ISS Space Grant Team

“Don’t Bet on It” (Formerly Trappist-1)

Illinois Space Society
University of Illinois at Urbana-Champaign

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Team Mentor: Jonathan Sivier
Faculty Advisor: Diane Jeffers (djeffer@illinois.edu, 217-898-5888)
Team Lead: Connor Latham (connorl2@illinois.edu, 847-421-1248)

Niharika Agrawal, Reisha Chellani, Gianna Ciaglia, Tori Colthurst, Matthew Dickinson, Aiden Dreher, Destiny Fawley, Brian Hardy, Elena Kamis, Jihyun Kim, Cameron Palte, Quentin Shaw, Zach Wang, Wesley Warton

Executive Summary

The Illinois Space Society's "Don't Bet on It" rocket was successfully launched and recovered safely twice on May 20, 2017. It was only able to satisfy some the data acquisition requirements, including a downward camera view of flight on its second flight and velocity sensing through the pitot tube. The active drag system was successfully activated after motor burnout and retracted prior to apogee, with the effect of decreasing the apogee by approximately 1,000 ft. The two team members at the competition were not able to successfully disassemble and ready the rocket within the hour time frame and consequently lost points because of it. The rocket also only achieved an altitude of 2,935 ft. on the J415W powered flight, lower than the required 3,000 ft. and resulting in more deducted points.

The experience gained from the competition and build in general have given a more realistic sense of what is possible for next year's team. This includes soldered boards or possibly custom printed PCB boards to replace the rat's nest that are breadboards, and possibly two separate avionics bays to decrease the crowd of wires inside the single coupler piece.

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Rocket Operational Assessment

Flight on J415W Motor	Status
Up Video	Failure
Down Video	Failure
Parachute Detection	Partial Success
Velocity Measurement	Success
Utilization of Drag System	N/A
Altitude	2935 ft.
Maximum Velocity	491 ft./s
Maximum Acceleration	515 ft./s^2
Mass	233 oz

Flight on K1103X Motor	Status
Up Video	Failure
Down Video	Success
Parachute Detection	Partial Success
Velocity Measurement	Failure
Utilization of Drag System	Success
Altitude	3534 ft.
Maximum Velocity	712 ft./s
Maximum Acceleration	531 ft./s^2
Mass	246 oz

Table 1 - Tables of Flight Attributes

Flight Anomalies

Many anomalies affected the performance of the rocket on each flight. Most notably, the AltimeterTwo was not properly utilized and therefore provided no altitude data. This comes down to a few factors. These factors include improper utilization of the altimeter and a misunderstanding of how long it would take to fully assemble the avionics bay. For the J415W flight, the team had underestimated the time required to assemble the coupler section, and so once the rocket had been assembled, tested for continuity, and readied for flight, the altimeter had switched back to its main menu and was not ready to take data. For the K1103X flight, the altimeter was simply not switched on, and so was also in the main menu when the rocket took flight. However, this was taken care of by supplying the altimeter data from the two StratoLoggers onboard the rocket, which also provided accurate data throughout the flight.

On the J415W flight, there was no recording of video, neither up nor down. This was due to the cameras' relatively short battery life. Once the rocket was assembled, it had already been so long, that each had shut itself off. To prevent this from happening on the K1103X flight, the camera mount was cut such that the cameras could be inserted from the outside of the rocket, and then secured using sufficiently strong aluminum tape. However, on the K1103X flight, only the downward facing camera was capable of capturing footage as the other was not turning on at the launch-pad.

On the J415W flight, only the main parachute ejection was detected by the photo resistors on the end of the coupler. This is likely due to a wiring error or disconnect during flight that made it impossible for the Arduino to take any readings from the drogue parachute.

On the K1103X flight, the SD card was not inserted properly into its slot on the Arduino, so it was unable to collect data from the pitot tube or the parachute detection photo resistors. Luckily, the system did not need the SD card to operate, and it was still able to control the active drag system.

On the K1103X flight, both StratoLogger altimeters lost power at one point, but both parachutes deployed successfully. Thanks to the motor ejection charge and the secondary altimeter, the drogue and main parachute deployed slightly later than intended.

Propulsion System Assessment

Both motors performed optimally on the day of the flight. The rocket achieved an altitude of 785 ft. at motor burnout on the J415W, slightly lower than predicted with OpenRocket. The rocket achieved an altitude of approximately 750 ft. at motor burnout on the K1103X, again slightly lower than predicted by OpenRocket. We had based the deployment of the drag system on the altitude of motor burnout for the K1103X, so the drag system deployed slightly later than needed, missing a crucial amount of time where high drag could have been created to lower the apogee.

