MIN-D

NASA's Space Grant Midwest High-Power Rocket Competition

University of Illinois at Urbana-Champaign

Illinois Space Society

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1. Summary and Background

1.1 Motivation for Launch and Summary

The Illinois Space Society successfully completed two flights on August 10th, 2019, one with the required Cesaroni I-218 motor and the other with the team's choice of the Cesaroni J-430 motor. August 10th was the team's second day of flying following the competition and were the 4th and 5th flights the team completed. The team launched again on August 10th to improve the flight score by receiving non-commercial data and launching in a safer manner.

The first flight took place on July 6th, 2019. The rocket was successfully launched and recovered twice. However, the non-commercial avionics system did not operate for either flight, so the bonus challenges were incomplete. Additionally, the TeleMetrum did not have continuity prior to the supersonic flight, so the rocket relied on only the StratoLogger for parachute deployment. The discontinuity was likely due to incorrect terminal wiring. One other problem during July 6th was that the tip-to-tip on the fin tore slightly after the supersonic flight. However, the damaged fin did not change the predicted maximum velocity greatly.

The team was confident that the rocket could perform better than the July 6th flights. Plans were made to repair the avionics package and the torn fin. Preflight procedures were also reviewed, and new wires were used in order to launch safely. Continuity was then confirmed by both the StratoLogger and TeleMetrum. The team decided that the benefits of receiving non-commercial data and completing the bonus challenges outweighed the risks associated with flying again.

Between flights, the team researched and executed the best way to fix the fin. RocketPoxy was used to glue the torn "tip-to-tip" part onto the fin. The team also constructed two new nosecones with pitot tubes, found a solution to ensure Raspberry Pi data collection, and had backups for different failure modes that could potentially come up to prevent Raspberry Pi failure.

On August 10th, the team successfully launched and recovered the rocket twice. Pre and post flight procedures went smoothly, so the team had ample time before the range closed to launch twice. Data and onboard video were acquired from the Raspberry Pi for the first flight. The supersonic flight only yielded commercial data, as the team believed that vibrations from the flight corrupted what was stored on the SD card. Again, on board telemetry did not transmit data on either flight. Figure 1 shows the team excited to launch throughout all three launch dates.

Throughout the rest of this paper, "flight one" and "flight two" refer to the two different flights happening on the same day. All flights reference the August 10th launch unless otherwise specified.

Figure 1: The ISS team ready to launch for the test flight on April 13th (left),and competition flights on July 6th (middle) and August 10th (right)

2. Rocket Operation Assessment

2.1 Flight 1: Required I-218 Motor

2.1.1 Flight Anomalies

The only anomaly on the first flight was that the non-commercial telemetry did not transmit data to the laptop acting as the ground station. The flight algorithm was configured to send data only during the descent portion of the rocket's flight. This measure was put in place because of the slow rate of data transfer. By sending data packets only during descent, the team hoped to ensure that the most crucial data from ascent, including maximum velocity, acceleration, and altitude, would be recorded more accurately.

On the launch pad for the first flight, there was no trouble with telemetry initialization. However, the ground station did not receive any packets of data during or after the flight. After recovering the rocket, the team examined the data collected by the onboard Raspberry Pi and identified the cause of failure. Due to a logic error in the descent calculation code, the telemetry system never detected descent and therefore never sent any data packets. The error was resolved before the supersonic flight. Additionally, the code was modified to send data packets twenty-two seconds after launch (which is a little more time than the rocket would take to reach apogee, according to OpenRocket), in case the descent detection failed again. Other than being unable to complete the telemetry bonus challenge, the first flight went according to plan.

2.1.2 Propulsion System Assessment

For the first flight, the team used the Cesaroni I-218 motor required by the competition. A single grain case was selected over a dual grain case with a spacer because it would yield better speed, acceleration, and altitude. The I-218 had an actual burn time of 2.09 sec, which was 9.1% less than the predicted burn time of 2.30 sec.

The engine assembly process was successful. The only difficulties faced were removal of the spent propellant and the motor ejection charge. The burnt propellant was stuck in the motor case. The team tackled this problem by using a wrench to pull out the nozzle, and then used a dowel to push out the rest of the burnt propellant. The engine casing was then cleaned and prepared for later flights.

