Sharing Airspace: Simulation of Commercial Space Horizontal Launch Impacts on Airlines and Finding Solutions

Abstract

Commercial space transportation is becoming more affordable and accessible. Consequently, we expect to see significant expansion of commercial space launch activities in the coming decade. As space vehicles travel through the national airspace systems (NAS) during the launch and re-entry stages, they potentially disrupt the regular operations of traditional users of the NAS. This paper estimates the potential impacts of commercial space launch activities on airlines under various launch scenarios using predictive fast-time simulation modeling, focusing on Cecil Air and Space Port in Jacksonville (Florida). Our results indicate that the existing 4-hour airspace closure rule impacts a significant number of flights, resulting in flight time delays, additional flight distance, and additional fuel burns. Reducing the duration of airspace closures could serve as a simple solution to mitigate the impacts on airlines and other traditional NAS users. More importantly, treating the Concept Z vehicle as an aircraft and opening the departure/arrival corridor to air traffic during a horizontal launch would potentially reduce the impacts on airlines significantly, depending on the location of the spaceport, planned flight paths and the trajectory of the launch.

1. Introduction

The commercial space transportation industry has been growing by leaps and bounds over the last two decades. Development of reusable and more efficient launch vehicles has started to bear fruit in helping to reduce launch costs. Commercial space transportation is becoming more affordable and accessible. Consequently, we expect to see significant expansion of commercial space launch activities in the coming decade. While many will reap significant economic benefits, key stakeholders outside the commercial space industry, including commercial aviation, view commercial space transportation with intrigue and caution. As space vehicles travel through the national airspace systems (NAS) during the launch and re-entry stages, they potentially disrupt the regular operations of traditional users of the NAS.

There is an average of 28,000 commercial flights across the globe per day, carrying 2.4 million passengers and 58,000 tons of cargo [1]. In addition, hundreds of thousands of business and private flights also share the airspace. Therefore, there are well-established rules that all aircraft operators, including commercial airlines, must follow when they share the airspace. These rules are intended to ensure the safety of aircraft and efficient use of the airspace, by specifying flying altitudes, separation distances, airways/routes to follow, and requesting permissions to enter certain airspaces, etc. Yet, there is some flexibility for aircraft to alter their planned flight paths if necessary. On the other hand, space vehicles have extremely limited ability to alter their trajectories and no capability to take a different route. Consequently, it is left to airlines (and other NAS users) to alter their operations to allow space vehicles to pass through the airspace in order to reach their final destinations. That is, when a space vehicle is launched from a spaceport, a pre-determined area of the airspace surrounding its trajectory is closed to other users of the NAS for a period of time to allow for the safe operations of both the space vehicle and aircraft. The impacted commercial flights are either re-routed or held on the ground (delayed departure), resulting in additional costs to the airlines and flight delays for passengers and cargo shippers, and, more importantly, the associated uncertainties.

In the past, airlines and other NAS users bore the impacts of government space activities without demurs for the goodness of humankind when limited space activities with sporadic frequency were carried out by governments for the purpose of space exploration and national security. Nowadays, however, the number of commercial space launches has increased significantly, and the commercial space industry has become a multi-billion-dollar industry. Inevitably, there has been a growing conflict of interests between commercial space operators and other NAS users over the disruptions caused by commercial space vehicles passing through the NAS. How to share the airspace in a fair and efficient manner becomes a critical issue for the growth and development of both the commercial space industry and the continuously growing commercial aviation industry as well as other NAS users. The first step to find an answer to this critical

question is to have a clear understanding of the impact of commercial space activities on airlines. Therefore, the first objective of this research is to assess the potential impacts of commercial space launch activities on airlines by developing simulation models to estimate flight delays and additional operating costs associated with various space launch scenarios. The results from the simulations are then used to evaluate possible solutions to mitigate the potential impacts of commercial space activities on airlines. The study applies predictive fast-time simulation modeling in a comparative analysis of current and future airline traffic in the surrounding areas of a spaceport with horizontal space launch operations, focusing on the predicted space activities at Cecil Air and Space Port in Jacksonville (Florida). The anticipated launch frequency is 52 horizontal launches of sub-orbital launch vehicles per year [2].

The rest of the paper is organized as follows: Section 2 provides a brief background on the operations of various space vehicles as well as the current FAA practice of airspace closures associated with space launches; Section 3 reviews past studies on airspace simulation and modelling; Section 4 describes our simulation modeling process including the flight data, the simulation software, and alternative scenarios; and the results from the simulations are discussed in Section 5; Section 6 offers concluding remarks and explores future research.

2.   Commercial Space Operations

According to the Space Foundation [3], commercial space industries account for 80.1% of the $ 383.5 million space activities. There were a total of 114 orbital launches in 2018, of which 24 were commercial launches [4]. The majority of the commercial launches are in the United States. SpaceX has been the most successful commercial launch operator with 69 successful missions since its first mission in June 2010, and 34 planned missions.

Space launches to date, whether using expendable launch vehicles or reusable boosters, commonly take off vertically, and the reusable boosters return vertically. However, there have been tremendous efforts to develop horizontal takeoff and horizontal landing concepts. There are three general space vehicle categories for horizontal operations that are emerging in the commercial launch market. Each vehicle category requires specific facilities and operating license at the spaceports they operate. Spaceports are generally not licensed for all types of launch vehicles. Instead, they are "specialized" in one or two vehicle concepts.

A "Concept X" launch vehicle is an all-in-one RLV, similar to an airplane that takes off from a runway using jet power and flies to a safe location before igniting its rocket engines to complete its launch profile. Upon completion of its mission, the Concept X launch vehicle will return for a horizontal landing by either restarting its jet engines or by gliding unpowered. Current generation Concept X launch vehicles would be capable of providing suborbital flights for both passengers and cargo. An example of a Concept X launch vehicle is the Airbus Spaceplane. In comparison to other spaceflight models, Concept X represents a possible competitor to traditional aviation,

offering a service potentially disruptive enough to lead to changes in the industry. While this business potential exists, there has yet to be a successful commercial development of a Concept X vehicle.

A "Concept Y" launch vehicle is an all-in-one RLV that ignites its rocket engines while on the ground and takes off horizontally from a runway. This RLV is under rocket power until engine cutoff during ascent of its suborbital trajectory. Upon completion of its launch profile it then returns gliding unpowered for a horizontal landing. An example of a Concept Y launch vehicle is the Lynx that was being developed by XCOR Aerospace. Unfortunately, XCOR filed for Chapter 7 bankruptcy in 2017.   As of this writing, there is no known Concept Y vehicle in development.

A "Concept Z" launch vehicle is a two-part launch vehicle consisting of a reusable carrier aircraft and a reusable or expendable launch vehicle. The carrier aircraft is powered by jet engines and designed or modified to carry the launch vehicle to a high altitude where the two components detach, and the rocket engine of the launch vehicle is ignited. The carrier aircraft flies back to the spaceport and lands normally as an aircraft. The launch vehicle, which can be either suborbital or orbital, completes its mission profile and either returns for a horizontal landing or is expended. Two examples of Concept Z launch vehicles include the Northrop-Grumman Pegasus and its carrier aircraft, a modified L-1011, and Virgin Galactic's SpaceShipOne and its carrier aircraft the White Knight. Current generation Concept Z launch vehicles are capable of providing suborbital flights for both passengers and cargo, and as in the case of the Pegasus, orbital launch capability for satellite payload.

All space vehicles create safety hazards as they pass through the national airspace systems to reach orbits, particularly at this early stage of development and test. Therefore, the United States Federal Aviation Administration (FAA) issues temporary airspace restrictions during space launches. These restrictions, known as standard hazard areas, usually take effect as Temporary Flight Restrictions (TFRs) or Special Use Airspaces (SUAs), which prevent aircraft from entering the hazard areas. A TFR is a type of Notices to Airmen (NOTAM). A TFR defines an area restricted to air travel due to a hazardous condition, a special event, or a general warning for the entire FAA airspace. The text of the actual TFR contains the fine points of the restriction. SUA consists of airspace of defined dimensions identified by an area on the surface of the earth wherein activities must be confined because of their nature, or wherein limitations are imposed upon aircraft operations that are not a part of those activities, or both.

These TFRs and SUAs result in commercial airline flights being delayed and/or rerouted and the temporary shutdown of operations for smaller general aviation companies such as flight schools and aircraft rental businesses. Although there have been anecdotal reports on the impacts of the

TFRs and SUAs have on air traffic[1], the issue has received very limited attention among the academics. This study is intended to fill in this gap.

3. Literature Review of Airspace Simulation and Modelling

Most of the literature on the space traffic interspersing with air traffic in the national airspace systems focus on risk analysis, estimation and projection of hazard areas of space launch and reentry, and developing air traffic control tools to integrate space activities into the airspace safely and efficiently. It is noted that many of the studies stemming from FAA's various initiatives and efforts in addressing the emerging issues in the rapidly evolving industry.

Larson [6] discusses the computation of risks of space operations to aircraft and the modeling of aircraft vulnerability as well as potential methods to mitigate the impacts of space operations on airspace. Anselmo and Pardini [7] provide a brief overview of the risks associated with reentries of satellites and debris and discuss the methods and techniques for estimating and predicting such risks. Larson, Carbon and Murray [8] describe the development of FAA's Shuttle Hazard Area for Aircraft Calculator (SHAAC). Although SSAAC was developed for NASA Space Shuttle, the underlying methodology could be applied to predict the hazard areas of other space vehicle operations.

Mazotta and Murray [9] note the fact that the current process for integrating space operations into the NAS is entirely manual and stress the need for developing technology and infrastructure vital for safer and more efficient NAS integration. Murray and Van Suetendael [10] discuss FAA's initiative in developing an integrated Space and Air Traffic Management System (SATMS). Mutuel and Murray [11] expound FAA's effort in developing Space Data Integrator (SDI) to provide a rapid and flexible method for integrating launch and reentry operations into the NAS.

Colvin and Alonso [12] proposes a new class of hazard area for space launch and re-entry, termed as compact envelopes that are "dynamic in time, contour in space as a function of altitude". The paper further compares the effects of the proposed compact envelopes with traditional hazard areas through simulations and conclude that compact envelopes could potentially decrease disruption to the NAS significantly. Colvin and Alonso [13] presents a probabilistic analysis of the disruption to the NAS by space operations using traditional hazard areas and the compact envelopes proposed in the authors' previous paper. Their results show near complete elimination of disruption to the NAS when the hazard areas are defined by the compact envelope.

