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SpaceShipTwo (SS2) nominal flights were conducted by various pilots and compared with other nominal flights as part of the Polar Suborbital Science in the Upper Mesosphere (PoSSUM) program. The first set of nominal flights was performed by student pilots in the left seat of the Suborbital Space Flight Simulator (SSFS). The second set of nominal flights was flown by the same student pilots but instructed by Scientist-Astronaut Candidates (SAC). The SAC, who occupied the right seat of the SSFS, wore an intravehicular activity (IVA) pressurized suit designed by Final Frontiers Design (FFD). Since the SAC's goal was operation of scientific instrumentation inside the cockpit during the flight, the SAC communicated instructions to the pilot to adjust the trajectory to meet the science requirements as the vehicle transited the mesosphere. Mesospheric measurements were obtained during ascent and descent at an altitude of approximately 76,200 meters. This phase lasted between 140 to 150 seconds. During this phase the SAC instructed the pilot to maneuver SS2 along a trajectory required to optimize data collection. These attitude maneuvers performed by the pilot using SS2's reaction control system can significantly affect the flight corridor. These operations will help characterize operations above 18,288 meters in analogue suborbital missions and can alleviate communications between ATC and STM controllers and may improve the Concept of Operations (CONOPs) as part of the FAA initiative.

Nomenclature

AAS = Applied Aviation Sciences
AoA = Angle of Attack
ATC = Air Traffic Controllers
CSV = Control Space Volume
ERAU = Embry-Riddle Aeronautical University
FFD = Final Frontiers Design
IVA = Intravehicular Activity
PoSSUM = Polar Suborbital Science in the Upper Mesosphere
RCS = Reaction Control System
SAC = Scientist-Astronaut Candidate
SS2 = SpaceShipTwo
SSFS = Suborbital Space Flight Simulator
STM = Space Traffic Management

I. Introduction

Faculty and student researchers in the Applied Aviation Sciences (AAS) Department at Embry-Riddle Aeronautical University (ERAU) have observed over 60 scientists-astronaut candidates (SACs) conducting simulated suborbital flights in the Space Flight Suborbital Simulator (SSFS) since February 2015 during the Polar Suborbital Science in the Upper Mesosphere (PoSSUM) training platform at the Daytona Beach campus.

Based on specifications dictated by each scientific mission and data collection procedures, the flight path of the suborbital flight vehicle is subject to deviations from the nominal flight path. These deviations are a direct result of the orientation of the vehicle – pitch, flight path angles, and angle of attack (AoA) – during the data collection process. Methods of integrating these suborbital flights into the National Airspace System (NAS) is dependent on understanding each scientific mission's effect on the flight trajectory of the vehicle. The flight data collected during

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the PoSSUM 1702 campaign was used to generate flight trajectories comparable to nominal flights flown by SSFS trained student pilots earlier in the year.

Understanding these flight paths and the orientation of the vehicle will aid in the generation of dynamic flight corridors to increase the predictability and forecasting of the integration of commercial space vehicles into the NAS. The development of flight corridors from data acquired during flight simulations will operate as a functional tool for training future SACs and commercial space pilots while serving as an operational forecast system for ATC and STM managers for nominal and contingency scenarios during suborbital operations.

This paper provides results specific to suborbital flights gathered during the PoSSUM 1702 campaign in October 2017. Nominal flights were flown by SACs in a pressurized intra vehicular activity suit (IVA) on various research platforms, such as XCOR Lynx and Virgin Galactic's SpaceShipTwo (SS2).

Previous studies[3] suggested different approaches to analyze space vehicle operations (SVO) under various modern regimes in Europe and the US. Some of these operations include: 1) land-based rocket launch to orbit, 2) air launched rockets to orbit, 3) de-orbiting space vehicle, 4) suborbital flights, 5) suborbital point-to-point travel, and 6) hight altitude operations. In this research we analyzed some of these hybrid operations using the air launched SS2 space vehicle into a nominal suborbital flight. Although this study only deals with nominal suborbital flights, previous studies[5,6] addressed contingency scenarios and how to integrate this data into the NextGen.

II. Suborbital Space Flight Simulator

This study represents the first time research was conducted on participants using the SSFS since its installation in 2015 at the Space Operations Laboratory at ERAU's AAS department (Figure). Developed out of the shell of a Cessna cockpit previously used as an Airplane Flight Training Device (FTD), the SSFS is a stationary simulator capable of modeling the flagship vehicles of prominent commercial space companies such as XCOR's Lynx, and Scaled Composites' SS2. With companies such as Virgin Galactic and Blue Origin planning on sending private citizens to space (some with payloads) at a frequency of 3-4 flights per week within the next decade, this research will help identify any risks associated with training commercial astronauts by providing a comprehensive human factors data set.

Project PoSSUM aims at certifying citizen scientist-astronauts capable of collecting data on noctilucent clouds during suborbital flight. Accordingly, the SSFS provides an ideal mockup to train SAC's. In previous studies[1], training SAC's helped identify and assess human/medical factors, external/environmental variables, and flight control complications (i.e., mission profiles, and contingency management issues) on suborbital flights. The SAC was seated on the right (passenger) side of the cockpit while the pilot was seated on the left seat of the SSFS. The SAC was in a pressurized IVA suit (see Figure 1) during the suborbital flight which took 20-25 minutes. Table 1 shows the total number of landings, number of hours flown, and successful flights per hour performed by certified student pilots from 2015 to summer 2017. The research flights flown were conducted in October 2017 by the two pilots (P1, P2) that had the most experience flying the SSFS, as displayed in Table 1, however their flown flights were not recorded in Table 1.

Table 1: SSFS training by student pilots

Pilot	Number of Landings	Number of hours flown	Successful flights per hour
P1	109	49.5	2.2
P2	82	46.5	1.8
P3	80	41.2	1.9
P4	55	29	1.9
P5	55	33.3	1.7
P6	8	4.5	1.8
P7	8	4	2
P8	7	3.4	2.1
P9	7	3	2.3
P10	6	2.1	2.9
Total: 10	**Total: 417**	**Total: 216.5**	**Average: 2.1**

Observing SACs during various training phases[1] generated pertinent information about the safe operation of the SSFS and addressed operational capabilities and tolerance levels that will help lead to FAA-approval for the simulator to be used to train future suborbital commercial astronauts.

The SAC's mobility data while in the pressurized suit and operating the scientific instrumentation (camera) was not directly quantified, but different range of motions (ROM) inside the cockpit were observed and revealed limitations to movement (Figure). It was observed in egress procedures that the SAC was unable to quickly exit the vehicle due to limited space and mobility restrictions imposed by the spacesuit and the placement of the scientific camera. SACs (5 feet to 6.4 feet) had sufficient ROM to operate the camera, although at times with some degree of difficulty. Occasionally, the SAC would need to grab the camera handle from the very bottom as they were unable to reach the top, soft part of the handle (chin level to face level depending on SAC height). On the other hand, each SAC was able to easily access the 6 instrumentation controls and operate the two concentric knobs, zoom, and iris control. The instrumentation controls could be reached at chest level, indicated by the red and green switch lights displayed in Figure. These were operated by the left arm of the SAC. The zoom control was used to enlarge a micro feature of the noctilucent cloud, and the iris control was used to control the amount of light. The zoom and iris control were operated with the right arm of the SAC. In this preliminary study, each SAC performed single-handed tasks, but in future studies, the SAC will perform two-handed tasks to assess the performance of the work envelope.