2.1.3 Flight Trajectory Assessment

The rocket was initially guided by the rail. Then it started banking clockwise by about 10 degrees, as shown in Figure 2, as soon as it left the rail at 84.4 ft/sec. There are many possible reasons that the rocket started banking. One of them could be that there was a large amount of friction between the rail and rail guides, causing the rocket to tilt. Since the rocket did not bank at the start of every launch, another possible reason for the banking could be that a strong gust of wind caused the rocket to tilt during the first flight. Soon after, the rocket corrected its path from an increase in stability as the motor propellent burned. For the remainder of the flight, the rocket flew straight until it started coning. Coning can occur when the center of gravity is too far forward, or the fins are too small to counteract rotation. Overall, the first flight was successful, but it would have been better without banking and coning. The banking and coning likely decreased the maximum velocity and altitude of the rocket, since the thrust vector of the rocket does not point completely perpendicular to the ground. As a result, propellant and energy is wasted in forcing the rocket to correct its path. The effects of coning and banking on the rocket's actual velocity and altitude compared to its predicted is shown in Section 3.

Figure 2: Smoke trail from beginning of first flight (left); smoke trail when rocket starts banking during first flight (right)

2.1.4 In-Flight Recovery Assessment

The rocket's recovery system performed as anticipated. The drogue parachute was deployed as a result of the primary ejection charge at an apogee of 5199 feet. The rocket used the StratoLogger as the active set of avionics to deploy the primary ejection charge of 0.75 grams of black powder at apogee. A redundant set of avionics was used to deploy the backup charge of 1 gram with a 3 second ignition delay from apogee using the TeleMetrum. Under the drogue parachute, the rocket fell with a descent rate of 61.7 feet per second, meeting the competition requirements. All components of the rocket remained intact during this portion of the fall.

The Jolly Logic Chute Release successfully deployed the main parachute once the rocket reached the designated altitude of 700 feet. Under the main parachute, the rocket descended at a rate of 17.6 feet per second, resulting in a total flight time of 121 seconds.

2.1.5 Ground Recovery Assessment

The rocket landed in a field past a set of trees and bushes at a distance of 1115 feet from the launchpad. When the range was clear, team members were able to use the attached radio tracker and GPS coordinates to locate the rocket. Once found, the rocket was assessed for any damages that might have occurred. Members followed the post-flight checklist to ensure the rocket was recovered in a safe manner.

As found in the launch procedures in Section 2.2.6 Pre- and Post-Flight Procedure Assessment, the team checked for any unexploded black powder charges and found that both ejection charges had been activated. Subsequent examination of the StratoLogger data confirmed ignition of the charges at apogee. Upon recovery, as seen in Figure 3, the rocket and shock cord system remained intact. However, the nosecone landed in the ground on impact, causing the pitot tube to be clogged. After going through the post-flight checklist, the rocket was taken back to collect data and transition into the next flight. The backup nosecone was used for the second flight due to the original pitot tube damage.

Figure 3: Nosecone and pitot tube after recovery (left), upper body tube and parachute (middle) and lower body tube (right)

2.1.6 Pre and Post-Flight Launch Procedure Assessment

Avionics

Following the test launch, the avionics sub team decided to revise the launch procedures to make the steps more detailed and easier to comprehend. The ordering of the steps was further revised to divide up tasks such that different sections of the rocket could be worked on simultaneously. The updated procedures are shown in Figure 8. The team chose to further elaborate on the attachment of new threaded wires to the StratoLogger and TeleMetrum terminals, detailing the exact placement of the proper terminals which were designated for the main and backup charges. The wire used was also changed to a smaller gauge, which allowed four wires to fit more easily through the small hole near the terminal blocks. For the final flights, commercial sensor procedures explicitly included the proper call signs, voltage, continuities, and "pull tests" on each of the connected wires to ensure connection.

After successful recovery of the rocket, post flight procedures were conducted for avionics at the inspecting table. Nothing significant here was changed from the test launch procedures; however, "inspect avionics bay" and "remove PCB from rails" were divided into two steps for clarity.

Structures

All recovery and engine pre-flight procedures were followed. Following the July 6th launch, several extra steps were also added. These steps entailed sprinkling baby powder onto the parachute and parachute protector as they were folded. This reduced friction inside the body tube, making the recovery system easier to deploy. Also, in order to accommodate the modified competition guidelines, steps were added to the post-flight procedures as well. The new rules state that the launch, the recovery, and physical inspection of the rocket was to be filmed. As a result, the team assigned several people to document these events before the flight.