Tompa, et al [14] apply Markov decision process to model commercial space launches and their interactions with aircraft in the surrounding airspace. Based on launch vehicle trajectory,

---

[1] A White Paper produced by ALPA notes the differences in treatment of space launches versus aviation activities and discusses the negative effects increasing launch rates could have on commercial aviation [5].

probability of anomaly, and potential debris trajectories of a two-stage-to-orbit launch from Cape Canaveral, and commercial aircraft at 35,000ft in the NAS, the model produces dynamic safety regions and optimal rerouting policies that minimize disruption to the NAS while maintaining safety. The paper shows that the proposed dynamic safety regions would result in 3% less rerouted flights, and rerouted flight distances being cut in half, compared to the existing launch hazard areas. Tompa and Kochenderfer [15] proposes an adaptive spatial discretization (ASD) method to overcome the issue of computational tractability associated with Tompa, et al [14]. The proposed ASD solution defines a smaller dynamic safety area, resulting in safer re-routes with smaller flight deviations. Moreover, their analysis shows that the number of impacted flights with ASD was less than 10% of the historically impacted flights.

Srivasta, et al [16] presents their ongoing research on developing models to project, up to one year in advance, the impact of airspace closure associated with space operations. The authors state that their ultimate goal is to develop a projection model that will enable instantaneous assessment of the impact of blocking airspaces using a what-if analysis paradigm, and be accessible to a broad range of airspace users with no prior knowledge of air traffic. The authors believe that such capability will help increase transparency and promote collaboration among airspace users and air navigational services providers. Their current model uses yearly historical traffic patterns within the U.S. airspace to project NAS impacts.

There are a broad range of literature using simulations to study various issues related to airspace. For example, Sweet, et al [17] evaluate new operational concepts for air traffic control using fast time simulations; Gaxiola, et al [18] use simulations to assess the impact of Northern Europe Free Route Airspace deployment in terms of the aircraft loss of separation and the airspace complexity; Luchkova, et al [19] conduct multiple simulations to analyze the impacts of volcanic ash on air traffic. However, studies that provide quantitative estimates of the impacts of space activities on the airspace are sparse.

Srivastava, et al [20] propose a two-step approach to estimate the impact of a future space launch or reentry on airspace in terms of extra flight distances and delays of impacted flights, either delayed or re-routed, based on a sample of historical days similar to a scheduled launch day. The study considers two options for each impacted flight, re-routing or ground delay, and estimates a "cost index' for each option. Their model chooses the option with a lower "cost index" for each impacted flight in estimating the extra flight distance and delays. The study applies the proposed model to estimate the impact of NASA's Exploration Flight Test-l (EFT-1) operation that launched the Orion spacecraft from Cape Canaveral on 5 December 2014. The launch was originally scheduled for December 4, and the affected airspace (hazard areas) was blocked for the entire planned duration despite the launch being re-scheduled for the next day. The proposed model estimate that the impacted flights would travel an extra 4.34 NM with an average 0.72-

minute delay as a result of the originally planned launch on December 4. The actual impact analysis of the blocked airspace on December 4 shows a total of 141 impacted flights with an average increase of 28 NM per flight. The paper notes that the "impacted flights" include those that may have rerouted due to unrelated reasons.

Young and Kee [21] perform a statistical analysis of the impacts of blocking airspace during SpaceX Falcon 9's launch from Cape Canaveral on March 1, 2013, and the subsequent re-entry of Dragon capsule off the California coast on March 26, 2013. Their results show that the Falcon 9 launch caused 25 to 84 NM extra flight distances, 1 to 23 minutes delays, and 275 to 2,387 lbs extra fuel burns for the impacted flights. However, the launch did not have any significant negative impact on the operations at the major airports in the region. The results also show that the reentry of Dragon capsule impacted flights to/from Hawaii and Australia, but not U.S. domestic and other international flights. Flights to/from Hawaii and Australia experienced 1.5 to 7 minutes delay, extra 15 to 27 NM flight distance, and extra 458 to 576 lbs fuel burn. Their operational analysis indicates that the air traffic controllers implemented procedures to fully utilize all available airspace surrounding the blocked airspace and to minimize the impact of the launch and re-entry on the NAS.

Young, Kee, and Young [22] conduct three sets of fast-time simulations on six sample days using AirTOp to analyze the impact of future space launch and reentry on the NAS under the existing airspace closure procedure, and to assess the potential benefits of the compact envelope proposed by Colvin and Alonso [12]. The impacts of the space operations are measured in terms of flight distance, fuel burn and flight delay as in Young and Kee [20]. The study finds that the compact envelopes would help reduce flight distance by 3.5 to 18.7 NM, fuel burn by 43.1 to 200.3 lbs, and flight time by 0.4 to 2.6 minute, compared to the existing airspace closure procedure. Their results also suggest that compact envelope could help alleviate air traffic controllers' workload.

Luchkova, et al [23] attempt to examine the potential impacts on European airspace of SpaceLiner, a two-stage suborbital Reusable Launch Vehicle, still in its early development phase at German Aerospace Center. The paper first discusses alternative scenarios of the trajectory of the SpaceLiner, then develops an airspace model based on EUROCONTROL`s Demand Data Repository (DDR2) and the European AIS database (EAD) and a provisional hazard area model based on NASA's Columbia space shuttle accident debris data. The airspace model and the hazard area model are then used in simulations to evaluate the effect of SpaceLiner operations without closing any of the hazard areas. The objective of the simulations is to estimate the number of flights to be impacted, e.g. those flying through the hazard areas, and consequently affecting air traffic controller workload if any rerouting will be necessary.

While modeling and simulations continue to improve analytical solutions to airspace conjunctures, regulatory and operational solutions are slowly evolving. Kaul [24] discusses the

need and the plausibility for ICAO (International Civil Aviation Organization) to take over Air and Near Space Traffic Management. This paper provides new evidences for the impacts of space activities on commercial aviation, and discusses possible operational solutions, which will contribute to the ongoing dialogues on how to better integrate space activities into the airspaces.

4. Methodology

Predictive fast-time simulation modeling is used in this study to analyze the impacts on airline traffic of horizontal launches of Concept Z space vehicles taking off from Cecil Air and Space Port (VQQ) in Jacksonville, Florida. The spaceport is owned and operated by Jacksonville Aviation Authority, and licensed to support horizontal launches of both Concept X and Concept Z space vehicles with dedicated launch corridors and related warning areas. The spaceport forecast 52 launches per year (48 Concept X and 4 Concept Z) in its 2014 Launch Site Operator Renewal Application [25]. This study focuses on the Concept Z vehicle as it was the space vehicle considered in Cecil's initial launch site operator license, and the planned airspace closure information is readily available.

As there has been no actual commercial space launch from Cecil yet, the first step to develop our simulation model is to establish the anticipated operational and launch conditions, including flight characteristics of the Concept Z carrier aircraft and launch vehicle, launch window, airspace closures, and schedules and flight paths of the commercial flights that are potentially to be impacted. Jeppesen's Total Airspace & Airport Modeler (TAAM)[2] is then used to simulate the interspersing of the launch from Cecil with the regular commercial airline flights the impacted the area during the anticipated launch window under various scenarios. The rest of this section provides details on collecting and compiling the basic data, setting up alternative scenarios and the development of our simulation models.

4.1. Establishing Operational and Launch Conditions

As mentioned earlier in the paper, launching a Concept Z vehicle is a two-stage process. For the intent of this research, the carrier aircraft with mated spacecraft taking off on a runway from the spaceport is defined as the primary launch, and the secondary launch is when the spacecraft is air launched once they reach an altitude of 40,000 feet – 60,000 feet. Since airplanes do not currently fly above 40,000 ft in altitude and the airspace is closed due the TFR, secondary launch

---

[2] TAAM Version 2018_3_0_R13_01. TAAM is a workstation-based, object oriented, computer program designed by Jeppesen (One Boeing) and simulates 4D (3D plus time) models of airspace and airports to facilitate decision support, planning, and analysis.

is not considered important for this research except for the possibility that the carrier aircraft and/or the separated RLV will return to the spaceport within the airspace closure time window.

Figure 1 illustrates the anticipated flight path of the carrier aircraft with the mated spacecraft, heading in the southeast direction from Cecil spaceport, and the launch point where the spacecraft will be released from the carrier aircraft and rocket motors ignited to propel the spacecraft on its suborbital trajectory. The carrier aircraft will return for a jet-powered horizontal landing with a projected path from the southeast through the same corridor while spaceship will return at a later time to the spaceport, also from the southeast via the same corridor, functioning as a glider with no rocket or jet power for a horizontal landing. Figure 1 also shows the estimated boundaries of the flight corridor, and the marked offshore warning area.
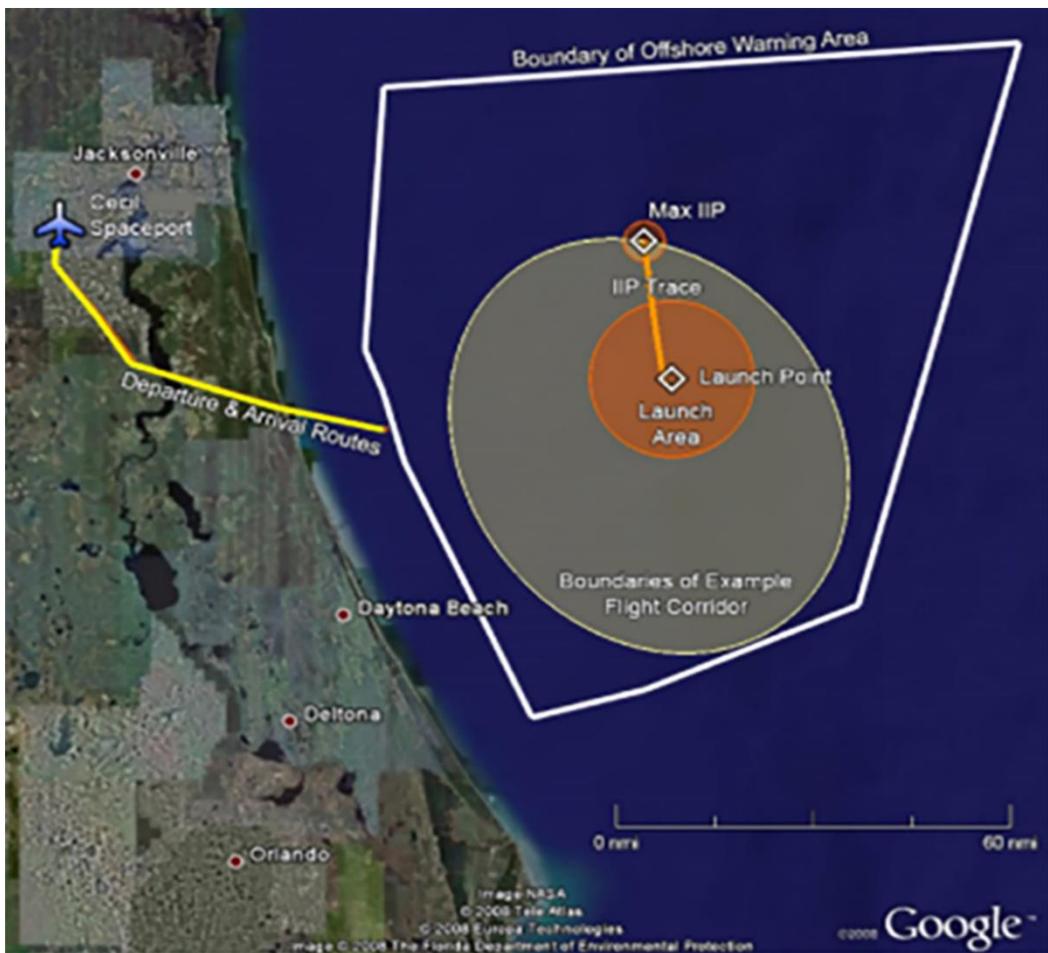