Also, note that had the pilot been in a pressurized IVA suit like the SAC, the suborbital flight profile would have been also different. This metric research analysis will be addressed in future studies.

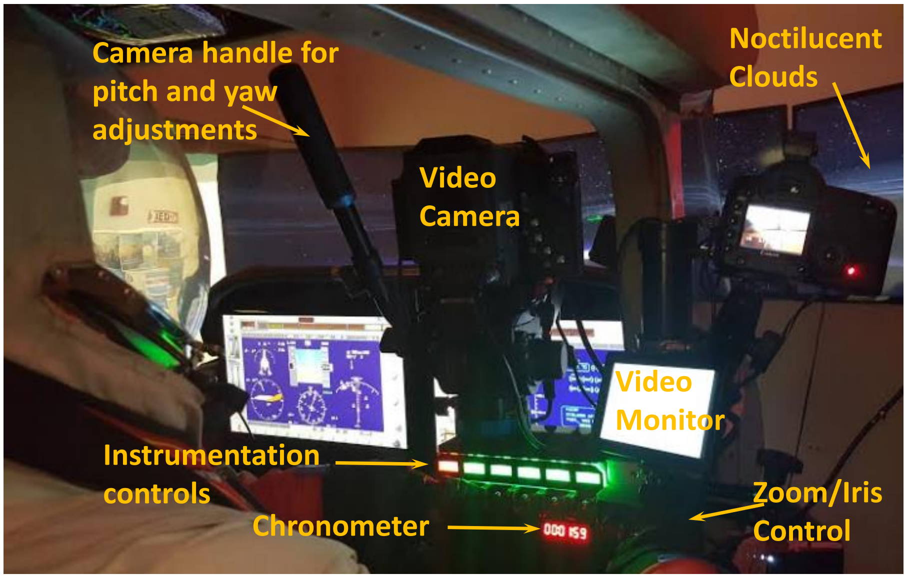

Figure 1. a)-b) Stationary Suborbital Space Flight Simulator in the AAS department at ERAU showing a SAC in pressurized IVA suit performing data collection samples with PoSSUM instrumentation during the 20-minute suborbital mission.

III. Flight Trajectory

Each of the PoSSUM and Control flight patterns followed the same procedure to most accurately maeasure the deviations of the PoSSUM Flights. The flight procedure is outlined below:

1. Air Launch Takeoff Procedure
2. Boost Phase
3. Coast/Microgravity Phase
4. Deceleration/Reentry Phase
5. Glide Phase

The primary areas of concern of this paper were the Microgravity, Reentry, and Glide Phases, because the key elements of the scientific missions occurred within these flight phases. As shown in Figure 2**Error! Reference source not found.**, PoSSUM and Control flights followed the same path through the beginning phases of the flight (Air Launch Takeoff and Boost Phase). The two configurations differ slightly in ascent angle with the PoSSUM flights climbing at a steeper rate when compared to the average control flight. This resulted in a steeper descent angle for the majority of the PoSSUM flights. As a result, general trends suggest the diameter of the flight corridor for the PoSSUM flight ballistic trajectory (MECO to Glide) is significantly smaller than the diameter of the Control flight corridor– resulting in longer glide distances for these flights.

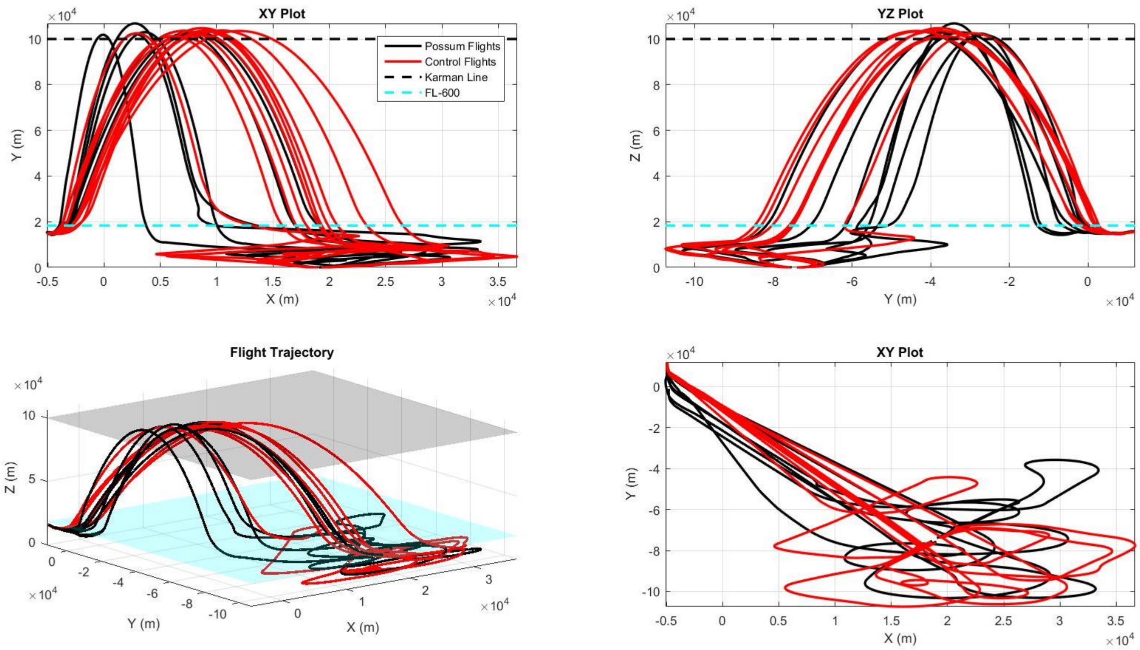

Figure 2. Flight Trajectories of PoSSUM (black) and Control Flights (red), in comparison to the NAS ceiling (FL-600), in cyan, and the Karman Line, in gray.

The trajectories modeled in Figure 2 are with respect to the Karman Line (100 km) and the NAS ceiling, FL-600 (60,000 feet or 18,288 m). This is the so called Near Space region[2] that, one day, might be populated by space vehicles operated by space traffic management (STM) controllers and air traffic controllers (ATC). The portions of the flight trajectory under the NAS ceiling are under the control of the ATC system, while the rest of the flight is under STM jurisdiction. Proper interfacing of jurisdiction and flight control transition between these two management systems may be accomplished via an understanding of the flight characteristics of the vehicle given certain initial conditions and flight profile. As observed within the NAS, below the dotted cyan line, the glide phase is prominent and the vehicle is primarily under the pilots command as the vehicle is prepared for landing procedures. This process comprises various techniques to reduce energy, and maneuver into the appropriate landing position. For PoSSUM flights, the glide flight distance was generally larger while both incorporated dog-leg and cloverleaf (pull of a loop, roll of a barrel roll, pull through a S-turn) maneuvers to set up for final approach.

