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Integrating ERAU’s Suborbital Space Flight Simulator - ADS Data into NextGen TestBed Simulations

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INTEGRATING ERAU'S SUBORBITAL SPACE FLIGHT SIMULATOR ADS DATA INTO THE NEXTGEN TESTBED SIMULATIONS

Pedro J. Llanos[*] Randall Triplett[†]

The static Suborbital Space Flight Simulator (SSFS) in the Applied Aviation Sciences (AAS) department at Embry-Riddle Aeronautical University (ERAU) is working together with the Next Generation ERAU Advanced Research (NEAR) laboratory on the Daytona Beach campus. The NEAR lab will support the SSFS by using an Energy Management Display Indicator (EMDI) display for rendering live ADS-B (Automatic Dependent Surveillance-Broadcast) data. The data simulated at the SSFS lab will be later shared and transferred to the FAA Next Generation Test Bed (NGTB) at Daytona International airport to be integrated into the National Airspace System (NAS) for research and educational purposes. Several questions will need to be addressed: What key elements will need to be considered or integrated into international suborbital flights that use different links? How many ground stations will be required to obtain continuous functionality of the ADS-B data given minimum ADS-B coverage at the moment?

INTRODUCTION

Suborbital Space Flight Simulator

The SSFS was born in the spring of 2015 as a research, training, and educational testbed facility for suborbital space missions. There have only been eight manned suborbital spaceflights to date. The only record of crewmember data acquired during suborbital flights includes the X-15 aircraft, Mercury space vehicle, Soyuz 18a spacecraft and the first commercial space vehicle SpaceShipOne. All of these flights reached altitudes of about 100 km.

ERAU has the only commercial available suborbital simulator in the world where astronaut scientists are being trained. Through cooperation with project PoSSUM (Polar Suborbital Science in the Upper Mesosphere), the SSFS is used to train astronaut scientists for suborbital missions as high as 100 km, just above where the noctilucent clouds are formed and thought to have an impact on Earth's climate. The mission will last about 30 minutes from takeoff on a conventional runway to landing on the same runway.

The SSFS has also been used as a research tool to gain perspective about the performance of suborbital spaceflight participants. With several private companies planning to send the first suborbital astronauts into space within the next 2-5 years, the SSFS will help to reduce the risks associated with training the next group of commercial suborbital astronauts by providing comprehensive training in several disciplines such as astronautics, air traffic management, meteorology, human factors and commercial space operations.

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Some of these companies (the SSFS is based on one of the current suborbital vehicles, the Lynx, by XCOR) will fly astronauts and payloads on 3 to 4 flights per day with minimal logistical complexity. Some payloads will require special attention and for astronauts must remain functional while encountering several discomforts, such as; cabin noise, vibration, weightlessness environments, cardiovascular/neuro-vestibular effects and motion sickness. At present we do not know how astronauts will respond when flying several times a day. This research will help with future preflight medical considerations so to better accommodate future astronaut's in future suborbital flights. Ultimately, the SSFS will also assist in the development of the next generation of pressurized space suits.

Figure 1 shows the cockpit of a Cessna 172, the suborbital space flight simulator (SSFS). This twin seat cockpit with four single release harnesses was rebuilt from the tornado that struck Daytona Beach on December 25th of 2005. The cockpit has an ultra HD glass cockpit with rudder-pedal assembly and a multiscreen display. These screens are used to help the pilot and mission specialist to navigate the vehicle along the suborbital flight trajectory while pointing the instrumentation at the right location of the atmosphere. Outside the cockpit, there are three main screens that display the trajectory of the suborbital flight profile, as seen from inside the cabin seat.

Figure 1. Suborbital Space Flight Simulator lab in the AAS department at ERAU during a pressurized space suit dry run and instrumentation tests. Credit: ERAU

The SSFS will incorporate real weather scenarios that are currently being processed at the AAS department to mimic real suborbital trajectories or point-to-point (PTP) trajectories between different spaceports. Some of the spaceports to be considered for the National Air Space (NAS) include the Midland spaceport in Texas, Spaceport America in New Mexico, Kauai spaceport in Hawaii, Kodiak spaceport in Alaska and Cecile spaceport in Florida. Also, PTP trajectories will be generated between the NAS and other international spaceports within the Single European Sky Air Traffic Management Research (SESAR) program among others.

WHAT IS ADS-B?

The Automatic Dependent Surveillance-Broadcast (ADS-B) system is the FAA's new Air Traffic Control system based on a set of ground stations nationwide that receives navigation parameters, such as the altitude, position, direction, and velocity. The Next Generation Air Transportation System (NextGen) will require any aircraft using the NAS to be equipped with ADS-B OUT to increase the through-put and use of increasingly congested airspace.