Fig. 1 General Departure and Arrival Routes with Example Spacecraft Launch Point [26].

To ensure the safety of both aircraft in the NAS and spacecraft, airspace is closed during space launches (and re-entries). Figure 2 highlights the airspace closure area (in pink, bold) during the launch of a Concept Z space vehicle from Cecil. The information used to define the airspace closure area was obtained from Cecil Spaceport's launch site operator license application [27] and interviews with key individuals at the spaceport and at the FAA Jacksonville Center.

Worth noting in Figure 2 is the presence of a Military Operations Area (MOA) at the western edge of the RLV airspace closure zone denoted by the red rectangle. This section of airspace marks areas where military aircraft carry out training or operational activities (it can also include the utilization of other military systems). To the east of this airspace is a high-military-traffic zone wherein military aircraft can be expected to frequent for training purposes. These areas do not extend in altitude to a height which would be disruptive to launch or commercial aviation. Despite this, airlines and commercial space launch operators may seek to avoid any restrictive airspace such as to minimize possible disruptions to their operations. As sections of the borders of the military air traffic zone come in contact with the RLV airspace, closure of the RLV area may cause flights to reroute further west than may otherwise be expected.
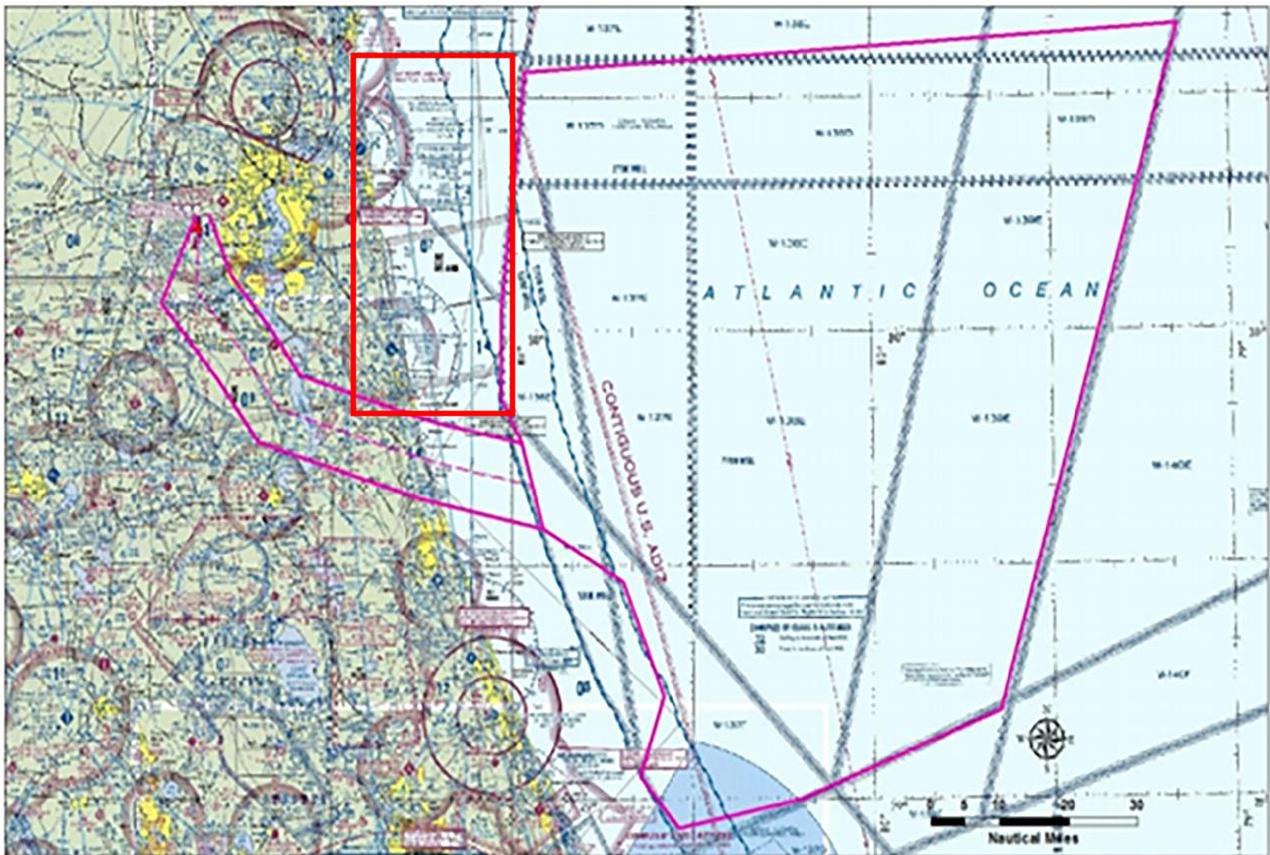

Fig. 2: Airspace Areas of Closure During Launch Operations for Concept Z (Ref. Cecil Spaceport Flight Corridor and Warning Area. Source: Obtained through private communication with Cecil Air and Space Port.

As for the airspace closure times (launch windows), the Letter of Agreement for operations in Cecil Spaceport's launch site operator license application [27] specifies that all space launches should occur prior to 9AM on Wednesdays and Saturdays, during which time, there are generally less airline traffic in the area. Our simulation models, however, are built based on the most congested airspace time period in order to examine the impacts under the worst-case scenario. Review of the FAA Aviation System Performance Metrics (ASPM) data indicates that the 8AM to 12noon period on 2 May 2017 (Tuesday) was the busiest time period, thus chosen as the "launch window" for the simulation. Further, based on our interviews with FAA air traffic control personnel, airspace closures for space launches are typically 4 hours in duration: beginning 2 hours prior to the launch and remaining closed 2 hours after launch. It is noted that the FAA can re-open the restricted airspace following successful launches as soon as conditions are considered safe with no launch anomalies. Therefore, the most restrictive case scenario in our simulations representing current practice considers the 4-hour launch window starting at 8am and ending at 12:00noon with the planned launch at 10:00am on 2 May 2017. Two other scenarios with reduced launch windows are also simulated to show the potential benefits of more flexible launch windows.

Actual airline flights data were obtained from FAA's Performance Data Analysis and Reporting Systems (PDARS)[3], and used as the basis for traffic schedules in the simulation process to mirror real traffic situations. In order to capture all flights that were impacted and to provide flexibility in scenario development, the flight schedules were developed for a 24-hour period. It should be noted that our research focuses on impacts on airlines, and the impacts on general aviation traffic were not considered.

Figure 3 shows actual airline traffic conditions with no flight restrictions for 2 May 2017 at 10 AM, including only the flights that were to be impacted by the airspace closure. The flights are identified by their flight numbers and altitudes. Most notable are U.S. carriers: United Airlines (UAL), American Airline (AA), Spirit Airlines (NKS), Southwest Airlines (SWA), Jet Blue (JBU), Delta Airlines (DAL), Frontier Airlines (FFT) and cargo carrier, United Parcel Service (UPS) and FedEx Express (FDX). The restricted areas for horizontal launches out of Cecil Spaceport are noted in Figure 3. We can see that airline flights are mostly routed down the eastern side of the Florida peninsula, largely over water, during normal operations, and most air traffic naturally refrains from entering the trapezoidal area of TFR-airspace closure, but they all cross the airspace corridor for the space vehicle departures and arrivals. The restricted areas near Kennedy Space Center/Cape Canaveral Air Force Station (KSC/CCAFS), Cape Canaveral, FL are also shown in Figure 3 but were not activated for our simulation.