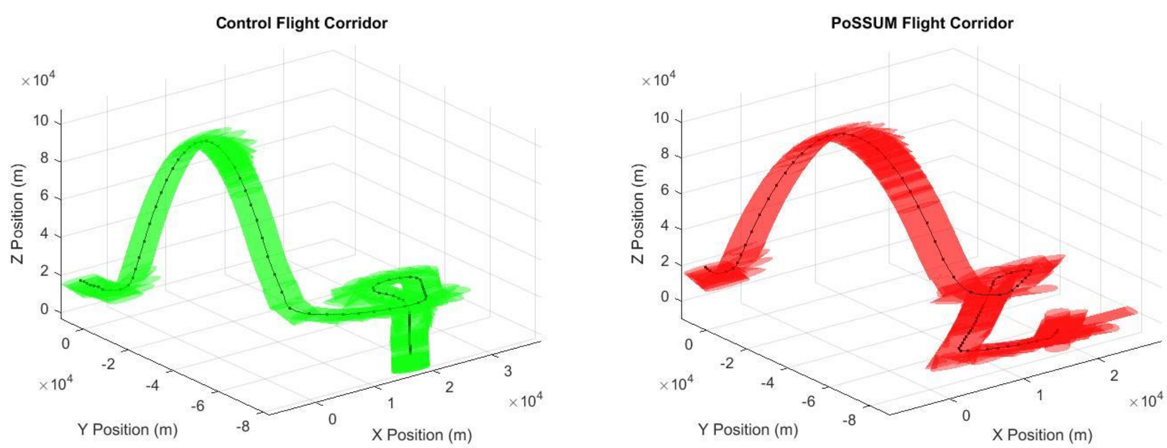

Figure 3. Flight Corridor generation for discrete points along flight path Control Flights (Left in Green) and PoSSUM Flights (Right in Red).

Figure 3 displays the generated immediate flight corridors surrounding the control space volume (CSV) at discrete points along the flight trajectory. These discrete points were set 30 s apart along each trajectory and flight corridors were generated surrounding each discrete point. These flight corridors are 4-dimensional envelopes[4], that is, a position state vector changing in time. The size of each corridor is 15 km in the direction of the velocity vector, 5 km to the side of the vehicle, and 1.5 km above and below the vehicle. The spacing between each point along these flight corridors is indicative of the velocity profiles of the flight. As the corridors become closer and overlap, the velocity is significantly smaller than the points at which the space between the flight corridors is larger. In both configurations the highest velocities observed are within the Reentry to Glide Phase transition with a significant decrease in velocity as the flights transit the NAS.

Control of trajectories is determined by vehicle orientation as it flies through each phase. As a result of change of vehicle orientation during each flight phase, these deviations must be monitored to predict the vehicle's trajectory. Because the time spent within the NAS upon Air Launch Takeoff is minimal, it is neglected when NAS operation is concerned. Therefore only the post-apogee flight trajectory is considered, beginning with the Microgravity phase. To better understand this phase, it is necessary to look at that altitude profile (see Figure 4).

The Science Collection phase of flight, within the Microgravity phase, is above 76,200 m (250 kft). Thus, it is of interest to see how these missions affect the overall flight trajectory.

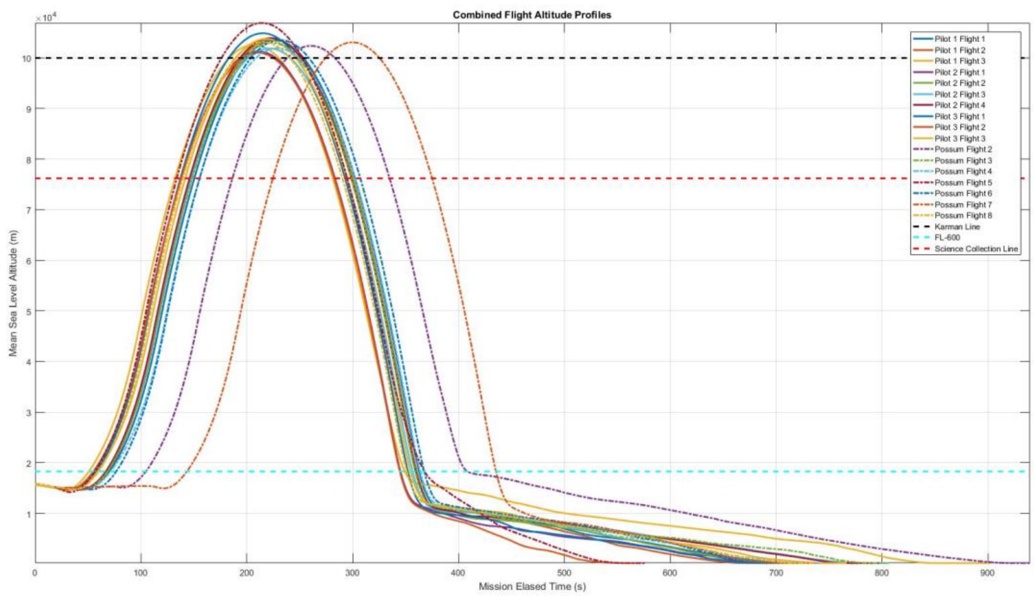

Figure 4. Altitude profile of PoSSUM (dotted line) and Control (solid line) flights compared to the Karman line (black dashed line), Science Collection Phase (red dashed line), and NAS ceiling (cyan dashed line).

The altitude vs. mission elapsed time graph (see Figure 4), displays Control Flights as a solid line and PoSSUM flights as dotted lines. Following each trajectory, comparisons can be made between the two flight configurations. Both configurations follow the same altitude profile with shifts in time accompanying some of the major flight points – ignition, apogee, glide start, and landing. Control flights tend to stay within the same region for each of these flights with ignition primarily occurring around 40 s with a maximum at 46 s, keeping a tight range of ignition times to approximately 6 s. However, the PoSSUM flights show a wider range of ignition times with a few flights igniting at 40 s, another igniting around 90 s, and the last igniting around 115 s. This ignition time range propagates throughout the rest of the flight profiles and can be seen again at apogee height and glide start time. Landing does not seem to be affected due to variability within the glide phase of the vehicle.

The ballistic parabolic arc, a consequence of gravity acting on the vehicle in between the boost and glide phase is crucial in determining flight contingencies that may occur. Because all flights were nominal, no significant shape deviation was observed. The time width of this arc is a consistent 200 s to 225 s for Control and PoSSUM flight configurations from Main Engine Cutoff (MECO) to the corresponding altitude on the descending flight path.

Within the microgravity flight phase, the AoA of the vehicle crosses the AoA of zero degrees threshold from negative AoA to positive AoA. It is around this point that the vehicle traverses the point of apogee and transitions from ascent to descent trajectories. Figure 5 depicts the effect of the science on the position of the trajectory at each time stamp. For example, the PoSSUM flights cross the zero AoA threshold within a range of 23 s (212 s to 235 s) with an outlier at 262 s. The Control flights cross the zero AoA threshold within a range of 10 s (215 s to 225 s) with no outlier. This indicates consistency within the Control flights not present within the PoSSUM flights that is most likely dependent on data collection processes conducted on these flights. Also, early within the PoSSUM flights two peaks are noticed between 140 s and 170 s for Flights 3 and 4. These peaks were generated by vehicle control inputs to ensure optimal data gathering.