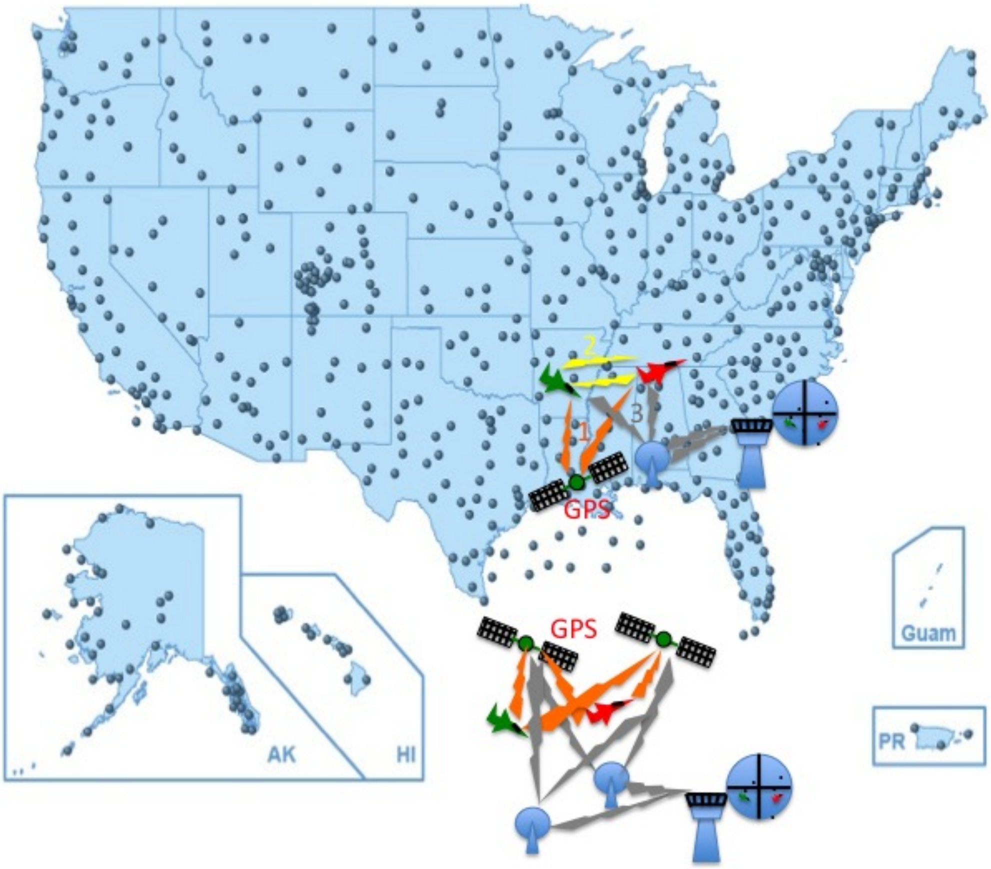


Figure 2. ADS-B coverage map from FAA as of October 2015.

Due to the volume of aircraft and cost of upkeep, the use of radar will not be an option and ADS-B will be required. Aircraft will also have to be equipped with a wide area augmentation system (WAAS), which will provide horizontal and vertical navigation correction information during all phases of flight (departure, enroute, arrival).

1. This system is **Automatic** because there is no intervention from the pilot or the controller to transmit the information.

2. This system is **Dependent** because the state vector (position and velocity) is obtained from the Global Positioning System (GPS) satellites.

3. **Surveillance** in that we can track the position/velocity of other aircraft and space vehicles.

~~4.~~ This system is a **Broadcast** system transmitting information to other aircraft and vehicles that like equipped.

Associated with the position and velocity, there are the position and velocity latency requirements.[1] The first latency requirement is the total latency, which is the difference between the time when the position is measured and the time when the position is transmitted from the aircraft. This time cannot exceed 2.0 seconds. The second latency requirement is the uncompensated latency, which is the difference between the time of applicability of the transmitted position and the time when this position is transmitted from the ADS-B system. This time cannot exceed 0.6 seconds.

In November of 2015, the International Telecommunications Union (ITU) addressed their concerns about improving the current civilian flight-tracking system. This concern was driven by the disappearance of Malaysia Airlines flight MH370 in March of 2014. The ITU has proposed the use of frequencies (that aircraft normally use to communicate with ground stations) to communicate with satellites that will then downlink the pertinent information to ground stations (see schematics of Figure 2).

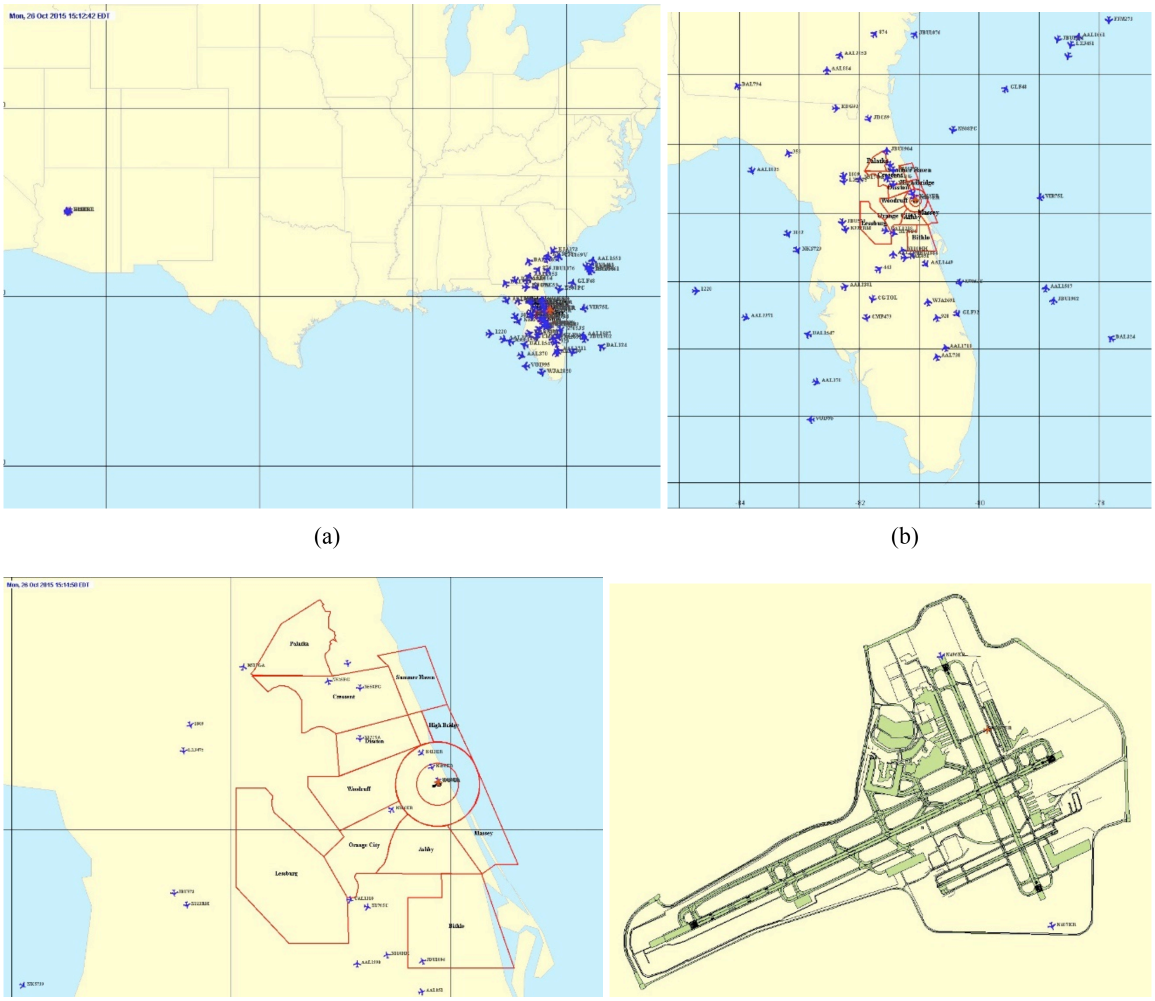
WHY TRANSITIONING FROM RADAR TO ADS-B?

