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Integrating SpaceShipTwo into the National Airspace System

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The increasing number of commercial suborbital space flights over the next decade may lead to the development of commercial suborbital transportation. This may lead to risks to civil aviation and the hazards that may arise from the interaction of suborbital spacecraft with controlled air space. To do this the National Airspace System will need to accommodate a growing number of suborbital spacecraft. An example of one of the suborbital vehicles being developed is Virgin Galactic's SpaceShipTwo. This paper analyzes the performance of SpaceShipTwo using simulated nominal flight research data conducted at Embry-Riddle Aeronautical University's Suborbital Spaceflight Simulator.

Nomenclature

ADS-B = Automatic Dependent Surveillance Broadcast
ALHL = Air Launch Horizontal Landing
ATC = Air Traffic Control
CONOPS = Concept of Operations
ERAU = Embry Riddle Aeronautical University
HTHL = Horizontal Take-off Horizontal Landing
NAS = National Airspace System
SA = Situational Awareness
SS2 = SpaceShipTwo
SSFS = Suborbital Spaceflight Simulator
STM = Space Traffic Management
VLHL = Vertical Launch Horizontal Landing

I. Introduction

The next decade will witness an increasing number of commercial suborbital space flights which may ultimately lead to the development of commercial suborbital transportation. As part of the long term plan for these flights it is important to define the risks to civil aviation and the hazards that may arise from the interaction of suborbital spacecraft with controlled air space. To do this the National Airspace System (NAS) will need to accommodate [1] a growing number of horizontal takeoff, horizontal landing (HTHL), vertical takeoff horizontal landing (VTHL), vertical launch vertical landing (VLVL) and air-launched horizontal landing (ALHL) suborbital spacecraft. Flight profiles for these spacecraft are distinct from conventional commercial aircraft operations. This means that space/airports supporting these spaceflights will need to coordinate launch and re-entry phases [2] with regional air traffic control (ATC) and space traffic management

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(STM) control centers to ensure the suborbital spacecraft operator and aircraft operator have the necessary situational awareness (SA) to safely transition vehicles through air traffic routes [3]. To date the FAA-AST has issued nine launch site operator licenses. Each licensed spaceport increases the number of corridors that will transition spacecraft through the NAS. Spaceport control centers will be responsible for coordinating the clearance of a suborbital flight profile and must communicate spaceflight operations with ATC and STM control centers through a centralized data network [4].

To achieve safe air traffic management, ATC control centers will need to coordinate air and space traffic activities in the NAS by issuing restrictions, re-routing air traffic, instructing a spaceport to delay a launch, and directing suborbital vehicles in the event of an emergency [5]. Part of this may be achieved using the Automatic Dependent Surveillance Broadcast (ADS-B) system for SA and enhanced vehicle tracking. The ATC control center will act as an information sharing node in the centralized data network and will transition spacecraft through the NAS [6]. This will require an ATC controller to interface directly with spaceport controllers, and vehicle operators, through the centralized data network. ATC controllers will transfer control of the suborbital spacecraft from the spaceport controller once the spacecraft has departed the runway, resume responsibility through the NAS, and transfer responsibility to the STM controller once the vehicle has left the NAS. This concept of operations (CONOPS) will require the development of a STM control center that will cover the operations of spacecraft transitioning to and from space [7]. The STM control centers will function similarly to traditional air traffic control, but will need to:

1. Monitor and coordinate near-Earth space traffic.
2. Receive information about weather conditions in the space environment.
3. Be responsible for collision avoidance
4. Have the authority to maintain separation between vehicles and objects in space.
5. Manage the satellite constellations that support links for voice, video, and data connections between the suborbital spacecraft and the ground station.
6. Interface with satellite networks, such as the Tracking and Data Relay Satellite System (TDRSS), for tracking, telemetry, and command capabilities.

II. Methodology

An example of one of the suborbital vehicles being developed is Virgin Galactic's SpaceShipTwo (SS2). SS2 (Figure 1) has captured the commercial spaceflight arena's attention on its mission to fly spaceflight participants into space. Based on the design of the X-Prize winning SpaceShipOne, SS2 is intended to provide ordinary citizens a chance to experience microgravity and provides the commercial sector opportunities to perform research in space on a moderate budget. But the challenges of executing a manned suborbital launch are significant. This paper analyzes the performance of SS2 using available simulated nominal flight research data conducted at Embry-Riddle Aeronautical University's (ERAU) Suborbital Spaceflight Simulator (SSFS, Figure 2) and outlines an operational plan to ensure mission success.

