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Space Operations in the Suborbital Space Flight Simulator and Mission Control Center: Lessons Learned with XCOR Lynx

Pedro Llanos
Embry-Riddle Aeronautical University, llanosp@erau.edu

Christopher Nguyen
Embry Riddle Aeronautical University, nguyenc7@my.erau.edu

David Williams
Embry Riddle Aeronautical University, WILLIAE8@erau.edu

Kim O. Chambers Ph.D.
Embry-Riddle Aeronautical University, chambek3@erau.edu

Erik Seedhouse
Embry-Riddle Aeronautical University, seedhoue@erau.edu

See next page for additional authors

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Space Operations in the Suborbital Space Flight Simulator and Mission Control Center: Lessons Learned with XCOR Lynx

Author(s)
Pedro Llanos, Christopher Nguyen, David Williams, Kim O. Chambers Ph.D., Erik Seedhouse, and Robert Davidson

Introduction and Motivation

Research Questions and Objectives

In 2015, the Commercial Space Operations Department and the Center for Teaching and Learning Excellence started a joint effort project at Embry-Riddle Aeronautical University's Daytona Beach campus, which involved using the Suborbital Space Flight Simulator (SSFS) and Mission Control Center (MCC) for education and research purposes. The SSFS/MCC or Space Operations Lab is located in the Applied Aviation Sciences (AAS) Department in the College of Aviation. In the spring of 2016, the Space Operations Lab was used for the first time to enhance the curriculum of several classes, such as the Selected Topics in Space and Aerospace (SP-425), Introduction to Aerospace Safety (SF-210), and Aircraft Crash and Emergency Management (SF-350).

In the Space Operations Lab, integrated suborbital missions were performed and assessed in which several disciplines played a crucial part in the functionality of the SSFS and MCC. The MCC has five different consoles: Air Traffic Control, Surgeon, Flight Director, Inco-Integrated Communications Officer, and Meteorology. This multidisciplinary educational and research tool will help students acquire new knowledge about the impending challenges of suborbital missions and their integration into the protected national airspace (NAS) (Llanos & Triplett, 2015).

This research will help students use SSFS-generated data in the classroom to improve their understanding of the fundamentals of suborbital space flight, improve the confidence levels of this research tool for training purposes, and generate large datasets of suborbital missions that can be used for flight operational quality assurance (FOQA). By analyzing these simulated suborbital flights, it will be possible to learn a great deal about the different parameters of various suborbital trajectories and assess pilot performance. It will also be possible to assess metrics aligned with the flight profile and to determine difficulties the pilot encountered when flying nominal and off-nominal profiles. Some of these difficulties are addressed herein and displayed in a graphical context to assist the reader's visualization. The aerodynamics model used in X-plane has not been proven yet, but provides a well-adjusted aerodynamic model to the real flight data, which allows researchers to simulate suborbital trajectories with a variety of space vehicle platforms.

Suborbital Space Flight Simulator and Mission Control Center History and Overview

The SSFS is a valuable tool for the analog research of the suborbital vehicles. With the SSFS, it is possible to characterize the flight characteristics of multiple conceptual vehicles, such as the XCOR Lynx and the Virgin Galactic's SpaceShipTwo. This paper focuses on the Lynx, which is a platform that has been subject to intensive testing for two years. This testing has enabled a detailed understanding of the performance parameters of the vehicle which have been subject to assumptions on the performance parameters made by Integrated Spaceflight Services in the design of the vehicle.

The suborbital space flight simulator (SSFS) was rebuilt 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 and mission specialist to navigate the vehicle along a suborbital flight trajectory while pointing the instrumentation at the right location of the atmosphere. Outside the cockpit, there are three primary flight screens that display the path of the suborbital flight profile through the atmosphere, as viewed from inside the cabin seat.

The SSFS has also been used as a research tool to gain perspective about the performance of suborbital spaceflight participants when performing data collection samples with PoSSUM

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(Polar Suborbital Science in the Upper Mesosphere) instrumentation during the 20-minutes suborbital mission while in the pressurized IVA suit (Llanos, Kitmanyen, Seedhouse, & Kobrick, 2017). The participants' performance was measured by subjective workload data provided with the NASA-Task Load Index (TLX). With two private companies (Moro-Aguilar, 2014) vying for the opportunity to send the first suborbital astronauts into space before the end of 2020, the SSFS will help 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.