The complexity of flight operations in the FAA's NAS (see Figure 3) is accelerating. The FAA has always been hampered by a highly centralized ATC control system employing technology first developed during WWII. The FAA is now taking aggressive steps in modernization and planning for the safe movement of aircraft in an increasingly crowded sky.

New concerns such as supersonic suborbital flights (trajectory based operations) and Unmanned Aerial Systems (UAS) will present new challenges in the evolution of protected airspace. The use of ADS-B and other interlaced technologies will play a critical role in surveillance protection and a reduction in the crippling cost of maintaining an antiquated system.

Figure 3. Complexity evolution of flight operations in the NAS.

Figure 2 illustrates the operational radio stations (ADS-B coverage) in the NAS as October of 2015. ADS-B provides digital messages between air traffic controllers and pilots. During peak traffic hours, a total of 1,500 messages per second can be broadcasted from Airport Surface Detection



(a) (b)

(c) (d)

Figure 4. a: Some ADS-B coverage nationwide. b: ADS-B coverage in the Florida area. c: ADS-B coverage centralized in the Daytona Beach international airport. d: ADS-B equipped aircraft arriving to and leaving from the Daytona airport. This example is representative of October 26, 2015.

System, Model X (ASDE-X) surveillance. This is a radar-based system with multilateration sensors and satellite technology to help air traffic controllers track movements of aircraft and other vehicles on the airport and on their final approach to the airport. ASDE-X data comes from many sources and one of the sources is the ADS-B data.

ADS-B OUT: The SSFS will be equipped with ADS-B OUT to increase surveillance during departure, in-flight and during the arrival of suborbital flights. The information of this flight trajectory will be sent to the NextGen and then made available to ground controllers and aircraft in the vicinity.

ADS-B IN: We will equip the SSFS with ADS-B so we can receive information (not available from normal radar-based surveillance systems) from other aircraft and ground stations to increase situational awareness and any type of conflict (detection or resolution).

The SSFS at ERAU has ADS-B capability as displayed in Figure 4. In the future, simulated suborbital trajectories will be generated and integrated into the NAS along with other aircraft traffic. The NAS traffic will be able to have the suborbital vehicle displayed in their cockpit screen as it moves through the NAS.

Figure 5. UAT antenna in the College of Aviation at Embry-Riddle Aeronautical University.

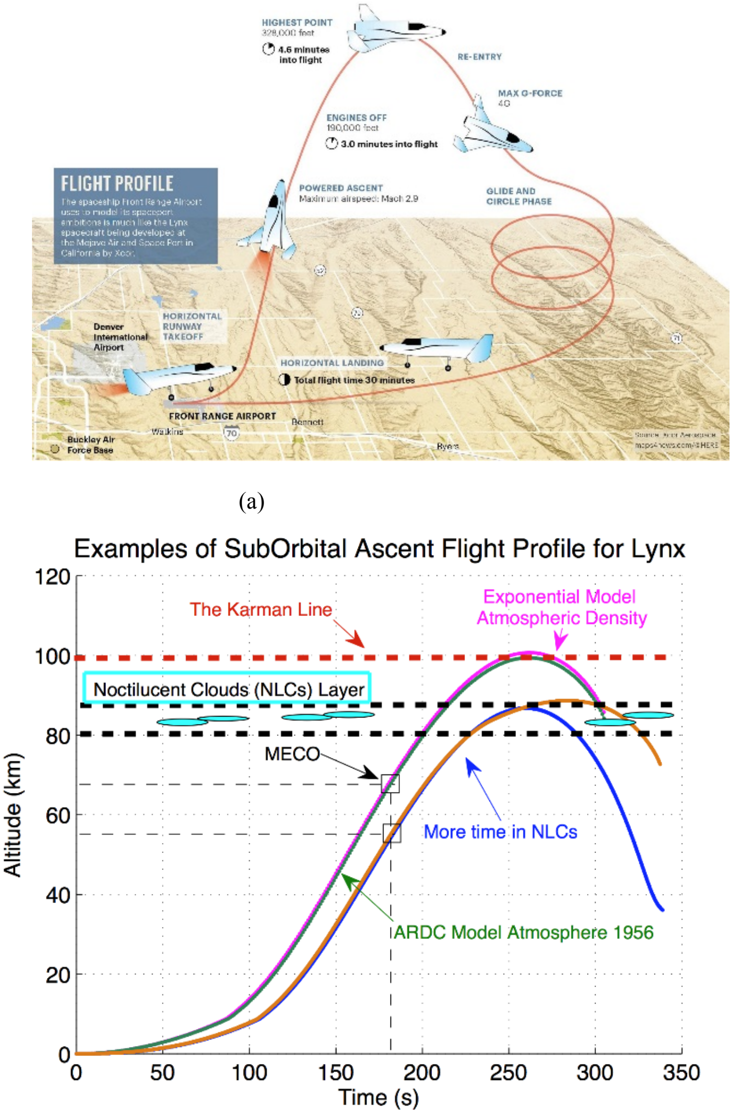
In the U.S. NAS, ADS-B OUT can be operated as a dual link (1090 Extended Squitter (ES) or 1090 MHz and UAT 978 MHz). The UAT (an UAT antenna at Embry-Riddle is shown in Figure 5 is only used in the U.S while the 1090 ES is used internationally, such as Canada, Europe, Asia, Central America and the Pacific. The third ADS-B link is known as the Very High-Frequency Data Link (VDL) Mode 4 and it is only used in Northern Europe. What key elements will need to be considered or integrated into international suborbital flights that use different links? How many ground stations will be required to obtain continuous functionality of the ADS-B data? Using different links will provide different data rates during each part of the suborbital flight.