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Figure 1. Virgin Galactic's SpaceShipTwo

Figure 2. Embry-Riddle Aeronautical University's Suborbital Spaceflight Simulator

Participants

Volunteering to participate in this study were 4 male pilots (age 22.4± 2.3 yr). Each pilot had at least 150 h of flying fixed winged aircraft within the previous 6 months. The study protocol was approved by ERAU's ethics committee prior to volunteer recruitment. Each participant provided written consent before participating.

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Equipment

Simulated flights were performed in ERAU's SSFS. The SSFS is based on a twin seat cockpit of a Cessna 172 equipped with four point single release harnesses. The cockpit has an ultra HD glass cockpit with a center stick, rudder-pedal assembly, and a multiscreen display. These screens are used to help the pilot navigate SS2 along a suborbital flight trajectory. Outside the cockpit, there are three primary flight screens that display the suborbital flight profile (Figure 3) through the atmosphere, as viewed from inside the cabin seat.

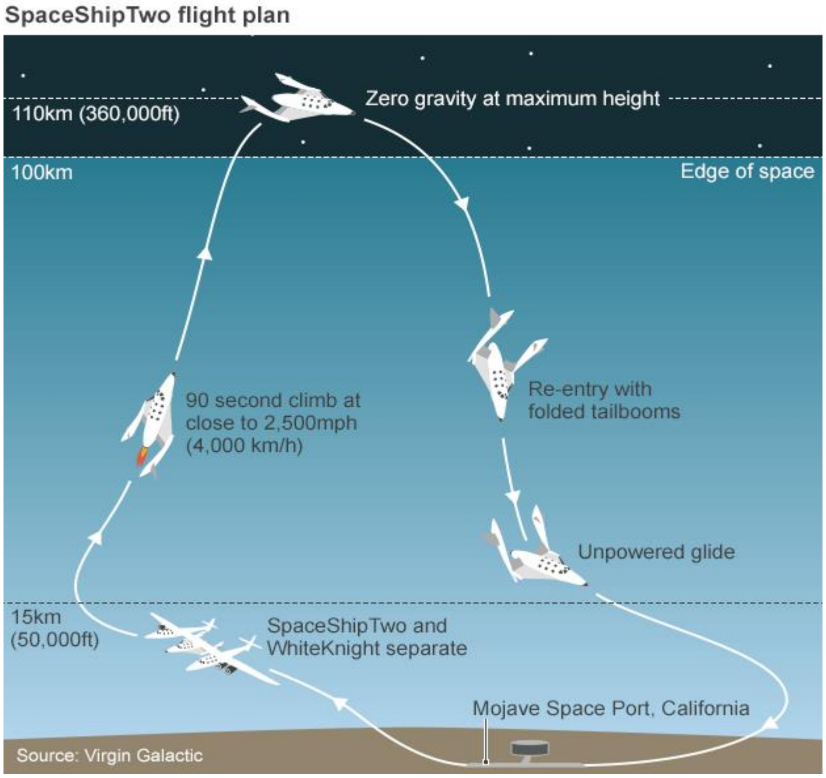

Figure 3. SS2 Suborbital profile

Procedure

Each participant performed between 4 and 12 practice sessions in the SSFS flying the test profile. The 4 pilot participants performed a collective total of 14 nominal flights with a minimum intersession interval of 48 hours flying the SS2 nominal flight profile in Visual Flight Regulations (Figure 4) with a simulated payload that equated to 2 pilots and 6 passengers as follows:

1. Takeoff/ Captive Carry/ Air Launch. The projected flight profile begins with a horizontal takeoff underneath the carrier aircraft "WhiteKnightTwo" with a flight to approximately 50,000 ft where SpaceShipTwo will be launched.
2. *Boost phase*: The boost phase will be 70 sec long and will have a maximum peak of 3.8 g (longest duration in +Gx with a brief spike in +Gz). Speeds will be Mach 1 at 8 sec and Mach 3 at 30 sec. Maximum speed will be 2600 mph.
3. *Microgravity/Coast Phase*: The 0 g coast phase will last approximately 4 minutes and will reach an apogee of 361,000 ft.

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4. *Deceleration phase*: The deceleration phase will have a maximum peak of 6 g, but the seats will recline to convert most of the forces to +Gx for the space flight participants. However, the flight crewmembers will experience most of the deceleration forces in the +Gz axis. The wings rotate to a feather position to increase stability and drag for entry.
5. *Glide phase/Re-entry*: At 80,000 ft, the glide phase will begin with a return to an unpowered horizontal runway landing that will occur after a glide of 25 min. Total flight duration will be 150 min.