During the August 10th launch, all procedures were followed including the modified recovery procedures. Figure 4 shows the team working on the procedures before flight one.

Figure 4: The team going through pre-flight procedures: listening to the TeleMetrum beeps (left), stripping wires and placing the parachute in the rocket (middle), and parachute packing (right)

2.2 Flight 2: Supersonic

2.2.1 Flight Anomalies

A few anomalies occurred during the supersonic flight. On the launch pad, the non-commercial sensor suite had no trouble with initialization. However, in a similar way to the first flight, no data packets were received from the non-commercial telemetry system during or after flight.

Additionally, the team could not wirelessly connect to the onboard Raspberry Pi after recovering the rocket, which was possible after the first flight. After extracting the SD card from the onboard Pi, the team examined the collected data and found that data collection cut out immediately after launch. The team suspects that the SD card lost electrical contact with the Pi shortly after launch, likely due to vibrations in the rocket. The Pi's SD card slot was oriented with the opening facing downwards, increasing the likelihood of the SD card being dislodged during flight. The team believes the disconnect caused the Pi to crash, bringing down the whole non-commercial sensor suite. This would explain the lack of data transmitted by telemetry, as well as the team's inability to wirelessly connect to the Pi.

2.2.2 Propulsion System Assessment

The team used the J-430 for the supersonic flight. The J-430 has a designed impulse of 823.1 N-sec, a max thrust of 546.8 Newtons, and an expected burn time of 1.90 seconds. The J-430 had an actual burn time of 1.87 sec which is 1.6% less than expected.

The J-430 assembly process, like that of the I-218, was smooth with almost no issues. After the flight, there was still a problem with taking out the burnt propellant which was again solved by using a wrench-dowel combination. The engine casing was then finally cleaned and prepared for other flights.

2.2.3 Flight Trajectory Assessment

This flight with the J-430 motor flew straighter than the previous flight and did not bank. Instead, its trajectory began straight off the rail at a speed of 112.0 ft/sec but started spinning soon after. Examining the video time stamps revealed a spiral smoke trail, which implied the rocket started coning about 0.5 seconds into the flight as shown in Figure 5. Coning is visible when the rocket spins as it ascends and when the nose of the rocket changes directions. Once again, without coning, the rocket would have likely flown higher and faster and would have come closer to the estimates shown in the OpenRocket simulations in Section 3.

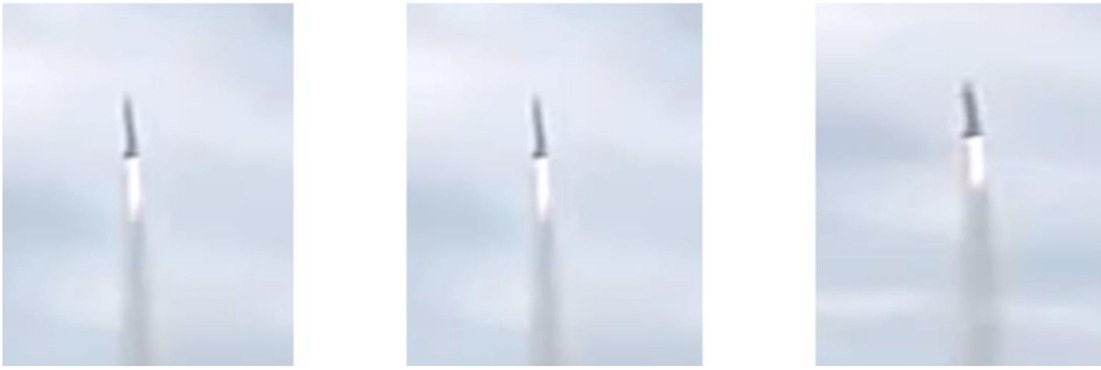


Figure 5: Rocket coning and changing its axis of rotation during flight

2.2.4 In-Flight Recovery Assessment

As in the first flight, both the main and drogue parachutes successfully deployed at the predicted altitudes. The team used the same set of active and redundant avionics to trigger the primary and backup charges. The amounts of black powder for each charge did not vary from the first flight. The rocket landed close to the launch site, only 1080 feet away. The team was also successful in tracking the rocket throughout flight and descent. The team had TeleMetrum and GPS data available throughout the flight, so the rocket was easy to locate.