In this research study, we flew eight experimental suborbital trajectories with XCOR Lynx. These trajectories were approximated solutions obtained with the Lynx simulation software, which uses publicly available vehicle data and best assumptions. The first four trajectories are nominal trajectories, that is, they have a smooth gliding reentry through the NAS. The last four trajectories correspond to an altered gliding reentry path with two control areas, as to mimic some contingencies scenarios or energy management operations in order to gain insight about the flight reentry through the NAS and the procedures by flight navigators. What does it take to perform a nominal suborbital flight? This is one of the research questions we are trying to analyze to better understand hazard and safety risks and establish procedures and preventive measures when the vehicle goes through the NAS.

Learning Objectives, Tools, and Techniques

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 under differing weather conditions between different spaceports. At the moment, the team has successfully managed to transfer the simulated data with the SSFS to the MCC room where it can be visualized on the large screen of the MCC.

Air Traffic Control Console

These suborbital trajectories will be embedded into the WSI Vision software that is installed in the ATM console. The WSI Vision software (WSI software, 2017) is the most advanced (e.g. currently used by Southwest Airlines) flight tracking applications used by industry since it visualizes real-time flight and airspace data that helps with the decision-making process for prospective suborbital operations. Once the SSFS data has been transferred to the ATM console, it will be possible to integrate and visualize suborbital flights in real-time using LabVIEW into the WSI software.

Flight Director

The Flight Director (FD) position oversees the operations in the MCC. The information the FD oversees is live data from the SSFS. Data is displayed via LabView through the large monitor in the MCC. The FD also communicates between the SSFS and MCC rooms. This person is in charge of MCC operations and is in constant communication with the INCO (Integrated Communication Officer), the Surgeon, Air Traffic Controller, and the Weather personnel. The FD is responsible to help the SSFS crew identify any problem using the Emergency Procedure checklist. Some of these problems may not have been previously identified, and they need to be analyzed and possibly solved for the mission to continue, unless abort is authorized by the FD.

Integrated Communication Officer

This console displays the four-feed camera system. INCO is responsible for monitoring. This person maintains communication with, and is in continuous contact with, the pilots during the flight. Any simulated anomalies are reported to SSFS and the MCC team.

Surgeon

This console displays the physiological metrics of the pilot and mission specialist. These metrics are generated by BioHarness or Hexoskin instrumentation to the MCC team to show the main physiological parameters, such as the ECG, heart rate, and breathing rate.

Weather Console

Although WSI Vision software has also a weather capability, this weather information will be only used as a secondary source. The primary weather source of information is currently displayed in the weather console by Meteorology colleagues in the AAS department. In the future, it will be possible to model hazard impacts such as weather in the NAS. According to Ichoua (2013), a time-space stochastic process, modeled with weather disruption, is used as a method to investigate air traffic flow. These researchers characterized weather disruption by occurrence time, centroid, duration, trajectory and intensity. Using the SSFS-MCC it is planned to simulate flights with various suborbital flight durations. Therefore, a new set of disruption constraints, that may affect the flight operations, will need to be addressed. In 2018 these questions cannot be answered because there have not been any manned operational suborbital flights. But, when revenue flights *do* begin, the efficacy of operability of suborbital vehicles will be driven by factors such as turnaround, spaceport access, weather, NAS integration and maintenance cycles. For example, Virgin Galactic have positioned themselves well with respect to these factors since they will be operating from a purpose-built spaceport in New Mexico, which is located well away from high density NAS operations.

Integrating Suborbital Space Flight into the National Airspace System (NAS)

The flight corridor (Llanos & Triplett, 2015) for suborbital missions is a continuous manifold with different flight durations depending on the space vehicle. The design of these flight transition corridors (FTC) must be planned in a way that best manages 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 FTCs will be used to better refine the mission profile, the space vehicle reliability, and failure and abort modes. The SSFS was used to generate different FTCs that may ultimately be integrated into the NAS (see Figure 1) according to several flight parameters.

