Pioneer Rocketry

University of Wisconsin-Platteville

Post Flight Performance Report

Minnesota Space Grant Consortium

Midwest High-Power Rocket Competition 2016-2017

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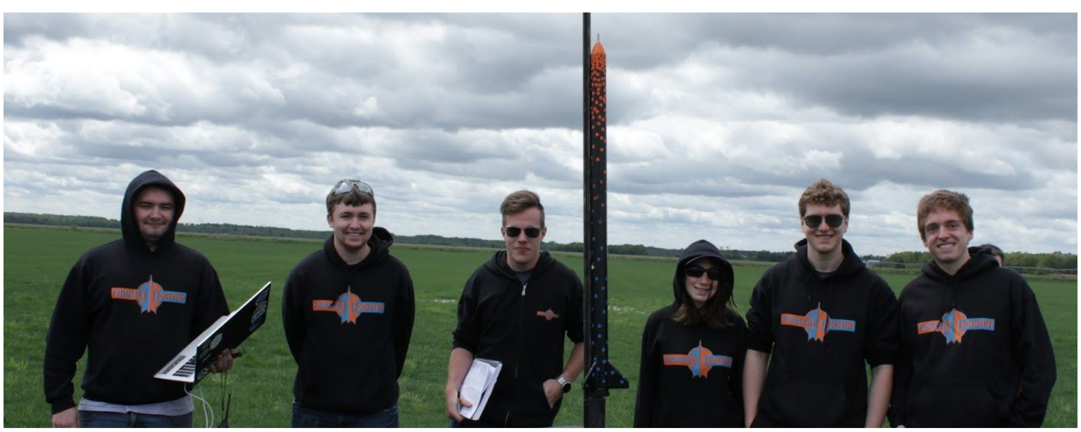

Table of Contents

Rocket Operation Assessment

Propulsion System Specifications

The Aerotech J90 White Lightning was selected as the lower power motor. This motor has both a very low thrust, and a very low impulse for a J motor, which we found to be ideal for this competition. It has a total impulse of 707 N s, making it a 11% J, and a initial thrust of 125 N,which gave our rocket a thrust to weight ratio of 6.2, and a maximum acceleration of 10.8 G as measured by our altimeter two. Due to the uneven nature of the thrust of the J90, the initial thrust was used to calculate this ratio instead of the average thrust as the initial thrust better describes the performance off the launch rail. The maximum acceleration occurs after the rocket leaves the rail. Even with the low thrust provided by this motor, our rocket was still able to leave the rail at 52.8 ft/s. One peculiarity is due to the tapering thrust profile of the J90, Timewarp started decelerating approximately halfway through the burn. This caused the AltimeterTwo to report that the burn time was only 3.96 seconds.

The Cesaroni K2045 VMAX was chosen as the higher power motor. This motor does not have as high of an impulse as other possible motors, but provides a greater thrust. It has a total impulse of 1417 N s, resulting in it being a 11% K. The K2045 provides 2045 N of thrust, giving our rocket a thrust to weight ratio of 83.0, easily pushing our rocket past the speed of sound. One issue that occurred during this high thrust period is that the accelerometer on the AltimeterTwo was saturated, due to the high acceleration of the rocket, resulting in a reading of greater than 40.6 G.

Flight Trajectory Assessment

Timewarp flew beautifully on both the Aerotech J90 and the Cesaroni K2045. Both flights experienced weathercocking, as can be seen in Figure 1 and 2 below, but otherwise had no stability related issues. Timewarp reached apogees of 6211 ft and 6220 ft on the J90 and K2045 respectively, a difference of only 9 ft (0.1%). This was achieved without the use of air brakes, or any other active system, relying only on the passive drag forces during flight.