PROSPECTIVE SUBORBITAL FLIGHTS

For a domestic suborbital flight, the data rate when the vehicle is going through the NAS of the ascent trajectory is the same as the data rate when it is descending through the NAS.

For a suborbital flight that may depart from a spaceport in the U.S. and arrive at an intercontinental spaceport as depicted in several flight configurations (see Figures 7, 8 and 9) the data rate during ascent and the data rate during descent may not be the same and the suborbital trajectory will require further assessment from the space operations point of view.

In Figure 6, we illustrate different suborbital flight trajectories for the Lynx vehicle. The vehicle will take off from a conventional horizontal runway and will land on the same runway (HTHL). The Lynx can reach altitudes of 100 km as indicated by the Karman line (horizontal dashed red line). One of the purposes of this vehicle is to gather scientific data from the region of the atmosphere between 80 km to about 86 km, known as the mesosphere (region between the dashed black lines). This is a very thin region of the atmosphere and maximizing the time in this region would be ideal for data collection and further refine the tomography of the mesosphere. The data collection would be obtained from the noctilucent clouds shown in cyan ovals. Figure 6 shows several flight profiles.



The spaceship Front Range Airport uses to model its spaceport ambitions is much like the Lynx spacecraft being developed at the Mojave Air and Space Port in California by Xcor.

Source: Xcor Aerospace
maps4news.com/©HERE

(a)

Examples of SubOrbital Ascent Flight Profile for Lynx

(b)

Figure 6. a: Lynx flight profile proposed by XCOR. b: Example of simulated suborbital flight profiles for Lynx vehicle during the ascent leg.

The first two flight profiles are displayed in magenta and green and were obtained using an exponential atmospheric model and the ARDC atmospheric model from 1956 for the atmospheric density, respectively. As we can see, both models provide very similar flight profiles. The vehicle goes through the mesosphere region in about fifteen seconds on the ascent leg and it would take another fifteen seconds on the way descent through the mesosphere. The total time spent with the vehicle at a 75° pitch angle through the mesosphere would be approximately thirty seconds. This is a short amount of time to obtain samples of the microstructures of the mesosphere that may provide critical information pertinent to the Earth's climate. The simulated trajectory of the Lynx reaches 15 km during the first 100 seconds and 67 km after 180 seconds after the main engine cut off (MECO). After MECO, the vehicle follows a ballistic trajectory until it reaches the apogee of 100 km at about 260 seconds (4 minutes and 20 seconds).

The other two flight profiles depict two trajectories where the time spent in the mesosphere is roughly one minute (blue trajectory) and ninety seconds (brown trajectory). While the vehicle is flying longer along the horizontal direction, it will be able to obtain additional samples of the mesosphere maximizing the time of science. These trajectories will be further analyzed in a future paper when considering further flight parameters that may affect operations. Some of these operations include communications with aircraft during the ascent suborbital trajectory, acceleration management of the trajectory, trajectory course corrections to aim at the right noctilucent (NLC) layer, maximizing the science during the short time in the weightlessness environment, re-entry concerns, and energy dissipation management and communications with the NAS during the descent trajectory.

Further analysis of these trajectories will consider other flight parameters including; wind speeds that are thought to reach about 50 meters per second in the mesosphere. These weather parameters may affect the flight trajectory and make continuing this research justifiable. It is during these ascent and descent segments of the suborbital trajectory (see Figure 6) where the space vehicle passes through the NAS.

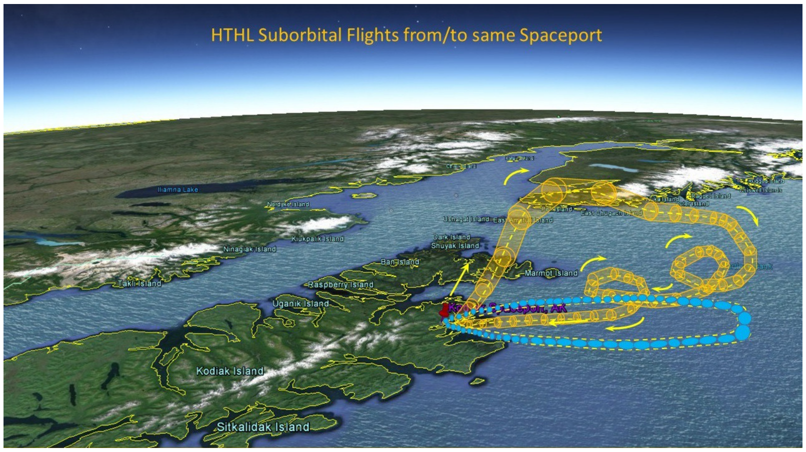


Figure 7. Suborbital flight example departing from and arriving at Kodiak spaceport (not to scale). The flight time is estimated to be about thirty minutes similar to the Lynx suborbital profile depicted in Figure 6a.

When the space vehicle passes through these segments, the Doppler Effect[2] will be dominant since the space vehicle travels at much greater speeds than nearby aircraft. In order to compensate for this diminished signal, ADS-B Ground Based Transceivers (ADS-B GBTs) and ADS-B IN receivers are suggested to improve navigation accuracy. When the space vehicle is in reaching apogee, its position will be almost perpendicular to the direction of the signal transmitted and, therefore, the Doppler Effect can be neglected but this will depend on the suborbital flight profile. If the space vehicle aims for a longer stay in the NLC layer (see Figure 6) to increase the science collection data, it will need more time for the ADS-B GBTs and ADS-B IN to operate and compensate for the loss of navigation accuracy.

