INTEGRATION OF SPACE VEHICLE OPERATIONS INTO THE UNITED ARAB EMIRATES AIR TRAFFIC MANAGEMENT – AN IMPACT ANALYSIS

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Abstract

The purpose of this study is to understand how future Space Vehicle Operations (SVOs) could be integrated into a highly dense and small airspace when operating from and to a United Arab Emirates (UAE) spaceport. The National Space Sector is a main pillar of the UAE's long-term strategic plan towards a knowledge-based economy and a sustainable scientific society. Besides several short and long-term projects spearheaded by the UAE Space Agency and the Mohammed Bin Rashid Space Centre (MBRSC), commercial space vehicles using the nation´s own spaceport for launch, re-entry and landing is foreseen. In fact, the UAE Space Agency has recently signed an agreement with Virgin Galactic and an MOU with Abu Dhabi Airports regarding the construction of a spaceport in Al-Ain. SVOs will have a significant impact on ATM operations, affecting levels of safety, fuel consumption, and carbon dioxide footprint of regular air traffic. The UAE's airspace is highly dense and rather small; while approximately 2 000 flights were handled daily in 2019, air traffic is expected to double in terms of aircraft movements and passengers within the next 20 years. The safe and non-disruptive integration of space vehicles – with their specific flights path and trajectory characteristics – into the UAE ATM environment is being investigated in order to identify strategies to minimize the impact on the regular air traffic.

Keywords: Space Vehicle Operation, Space Port, Environment, Risk Assessment, Air Traffic Management, Trajectory Based Operation

1. Introduction and Generals

The here applied approach consists in using a simplified air traffic event model calculation to assess the impact of SVOs on several UAE air traffic parameters; the analysis of such parameters will provide information of how many flights will be affected, and to what extent, by the space vehicle passing over and through the airspace. The calculations incorporate elements of the UAE airspace and airway route network, while integrating space vehicle trajectories and the potential spaceport location. Furthermore, the calculations include the application of the relevant hazard protection areas associated with the space vehicle for separation purposes against regular air traffic. These hazard areas are based on recognized risk assessment methods.

Ultimately, the objective of such research will be to understand how today's ATM environment is affected and how ATM systems and ATC controllers could cope with SVOs, which requires intensive dynamic re-routing of the prevailing air traffic with a minimum of detrimental effects.

Initial results show that a seamless implementation of next generation space vehicles in today's ATM is a considerable challenge. However, horizontal launches of space vehicles from a carrier airplane that have already been demonstrated as part of new operating concepts are also an interesting control tool. In particular, the navigational performance of the glider during descent, approach and landing continues to be a challenge for a safe and efficient operation that does not threaten and obstruct other airspace user. This applies all the more to highly frequented air spaces such as those on which this investigation is based.

First of all, it had to be determined on which data basis the investigation should be based. In order to make assumptions as realistic as possible, publicly available radar data was used [8], since pure flight plan data do not represent the route actually flown. For this initial investigation, the consideration was focused on an exemplary traffic hour. In terms of a worst-case scenario, an hour with the maximum number of flights was selected. Due to the ongoing COVID19 pandemic, data from 2019/2020 were not considered representative. After analyzing the available data, December 19, 2018 from 6:00 p.m. to 7:00 p.m. was selected as a traffic hour with a very high number of flights within the UAE airspace (peak hour). The data used in the further course are shown in Figure 1.