Software Tool: X-Plane 10

X-Plane 10 is a robust flight simulator that accommodates custom builds and airfoils. Because of the ability to take custom designed airfoils, the simulator can be used to test experimental aircraft such as the XCOR Lynx. X-Plane also takes user-customized applications easier than most other simulators. As such, the SSFS has a custom software suite developed by Integrated Spaceflight Services that simulates the XCOR Lynx and other vehicle suborbital missions, enabling tracking of up to 56 flight parameters, including ground track, latitude, and longitude, pitch angle, flight path angle, angle of attack, estimated G loads, lift and drag, lift and drag coefficients, and Mach number. The vehicle performance data characteristics used in X-Plane 10 was: takeoff mass of 4,808 kg (10,600 lb), fuel mass of 2,562.8 kg (5,650 lb), empty mass of 1,678.3 kg (3,700 lb), payload mass of 567.0 kg (1,250 lb), and a specific impulse of 360 seconds. Other parameters considered in the SSFS using X-plane were the wind speed and wind gust, shear direction and turbulence. In our simulations, we used 5 kt = 5.75 mph for wind speed and wind gust, 10 degrees for shear direction and no turbulence. These values were all assumed for different layer in the atmosphere: 18,000 Mean Sea Level (MSL), 8,000 MSL, and 2,000 MSL. These values can be easily changed in X-Plane 10 to simulate various suborbital missions.

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XCOR Lynx Results of Simulations

The XCOR Lynx suborbital trajectories were simulated with X-Plane software. The data output is expressed as a text file, which is read by a Matlab script that was written to generate all the graphical visualizations shown in this paper.

Figure 1 displays an example of a suborbital trajectory for the XCOR Lynx, and it is one of the eight XCOR Lynx flight profiles (Figure 2) that were flown in the SSFS. This single suborbital trajectory shows the key phases where suborbital operations are required to be performed by either the pilot, or the pilot in coordination with the mission specialist, who is in the right seat of the SSFS. These suborbital phases are: (1) Pull-up Maneuver, (2) MECO, (3) Apogee/Science, (4) Descent/Reentry, (5) Maximum Mach Number, and (6) Gliding.

Most of the simulated XCOR Lynx trajectories reached an apogee of about 110-112 km. This is slightly different from the expected apogee 103-107 km by this vehicle since the student pilot flew a pitch angle of about 85 degrees (instead of 80 degrees) during part of the ascent trajectory. These XCOR Lynx trajectories (performed by the same pilot) were compared with the Virgin Galactic's SpaceShipTwo vehicle suborbital flights (performed by three different pilots). The comparison of both platforms suborbital flights is shown in Figure 2a. The scope of this article is not about the SpaceShipTwo performance vehicle nor the pilot study based on the different suborbital flight performances; this will be addressed in a subsequent paper.

However, it can be seen from the simulations presented here that the SpaceShipTwo vehicle reaches slightly lower altitudes of about 100-105 km with shorter flight times.