The motors were substantially easier to assemble than during the test launch. During the test launch, the J415W reload was giving a considerable amount of difficulty to the mentor assembling it, as an O-ring would continuously pop out of place due to a chip in the motor nozzle. However, for both competition flights, it seems the reload kits were impeccable and provided a much better time for the team mentor.

There was also a flare-up seen while reviewing footage from the K1103X launch. This flare up is likely parts of the motor liner falling into the gas jet. This did not affect the flight, but it was certainly interesting to note. This is shown in Figure 1.

Figure 1 - Flare-up as seen from the ground.

Flight Trajectory Assessment

The rocket made two successful flights. On the first launch with the J415W motor, the rocket left the rail, and banked approximately 15 degrees clockwise as shown in Figure 2. This rotation off the rail has not been explained, yet it happened on the test flight which flew with the same motor. This could have cut into the apogee of the rocket, meaning that had it not happened, the rocket may have could achieve 3,000 ft. For the rest of the flight on the J415W motor, the rocket maintained a steady and straight path. This indicates that the flaps were stable throughout flight and the drag system did not impede the rocket.

During the K1103X flight, the rocket flew one of the straightest flights of the day. It left the launch-pad much faster than on the J415W, and did not meet any problems leaving the launch rail. Throughout the entirety of the motor's burn, the rocket maintained its initial geometry. About a second after motor burnout, the drag system activated. It was not initially possible to tell, but the drag system slowed the rocket substantially. Even after the flaps rotated, the rocket maintained a very straight and low rotation flight. Prior to apogee, the flaps retracted to their initial positions, as evidenced by the straight flight post-deployment. Once at apogee, the rocket did not fire its electronic ejection charge. This led to the rocket slipping backwards for approximately 2 seconds, before the motor ejection charge activated. This is interesting. Instead of pitching over completely, it stopped when nearly parallel to the ground. This may have ensured that the drogue parachute could deploy before the rockets' speed was too great.

Figure 2 - Liftoff with the J415W (left) and K1103X (right)

Recovery System Assessment

The rocket's recovery system of one main and one drogue parachute worked exceptionally well. Each parachute was ejected using black powder charges. To deploy the drogue parachute, 2.5 g of black powder was used as the primary ejection charge and 3.0 g approximately for the backup charge. To deploy the main parachute, ejection charges of 3.0 g were used for both the primary and backup charge. Using the same size was thought to be the best choice as any higher could have possibly damaged the body tube.

On each flight, both parachutes were fully deployed and safely slowed the rocket down to an appropriate speed. On the J415W flight, the parachute slowed the rocket to 22.8 ft./s, within the competition parameters. On the K1103X flight, the parachute slowed the rocket to 25 ft./s, slightly out of bounds of the competition requirements. Both values are higher than the predicted values, as each was expected to be approximately 18 ft./s. It would seem the drag coefficient is not correct in the OpenRocket simulations.

Both flights the rocket was recovered in flyable condition even with its excessive descent rate. No noticeable signs of damage have been found since the competition, even during disassembly.

Ground Recovery Assessment

Recovery of the rocket was simple and seamless. After the J415W flight, the rocket drifted back relatively close to the launch-pad, making it easy to recover on foot. The landing site can be seen in Figure 3. The radio transmitter did not need to be utilized. After the K1103X flight, the rocket drifted slightly farther than on the first launch. It was still in walking distance, however, and the rocket was recovered as easily as the first time. On arrival at the landing site after the K1103X flight, however, it was found that two of the ejection charges did not activate. These were both disconnected from their terminals, shorted, and kept out of the way of teammates recovering the rocket. The altimeters were also confirmed to be off, ensuring no accidental ignition could occur.

Figure 3 - Landing site after the J415W flight.

Procedures Assessment

To ensure safety to the team and equipment, the team created checklists that were closely followed for rocket setup, on the pad, and recovery. At the appropriate time for both flights, the team went over the checklists and performed any needed adjustments to the rocket. The checklists can be found attached. The Beep Sequence Guide aided the team in checking the StratoLogger settings.

Actual and Predicted Performance

The peak altitudes achieved on the J415W and K1103X flight were 2935 ft. and 3534 ft., respectively. The J flight went lower than the 3300 ft. the OpenRocket predicted, most likely due to an increase in friction from the camera mounts, flaps, and pitot tube. Although the J apogee is below the 3000 ft. stated in the competition requirements, it came close and could reach 3000 ft. if the camera mounts and pitot tube were designed to reduce drag. The J and K flight altitude vs. time trajectory can be seen in Figure 4.