---

[3] PDARS consists of a dedicated network of computers located at FAA sites that use specialized software for collecting detailed air traffic management system data, providing quality controlled flight track data.
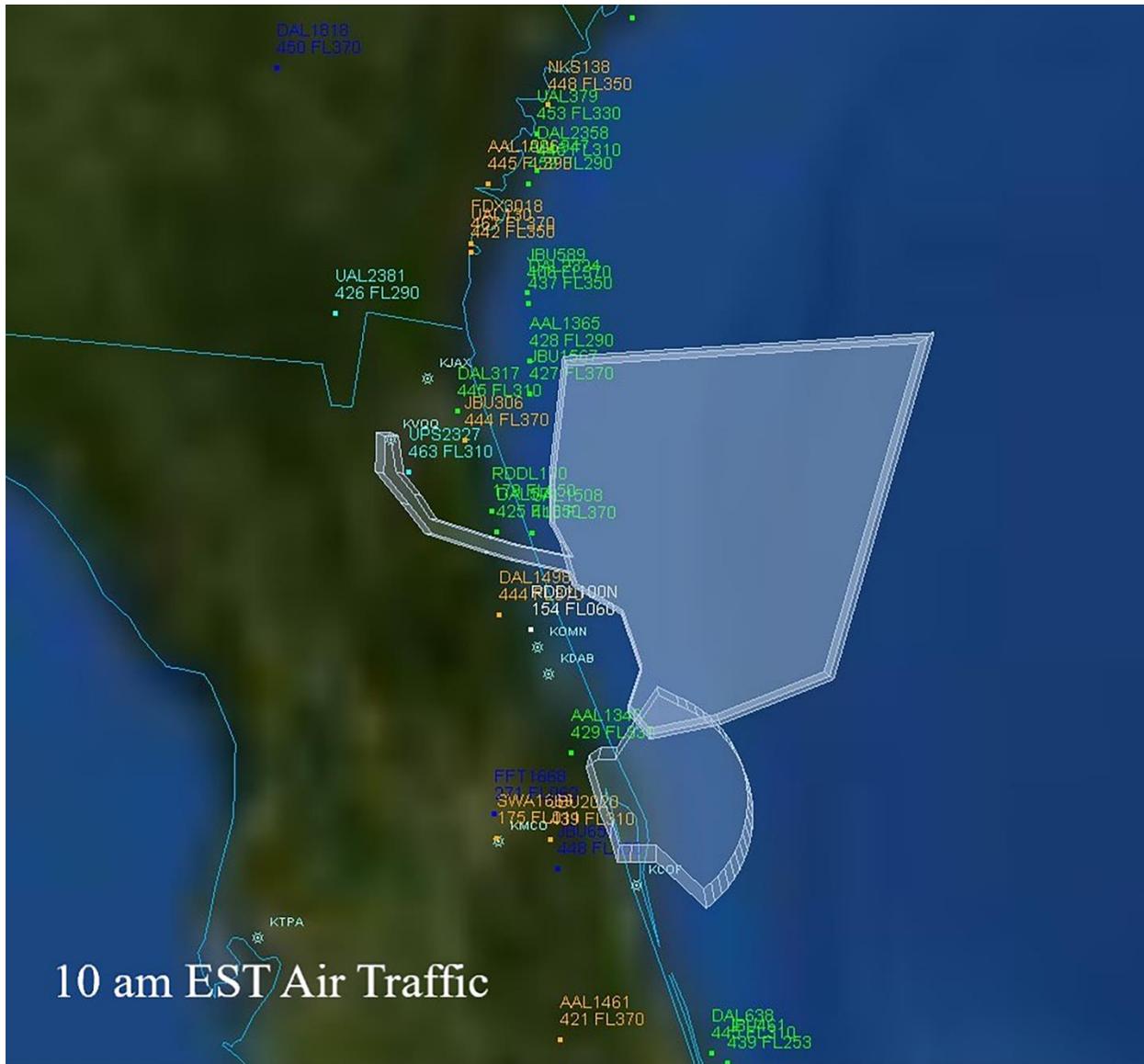
Fig. 3. Actual Airline Traffic on 2 May 2017 at 10AM

4.2 Developing Simulation Scenarios

Our baseline scenario mirrors the actual flights on 2 May 2017 without any launch operations. Four launch scenarios are established for a 10:00AM primary launch, reflecting various durations of launch windows and different extents of airspace closures. Scenario 1 represents the routinely planned 4-hour launch window for a 10:00AM launch and full airspace closure. Based on discussions with FAA personnel at ZJX, airspace may be re-opened prior to the completion of the 2-hour post-launch closure following a successful launch. Thus, Scenario 2 assumes a 1.5 hour launch window covering one hour before and 30 minutes after the 10AM launch, and a full

airspace closure; and Scenario 3 assumes a 2 hour launch window covering one hour before and one after 10:00AM launch with a full airspace closure. The following summarizes these three launch scenarios:

- Scenario 1 – Complete TFR with airspace blocked from 8AM to 12PM with a 10AM launch from Cecil

- Scenario 2 – Complete TFR with airspace blocked from 9AM to 10:30AM with a 10 AM launch

- Scenario 3 – Complete TFR with airspace blocked from 9AM to 11AM with a 10AM launch

As aforementioned, air traffic runs up and down the eastern side of the Florida peninsula, along the Atlantic Ocean coast. Although both the carrier aircraft and RLV are currently viewed experimental, popular understanding and FAA discussion indicate that neither are considered an extraordinary safety hazard during the take-off procedure and before they reach an altitude above 40,000 when the air launch occurs. It is assumed that the craft return to the spaceport with no extraordinary hazards, that is, either under normal jet power (carrier aircraft) or as a glider (RLV). Rocket propellant is assumed to be depleted from the RLV prior to its return to the spaceport. Therefore, Scenario 4 assumes no closure for the departure/arrival corridor airspace, as depicted in Figure 4, but retains the trapezoidal airspace closure. The MOA and military high-traffic areas are highlighted in the triangle in Figure 4. This no-corridor closure scenario is to examine the effects on airlines if the carrier aircraft is treated as a conventional aircraft through the entire duration of its flight, and does not require airspace restrictions, even if it is carrying the RLV. We also assume that the RLV would return as a glider during this time period with no additional airspace closures beyond those that are already in place. Thus,

- Scenario 4 - No Departure/arrival Corridor TFR with remaining airspace blocked from 8AM to 12PM with a 10AM launch

Finally, in order to account for the variances between our worst-case air traffic scenarios discussed above and those stated in the Letter of Agreement for spaceport operations at Cecil [26] that requires all launches before 9:00AM (Wednesdays and Saturday only), two additional scenarios are established as follows:

- Scenario 5 – Complete TFR with airspace blocked from 5AM to 9AM with a 7AM launch

- Scenario 6 – No Corridor TFR with airspace blocked from 5AM to 9AM with a 7AM launch
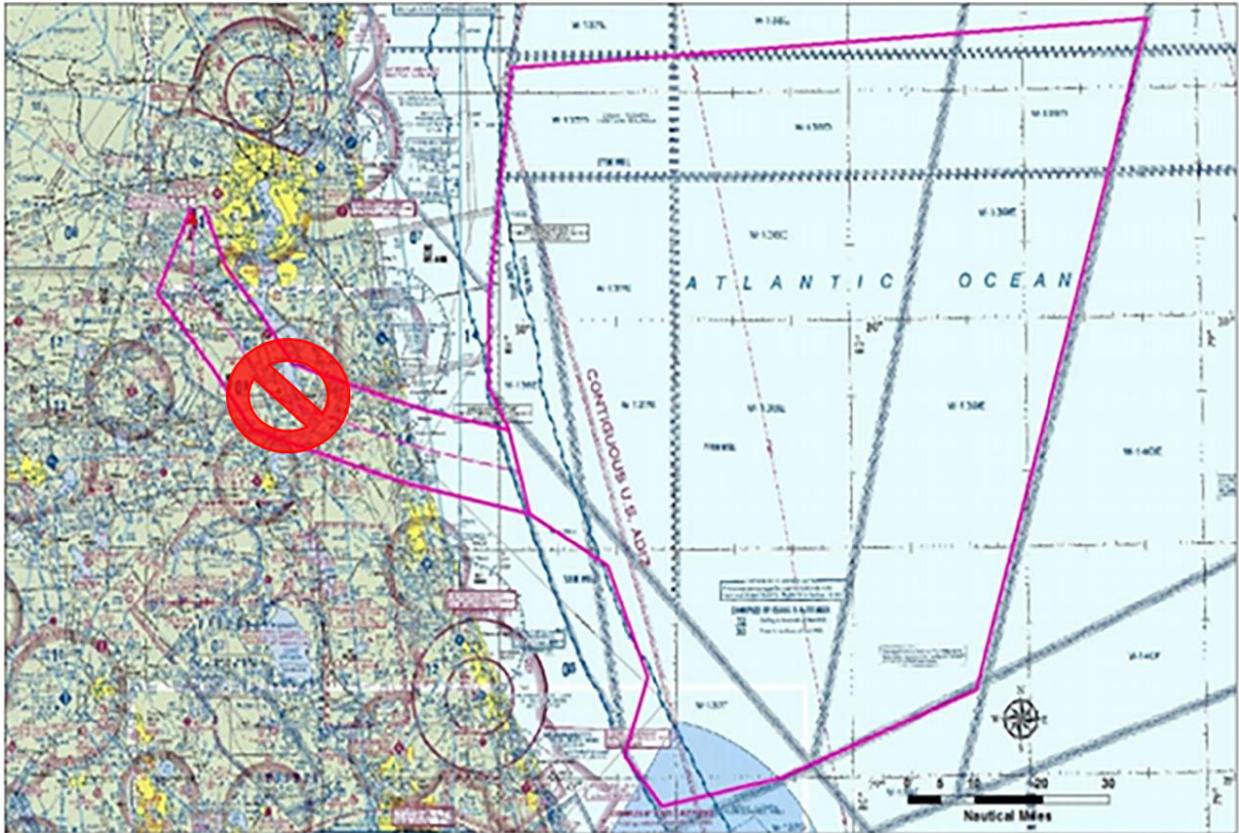
Fig. 4: Airspace Areas of Closure During Launch Operations for Concept Z with Launch Corridor Removed
Source: Original airspace closure information obtained through private communication with Cecil Air and Space Port.