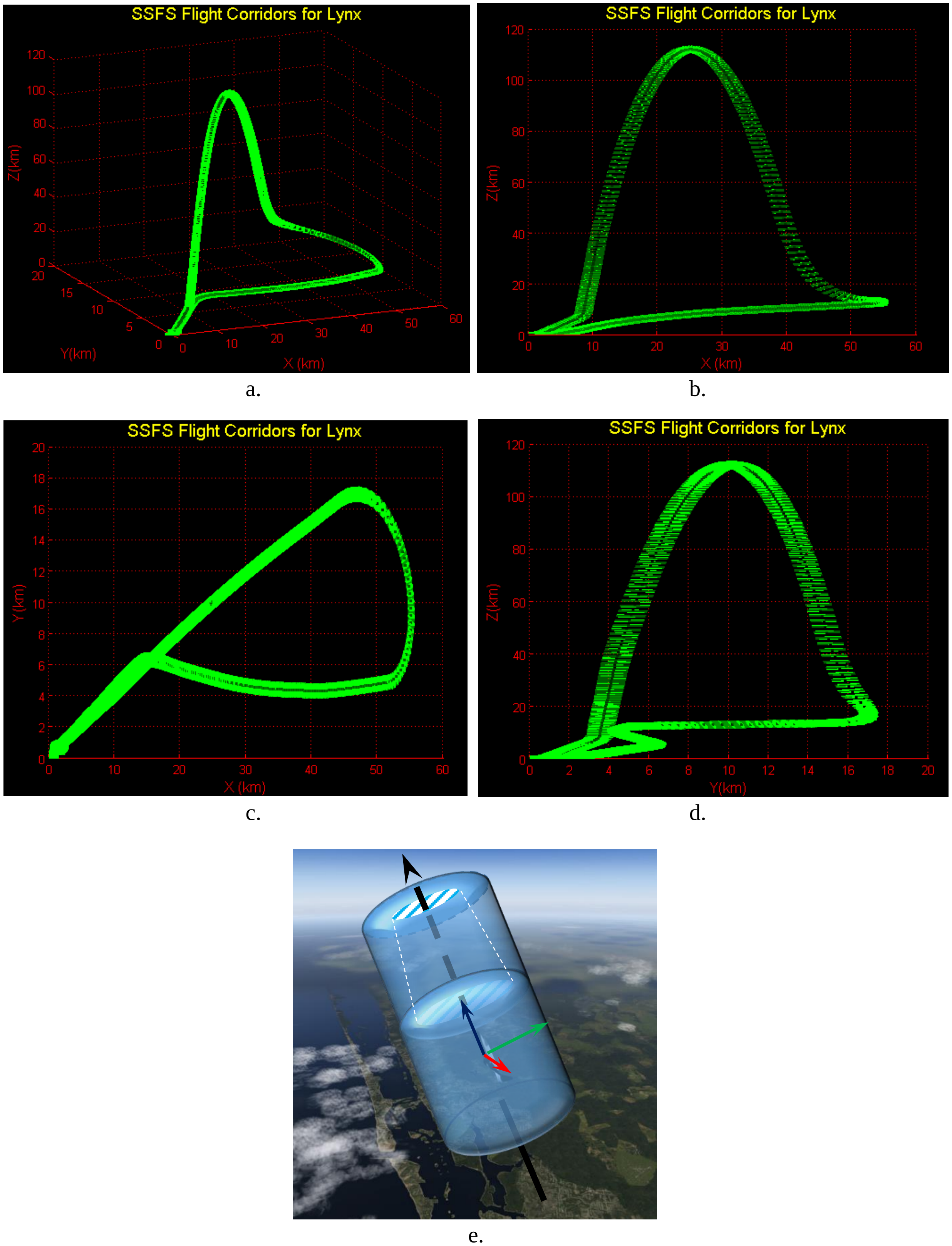
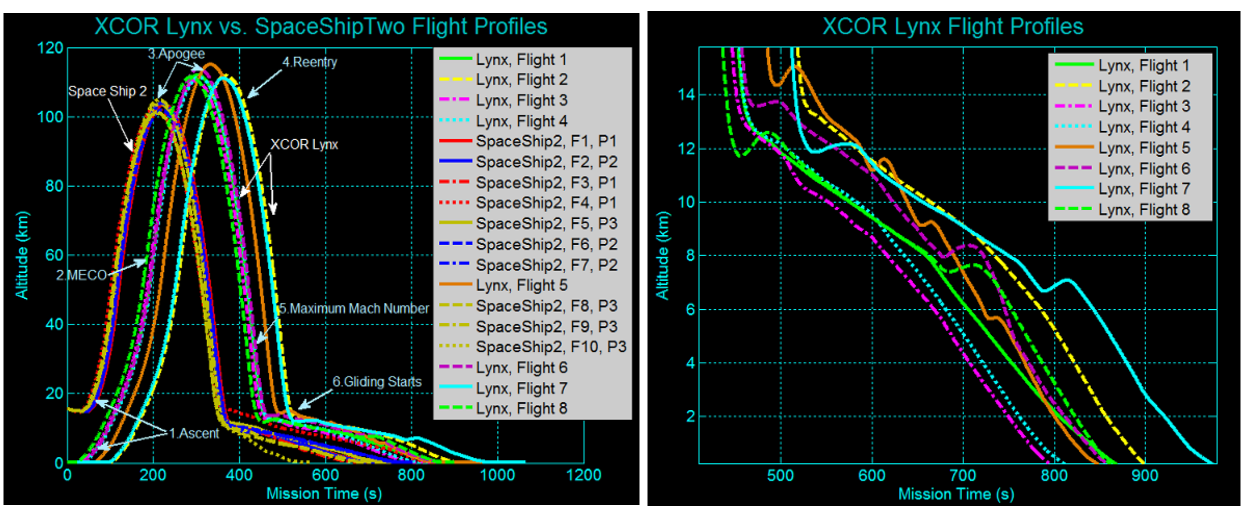


Figure 1. Space Transition (Flight) Corridors using the Lynx platform: (a) 3D trajectory of XCOR Lynx, (b) xz-projection of trajectory, (c) xy-projection of trajectory, (d) yz-projection of trajectory, (e) Sketch of the FTCs showing the safety limits for a nominal mission.

Figure 1a depicts XCOR Lynx 3D space transition corridors (STCs) (in green) and Figures 1b-1d show the xz-projection, xy-projection and the yz-projections, respectively. Figure 1e displays a sketch of a flight corridor and its safety limits indicated by the three arrows.