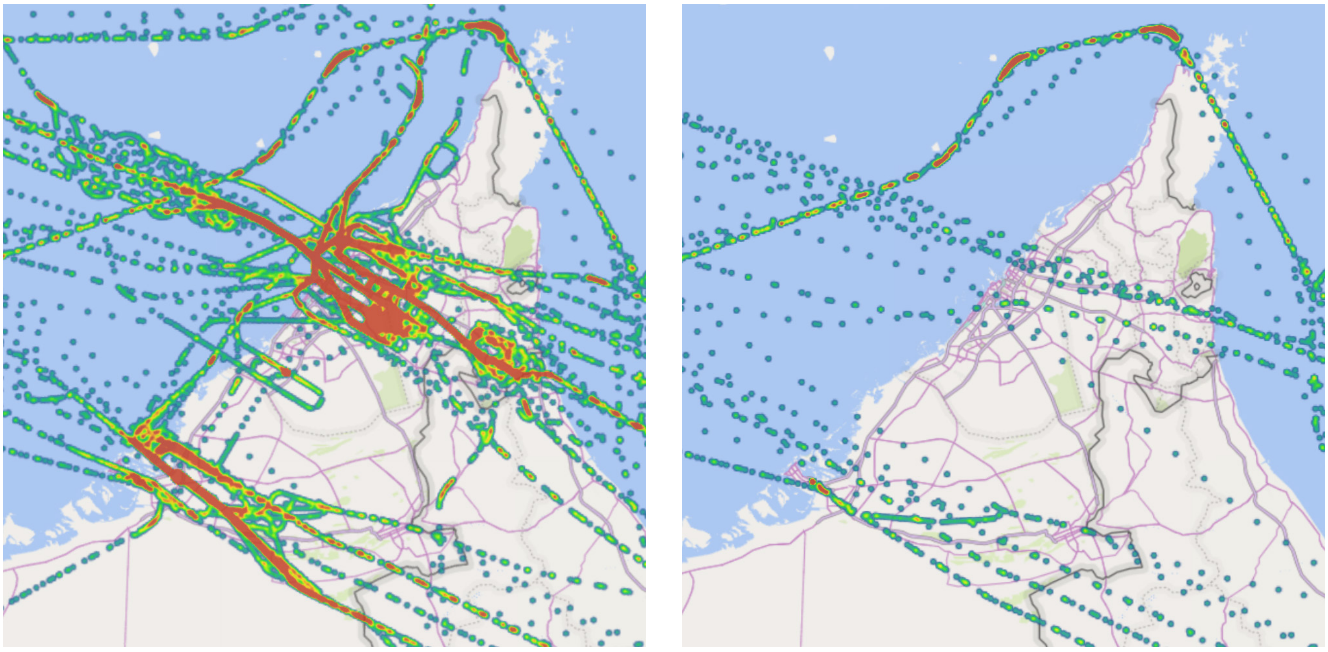

Figure 1: Reference Air Traffic Data – All Flights (left); Only UAE Overflights (right)

A total of 20,740 data sets were evaluated, which could be assigned to 233 different flights within the reference hour. In addition to position data (latitude/longitude) the altitude and the direction of flight, the data also contained the Callsign, the ADS-B identifier and the flight number.

It must be taken into account that approx. 5% to 10% of the flights actually conducted are not included in the data [7]. This can be due to missing or non-functioning or inactive ADS-B equipment of the aircraft or insufficient receiver coverage on the ground.

2. Impact on Current Airspace Users

2.1 Methodology of Airspace and Air Traffic Assessment

The most common approach of measuring the impact of space vehicle operations on air traffic is to conduct an airspace analysis using a dedicated fast time simulation platform along with comprehensive datasets made available by relevant air navigation service providers or other major ATM organizations [11]. While future studies will make use of such resources, the current approach consists in using a simplified air traffic event model calculation to assess the impact of SVOs on air traffic in the UAE.

The primary input parameter is the historical flight data for the UAE airspace provided by the FlightRadar24 internet-based aircraft flight tracking service, which collects data using a large ADS-B network with over 20,000 connected receivers. From this primary data source, along with data available in the UAE Aeronautical Information Publication (eAIP), a number of parameters may be derived, including aircraft position, points of origin/destination, ATS routes flown, as well as bearing and distance to/from key points such as the reference spaceport location.

2.2 Definition of Assessment Areas

Impacts analyses of this nature typically involve applying flight restriction areas along the SV trajectory [11]. This requires the application of suitable traffic separation criteria for such high-risk operations as well as hazard areas relating to non-nominal events such as the inflight breakup or explosion of the space vehicle, leading to a debris field spanning relatively large areas. Some studies have used debris models derived from actual inflight breakups of space vehicles, such as the Space Shuttle Columbia.