Figure 7 shows a suborbital trajectory departing from and arriving at the spaceport in Kodiak, Alaska. Figure 8 displays a suborbital trajectory departing from the spaceport in Kauai (latitude = 19.74°, longitude = −156.04°) close to the equator and arriving at spaceport in Kodiak (latitude = 57.79°, longitude = −152.40°). Figure 9 depicts a suborbital trajectory from Kauai spaceport to Puerto Rico spaceport (latitude = 18.45°, longitude = −66.1°). This last suborbital trajectory moves almost at constant latitude along the equator.

PTP suborbital flights have different applications, such as scientific research purposes (see Figure 7) and space tourism and PTP-transportation (see Figures 8 and 9). Recently, there has been a strong interest in further understanding the evolution of Earth's climate. Figure 7 is an example of a suborbital trajectory that will allow novel data collection in the mesosphere region providing unprecedented science that will be able to use to refine current mesospheric models and further analyze the mesosphere.

Other benefits of these simulated suborbital trajectories in the SSFS will be to incorporate these trajectories (ascent and descent segments) into the NAS to further familiarize Air Traffic Controllers (ATC) with rerouted aircraft, enhance airport situational awareness, and analyze other navigation parameters, Next, we will explain more in detail these concepts and the importance of the flight or space transition corridors in the NAS.

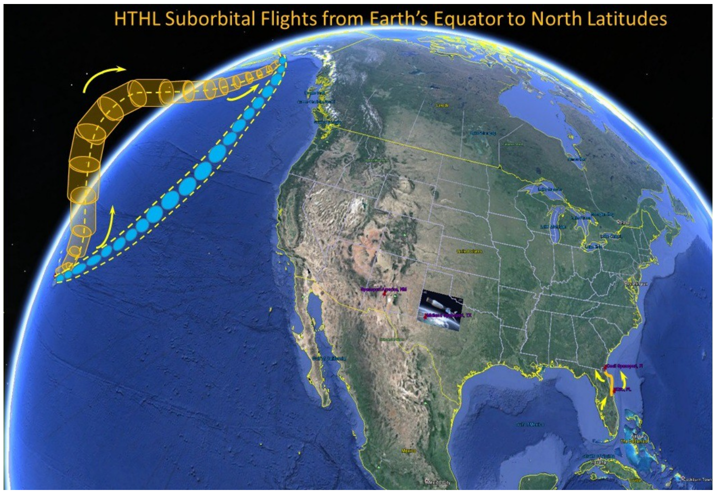


Figure 8. Suborbital flight example between two spaceports, one located along the Earth's equator and the other one at northern latitudes (not to scale). The flight time is about one hour and thirty minutes.

In Figures 7, 8 and 9, we show three different PTP suborbital profiles. Each trajectory is shown inside of an orange flight corridor. The sense of the trajectory is depicted by the arrows in yellow. Each flight corridor can be represented by a length and a containment radius, both varying in time. The length and containment radius can vary along the flight corridor depending on the navigation accuracy of the vehicle, which depends ultimately on the state vector (position and velocity) updates of the vehicle. The more updates we receive about the vehicle, the smaller the containment radius it will be along the flight profile. The length (and, therefore, time) of each of the segments along the flight corridor represents the range along which the vehicle has a determined position, velocity, and uncertainty in the state vector.

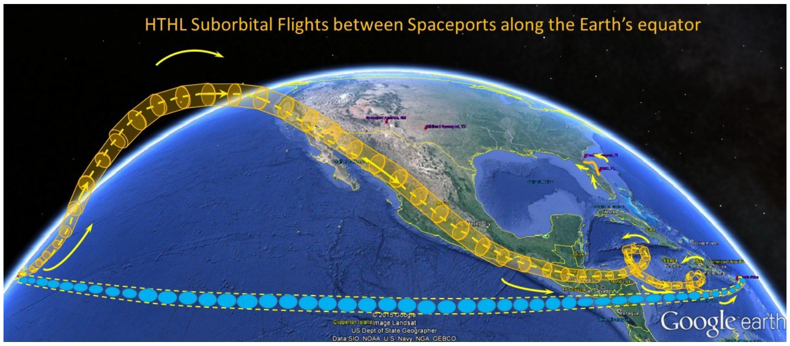


Figure 9. Suborbital flight example between two spaceports along the Earth's equator (not to scale). The estimated flight time is three to four hours.

The design of these flight transition corridors[3, 4] is crucial to better understand and manage the airspace system during launch and reentry operations while providing real-time capabilities to respond to different contingency scenarios in case of unexpected shortcomings. These flight corridors will be used to better refine the mission profile, the space vehicle reliability, and failure and abort modes, and how to utilize the patterns of air, ground and water* below the reference trajectory. Different flight corridors will be integrated into the NAS according to several parameters, such as azimuth, time window, length, and width and window midpoint duration.