As can be seen in Figure 5, there is still a considerable amount of air traffic at 7AM. Most notable are U.S. carriers: United Airlines (UAL), American Airline (AA), Spirit Airlines (NKS), Republic Airways (RPA), Southwest Airlines (SWA), Jet Blue (JBU), Delta Airlines (DAL) and Canadian carrier, Air Canada Rouge (ROU). Again, the restricted areas for VQQ and KSC/CCAFS are noted in Figure 5. KSC/CCAFS restricted areas were not activitated.
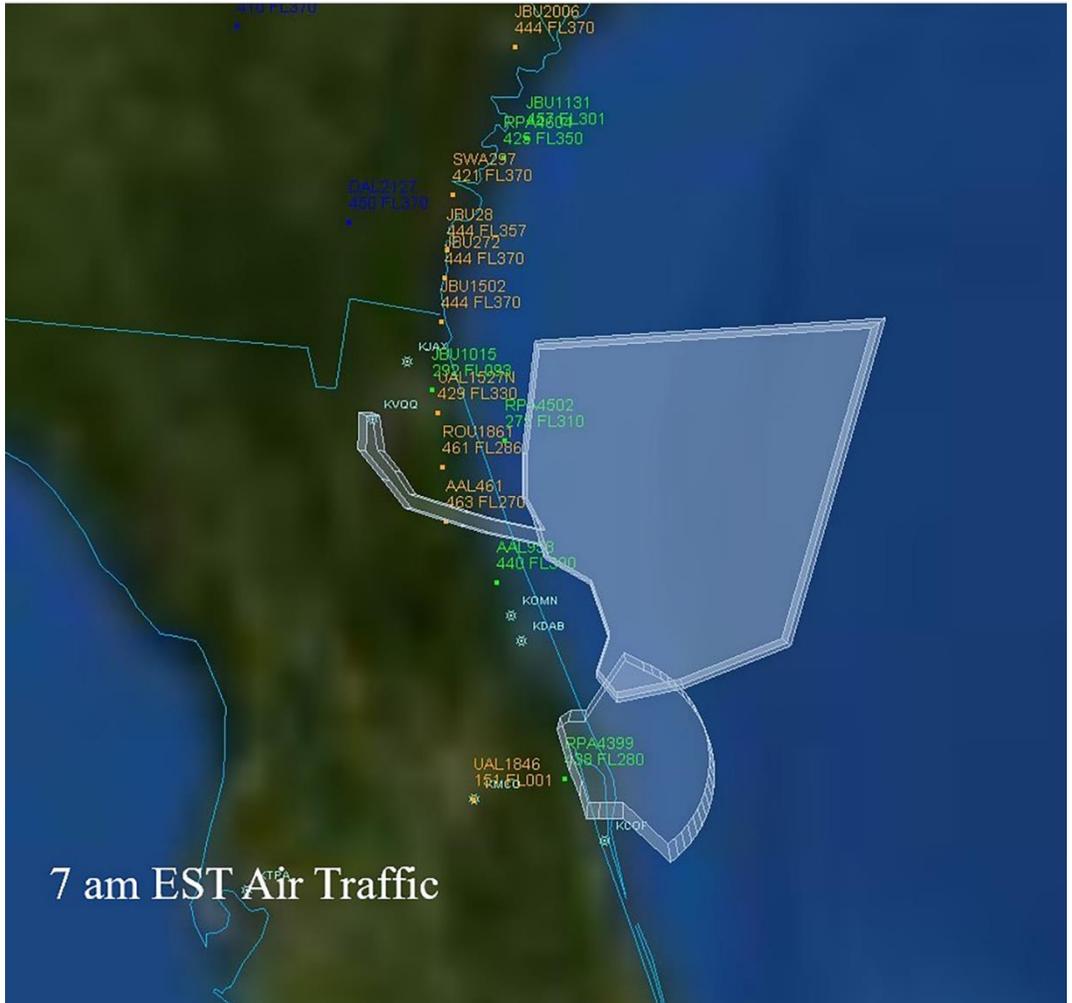
Fig. 5. Actual Airline Air Traffic on 2 May 2017 at 7AM

Both airline traffic and commercial space launches are expected to continue to grow over the next 20 years. As air traffic increases, the impacts on commercial aviation by a single space launch are expected to increase as well. Therefore, our simulations also estimate the impacts on airlines by a single space launch in 2027 and 2037 at the forecasted air traffic levels.

The 2027 and 2037 air traffic volumes in the simulated area are estimated based on FAA Aerospace Forecast for Fiscal Years 2017-2037 [28]. In particular, the air traffic growth in the impacted area is estimated as the weighted average of the FAA's IFR flights forecasts for Jacksonville center (ZJX) and Miami Center (ZMA). Eq. 1 and Eq. 2 calculate the traffic growth rates with respect to the 2017 traffic level.

$$2027\ Growth = \frac{(ZJX_{2027} - ZJX_{2017}) \times ZJX_{2027} + (ZMA_{2027} - ZMA_{2017}) \times ZMA_{2027}}{Total_{2027}} \qquad \text{Equation 1}$$

$$2037\ Growth = \frac{(ZJX_{2037}-ZJX_{2017})\times ZJX_{2037}+(ZMA_{2037}-ZMA_{2017})\times ZMA_{2037}}{Total_{2037}}$$ Equation 2

Where ZJX_i denotes the FAA traffic forecast for Jacksonville center in year i; ZMA_i denotes the FAA traffic forecast for Miami center in year i; and $Total_i$ is the sum of the traffic forecast of the two centers in year i. Table 1 presents the air traffic forecasts for ZJX and ZMA as well as the weighted average growth rates.

Table 1. Weighted Average Growths in IFR Flights.

Scenarios	ZJX	ZMA	Total	Weighted Growth
2017	2,281,714	2,529,959	4,811,673	---
2027	2,678,874	2,834,247	5,513,121	15%
2037	3,195,151	3,270,859	6,466,010	28%

Source: FAA Aerospace Forecast for Fiscal Years 2017-2037 [28]

Based on the calculated growth rates in Table 1, TAAM generates the flight schedules for 2027 and 2037 by randomly cloning flights. TAAM is able to resolve cloned flight airspace conflicts automatically with FAA separation distances enforced in the simulations. Table 2 summarizes the baseline scenario and Launch scenarios, including the established parameters of varying launch window durations and airspace closures.

4.3 Running Simulations

TAAM does not have the capability to automatically reroute flights with user-defined airspace closures. Since no launches have occurred from the spaceport to date, no aircraft flight data showing the actual disruption of such an event is available. Therefore, a set of the flight re-routing rules are developed based on the parameters of the airspace closure and current FAA regulation and procedures, and manually programmed into TAAM. These reroutes are activated on a case-by-case basis when affected aircraft encounter key waypoints prior to entering the airspace closure, but allowing sufficient time for aircraft reroute, thus optimized to minimize airline impacts.

Using this method, all impacted aircraft are detoured around the closure with minimal additional distance traveled, and the affected aircraft would rejoin the original flight path after rerouting. Aircraft could be rerouted either east or west of the restricted airspace, but any aircraft rerouted east over water has to be certified to do so. Because of this restriction, most aircraft are rerouted west of the airspace closure. Such procedure is in line with FAA norms. For example, per FAA interviews, aircraft impacted by launches from KSC/CCAFS are rerouted west over the Florida peninsula, away from the direction of the eastward rocket path.

Table 2. No Launch Baseline and Launch Scenarios

Scenarios	Parameters	2 May 2017	2 May 2027	2 May 2037
No Launch Baseline Scenario	No airspace closures	Actual Air Traffic	Forecasted Air Traffic	Forecasted Air Traffic
Launch Scenario 1	Complete TFR with airspace blocked from 8AM to 12PM; 10AM launch	Actual Air Traffic with Simulated Reroute	Simulated Air Traffic with Forecasted Growth and Reroute	Simulated Air Traffic with Forecasted Growth and Reroute
Launch Scenario 2	Complete TFR with airspace blocked from 9AM to 10:30AM with a 10 AM launch	Actual Air Traffic with Simulated Reroute	Simulated Air Traffic with Forecasted Growth and Reroute	Simulated Air Traffic with Forecasted Growth and Reroute
Launch Scenario 3	Complete TFR with airspace blocked from 9AM to 11AM with a 10AM launch	Actual Air Traffic with Simulated Reroute	Simulated Air Traffic with Forecasted Growth and Reroute	Simulated Air Traffic with Forecasted Growth and Reroute
Launch Scenario 4	No corridor TFR but with remaining airspace blocked from 8AM to 12PM with a 10AM launch	Actual Air Traffic with Simulated Reroute	Simulated Air Traffic with Forecasted Growth and Reroute	Simulated Air Traffic with Forecasted Growth and Reroute
Launch Scenario 5	Complete TFR with airspace blocked from 5AM to 9AM with a 7AM launch	Actual Air Traffic with Simulated Reroute	Simulated Air Traffic with Forecasted Growth and Reroute	Simulated Air Traffic with Forecasted Growth and Reroute
Launch Scenario 6	No corridor TFR but with remaining airspace blocked from 5AM to 9AM with a 7AM launch	Actual Air Traffic with Simulated Reroute	Simulated Air Traffic with Forecasted Growth and Reroute	Simulated Air Traffic with Forecasted Growth and Reroute

5. Discussions of Simulation Results

We extract the following sets of data from the TAAM simulations for each of the launch scenarios and the baseline scenario:

- Time Flown:
    - Total time flown by a specific aircraft. Specifically, from take-off until landing (wheels up until wheels down).
- Distance Flown
    - Total distance flown by a specific aircraft in nautical miles (nmi)
- Fuel Cost
    - Total fuel cost for a specific aircraft (wheels up to wheels down). Fuel costs are calculated assuming the fuel price at $1.51/gallon. This was the price of jet fuel on 2 May 2017, the day of the 2017 Baseline Scenario.

The potential impacts of a single space launch on airlines are assessed by comparing the results of the launch scenarios with those of the baseline scenario, and are measured in terms of the number of impacted aircraft, additional flight time (delay), additional distance flown, and additional fuel costs:

- Flight Time Delay (minutes)
    - The "Time Flown" difference between each of the launch scenarios and the baseline scenario
- Additional Distance Flown (nmi)
    - The "Distance Flown" difference between each of the launch scenarios and the baseline scenario.
- Additional Fuel Cost (USD)
    - The "Fuel Cost" difference between each of the launch scenarios and baseline scenario.

TAAM output data are sampled every 1 second, thus we first filter out sampling errors in the results by removing flights that are impacted by less than +/- 1 second in order to obtain a more rigorous output data set. Table 3 presents the estimated total impacts for Launch Scenario 1 to Scenario 3, as defined by the following:

- Number of Aircraft Impacted by a Single Commercial Space Launch
    - The number of flights for which a launch scenario's "Time Flown" is longer than that of the baseline scenario.
- Total Flight Time Delay (minutes)
    - The sum of the "Flight Time Delay" for all the impacted flights under each launch scenario versus the baseline scenario.
- Total Additional Distance Flown (nmi)

- o The sum of the "Additional Distance Flown" for all the impacted flights under each launch scenario versus the baseline scenario.
- Total Additional Fuel Cost (USD)
  - o The sum of the "Additional Fuel Cost" for all the impacted flights under each launch scenario versus the baseline scenario.