The rocket descended at a speed of 66.24 ft per second under the drogue parachute, and after the Jolly Logic Chute Release deployed as expected at 700 ft, the rocket descended at 19.32 ft/sec under the main parachute. During this time, the shock cord system successfully kept all components of the rocket attached as seen in Figure 6.

Figure 6: In-flight recovery sequence during the second flight

2.2.5 Ground Recovery Assessment

Upon recovery and inspection of the rocket, the drogue and the main parachute did not suffer any damage. The rocket had landed in open area, keeping the recovery system components from getting tangled. Following the post-flight procedures, the team checked for any unexploded black powder charges and found that both charges had ignited. There was no damage done to the nosecone, upper body tube, or lower body tube. See Figure 7 for the upper and lower body tube after flight.

Figure 7: Ground recovery after the second flight: upper body tube (left), lower body tube (middle), and torn tip-to-tip (right)

One of the rocket's fins experienced a greater amount of delamination of the "tip-to-tip" layering during the 2nd flight in July. The team thinks it originally occurred due to an insufficient amount of epoxy used in the carbon fiber layering. The fin was repaired for the August launch with RocketPoxy. The same tearing occurred again but this time on the upper part of the same fin due to lack of repair epoxy on the upper part of the fin. The team suspects the damage itself happened during flight due to dynamic instability or fin flutter which can occur near Mach speeds. See the right-most image of Figure 7 for the tip-to-tip tear.

2.2.6 Pre- and Post-Flight Procedure Assessment

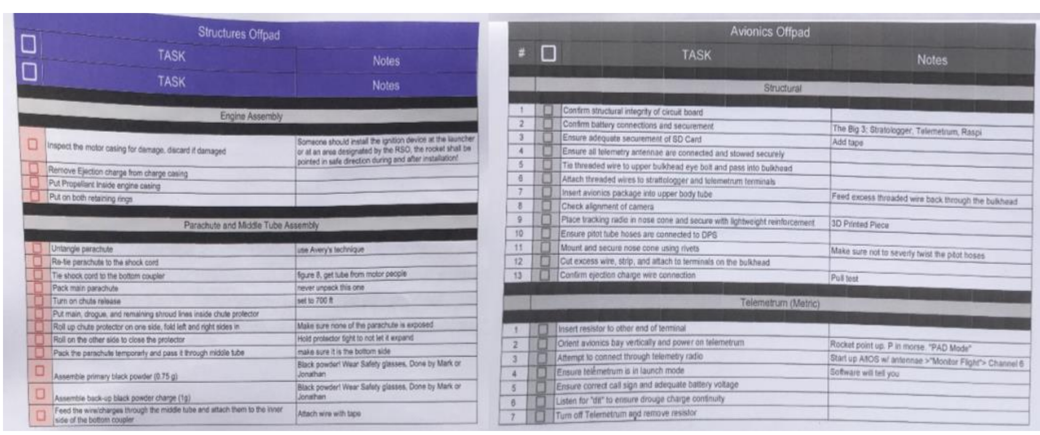
Avionics

The pre-flight procedures were conducted just as with the first flight. More time was allocated to debugging the code and investigating connection to the systems before the second flight.

After successfully locating the rocket, the team recorded the beeping avionics bay on video. Having returned to the off-pad tent, post flight procedures were conducted similarly to the first, and the sensors were turned off.

Structures

The modified recovery and engine procedures, including the changes detailed in 2.1.6 Pre and Post-Flight Launch Procedure Assessment, were followed with no further changes. Similarly, the post-flight procedures proved satisfactory in recovering the rocket. Figure 8 shows the pre-flight steps for structures and avionics for both flights.