These STCs, which are plotted in green in Figure 1e, have safety limits of 15 nautical miles back and front (black arrow), 5 nautical miles left and right (red arrow), and about one nautical mile up and down (green arrow), as confirmed by the FAA (Legal Information Institute [LII], 2000). Note that this suborbital trajectory reached 110 km in the z-direction, about 55 km in the x-direction and about 17 km in the y-direction. These dimensions will vary for various trajectories for nominal scenarios and for contingencies scenarios, such as thrust termination, explosion and debris propagation, loss of vector control, and tumbling turns. The team is already working toward assessing some of these contingencies on the XCOR Lynx and on the SpaceShipTwo, a more promising research platform to be flown in 2018 or 2019.



a. b.

Figure 2. (a) Comparison of XCOR Lynx and SpaceShipTwo flight profiles. Lynx is a horizontal take-off horizontal landing (HTHL) and SpaceShipTwo (begins horizontal takeoff underneath the carrier aircraft WhiteKnightTwo); (b) Zoom of the trajectories with different control areas before the pull-up maneuvers and gliding segment.

In this preliminary research study, eight experimental flights were performed. The first four flights were performed with a smooth gliding reentry while the last four flights were performed with an altered gliding reentry. The fifth flight had four control areas, and the last three flights had two control areas. This will be further analyzed in the second part of this paper.

These flights showed very similar performances from takeoff to the point where the vehicle starts to glide at about 50,000 ft or about 15 km in altitude as displayed in Figure 2b.

These trajectories were flown by a CFI (Certified Flight Instructor) qualified pilot and student (future experimental flights will be conducted by other pilots: during these flights, a comparative analysis of each pilot's control sensitivity will be conducted to learn more about the vehicle performance). In these entry simulations, the Lynx vehicle starts from a steep descent trajectory and its energy needs to be converted into a more horizontal flight path. The pilot needs to control pitch or roll of this phugoid oscillatory motion (Han, Liu, & Shi, 2015; Lu, 2014) before and during the pull up maneuvers to avoid the vehicle having too steep a trajectory into the flight corridor since this may have caused excessive stress on the structure of the vehicle caused by high thermal loads, dynamic load stresses, and dynamic pressure (Han et al., 2015; Lu, 2014). After the pilot has recovered from the pull up maneuver and entered into a quasi-equilibrium glide trajectory, these phugoid oscillations are damped and the Lynx is free of such large oscillations. In part two of this paper, we will address this issue regarding time of effects, severity, and forces associated with the reentry phase. The flight control transition from RCS to aerodynamics takes place once aerodynamic forces are sufficient to sustain lift and control authority for the Lynx; the following research will be done regarding this transitional phase.

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Lessons Learned and Future Applications

Curriculum Development in SP-425

In the SP-425 class, students gained a general understanding of the upper atmosphere (mesosphere and lower thermosphere or MLT) and the science that can be conducted in this region that is dominated by neutral dynamics, such as gravity waves, tides, oscillations, and noctilucent clouds imagery and tomography. Students gained insight into the spaceflight operations of suborbital missions and life support systems. Some of the students continued working towards sending a payload to suborbital space onboard Blue Origin's New Shepard vehicle that was launched December 12, 2017. This payload will be a precursor to future payloads that may be flown to the International Space Station in the near future.

One of the objectives of the SP-425 class was to assess the interaction and crew resource management of each crew mission team of students using the SSFS and MCC while the rest of the students were in class watching the live-video feed. This SP-425 course was a new course where the XCOR Lynx was chosen since it was one of the commercial vehicles to soon conduct suborbital flights in 2015, however, due to the decommission of this vehicle, our SSFS started using the SpaceShipTwo vehicle in 2017. The pilot was in the front left seat of the Simulator controlled and operated the vehicle on a suborbital mission and communicated with the mission manager. This person assisted with other duties that may have been required during the mission. The Mission Specialist (MS), seated in the front right seat next to the pilot, was in charge of performing science checklists. The MS was the expert on the instrumentation required to collect data about the noctilucent clouds for this particular mission by following written procedures, which included when to power on/off the video camera, when to activate the wide-field imager sequencer to collect noctilucent cloud samples when going through about 286,000 feet during ascent and descent segments of the trajectory, understand the solar-position elevation of these features for pointing purposes (communicate to pilot), and handle the zoom control and iris control to enhance light conditions during the data collection process. This crew member was responsible for reading the pre-flight, in-flight, landing checklist and helped monitor and log all the mission operations from launch to landing. The Mission Observer (MO) was responsible for logging any data pertinent to the mission and intra-communications between the pilot and MS (part of the Space Flight Resource Management). The MO interacted with the Mission Manager (MM). The Mission Manager (MM) or Flight Director was in charge of supervising the communications, science and operations pre-, during, and post-flight mission. The MM was responsible for the execution of the procedure within the simulation environment. This person was responsible for the space vehicle, crew (pilot and MS), mission success and safety of the flight, and for making final decisions regarding the space vehicle operations. Some of these student outcomes were:

1. A video-feed (see Figure 3) to the classroom provided an opportunity to observe, analyze, and document the operations of the other teams following a mission transcript that students completed.