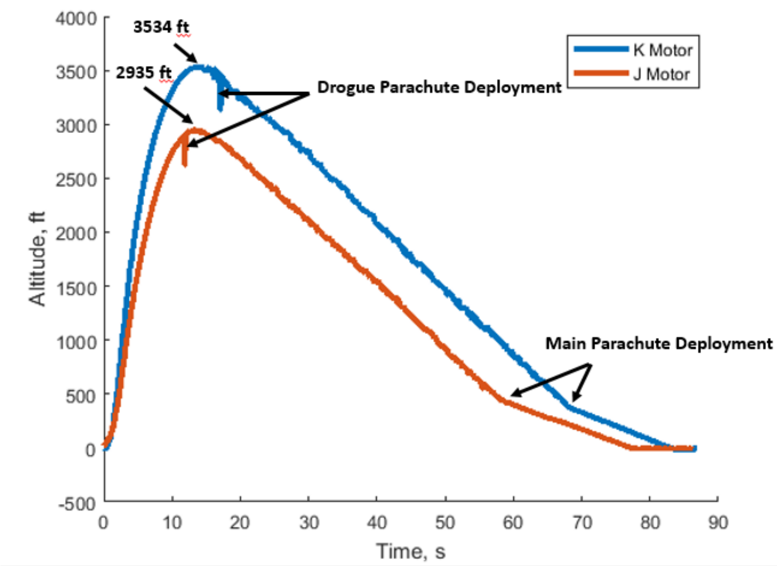


Figure 4 - J415W and K1103X Altitude vs. Time Graph

The K flight went significantly lower than OpenRocket's predicted apogee of 4544 ft., demonstrating the success of the active drag system. With a true apogee of 3534 ft., the apogee was approximately 1000 ft. lower than the prediction. The drag system was set on an altitude delay, so the flaps opened when the altitude reached 820 ft. (250 m) and closed when rocket reached 2789 ft. (850 m). The altitude at which the flaps closed was set conservatively to ensure the same geometry at launch and apogee, so they closed early and caused the K apogee to be higher.

With both motors, both parachutes successfully deployed and landed the rocket with no damage. On the J flight, all three charges went off at the appropriate time, and the motor ejection charge occurred at 14 s. However, only the main backup charge went off in the K flight because the primary altimeter lost power near the beginning of flight. After a 14 s delay, the motor ejection charge deployed the drogue parachute. The backup altimeter maintained a connection to the battery until the backup charge for the main parachute deployed. The backup altimeter also lost connection to the battery after the rocket landed because the battery wires sheared, but the altimeter logged all the necessary flight data. The remaining two charges that did not work were dealt with in a safe manner by the team.

Collected Velocity Data

The team decided to 3D print a pitot tube to measure velocity to allow easy replacement in case one got damaged. On the J flight, the team's pitot tube successfully collected pressure data and used the isentropic flow equation to calculate velocity. The curve matched reasonable well with the StratoLogger data after being scaled. Unfortunately, the SD card was not completely in the slot for the K flight, so no data was recorded. The pitot tube used by the team can be seen in Figure 5.

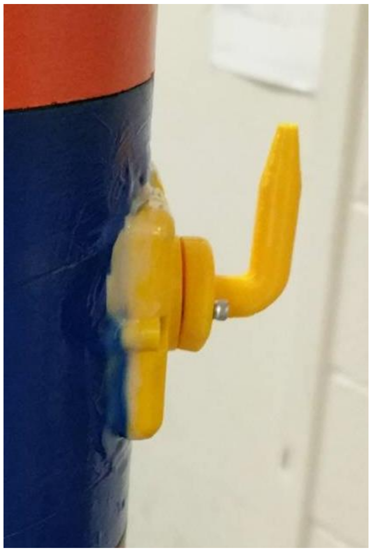


Figure 5 - Close-up of the Pitot Tube

The team used the BMP280 Barometric Pressure Sensor to measure both static and dynamic pressure. One sensor was in the avionics bay, and various holes in the coupler allowed it to read the static atmospheric pressure during flight. The other sensor was in a chamber inside the pitot tube, and it measured dynamic pressure as air was directed in the chamber during flight. The two pressures were used to calculate velocity using the following isentropic flow equations:

$$V = Ma$$

Where:
V = fluid velocity
M = mach number
a = speed of sound

$$a = \sqrt{yRT}$$

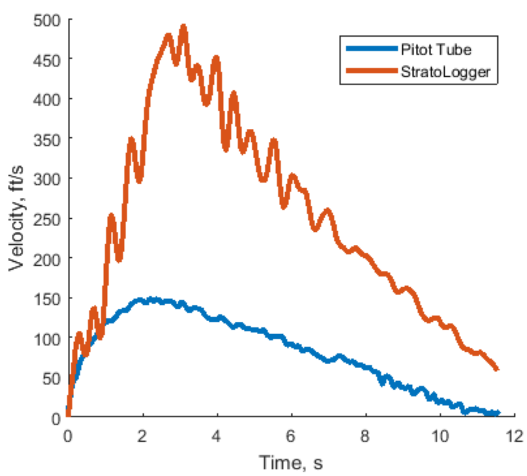
Where:
y = Adiabatic Index of Air (~1.4)
R = Gas Constant
T = Temperature

$$M = \sqrt{((\frac{P_{static}}{P_{total}})^{\frac{y-1}{y}} - 1) * (\frac{2}{y-1})}$$

Where:
M = Mach Number
P = Pressure
y = Adiabatic Index of Air (~1.4)

The velocity was then measured against the StratoLogger altimeter velocity data. Because the chamber of the dynamic pressure sensor affected the pressure reading due to airflow, the velocity readings needed to be scaled to match the real velocity. The team expected this to be necessary as the 3D printed pitot tube chamber size did not account for different the dynamic pressure readings, so the curve would be the correct shape, but the values would be off. Additionally, the tube that directed air flow into the pressure chamber may not have been the optimal size. Earlier iterations of the design output inconsistent readings due to a large tube that caused turbulence. The team found that a small tube approximately .1 in. in diameter minimized turbulence and still allowed enough air to enter for an accurate reading.

To scale the pitot tube data, the team took the max velocity measured by the StratoLogger and divided it by the max velocity measured by the pitot tube to get the scale factor. The max velocity measured by the StratoLogger was 491 ft./s. The pitot tube velocity was then multiplied by that scale factor to get the pitot tube velocity measurement. The scale factor was 3.3, and this number is expected to be similar on all flights utilizing this pitot tube. Plots of the unscaled and scaled pitot tube velocity measured against the StratoLogger can be seen in Figure 6. Unfortunately, the scale was not able to be tested on other flights due to a lack of data on the K flight.



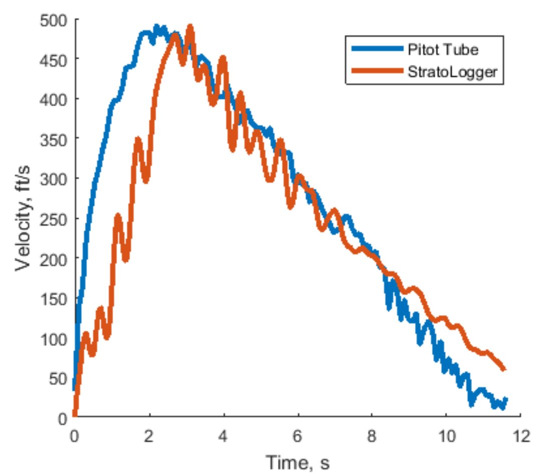


Figure 6 - Unscaled Velocity Curve (left) and Scaled Velocity Curve (right)

Per the StratoLogger, the max acceleration was 515 ft./s^2. Interestingly, the pitot tube data was smoother than the StratoLogger data. This is likely because the StratoLogger calculates velocity using the derivative of altitude with respect to time, and the pitot tube calculates velocity directly using measured quantities. The pitot tube detected a higher acceleration earlier into flight, but both velocity measurements matched closely after motor burnout, which was where the velocity measurements were maximized. The pitot tube received low readings toward the end where the actual velocity was low because the pitot tube design was built to read higher velocities and was not as accurate at lower speeds. Flight data after apogee in not shown because the pitot tube could not accurately measure dynamic pressure.

Drag System Analysis

The drag system worked optimally for the K1103X flight. Due to programming issues and being pressed for time, it was determined that simply setting an activation and retraction altitude would be the best for the system. Between flights, the algorithm for when the flaps should activate was altered to adjust for this decision. Once the rocket was assembled, the flaps were tested to ensure that they were going to stay straight while heading to the launch-pad and during motor burn. With the coupler assembled, there was no way to adjust the servos electronically, so to straighten one of the flaps, it was disassembled and reassembled into a more vertical orientation.

Once on the launch-pad, the servos were tested once more to ensure power was still getting to them and no connections had been compromised while putting it on the pad. All flaps were oriented vertically and the rocket was deemed ready for flight.