Structures Offpad

☐	TASK	Notes
☐	TASK	Notes
	Engine Assembly	
☐	Inspect the motor casing for damage, discard if damaged	Someone should install the ignition device at the launcher or at an area designated by the RSO, the rocket shall be pointed in safe direction during and after installation!
☐	Remove Ejection charge from charge casing	
☐	Put Propellant inside engine casing	
☐	Put on both retaining rings	
	Parachute and Middle Tube Assembly	
☐	Untangle parachute	use Avery's technique
☐	Re-tie parachute to the shock cord	
☐	Tie shock cord to the bottom coupler	figure 8, get tube from motor people
☐	Pack main parachute	never unpack this one
☐	Turn on chute release	set to 700 ft
☐	Put main, drogue, and remaining shroud lines inside chute protector	
☐	Roll up chute protector on one side, fold left and right sides in	Make sure none of the parachute is exposed
☐	Roll on the other side to close the protector	Hold protector tight to not let it expand
☐	Pack the parachute temporarily and pass it through middle tube	make sure it is the bottom side
☐	Assemble primary black powder (0.75 g)	Black powder! Wear Safety glasses. Done by Mark or Jonathan
☐	Assemble back-up black powder charge (1g)	Black powder! Wear Safety glasses. Done by Mark or Jonathan
☐	Feed the wire/charges through the middle tube and attach them to the inner side of the bottom coupler	Attach wire with tape

Avionics Offpad

#	☐	TASK	Notes
		Structural	
1	☐	Confirm structural integrity of circuit board	
2	☐	Confirm battery connections and securement	The Big 3: Stratologger, Telemetrum, Raspi
3	☐	Ensure adequate securement of SD Card	Add tape
4	☐	Ensure all telemetry antennae are connected and stowed securely	
5	☐	Tie threaded wire to upper bulkhead eye bolt and pass into bulkhead	
6	☐	Attach threaded wires to strattologger and telemetrum terminals	
7	☐	Insert avionics package into upper body tube	Feed excess threaded wire back through the bulkhead
8	☐	Check alignment of camera	
9	☐	Place tracking radio in nose cone and secure with lightweight reinforcement	3D Printed Piece
10	☐	Ensure pitot tube hoses are connected to DPS	
11	☐	Mount and secure nose cone using rivets	Make sure not to severly twist the pitot hoses
12	☐	Cut excess wire, strip, and attach to terminals on the bulkhead	
13	☐	Confirm ejection charge wire connection	Pull test
		Telemetrum (Metric)	
1	☐	Insert resistor to other end of terminal	
2	☐	Orient avionics bay vertically and power on telemetrum	Rocket point up. P in morse. "PAD Mode"
3	☐	Attempt to connect through telemetry radio	Start up AltOS w/ antennae >"Monitor Flight"> Channel 6
4	☐	Ensure telemetrum is in launch mode	Software will tell you
5	☐	Ensure correct call sign and adequate battery voltage	
6	☐	Listen for "dit" to ensure drouge charge continuity	
7	☐	Turn off Telemetrum and remove resistor	

Figure 8: The first page of pre-flight procedures for structures (left) and avionics (right)

3. Actual versus Predicted Performance

3.1 Flight Characteristics

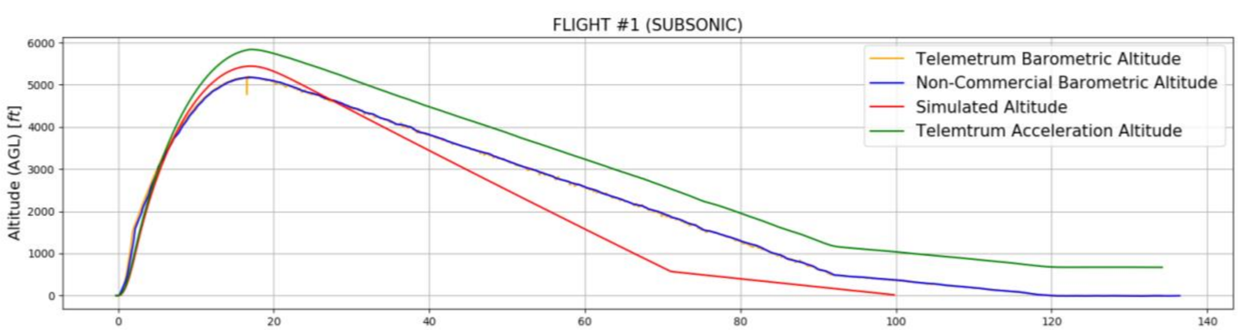
Table 1: Flight characteristics from the TeleMetrum compared to predicted characteristics for both flights