The application of traffic separation criteria will not be required since the entire portion of the SV trajectory that is being considered in this this study lies above 60,000 ft, where civil aviation traffic is not present. The main concern, therefore, is the application of hazard areas relating to debris dispersal following a non-nominal inflight event. However, the application of a debris dispersal model based on the Space Shuttle Columbia accident is not appropriate in this case since the flight characteristics of SpaceShipTwo (SS2) differ significantly. For example, while the Space Shuttle would reach speeds above Mach 20 and required relatively long reentry trajectories, SS2's launch and reentry flight trajectories are much steeper and speed remains below Mach 4 [13]. One study involving SS2 flight simulations applied flight corridors that were 15 km in the direction of the velocity vector and 5 km to the side of the vehicle [14]. However, it's unclear whether or not these values take any specific debris dispersal model into consideration. Therefore, this current study will apply a 10 NM (19 km) hazard area along the entire trajectory and extending down to surface level. This may prove to be excessively conservative, but still allows for initial observations to be made.

Furthermore, since the exact launch point of SS2 is currently unknown, two large geographical areas have been identified as potential SV operational areas. The images below depict these general areas:

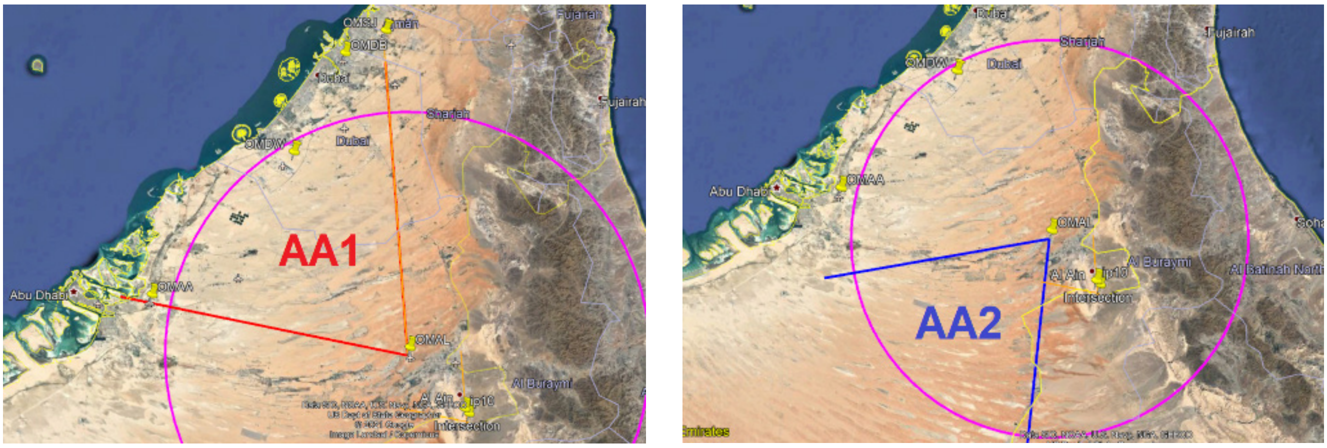

Figure 2: Assessment Areas 1 (AA1) and Assessment Areas 2 (AA2)

In both cases, the pink circle represents the launch arc with a radius of 91km centered at the reference spaceport (OMAL – Al Ain International Airport reference point). The distance of 91km represents the maximum distance flown by the SS2 between the launch point and the top of glide during a simulation campaign in one study (Llanos et al 2018).