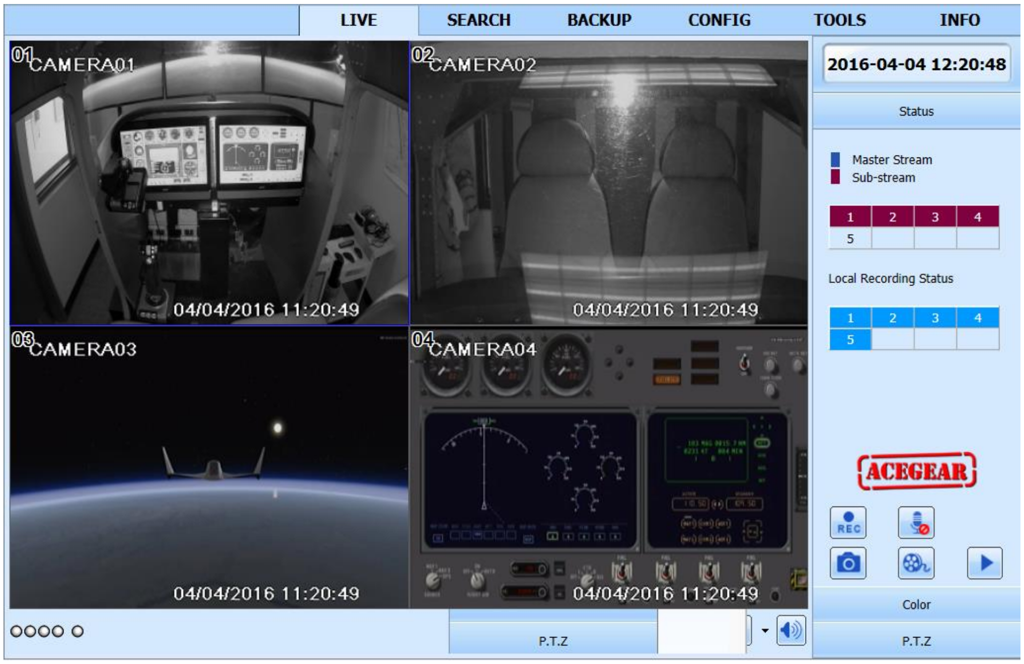

Figure 3. Four-feed camera system installed in the SSFS. Provides live-video feed to the MCC and any other remote computer. Top left: View of camera installed inside cockpit. Top right: View of camera placed on top of centered main screen in the SSFS. Bottom left: XCOR Lynx simulation at apogee. Bottom right: Navigation panel displayed in front of right seat of SSFS.

2. The SSFS allowed a group of students to conduct a Lynx mission. The mission started from launch all the way into suborbital environment and returned to Earth landing at the same spaceport they took off from (this simulator allowed the Lynx to land in other spaceport assuming both spaceports were within the vehicle propulsion capabilities).
3. During the mission, the crew teams documented the information that was verbalized by the pilot, mission specialist, mission observer, and mission manager. This mission was intended to provide students with basic in-flight dynamics, the history of the SSFS, and the history of suborbital space vehicles to foster interest in space exploration.
4. During this suborbital mission, the team experienced emergencies and these had to be identified, managed, and solved to complete the mission successfully. Examples of emergencies included communication failure, compromised vehicle health, reaction

control system failure, hydraulics malfunction, fuel leakage, landing gear malfunction, single engine failure, dorsal pod (Cubesat inside) malfunction, etc. The team had to develop a solution and make pertinent decisions as a team to manage the emergency. Communications between the pilot and mission specialist, and the MCC and the SSFS (pilot only) were very important, and the teams learned some aspects of crew resource management. Students demonstrated proficient performance during normal flight operations and managed emergency situations when they felt comfortable with nominal flight profile.