Characteristic	Simulation Flight 1	Competition Flight 1	Percent Error	Simulation Flight 2	Competition Flight 2	Percent Error
Motor	I218WT-8	I218WT-8	N/A	J430-WT-18A-8	J430-WT-18A-8	N/A
Mass (lbs)	3.880	3.880	N/A	4.370	4.370	N/A
Apogee (ft)	5440	5199	4.430%	7804	7357	5.727%
Peak Velocity (ft/s)	809.0	811.2	.2719%	1237	1236	.08084%
Peak Acceleration (ft/s2)	466.0	500.5	7.403%	847.0	833.9	1.547%
Drogue Parachute Descent Speed (ft/s)*	90.60	61.70	31.90%	93.60	66.20	29.27%
Main Parachute Descent Speed (ft/s)*	19.20	20.90	8.854%	19.60	23.90	21.94%
Ground Hit Velocity (ft/s)	19.20	16.40	14.58%	19.60	18.01	8.112%
Motor Burn Time (s)	2.300	2.090	9.100%	1.980	1.880	5.050%
Time to Apogee (s)	17.00	16.94	.3529%	19.10	19.04	.3141%
Duration of Flight (s)	101.0	121.0	19.80%	164.7	153.7	6.679%

(*) average descent rate for drogue and main parachutes

3.2 Peak Altitude Compared to Expectations

The graph shown below in Figure 9 compares the real altitude measurements of the rocket to the simulations made in OpenRocket for both flights. It is important to note that the accelerometer based altitude appears to be inflated as the altitude measurements are based on a double integrating acceleration data, and the team believes that the error factor in the data is compounded.



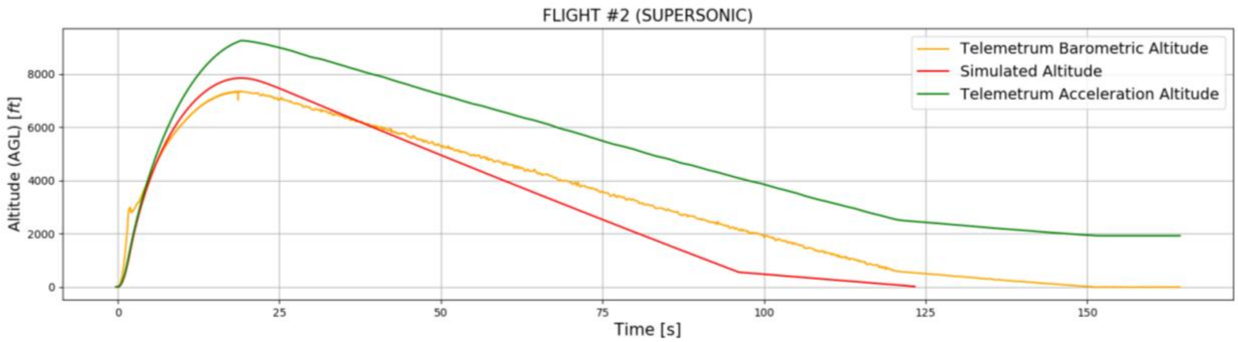


Figure 9: Altitude (AGL) vs. time plot for both simulated data and recorded data.

The maximum altitude for both flights was lower than predicted. As detailed in Table 1, the first flight was 202 ft below the predicted maximum altitude, and the second flight was 443 feet below the predicted maximum altitude. The percent errors in altitude for the first flight were only 3.8% and 5.7% respectively. Additionally, the rocket took longer than simulated to land for both flights and took longer to reach apogee for the second flight. Analysis of the descent part of the flight is further discussed in 3.4 Recovery System Performance and Descent Velocity.

3.3 Peak Velocity and Acceleration

Figure 10 shows the velocity versus time plot with the TeleMetrum, Raspberry Pi, and the OpenRocket simulations and includes measurements from the pitot tube for the second flight.