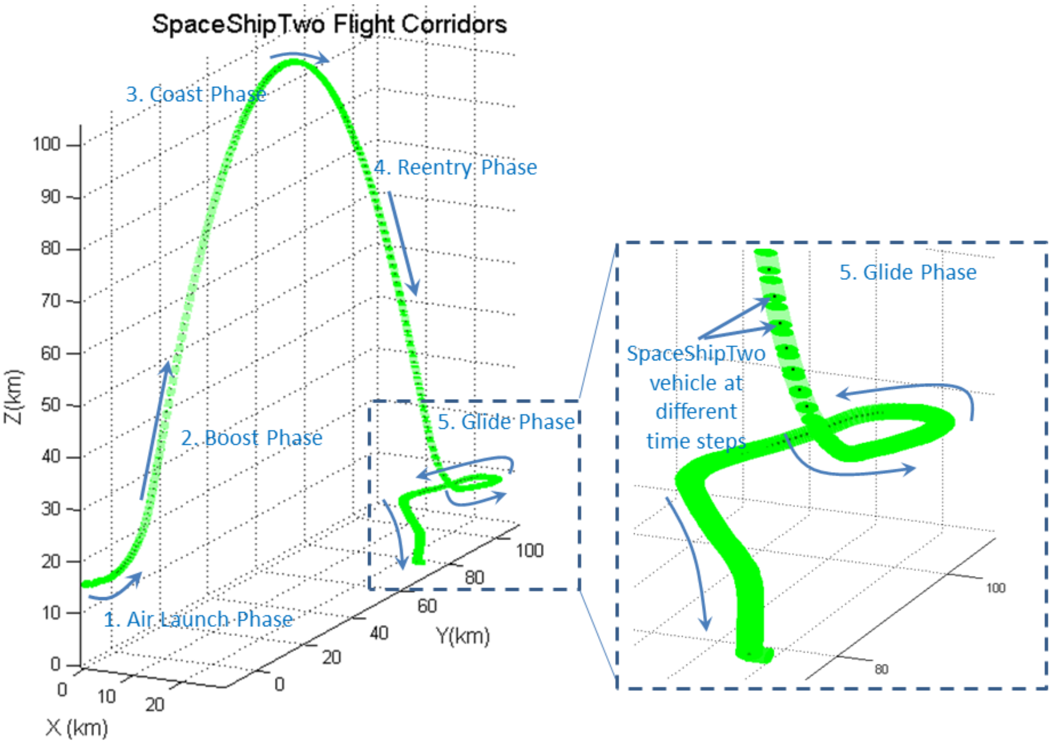

Figure 4. SS2 Nominal flight profile

Pilots were given a briefing prior to each flight. There was one test observer adjacent to the cockpit during each data run. The test operator and pilot initialized the equipment set-up, while the test operator activated data collection, and coordinated pilot activities.

Identical aircraft and weather conditions for each flight profile were scripted as follows: no air traffic, visual flight regulations, no wind, landing point Eilson Air Force Base, Alaska.

Flight data for nominal scenarios was also analyzed during the different segments of the suborbital trajectory obtained in the SSFS to assess characteristics of SS2's nominal flights:

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1) Horizontal takeoff
2) Boost phase
3) Microgravity/Coast phase
4) Deceleration phase
5) Glide/Re-entry phase

III. Results

The results of 14 nominal simulated SS2 flights are presented in Table 1. Flights were timed from the point of engine ignition following the drop from the WhiteKnightTwo mothership. Apogee was attained within 180 seconds of engine ignition and total flight time from engine ignition to landing took an average of 10 minutes 33 sec.

Table 1. Average of 14 simulated nominal SS2 flights

Release Altitude	49,350 feet ± 220 feet
Time to Mach 1	Ignition + 11.11 ± 3.95 sec
Time to Main Engine Cut-Off	Ignition + 81.62 ± 2.61 sec
Time to 200,000 feet	Ignition + 97.32 ± 4.8 sec
Time to 300,000 feet	Ignition + 139.75 ± 6.16 sec
Apogee altitude	**346440 ± 16,167.5 feet**
Time to 300,000 feet	Ignition + 214.3 ± 32.2 sec
Time to 200,000 feet	Ignition + 277.9 ± 11.1 sec
Time to 100,000 feet	Ignition + 337.8 ± 9.1 sec
Time to 50,000 feet	Ignition + 378.5 ± 9.3 sec
Landing	Ignition + 693.2 ± 16.4 sec