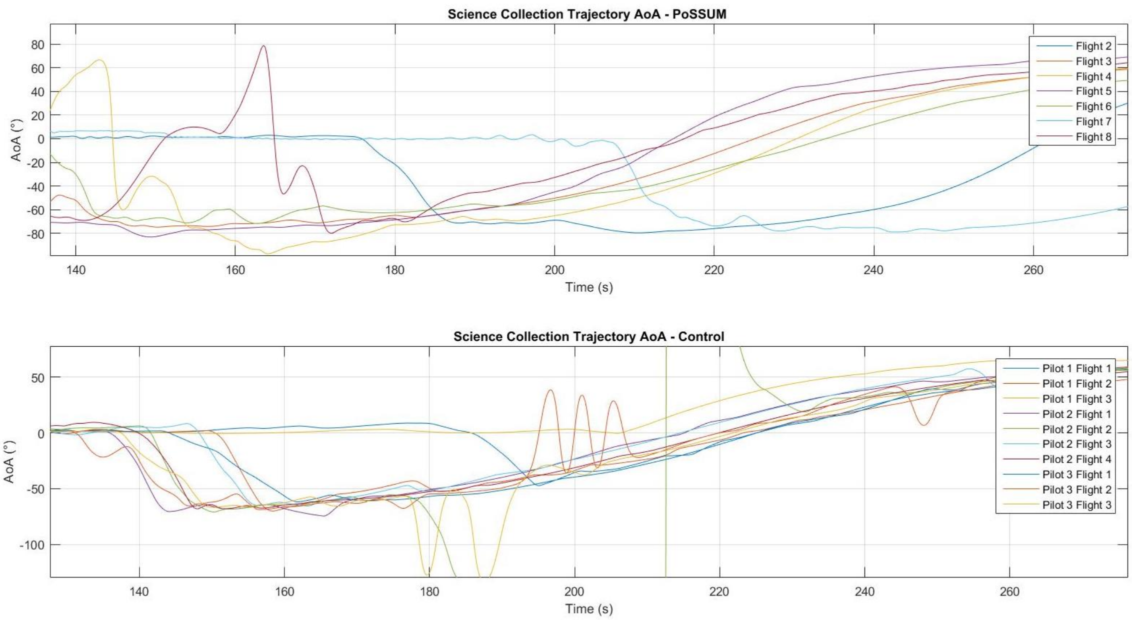

Figure 5. Angle of Attack across the Science Collection Phase (above 76,200m) for PoSSUM (Top) and Control (Bottom) Flights.

As the flights crossed the threshold from Science Collection to Reentry Phase, the AoA seems to reach a peak at 70° for Control and 80° for PoSSUM flights. The shape of these curves differ as the AoA vs. time graph reaches the peak. The Control flights follow a jostled tight curve to peak and then show the typical reentry profile, described later. The PoSSUM flights, however, show smooth widespread curves with AoA values between 60° and 70°, at which the graph takes a jump up to 80° before following the typical reentry trajectory outline. This jump in the graph is indicative of a control maneuver operated by the pilot to position the vehicle more appropriately for scientific data collection, and position the vehicle for reentry.

It is within the reentry trajectory that general glide phase execution begins, therefore the flight characteristics within this phase are of particular interest. The AoA for example, is important because it determines vehicle orientation. Shown in Figure 6, the AoA within reentry follows a similar pattern for PoSSUM and Control flights. Each configuration sees a severe drop in Angle of Attack as the vehicle begins to reenter the atmosphere. As a result of this aerodynamic loading, oscillations are seen within the AoA as time progress and altitude decreases causing the AoA to be damped near zero. Noticeably, the damping with the Control Flights resembles a severe overdamped system, while PoSSUM Flights resemble a *slightly* overdamped system, while the maximum Mach number of 4 is achieved as flights settle into an AoA of approximately zero. However, these oscillations seem to primarily occur within the flights that cross the Reentry flight threshold at later time stamps.

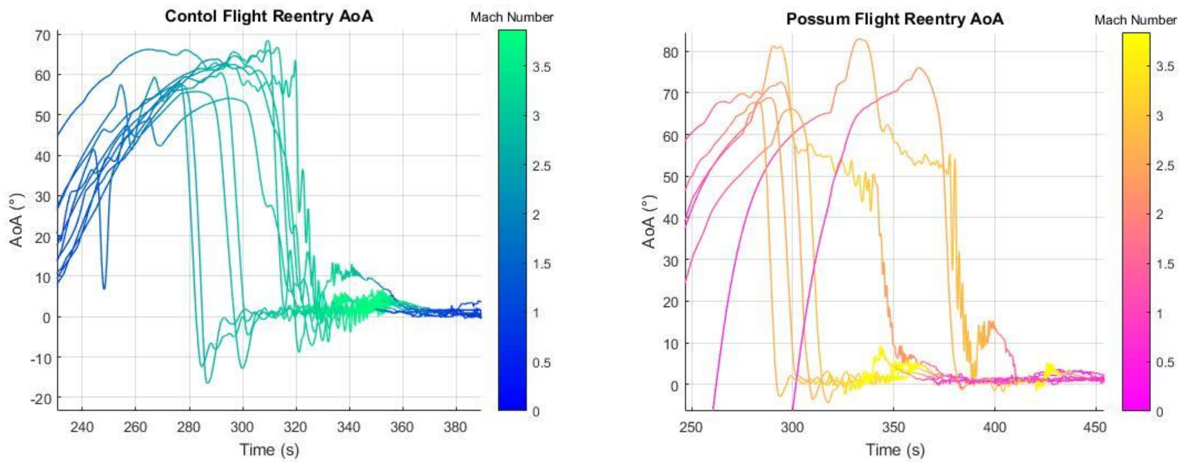

Figure 6. Control Flights (left) and PoSSUM Flights (right) Angle of Attack during Reentry Phase of vehicle. Mach Number mapped.

As the vehicle enters the NAS and Glide phases of flight, the oscillations seen during the Reentry phase are damped to small oscillations centered around AoA near zero degrees for control purposes. As the oscillations settle, the vehicle transitions into the NAS and Glide Phase. It is this phase that is of primary interest to air traffic controllers. **Error! Reference source not found.** shows the AoA of the vehicle as it traverses the NAS. A particular pattern stands out for each of the Control flights that is not present for PoSSUM flights. Each of the control flights undergoes an exponential increase in AoA directly before landing. These peaks are typically seen around 10° with a maximum at 13° and a minimum at 9°. After these peaks, the AoA drops steeply to approximately -5° where it enters a small slope to -5° as the vehicle touches down on the runway.