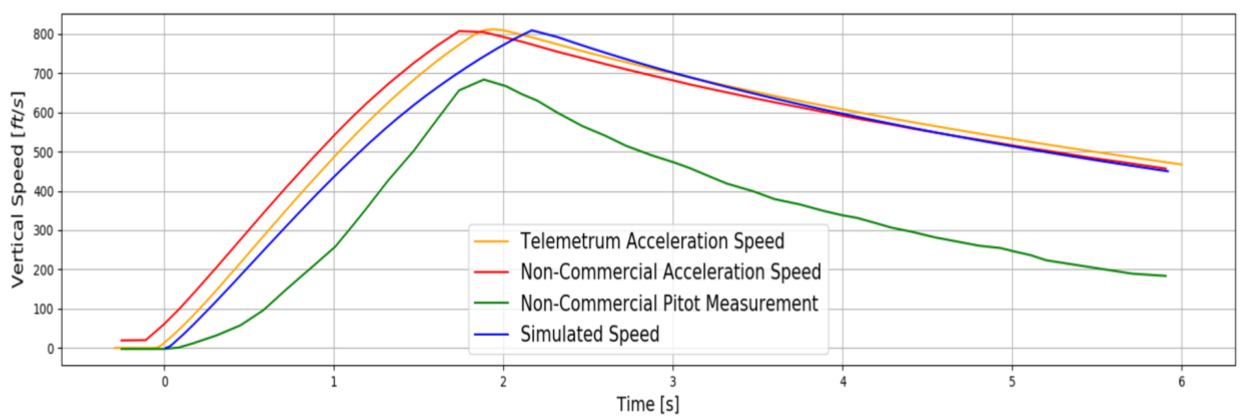


Figure 10: Flight 1 Acceleration and Velocity Measurements

Figure 11 shows the acceleration versus time plot with the TeleMetrum recordings and OpenRocket simulations.

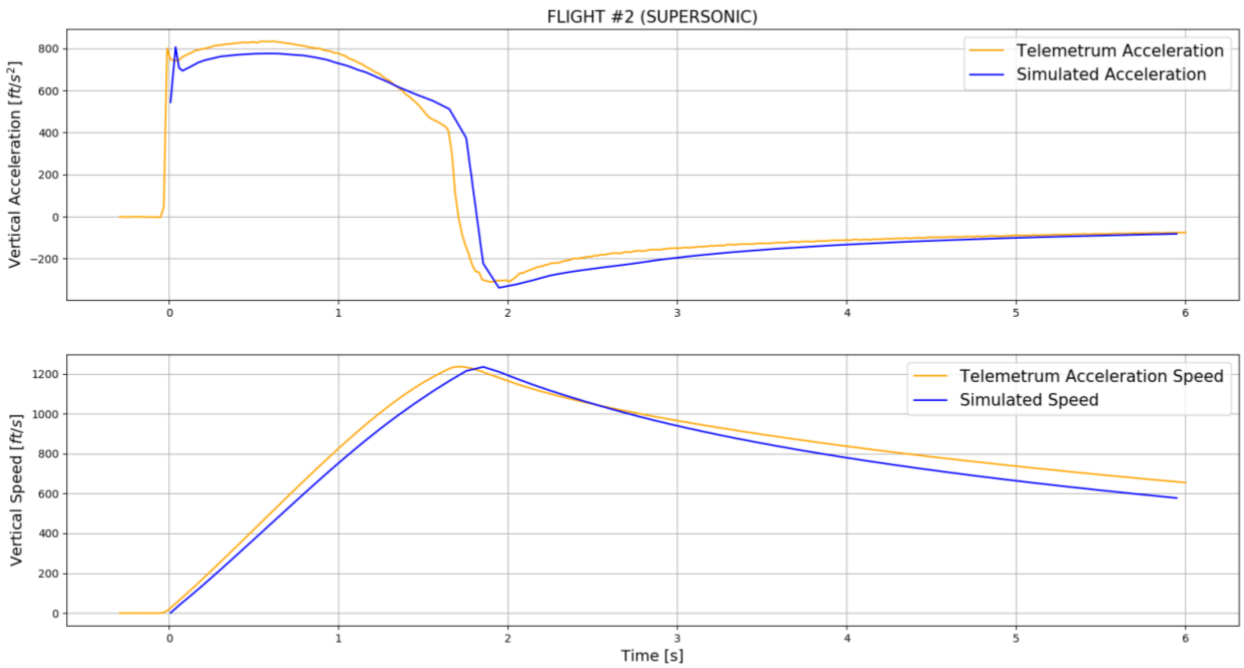


Figure 11: Flight 2 acceleration (top) and velocity (bottom) comparing actual velocity and acceleration to the simulated measurements

Unfortunately, due to the loss of the Raspberry Pi, the team was not able to receive any data from the pitot tube during the second flight. The maximum speed achieved in the first flight was 811 ft/sec, which is .3% greater than the predicted speed of 809 ft/sec. The Mach number varies according to altitude since the temperature of the atmosphere generally decreases with altitude, making it harder for air to conduct sound. Equation 1 was used to calculate the Mach value given the altitude and temperature, where a is the speed of sound, γ is the ratio of specific heats, R is the gas constant and T is the absolute temperature at the altitude in consideration.