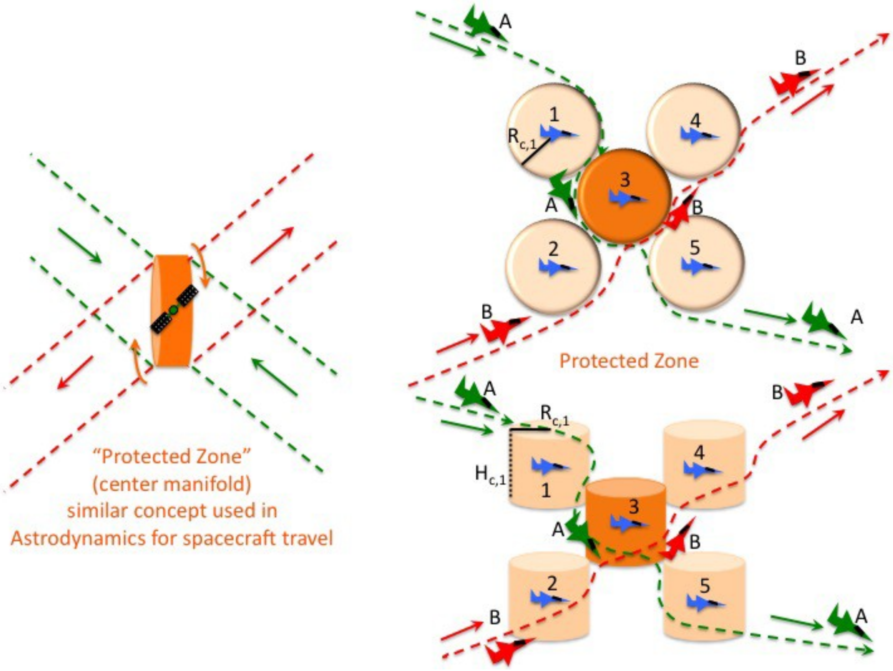


Figure 10. Left: In astrodynamics, the invariant manifolds are considered low-energy trajectories[5] where spacecraft can be transported between different planetary systems. The protected zone represents the center manifold (Halo orbit around a Lagrange point) and spacecraft can travel towards (green) or away (red) the protected zone. Right: Sketch of flight corridors in green (descent) and red (descent) in a complex configuration of aircraft flying in the NAS.

The flight corridor for suborbital missions is a continuous manifold with different flight durations (eg., about 30 minutes for Lynx vehicle and 90 minutes for Virgin Galactic's Spaceship Two). Other vehicles are becoming emerging technologies for suborbital flights, such as the hypersonic[6] airplane (hyplane), spaceplanes and the XP rocketplane[†]. These HTHL are envisioned to be used for PTP, space tourism and gravity research platform to perform remote sensing science experiments during the suborbital flight profile. The hyplane is expected to reach altitudes of about 65 km and travel up to 6,000 km in less than two hours. The spaceplane, Sidereous spaceplane, and XP rocketplane are expected to reach altitudes of about 100 km. The spaceport Hawaii flight corridor is the first proposed FAA licensed PTP for suborbital space travel.

Defining these flight corridors will need to meet public safety risk limits according to the Code of Federal Regulations[7] established by the FAA. Given an estimated vehicle's likelihood of failure,

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*Prospective suborbital flights may require using water beacons that can be used similarly to GBTs on the ground to provide navigation information to the space vehicle while flying overseas.

† The rocket plane suborbital flight trajectory is slightly different from other suborbital flights. This flight will start with a powered climb up to about 40,000 ft and 75 miles in range before it makes a 180°turn and start a more steep trajectory to apogee at about 100 km in altitude. The energy management, spiral descent maneuvers will follow before landing at the same runway.

safety will have to be assessed based on different mission parameters,[8] such as the departure launch conditions in the NAS, meteorology parameters, vehicle system status and ground support equipment for communications. These flight corridors can get quite complex depending on the individual configurations. In Figure 10, we outline several flight corridors for a specific configuration of five aircraft in the NAS at the time where we have one space vehicle going through the NAS either on the ascent or descent part of the trajectory.

For example, let's assume we have a vehicle, B, as shown in Figure 10. This vehicle could follow several feasible flight corridors for this concrete configuration. Some of these flight corridors are: 1) B going in front of aircraft 2, in front of aircraft 3 and in front of aircraft 4; 2) B going in front of aircraft 2, in front of aircraft 3 and behind aircraft 4; 3) B going in front of aircraft 2, behind aircraft 3 and behind aircraft 4; 4) B going behind aircraft 2, behind aircraft 3 and behind aircraft 4. Note that each aircraft has associated a protected zone with a certain radius of containment and height. Aircraft 1 has a protected zone with a radius of containment, $R_{c,1}$ and a height $H_{c,1}$, and the rest of aircraft have different associated radii and heights ($R_{c,2}$ and $H_{c,2}$ for aircraft 2, etc.). The size (radius and height) of these protected zones (cylinder volumes) may vary their volume properties in certain cases (eg., military operations area, other restricted areas operated by other flight controllers). There may be other situations where a space vehicle is coming down (gliding) through one of these flight corridors and its trajectory may be compromised by one or several intruders.*

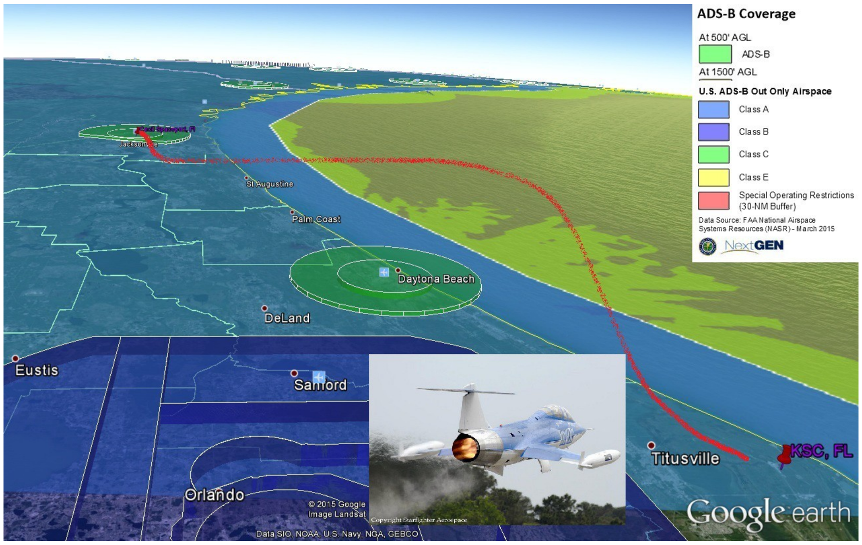

Figure 11. Low-Suborbital flight example (not to scale) departing from Cape Canaveral spaceport and arriving at Cecil Field spaceport in Jacksonville. The flight time is about one hour.