Table 3. Estimated Impacts by a Space Launch under Launch Scenarios 1 through 3

Launch Scenarios		# Impacted Flights	Total Flight Delay (min)	Total Add. Distance Flown (nmi)	Total Add. Fuel Cost (USD)
2017	Scenario 1	186	609.73	4,388	12,522.11
	Scenario 2	72	241.08	1,747	5,450.39
	Scenario 3	95	287.40	2,073	6,333.98
2027	Scenario 1	211	707.92	5,134	14,894.56
	Scenario 2	83	256.22	1,888	5,875.57
	Scenario 3	109	318.52	2,310	7,051.87
2037	Scenario 1	235	745.87	5,420	15,883.83
	Scenario 2	94	267.73	1,988	6,242.70
	Scenario 3	121	336.13	2,452	7,444.31

The estimated total impacted are also presented in Figures 6, 7, 8, and 9. It is not surprising to see that Launch Scenario 1 leads to the largest impacts on airlines over the course of the full 4-hour TFR with the number of flights impacted ranging from 186 in 2017 to 235 in 2037. As shown in Table 3, Scenario 1 results in an estimated total of 609.73 minutes of flight delays, 4,388 nmi additional distance flown, and $12,522.11 additional fuel costs in 2017. In light of the forecasted traffic growth, the impacts on airlines by a single space launch are estimated to increase to 746 minutes in flight delays, 5,420 nmi, additional distance flown, and $15,900 additional fuel costs in 2037, assuming the same fuel price.

Since TAAM only yields fuel costs for the simulated flights, we further estimate the impacts on airlines in terms of direct operating costs based on the simulated flight time delays and the average aircraft operating costs per block minute. According to Airlines for America (A4A), the U.S. passenger airlines' average direct aircraft operating cost per block minute was $68.48 in 2017, which includes crew, fuel, maintenance, aircraft ownership, and other expenses. Figure 10 shows that the estimated additional direct operating costs range from approximately $42,000 in 2017 to over $50,000 in 2037 under Launch Scenario 1. By reducing the duration of the airspace closures in Launch Scenarios 2 and 3, the impacts are greatly reduced. Scenarios 2 and 3 reflects the situations following successful launches, and/or when space vehicles have a safety record established.
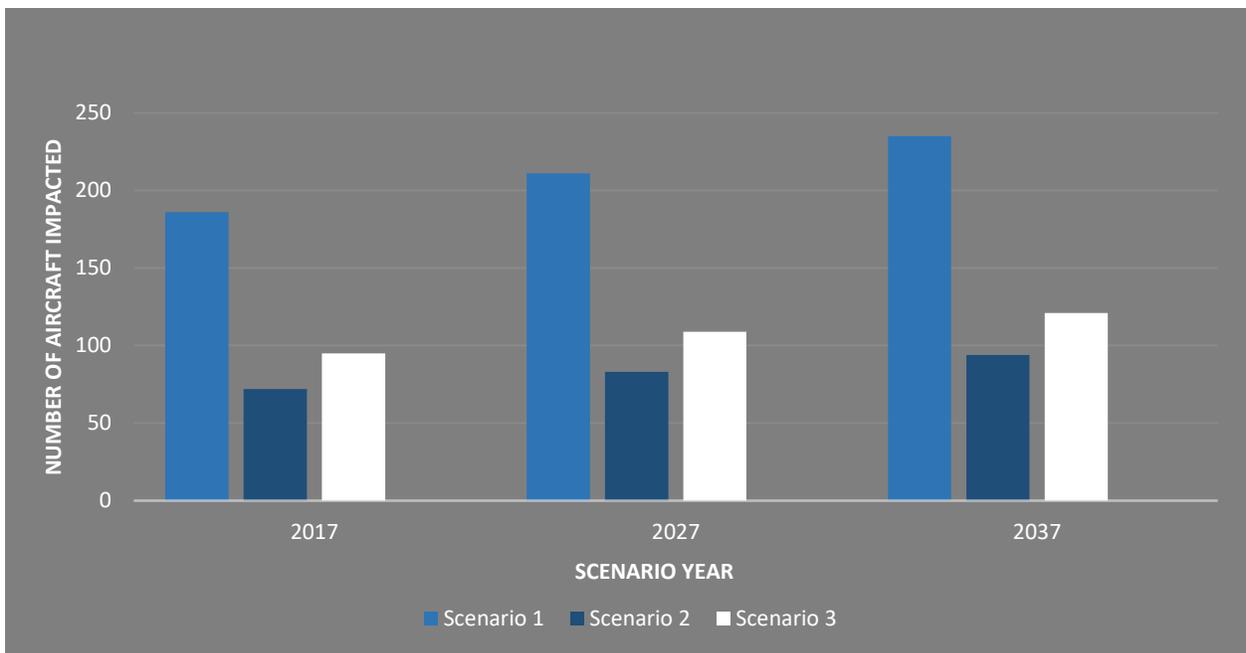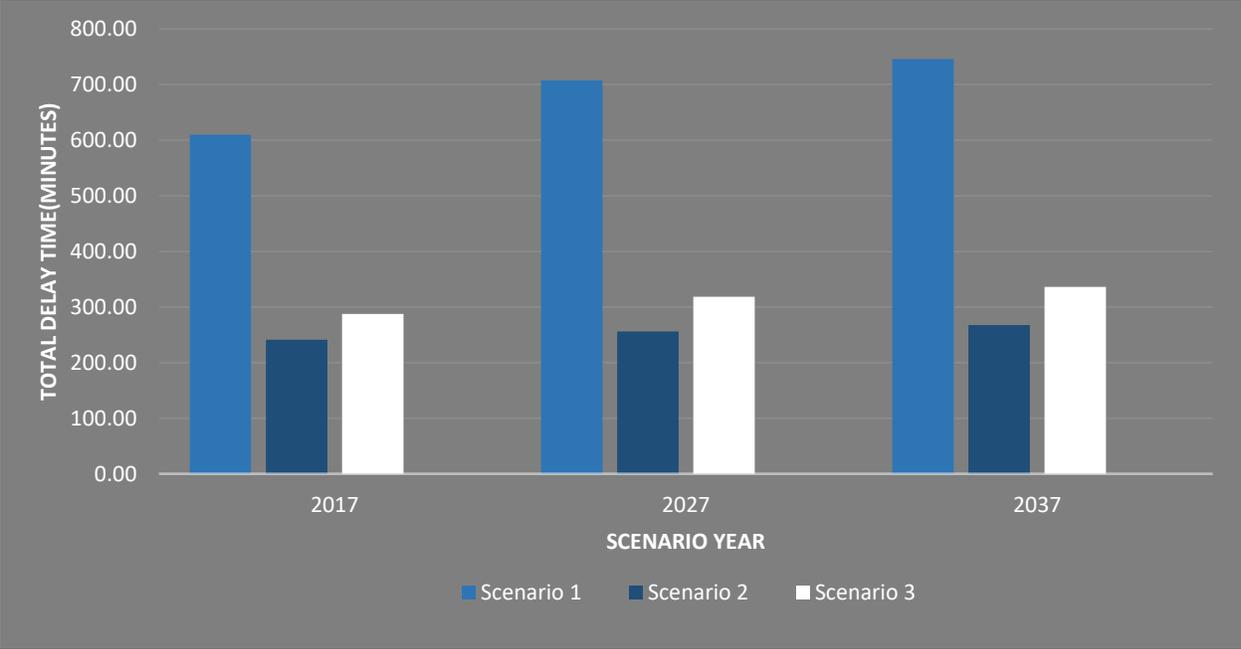

Fig. 6. Number of Aircraft Impacted

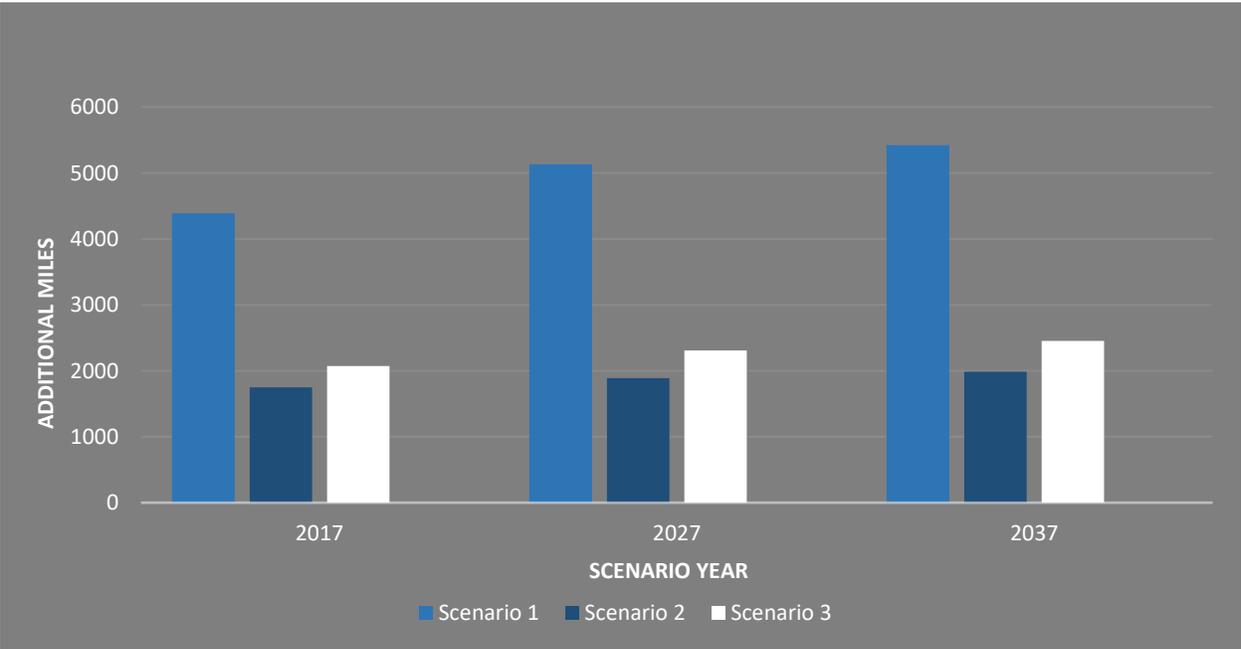*Fig. 7. Total Flight Time Delay in Minutes*