At this stage, we have begun our analysis based on Assessment Area 1 only. The area is bounded by the two red lines that represent the bearing from OMAL to OMAA (Abu Dhabi International Airport) and the bearing from OMAL to OMSJ (Sharjah International Airport). For the purpose of this highly conservative study, we are considering that the launch could take place anywhere along the pink ark, in between the two red lines, and that in all cases the trajectory can be represented as a straight line ending directly above OMAL (at FL600). The vehicle would then proceed with its gliding procedure down to the runway. Once the 10 NM buffer (hazard area) is applied, the assessment area takes the following shape:

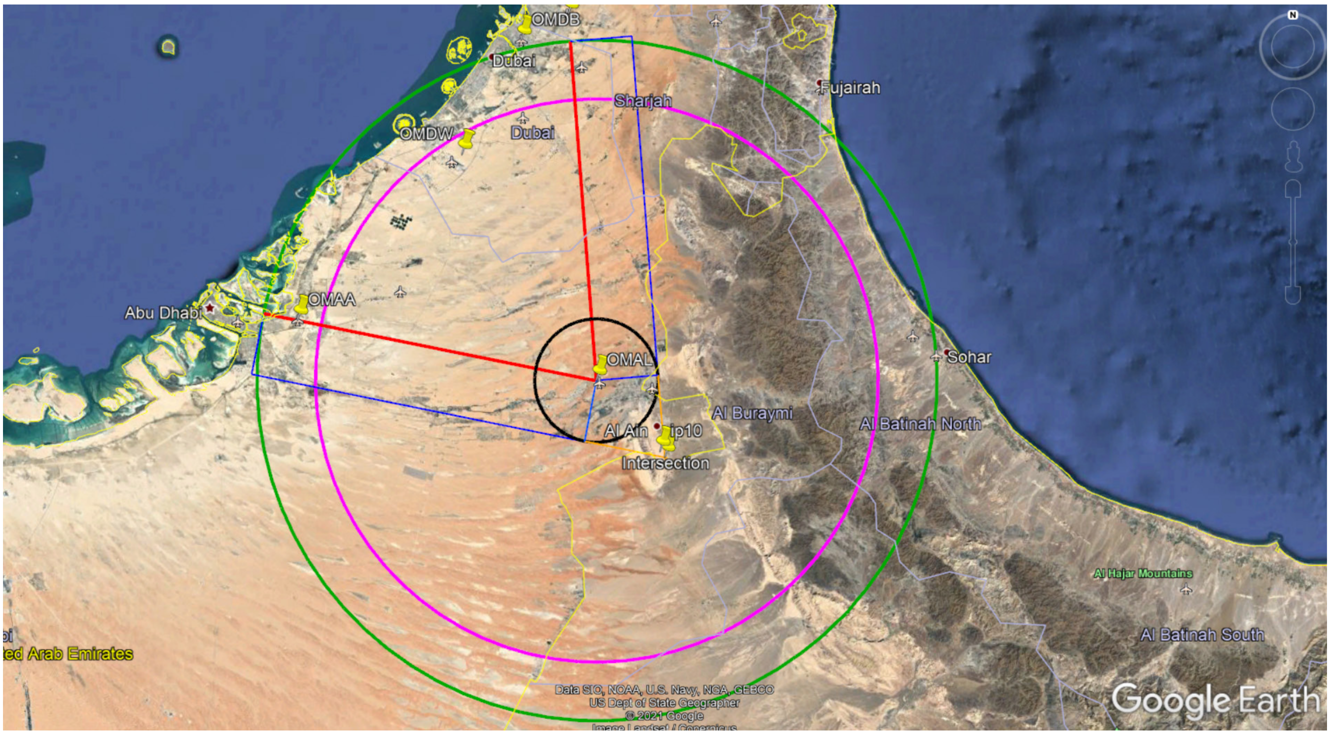

Figure 3: Final Assessment Area

The final assessment area is therefore bounded by the green arc, both blue lines, and the black circle with a 10 NM radius centered at OMAL.

2.3 Analysis

2.3.1 Total UAE Airspace

A total of 233 fights were counted in the UAE airspace during the defined peak hour. This include 61 overflights through the UAE airspace, 78 departures from UAE airports, and 94 arrivals into UAE airports. Here, “UAE airports” refers to Abu Dhabi International Airport (OMAA), Dubai International Airport (OMDB), Al Maktoum International Airport (OMDW), and Sharjah International Airport (OMSJ) only.

These figures provide an initial general idea of traffic demand and controller workload during the defined peak hour. However, by analyzing the traffic demand within the defined assessment area, we can begin to understand the impact on specific flights.