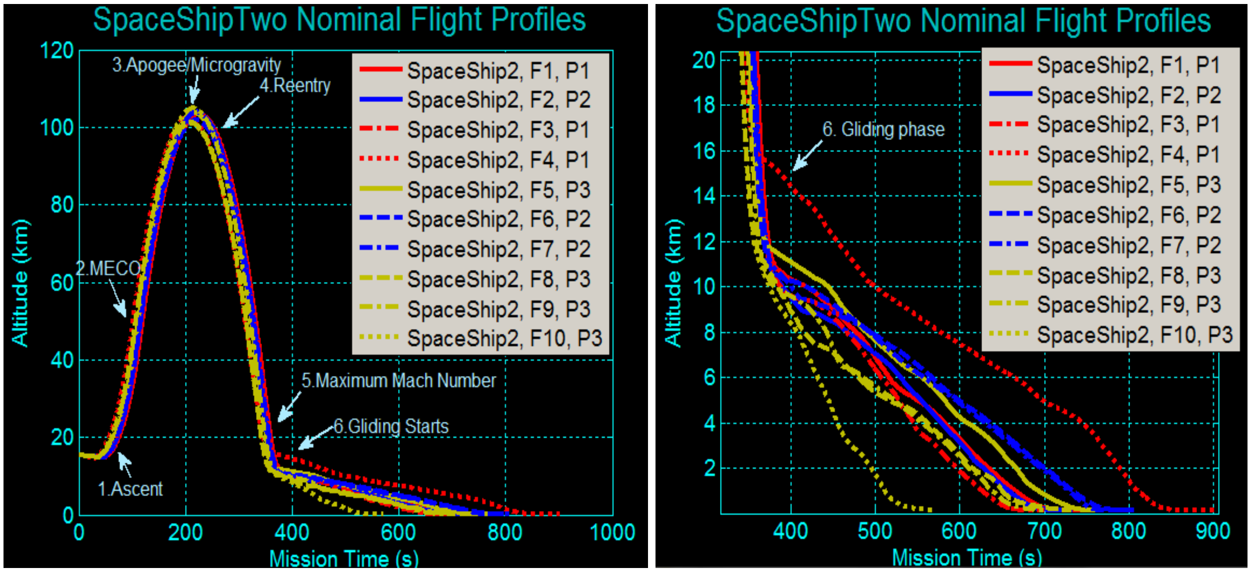

Figure 5 (a – left) and (b – right). SS2 simulated nominal flight profiles

Figure 5 (a) and (b) depict nominal SS2 flight profiles conducted in a preliminary study for the purpose of better understanding the vehicle's flight profile and the transition from the gliding phase and the vehicle's transition to the NAS at 60,000 feet. The glide phase (depicted in Figure 5b) begins at 60,000 feet and is characterized by the feather system being retracted. At this point, SS2 is a glider

IV. Conclusions and Future Recommendations

During operation of SS2 during a nominal flight profile, the vehicle, on returning from space, will fly in the NAS for approximately 5 minutes, during which time it will have limited maneuverability since it will be a glider. One way to safely integrate the vehicle into the NAS might be to apply a hazard volume around the vehicle. Whichever methods are adopted, the safe integration of suborbital vehicles into the NAS is a significant challenge. The FAA is developing the technical and regulatory standards, policy guidance, and operational procedures on which successful integration of suborbital vehicles into the NAS depends. The FAA and the suborbital industry expects to gain experience in applying existing regulations during the development of SS2 and other suborbital vehicles. Because of many distinct differences between suborbital vehicles and commercial aircraft, there are required technologies that must be matured to enable the safe and seamless integration of UAS in the NAS. Further research will be focused in the areas of deconfliction of traffic and response to contingencies.

The modernization of the NAS is based on an evolving concept of operations made up of a series of operational changes, some of which will need to be specific to suborbital vehicles such as SS2. Once routine suborbital operations are implemented, SS2 pilots will be expected to operate in the NAS with very high situational awareness due to the dynamic performance capabilities of suborbital vehicles. The integration of simulations such as those planned for ERAU's SSFS will allow pilots and controllers to experience the future, help define final procedures, and will reduce time to implementation. Future suborbital simulations at ERAU will be integrated so that operational scenarios can be developed and then flown with controllers and pilots through the combined use of ATC and aircraft simulators.

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