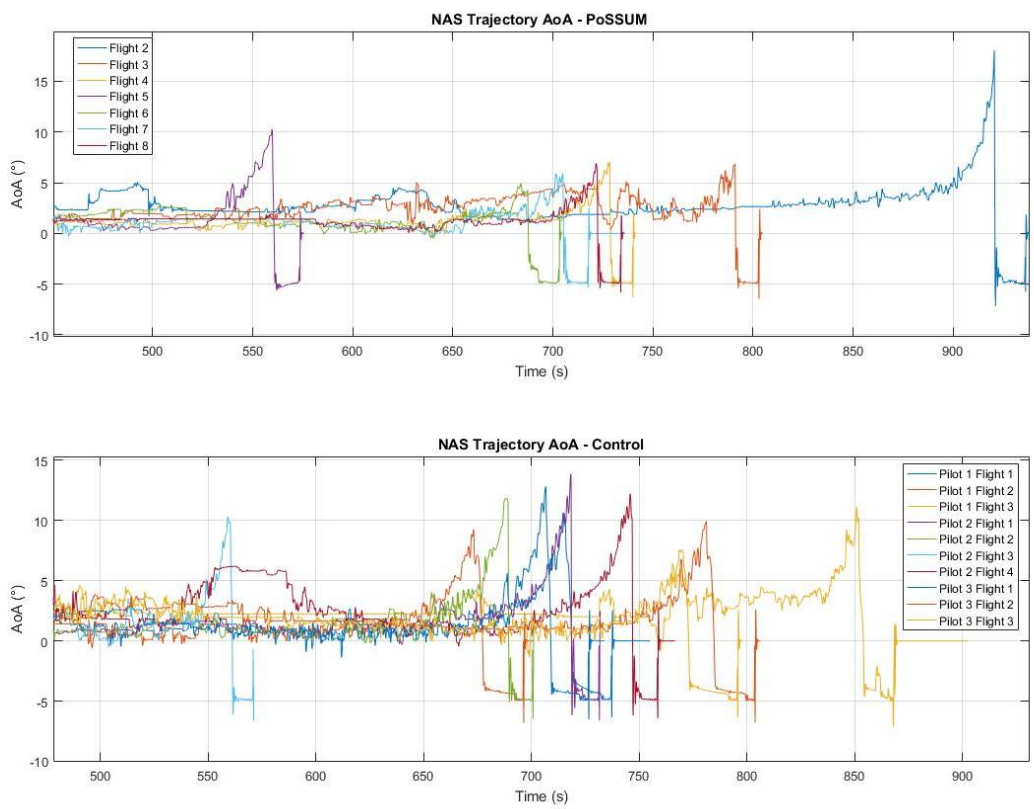

Figure 7. Angle of Attack within the National Airspace System and Glide Phases of the vehicle for PoSSUM (Top) and Control Flights (Bottom).

The PoSSUM flights, displayed in Figure 7, show some similarities. PoSSUM Flights 2 and 5 follow a similar pattern with flight 2 seeing a peak at 17° and flight 5 seeing a peak AoA at 10°, while PoSSUM Flight 8 displays a similar pattern with a smaller peak AoA at 7°. The other flights show peaks at approximately 7°, but do not show any siginificant AoA increase before the peak. However, a steep declination in the AoA for each PoSSUM flight is seen to -5°. Unlike the Control flights which show a linear decrease in the AoA from about -4° to about -5° for about 15 seconds during touchdown, these PoSSUM flights go directly to -5° and remain at these AoA until touchdown with no small decrease shown. The patterns observed in the Control flights suggest that these flights follow a trajectory that is fairly constant from flight to flight. This is important from the NAS perspective because it means these flights follow a pattern that is reliable from flight to flight.

Due to the relationship between the AoA (Figure 7) and pitch angle (Figure 8), the plots look similar with an exponential increase in pitch angle as the vehicle approaches landing. However, the pitch angle graphs show a more accurate representation of the orientation of the vehicle as it traverses the NAS. The peaks of the AoA and pitch angles as a function of time occur at the same time stamp for each flight indicating a maximum for both pitch and AoA. However, there is a noticeable difference in the magnitude of the AoA and pitch for each flight. For the majority of the time within the NAS the Control and PoSSUM flights stay within a 20° wide area from -20° to 0° with a few outliers in the earlier portions of the glide phase.

The AoA is effectively controlled by adjusting the pitch of the vehicle, so understanding how the pilot guides the vehicle to maneuver it into the desired position is necessary to reliably predict accurate flight trajectories. The pitch angle of the vehicle is taken with respect to the local horizon, while the AoA is taken with respect to the velocity vector of the vehicle. For this reason, the pitch angle is a more accurate representation of the vehicles orientation within an inertial space coordinate system and will be more effective when generating the immediate flight corridor surrounding the flight vehicle. However, the AoA is more significant when discussing the control of the vehicle, as it is relevant to the lift, drag, and moments necessary to maintain proper maneuverability and positioning of the vehicle. Figure 8 shows the pitch distribution across the time spent in the NAS for each of the simulated flights for Control and PoSSUM scenarios.

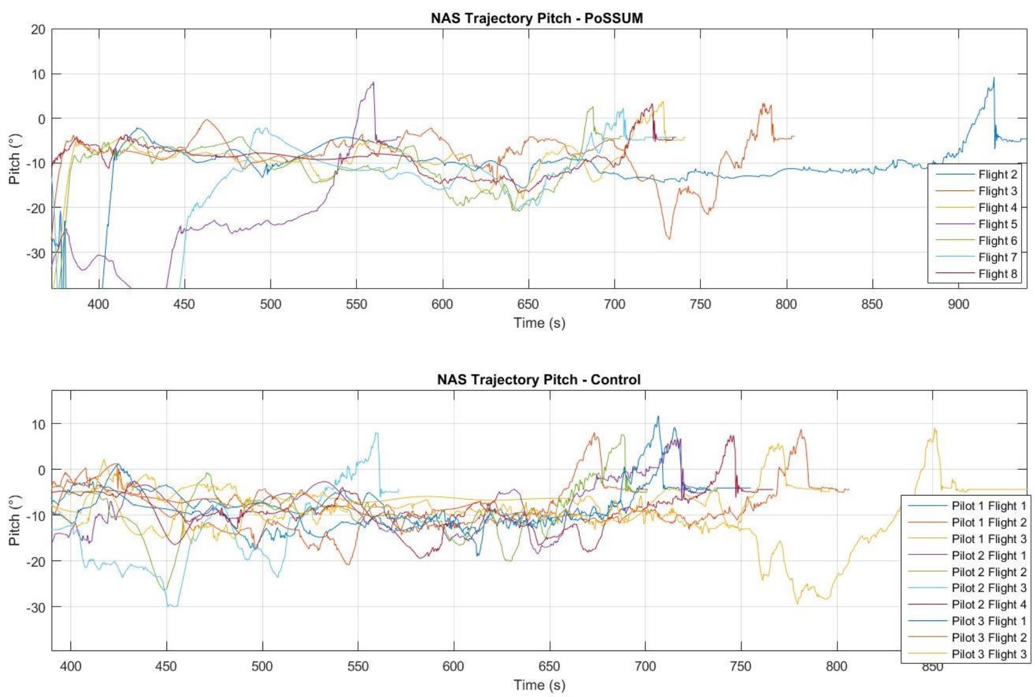

Figure 8. Pitch Angle through the NAS and Glide Phases of the vehicle for PoSSUM (Top) and Control (Bottom) Flights.