Figure1: Successful launch on the J90

Figure 2: Timewarp successfully launching on the K2045

Recovery System Assessment

Successful recovery is a crucial part of any launch. The recovery system of Timewarp performed as expected on both flights. On the J90 configuration, Timewarp descended at 71.5 ft/s under its drogue chute, and 22.9 ft/s on its main parachute. On the K2045 configuration, the rocket descended at 77.7 ft/s on drogue, and 25.0 ft/s on main. The descent rates on main for both flights were slightly higher than anticipated, and this could be due to a few factors. First, the rocket was likely heavier during the competition launches than it was during the test launches due to the additional weight of the final version of the electronics. Another explanation, which describes the slightly uneven descent rate under main, would be that the shroud lines of the main parachute became tangled with the Jolly Logic Chute Release during deployment

Deployment state vs time

Timewarp's separation detection system used pull pin switch design, in which the pin is attached to the shock cord. During the lower powered J90 flight the system worked flawlessly. With coordination of the pitot tube to determine liftoff, the time between launch and separation detection was measured to be 18.48 seconds which very closely matches the video data at 19 seconds as well as the predicted data at 18.4 seconds.This gives an error of less than 1%

On the flight of the K2045 the pull pin system had some anomalies in the data. Since the pull pin switch is mounted in the direction of acceleration, it was pulled loose during the boost phase of the rocket. After motor burnout, the data shows the the pull pin switch returned to its expected position. We know that the high acceleration of the K2045 caused this to happen because the data shows that the pull pin switch was out of position for 0.646 seconds, which is similar to the burn time of the motor of 0.7 seconds. After that anomaly in the data the rest of the flight was normal and the pull pin switch showed the deployment at apogee, which can be seen below. The measured time between liftoff and our separation detection system was 17.32 seconds, the camera shows 17 seconds and the predicted time was 16.3 seconds. This gives an error of 6.12%

Ground Recovery Assessment

Timewarp was successfully recovered after both flights, as can be seen in Figure 3 and 4 below. Although Timewarp did land in a tree after its second flight, no damage was caused by removing it from the tree. The GPS system proved invaluable during recovery, and allowed the team to recover the rocket in minimal time after both flights.

Figure 3: successful recovery after the J90 flight

Figure 4: the rocket's landing position after the K2045 flight

GPS System

The GPS system performed almost perfectly except for the known issue of artificially imposed limits by the GPS module's manufacturer. The GPS module used in the system is the MTK3339 which comes with the Adafruit Ultimate GPS Breakout module. According to the datasheet of the MTK3339, the GPS has maximum operational limits of 515 m/s and 4 G of acceleration. Previously, we have seen a loss of GPS fix on the J90 motor, but our K2045 test flight did not have a GPS logging system. Therefore, the 4 G acceleration limit was a surprise.

During the launch, we thought the signal of the telemetry system may have been obstructed by the clouds. What actually happened was the GPS system was trying to reacquire a fix on the rocket. The GPS system only transmits a location when it has a new location to share. This is a functionality that should be changed for future iteration of the GPS system in order for us to be certain that we still have a connection to the rocket. This functionality would act as a heartbeat so we know that the radio link and electronics are still active.

The difference in the impulse between both motors resulted in a difference of the quality of GPS data received. Figure 5 and Figure 6 show the J90 flight and the K2045 flight respectively. The J90 flight has some GPS data straight off the launch pad, but it eventually cuts out until after apogee. The K2045 flight has no GPS data until after apogee. This is due to the huge accelerations in the K2045 flight. The recovery aspect of the GPS system still performed as planned, as both flights regained a GPS fix before landing.

Figure 5: GPS data of the J90 flight overlayed on Google Maps

Figure 6: GPS data of the K2045 flight overlayed on Google Maps

Slackbot

We created a Slackbot system for retrieving telemetry updates in an easy and efficient manner. It receives updates from our telemetry system, parses it into useful information, then sends any useful events to all interested team members via Slack. We use Slack, a team messaging tool, for most of our intra-team communications. Our Slackbot has several aliases, such as boom_bot and Rocket Racoon. We will refer to it in this report as simply "the Slackbot".

The Slackbot system performed admirably and decreased our retrieval times tremendously. On our K2045 flight, we landed on the east side of Hay Creek, in a tree. While retrieval for a flight like this would usually take a long time, the Slackbot and GPS system allowed us to have the rocket fully retrieved and back at our tent in about 30 minutes.

Despite the fantastic performance of the Slackbot system, there are still improvements that can be made. The first improvement that should be made is using a mobile device instead of a laptop to receive the radio signal. Hiking through marshy areas would be safer and easier with a smaller device than with a laptop, especially in scenarios with only one or two people on a recovery team.