Ultimately, these flight corridors and, therefore, their space-time volume propagation in time will be extremely useful to better estimate the probability safety limits of debris striking another aircraft in case of an anomaly.

The use of ADS-B data will provide more accurate updates about the state vector of the vehicle during the PTP suborbital flights assuming this data information is provided.

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*These aircraft could generate various levels of air traffic discomfort depending on their level altitudes and may not be able to fully communicate their state vector. Some of these aircraft (within 30 nm of any airport or below 3,000 MSL) do not require ADS-B installation even after January 2020.

It is still unknown how various PTP suborbital profiles will benefit from using ADS-B data on long transoceanic flights as depicted in Figures 8 and 9. If insufficient data is provided, the uncertainty of the trajectory may grow. The uncertainty is indicated by the blue ellipses shown in these PTP illustrations. How can we maximize the knowledge of the vehicle trajectory when ADS-B data is not provided? How many ADS-B facilities will it be required to provide an acceptable (TBD) flight profile?

Recently, ERAU has sent a proposal to utilize the Starfighters TF-104 aircraft as flight demonstrations to gain insight about prospective PTP flights around the globe. Examples of PTP suborbital trajectories are displayed in Figures 7, 8 and 9. An example of this low-suborbital trajectory (≈108,000 ft) is depicted in Figure 11. The aircraft leaves from KSC spaceport (latitude = 28.52°, longitude = −80.65°) to Cecil Field spaceport (latitude = 30.49°, longitude = −81.69°) in Jacksonville.

Understanding suborbital requirements, procedures and ADS-B performance are critical to better assess prospective PTP suborbital flights. Figure 11 illustrates a trajectory (in red) of the trajectory of the aircraft from Cape Canaveral spaceport to Cecil Field spaceport as going throughout the NAS. The TF-104 is a high-altitude performance aircraft that flies at high-speed and is of interest in testing the functionality of ADS-B technologies during these analog suborbital trajectories.

ADS-B EXPERIMENTS TO SUPPORT COMMERCIAL SPACE TRANSPORTATION

Within the next five years, the NAS will be experiencing a higher volume of reusable suborbital space vehicles (RSLVs). In order to support these RSLVs flight profiles, we will need more ADS-B facilities to increase the navigation accuracy during the ascent and descent segments of the trajectory (see Figure 6). The ADS-B system will support the air traffic in the NAS below 60,000 ft (≈18 km). As an example, the Lynx vehicle in Figure 6 will take about 2 minutes to go beyond the 60,000 ft line (the Armstrong line is about 62,000 ft) during the ascent part of the trajectory. During the last part of the descent and gliding part of the trajectory, the vehicle can take several more minutes to go through the NAS.

ERAU has developed a UAT ADS-B transmitter prototype[9] for commercial space transportation that will become a standard payload on an RSLV and that will demonstrate the viability and functionality capability of ADS-B payloads. This prototype has reached a Technology Readiness Level (TRL) 7 and now it can be tested within its operational environment before transitioning to the prototype phase (TRL 8).

The next goal would be to refine this emerging technology so that not only RSLVs but also expendable launch vehicles (ELVs) could be tracked more accurately at higher altitudes and velocities. This more mature technology will eventually help longer and higher suborbital trajectories as the ones depicted in Figures 8 and 9.

Another flight experiment[10] is the Suborbital Flight Environment Monitor (SFEM) which intends to monitor and record onboard environmental parameters (shock, vibration, temperature, pressure and relative humidity) that will be of interest for future SRLV flights. This experiment will help in further characterizing the payload environment and payload design of future suborbital flights. The SFEM is at TRL 8 and will reach TRL 9 when reaching 100 km on an SRLV. This technology will provide unprecedented information about the instrument performance during the takeoff, ascent and reentry segments of the trajectory.

Recently, NavWorx[11] a Texas avionics firm offered a new ADS-B emerging technology known as ADS600-EXP. This new ADS-B has been certified by the FAA Technical Standard Order (TSO).

ADS-B600-EXP is based on ADS600-B which has been successfully tested at 95,000 ft. This is the first step to test and validate the ADS-B technology on satellite stations. These stations could be used as ADS-B depots to expand the navigation capabilities of prospective commercial suborbital flights.

ADS-B VS. TCAS AND HUMAN-MACHINE INTERACTION

The cockpit of the SSFS could be equipped with ADS-B or traffic alert and collision avoidance system (TCAS) capability. Using ADS-B inside the cockpit may not be very effective since the pilot and mission specialist may be overloaded with tasks during the suborbital flight profile. Instead, the use of TCAS would be more appropriate inside the cockpit of the SSFS. The TCAS could be displayed on an iPad and attached to their lap similar to commercial pilots. TCAS will help the pilot and mission specialist navigate the suborbital vehicle through the proper flight corridors, especially during the beginning of the ascent and the end of the descent. This TCAS system should be visually accessible to the pilot and mission specialist with adequate lighting conditions, and accommodate inflight vehicle environmental perturbations, such as structural vibrations.

However, the installation of ADS-B will be very useful in the mission control center (MCC) for future data processing. For this to happen, we will need a transponder inside the cockpit of the SSFS and a receiver in the MCC. Once this data is received in the MCC, it can be transferred to the NextGen testbed facility at the Daytona International airport, and then further distributed to other centers.

MCC could provide ADS-B data to the cockpit of the SSFS if required in order to improve the pilot awareness and not having the pilot to actually type on any ADS-B display. Although pilots could be distracted to the degree that their performance could be called into question, this impairment is thought to be offset because traffic activity is continuously available and updated automatically into their screen without monitoring any displays. During these short suborbital flights (30 minutes), the vehicle (see Figure 6) travels at variable high speeds, and this ADS-B data information may not be provided on time for the pilot to receive it. How will be these vehicles tracked then other than with GPS?