The initial phases of each NAS trajectory are observed to have a significant increase in pitch as the vehicle transitions into the glide phase from the reentry phase. This reentry phase incorporates characteristically negative pitch angles due to the nature of the flight path during this phase. Figure 9 displays the pitch angles for each flight within this reentry phase. The characteristic reentry phase profile begins at 0° pitch and a dramatic decrease down into -70° to -80° pitch as the vehicles transitions from a belly-down to nose-down orientation. This process is rapid and is shown as a significant decrease in the pitch angle within the 280 s to 320 s range for Control flights, and the 290 s to 370 s range for PoSSUM flights. Note that the pitch angle for all Control flights during the time span of 320 s to 340 seconds is between -70° to -80°; the pitch angle for four of the seven PoSSUM flights in the same time span is also about -70° to -80° while the other three PoSSUM flights have variable pitch angles during this time span of about -5°, -25° and -30° to -60°. This extended range is noted within each flight characteristic and is presumably inidicative of the science operations conducted by the SACs that cause the flights to cross thresholds later than typically expected for nominal flights.

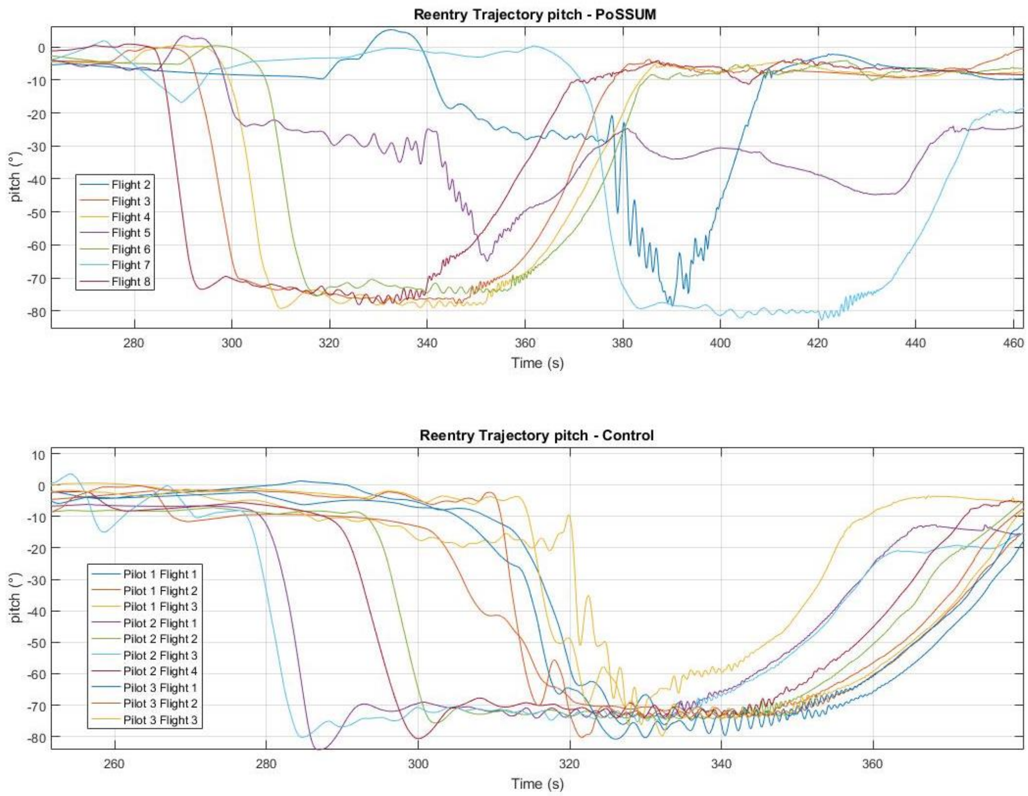

Figure 9. Pitch across the Reentry Phase of the PoSSUM (Top) and Control (Bottom) Flights.

Like the AoA, the pitch undergoes heavy oscillations as it travels through the reentry phase. This is due to the increased aerodynamic loading experienced by the vehicle. The pitch of the Control flights undergoes overdamping as the pitch levels out to the desired reentry pitch, while the pitch of the PoSSUM flights has a slight overdamp before leveling off. This is reflective of the same type of damping observed in the AoA during the reentry trajectory. However, unlike the AoA, the pitch remains at a minimum for approximately 40 s-50 s for PoSSUM and 20 s to 60 s for Control flights, before returning to -10° to 20° pitch as the vehicle enters the glide phase. The shape of the oscillations are of interest. For Control flights, the shape remains generally the same for each flight with oscillations following a steady damping function with flights with later timestamps deviating slightly with the incorporation of slight oscillations while the pitch is still decreasing through the transition into the reentry phase. As for the PoSSUM flights, no such clean shape is seen in Figure 9. Traces of this outline can be made out in PoSSUM Flights 3-6. However, even for these flights the reentry oscillations are jagged, following no defined damping function and only remaining at minimum pitch for a maximum of 45 s. Figure 9 depicts the variation of the pitch angle for the PoSSUM and Control flights from about 260 s to the time where the pitch angles begins to stabilize again. This stabilization time is 460 s and 380 s for PoSSUM and Control flights, respectively. At 260 s, the pitch varies from about 0° to -5° for PoSSUM flights, and from about 0° to -10° for Control flights. At the end of the 460 s, the pitch angle has a variation of about 24° (0° to -24°) for PoSSUM flights, whereas for the Control flights the pitch variation is about 15° (-5° to -20°) by the end of the 380 s as displayed in Figure 9.

Even as later timestamps are observed, this pattern only deviates further from the normal with the continued choppy oscillations persisting well into the microgracity-reentry phase transition period (pitch declination). Because the flights were flown using a SS2 profile, these severe declinations in pitch were a result of the defeathering of the vehicle and pushed later in the flight trajectory. If another flight vehicle was used this pitch declination would be pushed further ahead in time as a result of the necessary nose-down procedure required for the other commercial space vehicles.