Curriculum Development and Student Outcomes in SF-210 and SF-350

Education material was obtained during the training and observation by the students of the candidates during PoSSUM Class 1502 and 1503, and during pilot training missions. The purpose of these observations was to incorporate new curriculum into two Aerospace and Occupational Safety Classes. Many safety issues were presented during these simulation flights and those issues were turned into a learning experience as well as learning outcomes for course development.

In SF-210, Introduction to Aerospace Safety, students are principally concerned with aviation safety. In the SF-210 class, students were exposed to an area of aviation safety between commercial aircraft operations and space operations of an orbital nature. SF-210 is an introductory course in Aviation Safety and historically has only dealt with aircraft operations below 60,000 feet. Students gained insight into the area of suborbital space flight missions and their effects on the National Airspace System, which has previously not been a part of this curriculum. By introducing students to these operations, the field of aviation safety is being expanded. Students in these classes analyzed the problems encountered in the SSFS during the training and identified and discussed aviation safety factors, such as human factors, medical/environmental factors, pilot error, and flight control issues. Suborbital mission profiles, as well as emergency management issues, personnel rescue, and aircraft recovery operations were discussed. Additionally, the unique problems created by spacecraft traveling through the NAS present a safety challenge to the Air Traffic Safety System and Air Traffic Controllers. By viewing the ATC Console position during simulated operations, the students observed and recognized the airspace challenges while in the NAS and the safety challenges to the Air Traffic Controller clearing the airspace for the Suborbital Aircraft.

Students gained an understanding of the safety issues within restricted and unrestricted airspace due to the speeds at which these aircraft travel and to some of the unique safety problems to commercial and private aircraft. Methods of addressing and controlling safety issues while operating these vehicles were presented by, and discussed by, the students as a class project/learning exercise. Some of these student outcomes were:

1. Students observed both live feeds and recorded videos of suborbital missions and analyzed the safety procedures followed and those not addressed during the flight.

2. Students identified the additional safety concerns of suborbital space flight above those of commercial passenger aircraft. These concerns addressed preflight and ground operations as well as flight operations.

3. Students were able to apply human factor issues relating to suborbital flight such as spatial disorientation, vestibular issues, and hypoxia onset.

SF-350 Curriculum Development

Education material was obtained during the training and observation by the students of the candidates during PoSSUM Class 1502 and 1503 and during pilot training missions. Similar to SF-210, the objective of this research is to provide updated curriculum related to emergency operations and the rescue of suborbital spaceflight personnel. As this class is Aircraft Crash and Emergency Management, the class focused on rescue and emergency egress scenarios. Suborbital spacecraft are technically advanced vehicles and have many onboard systems which are hazardous to first responders. The rocket fuel, thruster fuel, hydraulic fluid and liquid oxygen are just a few systems which can cause serious injuries for rescuers. Not yet identified are the crew initiated escape systems, such as ejection pods, seats, and the similar explosives which pose a hazard to first responders.

An observation and test of confined space egress by Pilot and Crewmember revealed issues which the SF-350 analyzed and discussed. As revealed by students' egress attempts in the SSFS, the Pilot and Crew were unable to extricate themselves quickly when strapped into their seats due to the limited space and constrictions of the spacesuit and scientific instruments onboard. Recognizing the simulator was a C-172, the students could grasp the rescue problems would be possibly very different, yet somewhat similar within a more confined space. This provided students with observable issues to consider when assessing the proper rescue procedures that must be implemented by first responders in suborbital aircraft confined spaces. The present simulator, a C-172 cockpit, does not approximate the problems which would be present in the Lynx aircraft. However, the C-172 was used to illustrate the concept of confined space rescue of two people in full space suits and onboard mission equipment. This configuration provided the students with an opportunity to experience a general aircraft confined space rescue with personnel who could not self-extricate efficiently. The exercise also lent itself to a discussion of the rescue of persons trapped in military fighter aircraft, or suborbital aircraft with ejection canopies and seats. The student outcomes were:

1. Students observed and discussed the elements involved in rescue of the suborbital crew with highly explosive rocket fuel, liquid oxygen, and explosive ejection seats.

2. Students identified the proper procedure to control aircraft fires involving rocket fuel and operations within a toxic smoke and fumes environment.