2.3.2 Assessment Area only

Firstly, it’s worth reiterating that the applied assessment method is highly conservative. Nevertheless, some initial useful insights may be derived.

An estimated 121 flights passed through the assessment area during the peak hour.

Since the SS2 flight time from the point of launch to the start of the gliding procedure is estimated at around five minutes [14], it would be interesting to estimate the distribution of flights passing through the assessment scenario in 15 minute increments (5 minutes flight time + 10-minute buffer period). This would provide a more realistic, albeit still highly conservative, indication of the actual number of flights affected as well as potential controller workload in case rerouting is eventually identified as a traffic flow measure.

Table 1 below shows the distribution of the number of flights passing through the assessment area during the defined peak hour in 15-minute increments.

From [UTC]	To [UTC]	Number of Flights
18:00	18:15	49
18:15	18:30	47
18:30	18:45	38
18:45	19:00	49

Table 1: Number of flights passing through the assessment area in 15-minute increments during defined peak hour

The 15-minute increment with the highest number of flights will be hereinafter referred to as the "peak period". The highest number of flights passing through the assessment area during the peak period is 49. Although two periods in Table xx contain 49 flights (18:00-18:15 and 18:45-19:00), only the period from 18:00-18:15 is considered as the "peak period" for the purpose of this study.

2.3.3 Phases of flight

Of the 49 flights passing through the assessment area during the peak period, 23 were departing from UAE airports and 22 were arriving into UAE airports. Only four flight flights were overflights passing through the UAE airspace.

Most of the affected flights are therefore either inbound to or outbound from the UAE. This may indicate that during SV operations, nearly half of affected flights (23 departing flights) could be delayed on the ground as opposed to being rerouted. Arriving flights may require other flow management measures including fix-balancing, re-routing, or airborne holding. Of course, these arriving flights could also be delayed at their points of origin. Overflights would most likely require rerouting. Table 2 below lists the routes which intersect the assessment area:

Operator	Call Sign	From	To	ATS Route
Air India	AIC975	GOI	KWI	SODEX-ELUDA-N563-NOBTO-N563-PARED-SIGMO-N563-TAPTO-N563-VUXOD-N563-KUGTO-N563-BOSEV-L565-UKUVO-G462-OXARI-G462-PURLI-G462
Gulf Air	GFA566	BAH	MCT	OVONA-N318-PUTIB-N318-KAPUM-N685-GIDOB-N685-PAXIK-N685-SUDUV-N685-RURAL-N685-NAPMA-N685-RETAS
Jet Airways	JAI574	BOM	KWI	MENSA-N571-LUBAT-N571-ENEGA-N571-RUKOR-N571-VELAR-N571-IVOXI-M557-SJ486-N571-MITIX-M557-MINA-ELIMI-KIXOG-M557-RIDAP-M557-OTIKI-TOTKU-M557-GODKI-M557-RALMI-M557-TUMAK
Oman Air	OMA2669	MCT	DOH	P899-ROVOS-P899-SIXIV-P899-LAGVU-MEKRI-P899-VATIG-P899-KUKMSI

Table 2: ATS routes which intersect the assessment area

Of course, the above analysis assumes that the entire assessment area would be closed to regular air traffic for the duration of the peak period. This implies that appropriate ATFM measures (mostly ground delays and rerouting) would need to be applied to all 49 flights identified above. Given the current levels of congestion in the UAE airspace, especially in the vicinity of the four major international airports, this represents a potentially significant impact on traffic movements and controller workload. Considering the possibility of more frequent space vehicle activities in the future, this approach would most likely become unsustainable.

A more promising approach would involve the dynamic opening and closing of airspace depending on the actual location of the space vehicle. Such scenarios will be investigated in future studies.

3. Impact on Flight Safety

3.1 Risk Assessment Methodology

Governments across the globe attempt to control the commercial spaceflight industry with heavy regulation to slow the progression of these activities deemed dangerous [19]. With the advancements in current technologies and with companies backed by the likes of Sir Richard Branson of Virgin Galactic, Elon Musk of SpaceX, Jeff Bezos of Blue Horizons, the SVO industry have been working towards sustained suborbital operations. It is the operations of these SVO and their integration into the current airspace system that creates risks that must be understood and mitigated before safe integration can begin.

