some capacity to assist spacecraft and spaceport developers in designing safer, more efficient vehicles and spaceports.

As the commercial space industry continues to grow and operations become more routine, there may be an opportunity to establish new special use airspace to accommodate launch and reentry operations. In the research and development process, a spacecraft operator may fly a different trajectory on each flight, as the vehicle's envelope of operations is slowly expanded. Under these circumstances, designating airspace with fixed boundaries to accommodate these activities would not be efficient. However, when the industry progresses to the point where operational vehicles are frequently flying along established routes to and from spaceports, there may be an opportunity to establish some form of special use airspace to contain those routes. Presently, the establishment of special use airspace requires extensive study and coordination, which can take years to accomplish. Experience gained in the design and operation of spaceports similar to the Oklahoma Spaceport described above may serve to expedite this process.

As vehicle technology progresses and experience is gained, there may be opportunities for spacecraft to begin to share airspace with aircraft. For example, hybrid vehicles, having characteristics of both aircraft and spacecraft, may be able to operate in a mode similar to aircraft while in the NAS and as a spacecraft while above it. Depending on the circumstances, there may be opportunities for these vehicles to be controlled like any other air traffic when operating in their aircraft mode. In this sense, a launch vehicle could be routed along existing air traffic routes in the presence of other air traffic to or from a designated corridor that would be free of air traffic prior to or following the undertaking of its launch and reentry operations. This might allow for spaceport operations to take place from a larger number of existing airports, especially those located in heavier air traffic regions and surrounded by denser populations.

4. CONCLUDING REMARKS

As additional potential spaceports begin to take shape, the process for their safe and efficient design relative to air traffic will continue to evolve. The processes for designing space vehicle flight corridors that maximize the utility of a proposed spaceport while minimizing the impact on existing air traffic will continue to be developed in order to provide safe access to all potential users.

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