Another limitation of the Slackbot system is the need for the master user to give the Slackbot all of its commands, including requests for status updates. This is quite unnecessary and cumbersome. The master user is most likely going to be busy with looking at the raw data received by from the GPS system and ensuring the bot is working correctly. For this reason, all team members should be able to request status updates from the Slackbot. Commands that affect the known state of the rocket should still be reserved for one master user.

The current iteration of the Slackbot is available on our github, along with all of the other code use in the MRL competition at https://github.com/Pioneer-Rocketry/MRL-2017.

Pre and post launch procedure assessment

Both the low-power and high-power launches took place within the allotted one-hour flight windows. Our team was able to accomplish this safely due to the implementation of pre-flight checklists that were developed and streamlined over our multiple test launches

There was only one anomaly that differentiated from our planned activities. The team encountered difficulties inserting the igniter before the J90 flight, and had to disassemble the motor on the pad in order to properly insert the igniter into the motor. The Aerotech J90 uses C-Slot geometry, meaning that the center of the motor, which would be free in a traditional bates grain geometry, is blocked by propellant, as can be seen in Figure 7 below. To mitigate this, Aerotech chamfers one end off the propellant grain. It is believed that the grain was installed backward in the motor, and the chamfered end was at the top. This did not have any noticeable effect on the performance of the motor during flight. The team was able to overcome this obstacle, and launch expediently.

Figure 7: The C-Slot geometry of the J90 propellant grain

Figure 8: Adrian and Chandler inserting the igniter into the J90

Discussion of Results

Table of Flight Characteristics

Altimeter 2				
Motor	Mass (g)	Max altitude (ft)	Max velocity (Mach)	Max acceleration (G)
J90	2070	6194.2	0.679	10.8
K2045	2511	6220.5	>0	>40.6
Strattologger cf				
Motor	Mass (g)	Max altitude (ft)	Max velocity (Mach)	Max acceleration (G)
J90	2070	6206	0.608	5.56
K2045	2511	6922	Inaccurate due to sonic effects	Inaccurate due to sonic effects
Pitot tube				
Motor			Max velocity (Mach)	
J90			0.65	
k2045			1.44	
Openrocket				
Motor	Mass (g)	Max altitude (ft)	Max velocity (Mach)	Max acceleration (G)
J90	2070	6207	0.69	7.33
K2045	2511	6870	1.67	94.8

Table 1: Table of flight characteristics

Altimeter Data Analysis

Based on the numerical analysis of our test flights on both the J90 and K2045 motors using a PerfectFlight Stratologger CF mentioned in the Flight Readiness Report, we had predicted their apogees to be 6200 ft ± 67 ft and 6800 ft ± 63 ft, respectively. According to the AltimeterTwo data, the rocket propelled by the J90 motor had reached an apogee of 6211 ft, and 6220 ft on the K2045 motor, a difference of 11 ft (0.177%, well within error bounds) and 580 ft (8.909%), respectively compared to our calculations. To explain the discrepancy between predected and actual apogees on the K2045 flight, it should be made clear that the rocket on the K2045 weathercocked at a nearly 15° angle and flew through dense cloud cover at high speeds, significantly impacting its apogee. We have also reached out to Jolly Logic on Thursday, May 25th, to help explain the discrepancy in the data between the AltimeterTwo, and our Stratologger CF. They suggested that it could have been the case that the device was not properly calibrated, since it was sitting outside of the electronics bay and compressed by the parachute is was packed next to, rendering the static vent holes essentially useless. We find this hard to believe, however, as the altimeter was activated before being inserted into the rocket, with plenty of time to get an ambient static pressure reading. Ultimately, the AltimeterTwo data was used as the official scoring altimeter, despite possibly being less accurate than the stratologger CF.

Continuing with the comparisons based on previous test flights, the maximum velocity and acceleration on the J90 flight was expected to be Mach 0.67 and 8 G, and Mach 1.75 and 98 G on the K2045 flight. The AltimeterTwo recorded a maximum velocity of Mach 0.67 and a peak acceleration of 10.8 G, very similar to our expected values. For the K2045 flight, the AltimeterTwo recorded a maximum velocity > 0 m/s, as the device was probably saturated going nearly Mach 2, and a peak acceleration of > 40.6 G, again due to device saturation.