WEATHER AND TRAFFIC FROM ADS-B

ADS-B avionics in the SSFS will not necessarily need to be installed as panels. Instead, we foresee portable ADS-B in a slimline iPad Kneeboard that will be firmly attached with straps around the users' leg to keep it from shifting. Several options are available for ADS-B receivers: Appareo (Stratus 1s, Stratus 2s), dual electronics (XGPS170) and Garmin (GDL 39, GDL 39 3D and GDL 3D with battery). The last two Garmin ADS-B receivers have a dual band and also built-in attitude heading reference system (AHRS). They also provide ADS-B traffic information using dual band. Connection can be achieved via Bluetooth, which would allow two iPads to connect simultaneously.

Flight information services (FIS) can be broadcast (FIS-B) to provide weather and non-control advisory information in the forms of texts and graphics via a cockpit display. FIS-B advisory services are only provided by UAT link or 978 MHz. FIS-B is not available with 1090 ES.

Traffic information services (TIS) can be broadcasted (TIS-B) to provide visual of traffic with transponders while increasing situational awareness.

SPACE ORBITER DESCENT

The Orbiter and other planes like the SR71 blackbird and the U2 spyplane cruised above 60,000 ft (≈ 18 km).

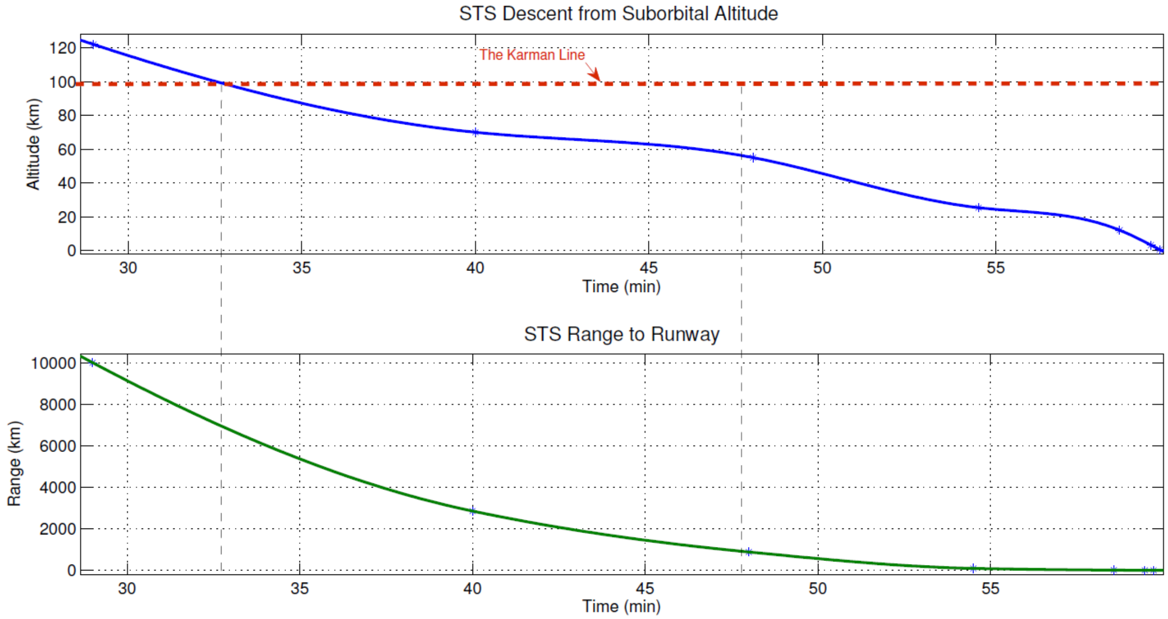

Figure 12. An example of descent profile (blue profile) for the Shuttle and range from the runway (green profile). The red dashed line represents the Karman line

Figure 12 shows an example of the Orbiter descent trajectory* (in blue) thirty minutes before landing at KSC. Thirty minutes prior to landing, the Orbiter is approximately 9,000 km from the runway. Ten minutes before landing, the Orbiter glided at about 45 km of altitude and used the Tactical Air Navigation (TACAN) System for navigation during the last stage of the descent. TACANs were the primary equipment for navigation information (bearing and range) during reentry of the Orbiter. The TACAN ground equipment operates in the ultrahigh frequency (UHF) band of frequencies and it is based on a fixed or mobile transmitting unit.

The Orbiter continued gliding and at about 20,000 ft (≈ 6.1 km), it used its microwave scanning beam landing system (MSBLS) to provide more precise three-dimensional navigation position data during the flight trajectory. The Orbiter had three MSBLS for redundancy to better manage the azimuth and elevation angles while providing more accurate flight information.

Prospective commercial suborbital vehicles will behave very similar during the reentry phase of the trajectory and will be required to obtain an extremely precise three-dimensional position using similar or emerging navigation technologies, such as the ground-based navigation instrument landing system (ILS) that could provide very precise navigation during the approach and landing phases of a vehicle. The desired precision will depend on the number of components needed for the ILS system and it will be directly related to the weather parameters. The required navigation performance (RNP) for various suborbital space vehicles will need to be characterized, and this will part of future study. The FAA has set a 95% for the RNP authorization required limits (0.3 nm < RNP < 0.15 nm) during the approach phase.

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*Maximum heating of the Orbiter occurs between 80 km and 55 km in altitude (about 12 minutes of communications blackout period)

SUMMARY AND FUTURE RECOMMENDATIONS

We expect to have ADS-B integrated into the SSFS by fall 2016. These suborbital trajectories will then be integrated into the NAS for several spaceports such as Cape Canaveral, Cecil in Jacksonville, Midland in Texas, Mojave in California, Spaceport America in New Mexico and Kodiak in Alaska.

These trajectories will include new realistic weather scenarios that will define the go/no-go decisions and realistic air traffic control scenarios to disaggregate the traffic during ascent and descent segments of the flight profile.

Finally, we will define the sensitivities for different space vehicles such as the XCOR's Lynx vehicle and the Virgin Galactic's SpaceShip II, and analyze how these will influence future suborbital flights. These trajectories will first be simulated with computer software and compared with trajectories obtained from the SSFS.

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