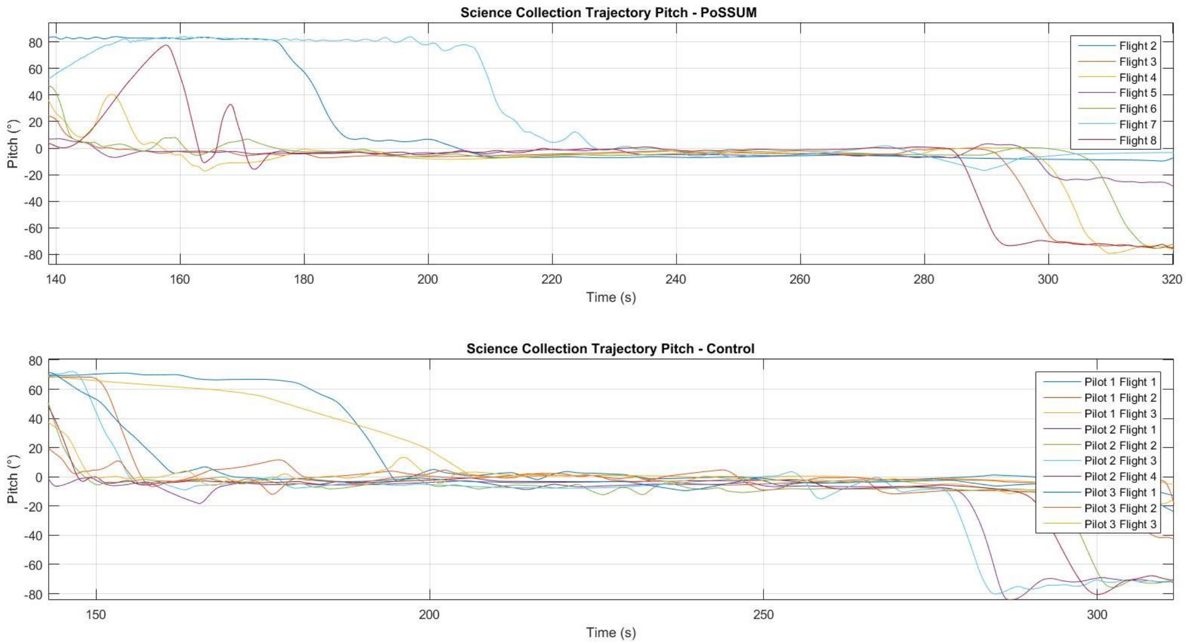

Figure 10. Pitch Distribution above the Science Collection Phase Line (76,200m) for PoSSUM (Top) and Control (Bottom) Flights.

The microgravity phase, as mentioned previously, is the primary phase in which most of the science data collection processes were conducted which is why this phase is of particular interest. Observing the Control flights in Figure 10, few changes were noted in the pattern from flight to flight. Beginning with a maximum pitch of 80°, the pitch is reduced to 0° as the flight vehicle approaches apogee. It then enters a narrow band from about -5° to +5° as it traverses the Science Collection phase. Observing the pitch declination in the early portion of the Science Collection phase more closely, each flight path exhibits a smooth curve indicating no pilot intervention within the trajectory other than that required to maintain the vehicle within its proper orientation. However, observing this same area on the PoSSUM flights, changes from this smooth curve displayed in Flights 4-5 where the pitch angle increases significantly within this portion of the phase. This indicates pilot intervention to properly orient the vehicle for data collection purposes as directed by the SAC. However, after this initial deviation, the pitch then follows the nominal procedure by falling back to between -5° and 5°.

One other primary indicator of pilot intervention in the flight trajectory for science data collection mission is vehicle roll angle. Because the primary data collection system for these missions was optical, proper orientation of the vehicle was imperative to gathering the best data. Many times, this would include changing the roll of the vehicle coupled with the pitch to achieve the most effective view for the optical camera system. Shown in Figure 11 is the roll angle of the vehicle versus time for Control and PoSSUM flights through the Science Collection phase of flight.

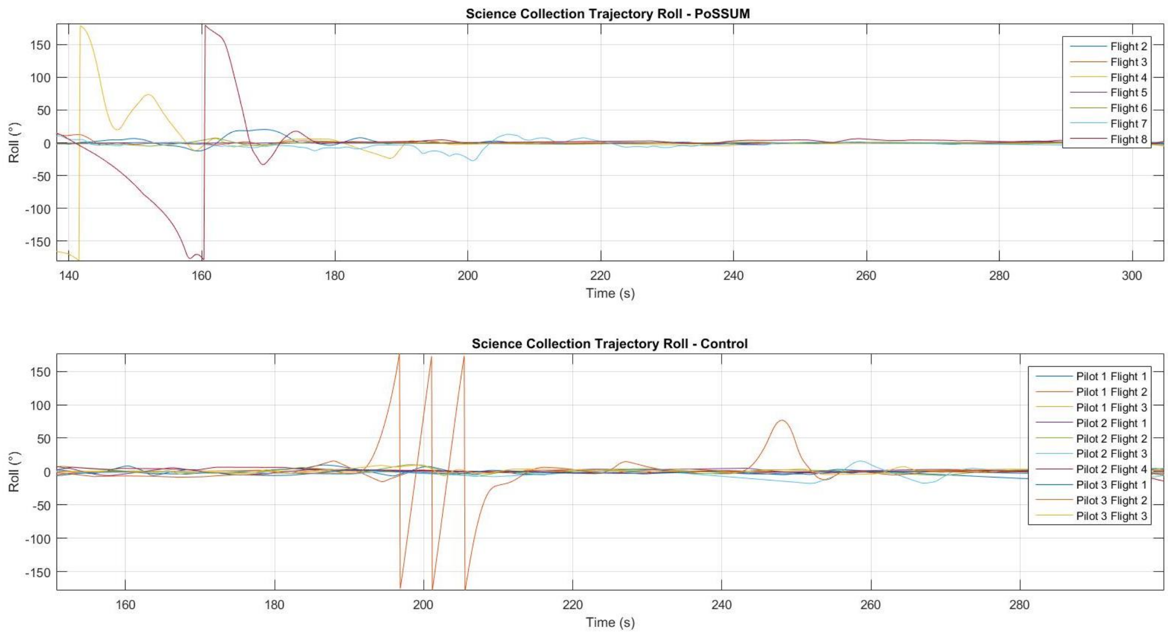

Figure 11. Roll Distribution with the Science Collection Phase of flight for PoSSUM (Top) and Control (Bottom) Flights.

There is no significant difference between the roll angle between PoSSUM and Control flights. However, PoSSUM flights show more characteristics of following a controlled pattern, one indicative of intentional maneuvering. These flights eventually fall into a band of random oscillations from -5° to 5° towards the later part of the Science Collection phase, displayed in Figure 11. The typical maneuvering sequence shows roll angles above the random band deviating up to -160° to +160°. The deviations in PoSSUM Flights 4 and 5 and Control Flight 2 flown by Pilot 3 seem to be a result of rapid rotations of the vehicle as it transitions into the Science Collection phase, presumably due to the pilot adjusting the vehicle for the SACs data collection procedures. However, it is yet unclear as to why these rapid oscillations occur in the Control flights. The reduction in the oscillation amplitude is a direct result of the reduction of aerodynamic forces on the vehicle and is indicative of its time spent above the Karman Line and within low atmospheric density regions. From this point, until reentry, the control of the vehicle is solely reliant on Reaction Control System (RCS). As the flight transitions into the Reentry phase, these oscillations decrease until the vehicle is well into the reentry phase as displayed in Figure 12.

At this point, each configuration follows similarly random Roll patterns dictated by the flight path of the vehicle and pilot. The maximum Roll angle for the PoSSUM flights in the Reentry Trajectory come within Flight 2 at 150°. Other than this flight, the PoSSUM flights remained within ±50° roll angle, while the Control Flights stayed within a -40° and +60° range. This same trend continued into the NAS profile (see Figure 13), with a shifted roll angle range of -40° to +60° for the PoSSUM flights, and an increased roll angle range of -50° to +60° for Control Flights.