Before diving into some of the risks associated with high-risk recreational activities, we must first define risk. Risk is the chance or probability that a person will be harmed or experience an adverse health effect if exposed to a hazard. It may also apply to situations with property or equipment loss, or harmful effects on the environment [3]. The risk assessment process includes:

1. Identify the hazard
2. Identify who or what might be harmed
3. Evaluate the risks
4. Identify control measure
5. Evaluate remaining risks
6. Record the finds in the risk assessment
7. Make contingency plans for residual risks
8. Review and revise.

Further guidance on risk assessment methodology can also be found in the ICAO Safety Management Manual Doc 9859 [10].

3.2 Adopted Approach for SpaceShip Two

In the case of SS2, the assessment follows:

Procedure	Task
1. Identify the Hazards/Risks	• SS2 takeoff to predetermined altitude and separation process. • SS2 does not separate from the transport vehicle. • SS2 does not ignite for the next phase of flight due to computer glitch. • Separation is outside normal parameters/or identified launch area. • Loss of one or both of the aircrafts
2. Identify who or what might be harmed	• Loss of occupants of both aircrafts • Colliding with another aircraft during the separation and return phase of orbiter. • Debris field beyond containment area • Civilian harm or injury below • Environmental damage from fuel or the aircraft
3. Assess the risks arising from the hazard – Initial risk assessment	• Initial take-off process • Conflicting traffic might force the mated ships beyond initial launch area • Integration of the space vehicle into the surrounding Airspace is burdensome. • Catastrophic loss of one of both aircraft

4. Determine the control measures required	• Ensure manual control of ignition system if necessary. • Automate the drag system to reduce human error • Coordinate with ATC to facilitate the liftoff and separation process
5. Assess the remaining risks arising from the hazard	• Possible environmental contamination due to fuel leakage or wreckage
6. Make contingency plans for the residual risks	• The contingency plan would be to reduce the various manual inputs to the system by the pilot. • Expand the underlying area below the separation point beyond 20 NM.

Table 3: Adopted Risk Assessment Process

Avoiding the use of Temporary Flight Restrictions (TFRs), Spaceship Two could be integrated into the mix with the other arriving or departing traffic, ensuring that there is a slight modification to the flight structure to protect both spaceship two and the overlying traffic. As suggest for future studies, the dynamic opening and closing of the surrounding airspace might be a temporary but viable solution for the future growth of SVO. Any integration solution must include characteristics associated with the suborbital launch platform. Some of the characteristics identified includes, launch system reliability, timing, and trajectory [18].

3.3 Refinement of Assessment Scenario

To better understand the status of the current airspace in Al Ain and surrounding areas within the UAE, we must first look at the current use of said airspace. Reviewing the flight data available including takeoffs and landing as well as overflights, points the project in a direction that will provide the data necessary to aid in the integration of SVO. Mitigation strategies must be incorporated to ensure that in the event of an unforeseen catastrophic failures, the debris field will be contained within the 10 NM buffer zone on either side of the launch trajectory but could be expanded as needed. During liftoff from the designated spaceport the mated aircraft will be under the guidance of air traffic control and will follow the proper procedures as it attempts to get to its designated altitude for separation above 50,000 ft. During the initial ascent, there should be no other commercial traffic above Spaceship two ignition altitude, where the aircraft would have no problems getting to its position to begin the weightlessness phase before its return. During the return phase of Spaceship two, the craft should still follow the same parameters coming back in once below 50,000 feet. Although now a glider, it should be able to circumnavigate whatever aircraft might be in the vicinity with the help of Air Traffic Control (ATC) to get back to its landing position at Al Ain International Airport. This can only be done through coordinated information sharing between managers of the airspace and launch providers.