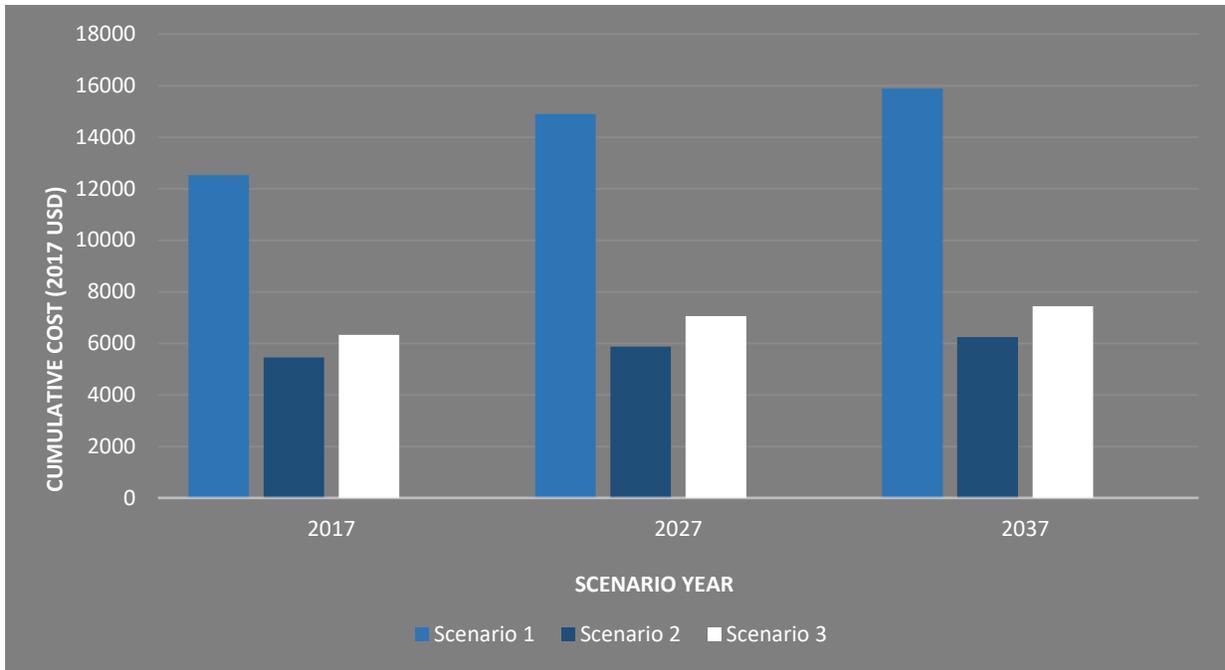*Fig. 8. Total Additional Distance Flown (nmi)*

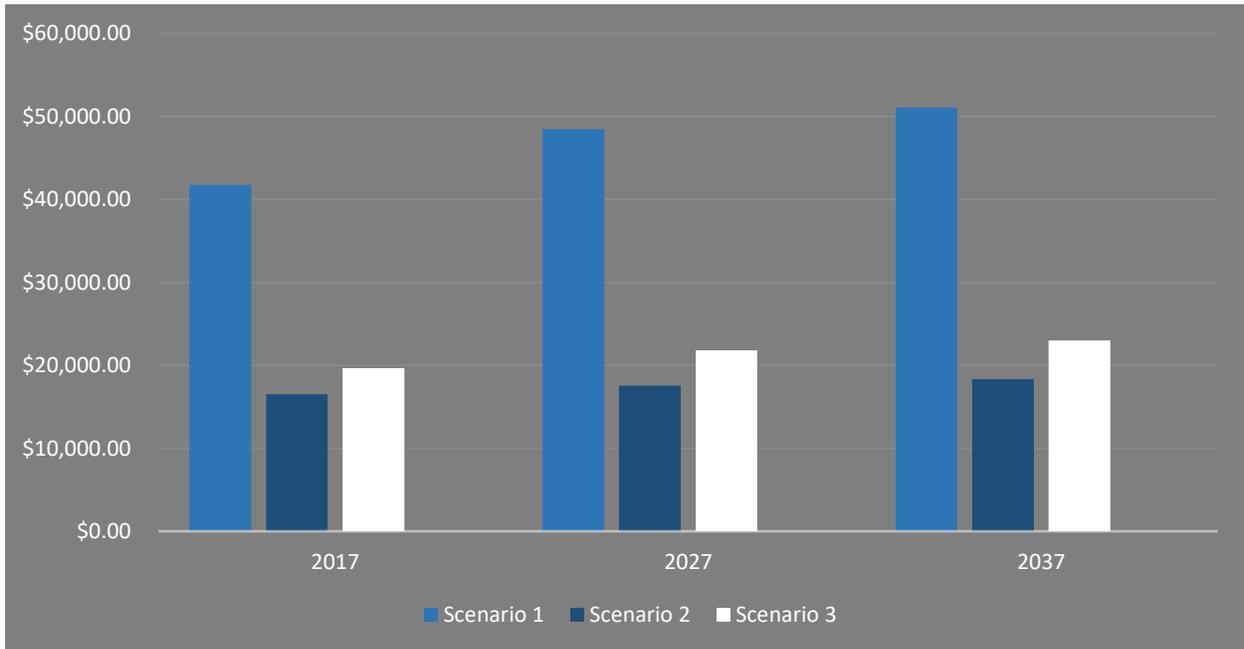*Fig. 9. Estimated Additional Fuel Costs*

Fig. 10. Additional Direct Aircraft Operating Cost Due to Flight Delays

By treating the carrier aircraft as a non-experimental aircraft and opening the departure/arrival corridor to regular air traffic in Scenario 4, we observe that no flights are impacted by the

trapezoidal airspace closure that is located off-shore during the launch window. Hence, there are no delays, no additional distance flown, nor increases in fuel costs.

Launch Scenarios 5 and 6 depict conditions stated in the Letter of Agreement for spaceport operations at Cecil [26]. Thus, these scenarios are established with launch windows of 5AM to 9AM and a launch at 7AM. Scenario 5 depicts a complete TFR and Scenario 6 removes the airspace closure along the departure/arrival corridor. Simulations are conducted for launch scenarios 5 & 6 with 2017 traffic only.

As expected, clearly less flights are impacted during the earlier morning hours, all other variables equal, when the results of Scenario 5 are compared with those of Scenario 1. With respect to Scenario 4 and 6, we observe that no flights are rerouted with the removal of the airspace closure along the corridor regardless of closure times. Table 4 presents the simulation results for Launch Scenarios 5 & 6.

Table 4. Comparison of Estimated Impacts with Corridor Airspace Closure and Without Corridor Airspace Closure

2017	Scenario 1 (With corridor airspace closure; 8 am to noon)	Scenario 5 (With corridor airspace closure; 5am to 9am)	Scenarios 4 and 6 (Without corridor airspace closure)
# Impacted Flights	186	114	0
Additional Fuel Costs ($)	$12,522.11	$6,930.33	$0
Total Flight Time Delay (min)	609.73	352.45	0
Total Distance Flown (nmi)	4388	2521	0
Direct Operating Costs ($)	$41,754.54	$24,135.78	$0

All of the launch scenarios depict a single space launch in one day, multiple launches in a day could lead to more negative impacts on airline fuel costs, delays and operating costs over an extended period. Further, as aforementioned, our simulations reroute only those aircraft that are to enter the TFRs. In reality, rerouted aircraft impact other aircraft, in a domino fashion. Such ripple effects are not considered in the simulations. Finally, it is noted that a very small number of simulated flights appear to consume less fuel with less distance travelled, which may be explained by the likelihood that the original flight paths of these flights are not optimal.

6. Summary and Concluding Remarks

Both the aviation industry and the commercial space industry need effective, safe and efficient integration of space activities into the NAS, and are seeking fair and equitable solutions to achieve the goal. The results from this study provides evidences on the impacts of horizontal

space launches on airlines as well as the efficacy of certain mitigating strategies, thus have important policy implications for governments and the industries.

Our results indicate that the existing practice of 4 hour airspace closure (Scenario 1) impacts a significant number of flights, forcing them to reroute, and resulting in flight time delays, additional flight distance, and additional fuel burns. Reducing the duration of airspace closure, as shown in Scenario 2 and Scenario 3, could serve as a simple solution to mitigate the impacts on airlines and other traditional NAS users, especially as ATC already often releases the TFR airspace early when the airspace is deemed safe following successful launches.

Our study further shows that opening the departure/arrival corridor to air traffic (Scenario 4) during the launch of a Concept Z space vehicle would effectively eliminate almost all the potential impacts on airlines, as very few flights are routed through the trapezoidal airspace closure area, and most flights are routed along the Florida coastline. This is a significant finding. Of the seven spaceports in the U.S. licensed for horizontal launch, four are licensed for Concept Z reusable launch vehicles. The question here is whether or not a Concept Z space vehicle could truly be considered as a conventional aircraft during the takeoff and/or landing procedure. It is likely that airspace closures for such launch vehicles will abate in the near future as the reliability of the vehicles continues to improve. To add further support, carrier aircraft with mated rockets have been treated as regular aircraft in the airspace (i.e. Lockheed 1011 with Pegasus rocket) for quite some time.

Internationally, the majority of the proposed spaceports are for horizontal takeoff and landing, and many of them would transition from current airports to become air and space ports. We anticipate this trend to continue. Particularly, for space tourism, Virgin Galactic is a driving force as Sir Richard Branson has reached agreement after agreement to enable his plans for this sector to be a viable reality in the near future. Point-to-point travel that includes a suborbital trajectory apogee without a full earth orbit will thrill space travel enthusiasts while allowing fast travel around the world. While Spaceport America in the U.S. may be the hub, Sir Branson plans to fly to the UAE, the UK, Italy, and other countries with spaceports that can accommodate the Virgin Galactic spacecraft and launch vehicle and where sufficient participant demand is forecasted.

The growing small satellite industry and corresponding launch provider services are also trends to watch. The use of a carrier aircraft with mated rocket is often the transportation mode of choice for these satellites, encased in the rocket fairing. Virgin Orbit, Generation Orbit, among others, will provide their small satellite launch services via this platform. Generation Orbit is already planning on launch from Cecil Air and Space Port in 2020.

With space launch increasingly becoming a commercial endeavor, and with suborbital launch activities (especially those focused on tourism) advancing rapidly into launch-capable status, space activities are expected to present a much larger disruption to the aviation industries due to more frequent and/or longer interactions with the NAS. Further, in the short term, the unproven

nature of these launch vehicles allows for an expectation of higher risk. As the primary goal of the FAA and other national aviation authorities is to ensure the safety of the traveling public, many possible mitigation strategies may be discounted in the short term until new space launch vehicles have been flight proven.

It should be noted that our research is limited to the launch of Concept Z space vehicles out of one spaceport in the U.S, a spaceport that sits close to the Atlantic Ocean and north of Cape Canaveral, Florida. The impacted airspace areas in this study consist of various "pre-existing" restricted airspaces which airlines and other NAS users stay away from in their regular operations, thus the estimated impacts on airlines are likely to be less than that if the spaceport is located away from the coast and without any restricted airspace. Airspace closures due to launch activities are unique to the geographical location. Proximity to Jet airways and Victor routes, areas of restricted airspace, prohibited airspace, other special use airspace and population centers, among many other considerations, impact the size, shape, and timing of airspace closures. Additionally, the type and orientation of launch vehicle, propulsion method, as well as anticipated payload will influence airspace closure requirements. Another limitation of this study is that potential disruption to airports is not considered. These limitations will be addressed in our future research endeavors.