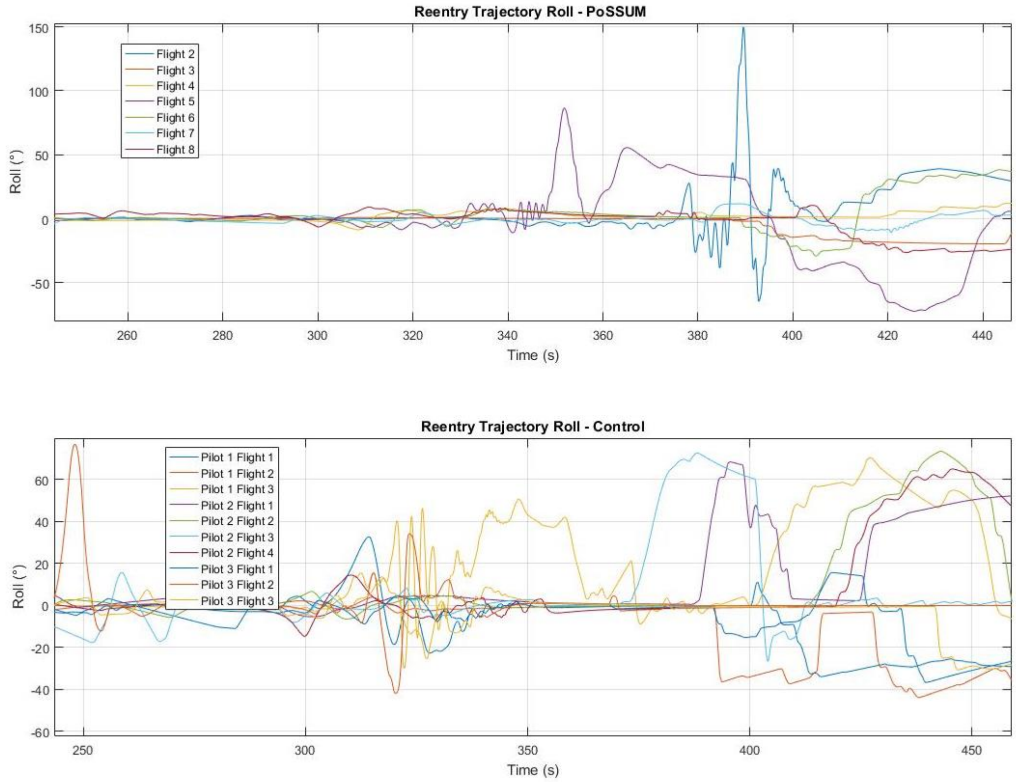

Figure 12. Roll angle across the Reentry Phase for PoSSUM (Top) and Control (Bottom) Flights.

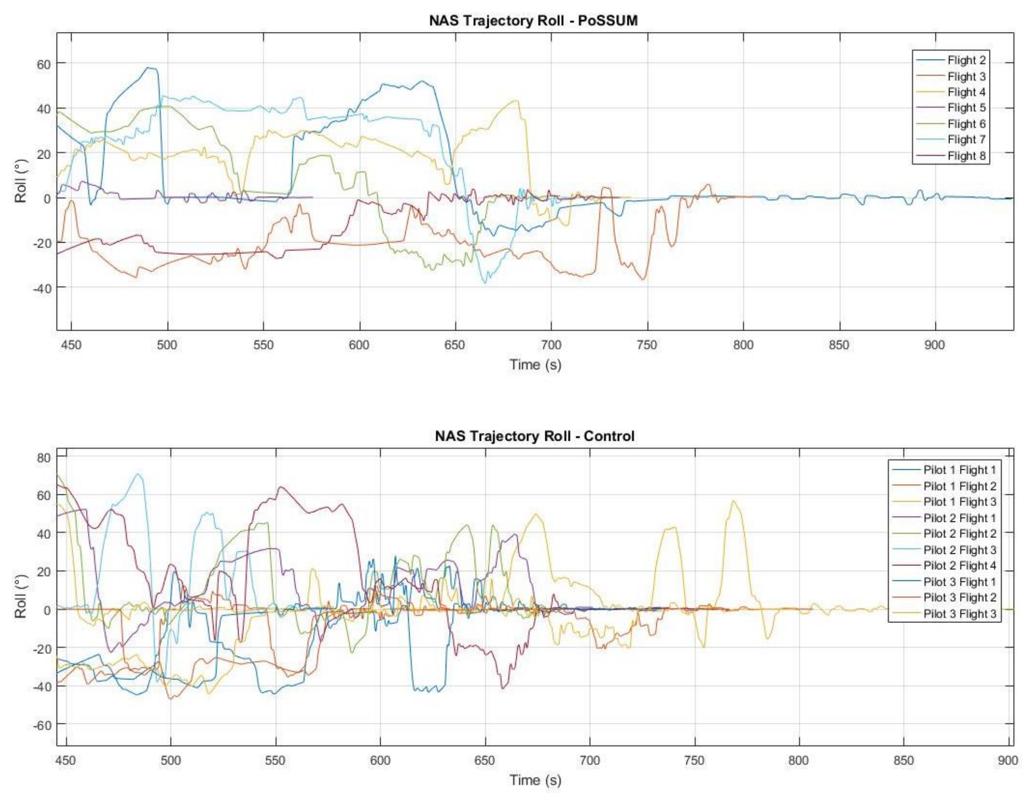

Figure 13. Roll angle within the NAS and Glide Phase for PoSSUM (Top) and Control (Bottom) Flights.

Conclusion and Future Work

From the results gathered, it can be concluded that the science mission trajectories deviate widely from the nominal flight scenarios represented by the control flights. Due to the strict conditions and operations dictated by the SAC, these science collection mission trajectories reflected the maneuvering and manipulation required to provide the SACs with satisfactory data. Maneuvers executed during the Science Collection phase resulted in trajectory changes that are observed in all remaining flight phases – Reentry and Glide. The effect these maneuvers had within these later flight phases presented itself mainly as a time delay to flight milestones, such as the apogee height time, and glide start time, as well as a significant effect on the AoA of the vehicle within each of these flight phases – primarily reentry. Other than the deviations, no significant effect was observed in the PoSSUM flight trajectories compared to Control flight trajectories. The shape of each flight configuration remained the same up until the beginning of the glide phase, at which point all flights become highly susceptible to pilot determination and behavior. This suggests significant changes to the flight corridor governing these scientific research flights are not warranted beyond that which is necessary for nominal flights. No significant effect was shown beyond relatively minor orientation changes that may be neglected in a full-flight trajectory model.

A significant number of flights will need to be flown to confirm the conclusions made, and ideally, provide the opportunity to identify more obscure patterns between scientific and nominal flight configurations. In addition, future work will need to identify key milestones within the scientific missions flight path that will allow prediction of flight trajectories. Using this method, more subtle patterns distinguishing PoSSUM and Control flight trajectories identified. A focus will need to placed on the ATC/STM interface as well as the flight path within the NAS. Once the ideal flight trajectory for all commercial flights is established, training future commercial space pilots to follow these trajectories will be possible with greater predictability. This will enable a more seamless integration of these vehicles within the NAS.

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