In a recent white paper submitted by Air Line Pilot Association (ALPA) to one of their annual conference,

> "the challenge to date has been to develop a data-exchange mechanism to pass this information to the other parties involved. The FAA's space data integrator (SDI) under development is a move in this direction and would serve as a testbed for what could potentially be used in the UAE to facilitate suborbital space launches in and around the region. According to reports, SDI would provide controllers and traffic managers with situational awareness of a spaceflight mission through real time data on vehicle state and operational status, calculate the location and extent of potential hazard areas, and provide visibility into mission progress. SDI will afford the capability for FAA and, by extension, other airspace users to benefit from a detailed level of knowledge of a space mission as it progresses through shared airspace. In addition, the real-time, detailed view provided by SDI allows alert and execution of contingencies if off-nominal events occur" [2].

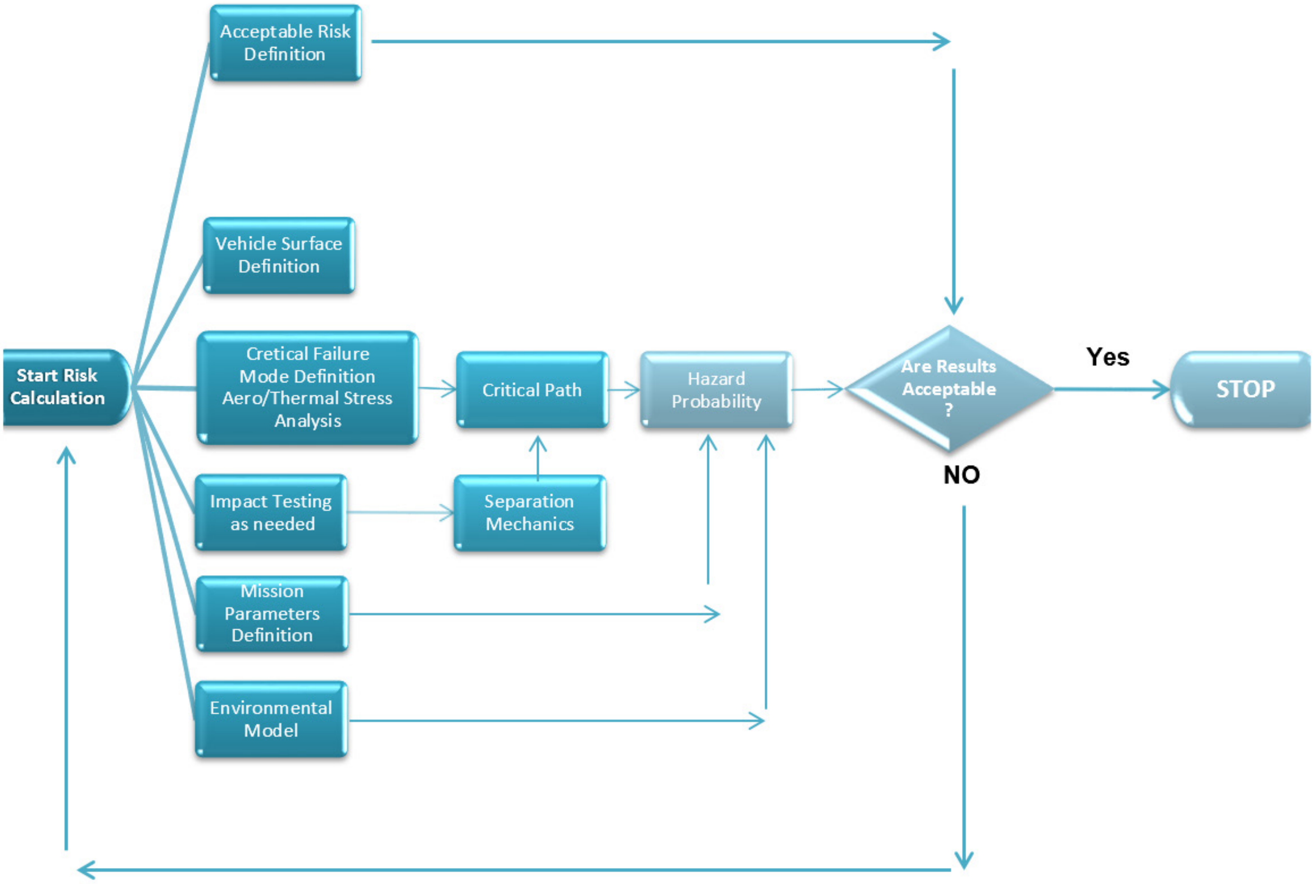

Figure 4: On-orbit impact analysis methodology [4]