References

[1] (2019, May 21). Retrieved from http://airlines.org/wp-content/uploads/2019/05/Heimlich-MediaBriefing-21May2019-FINAL.pdf.

[2] Final Environmental Assessment for Jacksonville Aviation Authority Launch Site Operator License at Cecil Field, Florida (2009). Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/media/20090626_Final_Cecil_Field_EA.pdf.

[3] Space Foundation. (2018). The Space Report: The Authoritative Guide to Global Space Activity. Colorado Springs, CO.

[4] Bryce Space and Technology. (2018). 2018 Orbital Launches Year in Review. Retrieved from https://brycetech.com/downloads/Orbital_Launches_Year_in_Review_2018.pdf.

[5] Air Line Pilots Association. (2018). Addressing the Challenges to Aviation from Evolving Space Transportation. Retrieved from https://www.alpa.org/~/media/ALPA/Files/pdfs/news-events/white-papers/white-paper-aviation-space.pdf .

[6] Larson, E. (2013). Safety Design for Space Operations. (F. A. Allahdadi, I. Rongier, & P. D. Wilde, Eds.). Kidlington, Oxford: Butterworth-Heinemann is an imprint of Elsevier. doi: 10.1016/B978-0-08-096921-3.00010-6.

[7] Anselmo, L. and Pardini, C. (2005). Computational methods for reentry trajectories and risk assessment, Advances in Space Research, Volume 35, Issue 7, Pages 1343-1352. doi: 10.1016/j.asr.2005.04.089.

[8] Larson, E. L., Carbon, S. L., & Murray, D. L. (2012). Automated Calculation of Aircraft Hazard Areas from Space Vehicle Accidents: Application to the Shuttle. Atmospheric Flight Mechanics Conference and Exhibit, American Institute of Aeronautics and Astronautics, 18-21 August 2008, Honolulu, Hawaii, USA. doi: 10.2514/6.2008-6889.

[9] Mazzotta, Gwendolyn and Murray, Daniel P. (2015). Improving the Integration of Launch and Reentry Operations into the National Airspace System. The 2nd Space Traffic Management Conference, Embry-Riddle Aeronautical University, 12 November 2015, Daytona Beach, Florida, USA. Retrieved from https://commons.erau.edu/stm/2015/thursday/21.

[10] Murray, Daniel P. and VanSuetendael, Richard (2012). A Tool for Integrating Commercial Space Operations into The National Airspace System. Atmospheric Flight Mechanics Conference and Exhibit, American Institute of Aeronautics and Astronautics, 21-24 August 2006, Keystone, Colorado, USA. doi: 10.2514/6.2006-6378.

[11] Mutuel, Laurence H. and Murray, Daniel P. (2016). Space Data Integrator: FAA's Innovative Platform for Launch and Reentry Operations, 54th AIAA Aerospace Sciences Meeting, American Institute of Aeronautics and Astronautics, 4-8 January 2016, San Diego, California, USA. doi: 10.2514/6.2016-0218.

[12] Colvin, T. J., and Alonso, J. J. (2015a). Compact Envelopes and SU-FARM for Integrated Air-and-Space Traffic Management, 53rd AIAA Aerospace Sciences Meeting, AIAA SciTech Forum, American Institute of Aeronautics and Astronautics, 5-9 January 2015, Kissimmee, Florida, USA. doi: 10.2514/6.2015-1822.

[13] Colvin, T.J. and Alonso, J.J. (2015b). Near-Elimination of Airspace Disruption from Commercial Space Traffic Using Compact Envelopes, AIAA SPACE 2015 Conference and Exposition, American Institute of Aeronautics and Astronautics, August 31-September 2, 2015, Pasadena, California, USA. Doi: 10.2514/6.2015-4492.

[14] R. E. Tompa, M. J. Kochenderfer, R. Cole, and J. K. Kuchar. (2015). Optimal aircraft rerouting during commercial space launches, 34th Digital Avionics Systems Conference, IEEE/AIAA, (DASC), 13-17 September 2015, Prague, Czech Republic, pp. 9B1-1-9B1-9. doi: 10.1109/DASC.2015.7311486.

[15] Tompa, Rachael E. and Kochenderfer, Mykel J. (2018). Optimal Aircraft Rerouting during Space Launches using Adaptive Spatial Discretization, 37th Digital Avionics Systems Conference, IEEE/AIAA, (DASC), 23-27 September 2018, London, United Kingdom. doi: 10.1109/DASC.2018.8569888.

[16] Srivastava, A., Clair, T., & Pan, G. (2018). On-Demand Assessment of Air Traffic Impact of Blocking Airspace. The Aeronautical Journal, 122 (1258), 1985-2009. doi: 10.1017/aer.2018.105.

[17] Sweet, D. N., Manikonda, V., Aronson, J.S., and Roth, K. (2002). Fast-Time Simulation System for Analysis of Advanced Air Transportation Concepts, AIAA Modeling and Simulation Technologies Conference and Exhibit, American Institute of Aeronautics and Astronautics, 5-8 August 2002, Monterey, California, USA. Retrieved from https://www.aviationsystemsdivision.arc.nasa.gov/publications/hitl/technical/2002_4593.pdf.

[18] César Antonio Nava Gaxiola, Cristina Barrado, Pablo Royo, Enric Pastor. (2018). Assessment of the North European Free Route Airspace Deployment, Journal of Air Transport Management, Volume 73, 2018, Pages 113-119. doi: 10.1016/j.jairtraman.2018.08.008.

[19] Luchkova, T., Vujasinovic, R., Lau, A., and Schultz, M. (2015). Analysis of Impacts an Eruption of Volcano Stromboli Could Have on European Air Traffic, Eleventh USA/Europe Air Traffic Management Research and Development Seminar, June 23-26, 2015, Lisbon, Portugal.

[20] Srivastava, Amal, St.Clair, Thomas J., Zobell, Steven, Fulmer, Dean (2015). Assessing Impact of Space Launch and Reentry Operations on the National Airspace System (NAS) using Historical Traffic Patterns, 34th Digital Avionics Systems Conference, IEEE/AIAA, (DASC), 13-17 September 2015, Prague, Czech Republic. doi: 10.1109/DASC.2015.7311486.

[21] Young, J. and Kee, M. (2014). SpaceX Falcon 9/Dragon Operations NAS Impact and Operational Analysis. Washington, D.C.: U.S. Department of Transportation NextGen Implementation and Integration Office.

[22] Young, J., Kee, M., and Young, C. (2015). Effects of Future Space Vehicle Operations on a Single Day in the National Airspace System: A Fast-Time Computer Simulation.

Washington, D.C.: U.S. Department of Transportation NextGen NAS Programming & Financial Management Division.

[23] Luchkova, T., Kaltenhaeuser, S., and Morlang, F. (2016). Air Traffic Impact Analysis Design for a Suborbital Point-to-Point Passenger Transport Concept, The 3rd Space Traffic Management Conference, 16-18 November 2016, Daytona Beach, Florida, USA.

[24] Kaul, Sanat. (2019). Integrating Air and Near Space Traffic Management for Aviation and Near Space. Journal of Space Safety Engineering, Volume 6, Issue 2, June 2019. pp 150-155. doi: 10.1016/j.jsse.2019.06.004.

[25] Jacksonville Aviation Authority. (October 2014). Cecil Spaceport Launch Site Operator License (LSO 09-012) Renewal Application.

[26] Cecil Spaceport. (2017). Spaceport Operations. Retrieved from https://www.flyjacksonville.com/content2015.aspx?id=1091.Dickey, B. (2015, April 07). NASA Advances Effort to Launch Astronauts Again from U.S. Soil to Space. Retrieved November 19, 2017, from https://www.nasa.gov/press/2013/november/nasa-advances-effort-to-launch-astronauts-again-from-us-soil-to-space-station

[27] Jacksonville Air Traffic Control Center, Jacksonville Approach Control, Fleet Area Control and Surveillance Facility Jacksonville, and JAACenter, Miami Center, Jacksonville Approach Control, Cecil ATC Tower, Fleet Area Control and Surveillance Facility Jacksonville, and Jacksonville Aviation Authority/Cecil Spaceport Operations Office. (October 1, 2009). Letter of Agreement, Operations at the Cecil Spaceport at Cecil Field, Jacksonville, Florida.

[26] Jacksonville Air Traffic Control Center, Jacksonville Approach Control, Fleet Area Control and Surveillance Facility Jacksonville, and JAACenter, Miami Center, Jacksonville Approach Control, Cecil ATC Tower, Fleet Area Control and Surveillance Facility Jacksonville, and Jacksonville Aviation Authority/Cecil Spaceport Operations Office. (October 1, 2009). Letter of Agreement, Operations at the Cecil Spaceport at Cecil Field, Jacksonville, Florida.

[28] Federal Aviation Administration. (2017). FAA Aerospace Forecast Fiscal Years 2017-2037. Retrieved from https://www.faa.gov/data_research/aviation/aerospace_forecasts/media/FY2017-37_FAA_Aerospace_Forecast.pdf.

[29] Airlines for America. (2017). U.S. Passenger Carrier Delay Costs. Retrieved from https://www.airlines.org/dataset/per-minute-cost-of-delays-to-u-s-airlines/.

Acronyms

ALPA – Air Line Pilots Association

ARTCC – Air Route Traffic Control Center (United States)

ASPM – Aviation System Performance Metrics

AST – Office of Commercial Space Transportation (United States)

ATM – Air Traffic Management

ESA – European Space Agency

FAA – Federal Aviation Administration (United States)

FMS – Flight Management System

IFR – Instrument Flight Rules

M&S – Modeling and Simulation

MOA – Military Operations Area

NAS – National Airspace System

NASA – National Aeronautics and Space Administration

NOTAM – Notice to Airmen

PDARS -Performance Data Analysis and Reporting System

RLV – Reusable Launch Vehicle

RNP – Required Navigational Performance

ROI – Return on Investment

SID – Standard Instrument Departure

STAR – Standard Terminal Instrument Arrival

SUA – Special Use Airspace

TAAM – Total Airspace and Airport Modeler

TAF – Terminal Area Forecast

TFMS -Traffic Flow Management System

TFR – Temporary Flight Restriction