Throughout the motor burn, the rocket went straight up, with no obvious deviation from its trajectory. This, along with the video displaying two of the three flaps maintaining orientation is deemed reasonable evidence to support that the flaps were not activated whatsoever during burn, and that rocket geometry was maintained. The flaps can be seen in Figure 7.

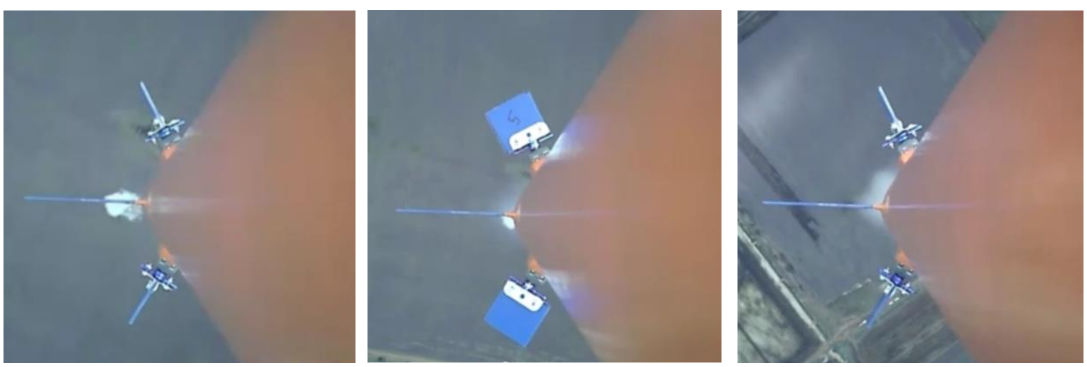


Figure 7 - Flaps After Motor Burnout (left), Flaps Activated (middle), Flaps Retracted (right)

Approximately a second after motor burn concludes, the flaps activate. The flaps were set to activate 850 ft. above ground level. Per OpenRocket simulations, this was approximately 30 ft. above the predicted altitude at motor burnout. The simulation was slightly higher than actual, however, so the flaps activated later than expected. This slight change may have been crucial to the active drag. Right after motor burnout, maximum velocity is achieved. Higher velocity means more drag to lower the rocket's apogee. This critical period was missed, so the apogee is higher than expected. What was also noticeable from the video and flight itself was the minimal amount of deviation from trajectory and minimal rotation. Some rotation was predicted because of the way the flaps must rotate, which could induce a torque on the rocket. This torque appears to have been negligible since in the video, the rocket rotates only slightly. The same goes for at flap retraction. The process of deployment and retraction is shown in Figure 8.

Figure 8 - Downward View During Flight on the K1103X Motor

Using MATLAB simulations, it was shown that the flaps could bring the apogee between flights to within 20 ft. However, the actual distance was 599 ft. This distance is much larger than expected. This is still much better than without the drag system active. Using OpenRocket and an updated rocket model better suited to the data acquired from the launches, there is a predicted apogee of 4544 ft. with the K1103X motor. This means the drag system successfully cut off approximately 1010 ft. from the apogee, a success for the first working active drag system in Illinois Space Society.

Deployment and Recovery System Data Collection

Up/Down Video Images and Links

The only video the team obtained was a downward view from the launch on the K1103X motor. This video showed off many aspects of the rocket launch, including ignition, burnout, drag deployment and retraction, coasting, and parachute deployment.

Although the deployment monitoring system was unable to record data throughout the K1103X flight, the camera provides insight to when the parachutes opened. The video shows tube separation of the lower body tube, drogue extraction, as well as the upper body tube, all seen in

Figure 9 - Drogue Below Coupler (left), Lower Body Tube Separation (middle), Upper Body Tube (right)

Figure 9. It does not directly show the main parachute, but because footage of the drogue parachute below the coupler is seen, it is implied that the main parachute deployed once the upper body tube was separated.

Interpretation of Data

The data from the SD card implies that the main parachute was deployed at 174.4 seconds after the launch of the rocket. However, intuition and data from the StratoLoggers implies that this value is incorrect. The likely source for this incorrect reading is that the Arduino detected an altitude change while on the launch-pad. The program controlling the Arduino was set so that when the static pressure sensor read that it was 8 ft. above its initial point, then data would start to be stored on the SD card. If the wind blew hard enough into the coupler section, it is possible that a low-pressure reading could have kicked off the program. It then would have created a start time much earlier than the actual launch time of the rocket.

The computer system was only able to verify the separation of the upper body tube and subsequent deployment of the main parachute on the J415W flight. However, using video data from the K1103X flight, it is possible to verify when the drogue and main parachute deployed for the second flight.