3. Students recognized the special types of hazards associated with suborbital aircraft for first responders' safety.

Research Simulations

With regards to flight characteristics, it was revealed that our simulated Lynx flight model shows short instabilities when taken past its critical angles of attack when achieving maximum Mach number during the last part of the reentry phase. Some stall instances involve utilizing the reaction control system to help nose-down the spacecraft. The spacecraft needs to move fast, as it sinks rapidly when airspeeds are under its best glide of 180-200 knots. The time to ascend is fast enough to avoid most airspace restrictions, and there is sufficient energy to meet target altitudes with some leeway. To avoid off-nominal re-entries it is necessary to maintain absolute stability on reentry. The subsequent glide distance is significant—enough to avoid most air traffic conflicts with a degree of safety. This is valuable information for the manufacturer as well as for the FAA/personnel who are in charge of air traffic. The information will provide controllers with the ability to predict, with a degree of accuracy, the flight characteristics of this spacecraft and will enable them to respond as required to routing changes. This is the utility of the MCC, since it is possible to simulate airspace restrictions for spacecraft trajectories.

Data from the SSFS and MCC has revealed how air traffic may be impacted from a spaceflight at a specified day and time. Utilizing this data in several different traffic models may help develop future procedures. Real-time data flow from the SSFS is displayed in the MCC room and the next step will be to embed this data (e.g. trajectory of space vehicle) into the WSI Fusion software in the ATM console, which will permit integrating the suborbital trajectory into the NAS. This on-going software suite is being developed with the help of several students from different colleges, and it will allow us to simulate traffic conflicts in real time and see the sequence of events that may lead to an incident, accident, or a solution to a traffic issue.

Summary and Future Work

The XCOR Lynx shows a robust flight profile, one that should have minimum impact on the NAS due to the speeds of ascent and the high glide ratio of the descent. The Lynx is the first platform used in the SSFS and in the future, other space vehicles, such as the SpaceShipTwo and other built-in space vehicles that may have an impact on the NAS, will be evaluated. The aim is to generate an extensive database of data for nominal and contingencies scenarios for each space vehicle. Contingencies will include thrust termination, explosion and debris propagation, loss of vector control, tumbling turns, etc. Future considerations will address FAA requirements (LII, 2000) to operate and launch site under 14 CFR Part 420, such as characterization of the probability levels in a risk assessment matrix from frequent, probable, occasional, remote and improbable. Then, an impact risk analysis will be performed for these emergency scenarios, including impact dispersion areas and casualty expectancy estimates for unguided suborbital launch vehicles. These space vehicles will be launched from different launch locations and in order to have a high-fidelity model of these FTCs, higher order perturbations in the Earth's gravitational field, such as the J2, J3, J4 spherical harmonics, and wind modeling (direction and magnitude) at different altitudes will be considered. Gradually, as a database of operational flights is generated, it will be possible to better define what constitutes the acceptable parameters of a FTC. These FTC's will be a product of the very unique flight characteristics of the suborbital vehicles that are in development today. For example, the FTC for the air-launched SpaceShipTwo will be different from the Vertical Launch Vertical Landing New Shepard vehicle being operated by Blue Origin. As an example, the New Shepard vehicle and the Crew Capsule launched on December 12, 2017, from West Texas Launch Site with an ERAU payload landed about two miles north-west and north-east, respectively from the launch pad, each landing about one mile from each other, proving a very well-defined FTC.

In the future, we envision collaborating with Embry-Riddle Aeronautical University's College of Engineering to make a prototype of different space vehicles, such as XCOR Lynx and Virgin Galactic's SpaceShipTwo that will be used in the wind tunnel at the John Mica Engineering and Aerospace Innovation Complex at ERAU's Daytona Beach, Florida Research Park (MicaPlex). These experimental results will improve our understanding of the vehicle's aerodynamic model, which will be compared against the current performance of the vehicle flown in the SSFS. Any deviations in the model flown will be very useful to provide companies with recommendations and further seek external research collaborations with suborbital vehicle providers and other companies, such as the FAA NextGen testbed and Mitre Corporation, and the Next Generation ERAU Advanced Research Center (NEAR Lab) to further develop procedures with such data. This model has not been proven yet; however, it is well adjusted to performance in real life once that data is available. This flight data provides fairly mimicked suborbital trajectories. Ultimately, there is also interest in developing a better understanding of the physiological performance of the crew when flying these space vehicles. The SSFS provides this biometric data when the participants wear a Zephyr Bioharness (Llanos et al. 2017) or HexoSkin bioinstrumentation devices. These non-invasive devices provide physiological data such as heart rate, blood pressure, sweating and body temperature variations. The changes in these data-sets, therefore, provide an indication of the physiological demands placed on a crew when operating a suborbital vehicle.

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