There are multiple risk assessment strategies to choose from across varying industries. The risk assessment associated with spaceship two and the transport aircraft comes from a complex set of systems that if not implemented correctly, would affect not only other users within the airspace, but could negatively impact the surrounding environment.

Launch & reentry operation window as short as possible –

- Avoid peak traffic times
- Optimize launch & reentry trajectories as far as possible
- Optimize air space usage alongside restricted areas
- Ensure real time monitoring and direct communication, connecting all involved stakeholders with ANSP managers and ATC facilities [12].

Analysis and optimization of SVO scenarios and concepts regarding air traffic impacts as suggested by Kaltenhaeuser et al can be seen below:

- Improved ATC procedure design
- Support of Spaceport site evaluation
- Integration of SVO Mission management and ATM
- Improved SVO implementation into AIM (e.g. System Wide Information Management)
- Provision of adequate evaluation and validation capabilities [12].

4. Conclusion

There is no doubt that space vehicle operations (SVO) once thought to be science fiction has moved beyond thought to now being at a phase where they are being tested for integration into the current National Airspace System. After conducting a basic analysis of the current air traffic system in the United Arab Emirates (UAE) and the four major airports in the region, it can be concluded that apart from the 10 NM buffer zone for unforeseen operations (catastrophic failure) suggested in the analysis, the current airspace system can incorporate these SVOs for the time being. There would be a need for future investigation if the current airspace system continues to expand as predicted.

With the complexities and the frequencies of these vehicles, risk continues to be a concern especially with the predicted increase in normal commercial traffic but for now, these risks can be mitigated with the implementation of a system that keeps the airspace managers and space vehicle operators sharing information in real time. Virgin Galactic's plans on launching these space vehicles from al Ain international Airport in the UAE would be a shining example to the rest of the world if implemented correctly. A proactive process should play a major part in the overall process and with so much at stake, need to be transparent so that the industry on a whole can benefit through realized synergies to make the system better for all that use it.

5. Outlook

However, the next research phase will involve the use of a fast time simulation platform and a much more comprehensive dataset allowing for a more detailed analysis of the UAE airspace and the impact of inserting SVO trajectories. We will then be able to consider how modern and emerging ATM concepts such as Trajectory Based Operation (TBO), Advanced Flexible Use of Airspace (AFUA), dynamic sectorization, and the role of aircraft-ground datalink requirements could support the situation. The impact of re-routings on overall fuel consumption and CO_2 emissions of the air traffic in UAE airspace will also be investigated.

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7. Abbreviations

ADEK........ Abu Dhabi Department of Education and Knowledge (UAE)
AIP............ Aeronautical Information Publication
ALPA .... Air Line Pilot Association
ANSP........ Air Navigation Service Provider
ATC .... Air Traffic Control
ATFM........ Air Traffic Flow Management
ATM.......... Air Traffic Management
CCOHS .... Canadian Center for Occupational Health and Safety
FAA .... Federal Aviation Authority
ICAO......... International Civil Aviation Organization
MBRSC .... Mohammed Bin Rashid Space Centre
MOU .... Memorandum of understanding
NM............ Nautical Miles
OMAA....... Abu Dhabi International Airport
OMAL .... Al Ain International Airport
OMSJ .... Sharjah International Airport
SDI .... Space Data Integrator
SS2 .... Scaled Composites Model 339 SpaceShip Two (The Spaceship Company)
SV .... Space Vehicle
SVO.......... Space Vehicle Operations
TFR .... Temporary Flight Restrictions
UAE .... United Arab Emirates

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