Since we had two ways of indirectly sensing the velocity of Timewarp (using numerical derivatives of Stratologger position data and pressure readings from the pitot tube), we have interesting results in comparison to the expected behavior of the rocket’s velocity. For the J90, the velocity from both the Stratologger and the Pitot tube match up with the simulations and the numerical analysis. In this case, the Timewarp was expected to reach approximately 230 m/s (Mach 0.67) in 2.67 seconds, which is what we see in the pitot tube flight data. For the K2045, it became apparent that sensing velocity via barometric altimeter would not work well enough to appreciably compare it with any expectations as it produced too much noise to work with. That being said, the Pitot tube data provided usable data which shows that Timewarp reached a maximum velocity of 500 m/s (Mach 1.46) in just under 0.7 seconds. However the data appears to clip at the maximum, which indicates the rocket probably went faster than recorded. Backing up this claim is the fact that the simulation and numerical analysis show that the rocket would reach 600 m/s (Mach 1.76) in the same time.

J90 Measured and Expected Velocities:

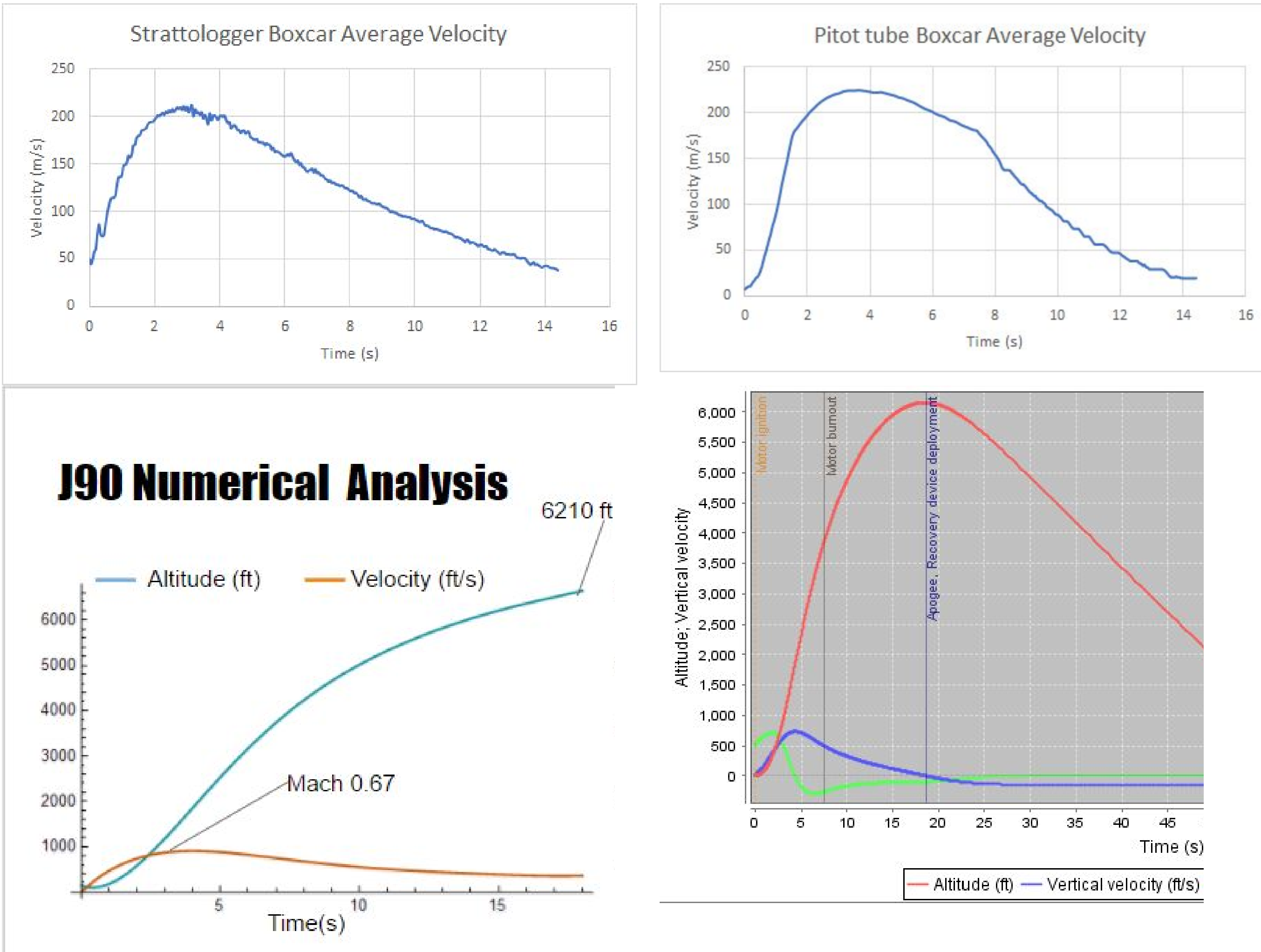

Figure 9: From left to right and top to bottom: the J90 velocity data extracted from the Stratologger, the velocity data from the Pitot tube sensor, the position and velocity expectations as numerically derived, and the OpenRocket simulation plot.

K2045 Measured and Expected Velocities:

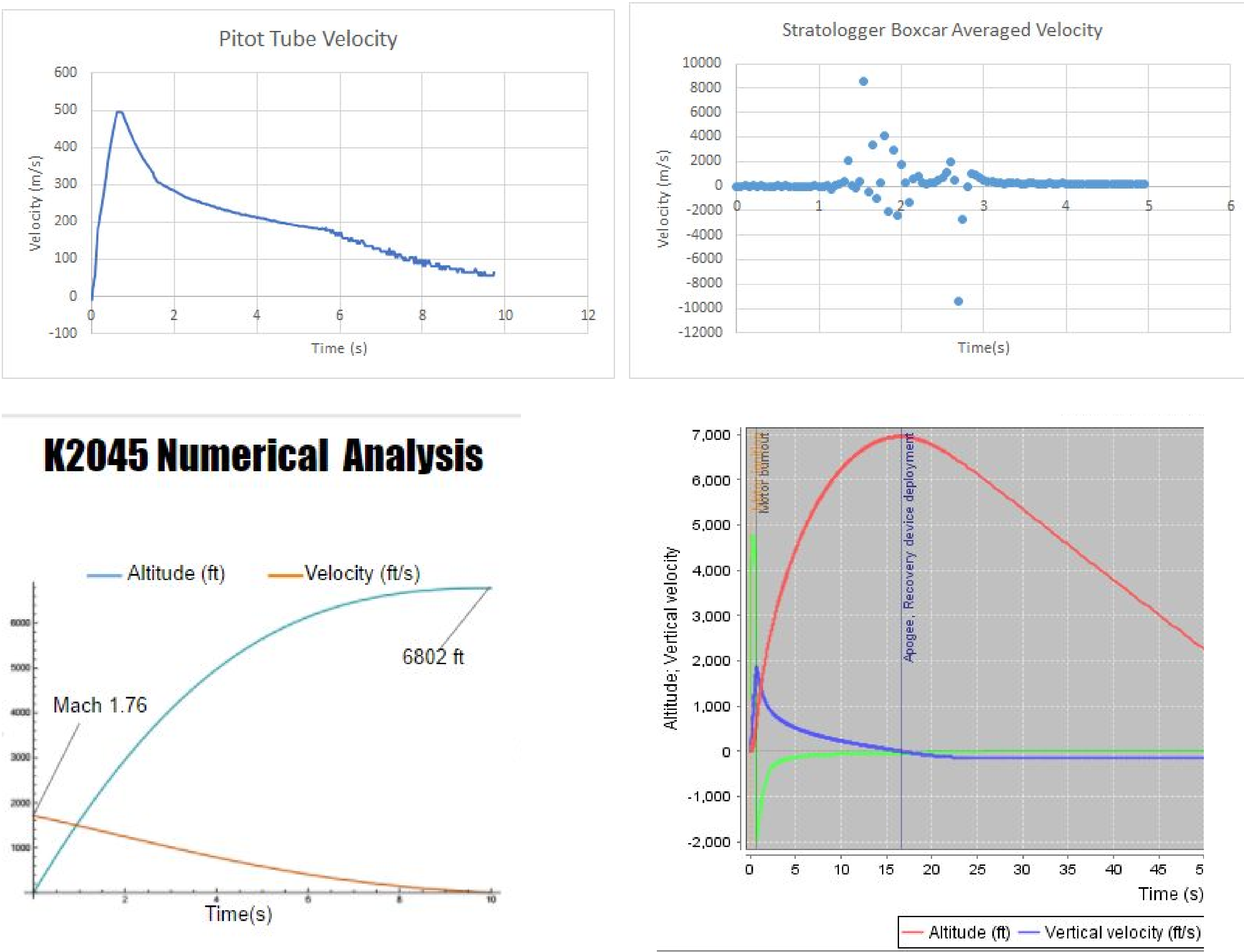

Figure 10: From left to right and top to bottom: the K2045 velocity data extracted from the Stratologger, the velocity data from the Pitot tube sensor, the position and velocity expectations as numerically derived, and the OpenRocket simulation plot.

On Board Video Summary

The images that can be seen below are from the up and down videos system on Timewarp. Due to the rapid spinning motion of the rocket and the sun/cloud combination, some of the video for both flights is quite blurry. Despite this, the cameras were still able to get some quality shots when the video is slowed down frame by frame. These videos can be seen in the links in Table 2 below.

Some stills from the video are shown in Figure 11 and12 below. Figure 11 shows the drogue parachute fully deployed and the main parachute retained by the Jolly Logic Chute Release. Figure 12 shows how the main parachute was tangled by the chute release during main descent, resulting in a higher than expected descent rate.

J90 downward video	https://youtu.be/K20kREH0hVA
J90 upward video	https://youtu.be/VPn3w-lkGyY
K2045 downward video	https://youtu.be/c9gaKqyKOR4
K2045 upward video	https://youtu.be/xLyAwKhnpGI

Table 2: video links for all in flight video

Figure 11: A still taken during drogue descent.

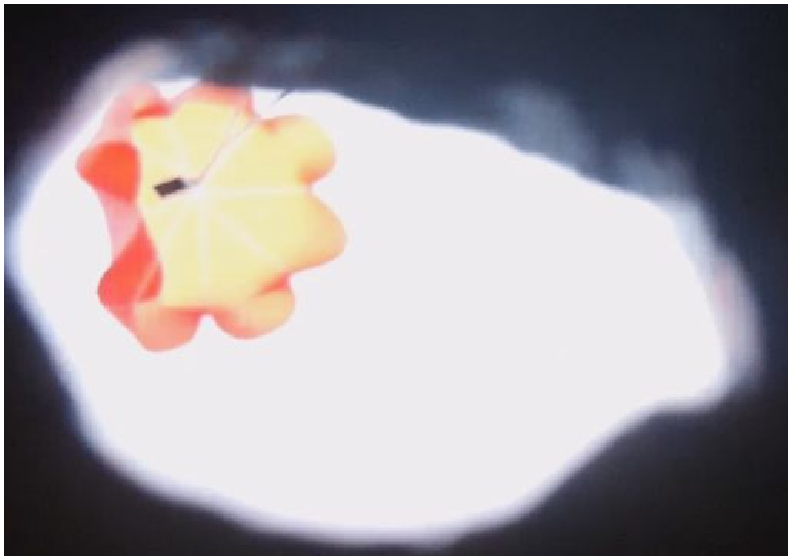

Figure 12: A still during main descent

Conclusion

We are very pleased with the results of our competition flights. While we did not achieve the highest flight score, we were very close to the maximum value achieved by any team. We are especially proud of how well our fully passive design worked, with an apogee difference of only 9 ft, a difference of only 0.1%. We did not achieve the highest flight score because one team flew to a slightly higher average apogee.

While our team was pleased that Timewarp successfully achieved the main competition objective, what most exceeded our expectations was the performance of the GPS/Slackbot recovery system. This system delivers a much more accurate location for the rocket than previous recovery aids, and can be implemented at a cost of less than $100. Minimum diameter rockets used to be nearly impossible for us to find. The GPS/Slackbot system has made rocket recovery nearly trivial. We will implement it in as many of our rockets as possible in the future.

We are very grateful to have this opportunity to not only explore our passion, but to also develop skills which will prove useful for the rest of our lives.

Ad Astra

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