$$a = \sqrt{\gamma R T}$$

Equation 1: Calculation of Mach value at given altitude and temperature

The absolute temperature itself was found using Equation 2, where h is the altitude of the rocket when it reaches its peak velocity and 299.817 K is the temperature at sea level at the time of flight.

$$T = 299.817 - 0.00649h\ (°K)$$

Equation 2: Calculation of absolute temperature

Table 2: Summary of peak velocity and acceleration calculations shows the rocket's peak velocity with the altitude the rocket was at when the rocket hit its maximum velocity. Again, the Mach number was calculated based on the site temperature and the altitude the rocket was at when the peak velocity was achieved. Maximum acceleration with percent error from OpenRocket simulations are also shown in Table 2: Summary of peak velocity and acceleration calculations. All the values in the table were recorded with the TeleMetrum.

Table 2: Summary of peak velocity and acceleration calculations

Flight Number	Peak Velocity	Altitude of Peak Velocity	Mach 1 in ft/s at Altitude	Rocket's Mach value	Peak Acceleration	Acceleration Percent Error
Flight 1	1236 ft/s	2231 ft	1148.0 ft/s	0.7066	466 ft/s$_2$	1.5%
Flight 2	811.2 ft/s	2788 ft	1145.9 ft/s	1.0754	833 ft/s$_2$	1.7%

3.4 Recovery System Performance and Descent Velocity

The main and drogue parachutes deployed as planned with the Jolly Logic Chute Release releasing the parachute at 700 feet for both flights. The descent speeds during both flights varied from the simulated descent speeds. Such variations could be due to weather conditions. During the first flight, the wind speed was 12 ft/s coming from the southwest. During the second flight, there was a wind speed of 9 ft/s from the north. Though these speeds are for the most part lateral, any deviation could have decreased the descent speed of the main or drogue parachute. Such wind speeds were not considered when simulating flight for the rocket. In addition, the estimated drag coefficients for the drogue and main chute respectively were 1.25 and 1.5. The effect of drag on the chute release bundled parachute was also not able to be accounted for. This along with potential disparities in drag coefficients explains why the drogue descent speed was much lower than expected.

Competition requirements dictate that the descent speed under the drogue parachute must be higher than 50 ft/s while the descent speed under the main parachute must be lower than 24 ft/s. As seen in 3.1, the average drogue descent rate for the first and second flights were 61.7 ft/s and 66.2 ft/s respectively, meeting the drogue velocity requirement. The average main parachute descent rate for the first and second flights were 17.6 ft/s and 19.3 ft/s respectively, meeting the main parachute velocity requirement. The rocket landed with a velocity of 16.4 ft/s for the first flight and 18.01 ft/s for the second.

3.5 Video Results

The camera system was only able to get results for the entirety of the subsonic flight. Although the shroud was foggy, key points of the flight can be identified. Within the video file, the team was able to identify the flames of the rocket on ignition and objects on the ground visually decreasing in size during ascent. The fire from the flames can be seen by looking for a burst of orange color in the bottom section of the screen. The team was unable to see deployment of either the main or drogue chute. However, the team saw the deployed main chute drifting in and out of frame occasionally during descent. The team could see the rocket descending using reference points on the ground. During landing there were no clear signs of impact. However, once the frame remains still, it can be inferred that the rocket has landed.

4. Data Collection Analysis

4.1 Commercial Evidence of Supersonic Flight

The Stratologger CF and the AltusMetrum TeleMetrum recorded data for the entirety of both flights. However, since the StratoLogger CF relies on barometric pressure measurements to determine altitude and velocity, it is susceptible to error at near-supersonic speeds due to the occurrence of shockwaves. For this reason, the TeleMetrum's peak velocity measurement is emphasized as it utilizes accelerometer-based measurements to determine velocity.

During the second (supersonic) flight, the TeleMetrum recorded a peak velocity of **1236.35 ft/s**, which occurred 1.71 seconds after launch was detected. Considering local air temperature and altitude, the rocket achieved a peak Mach number of **1.0754**. The rocket achieved supersonic flight 1.46 seconds after launch. Figure 12 details the vertical speed of the rocket during the first six seconds of the supersonic flight.

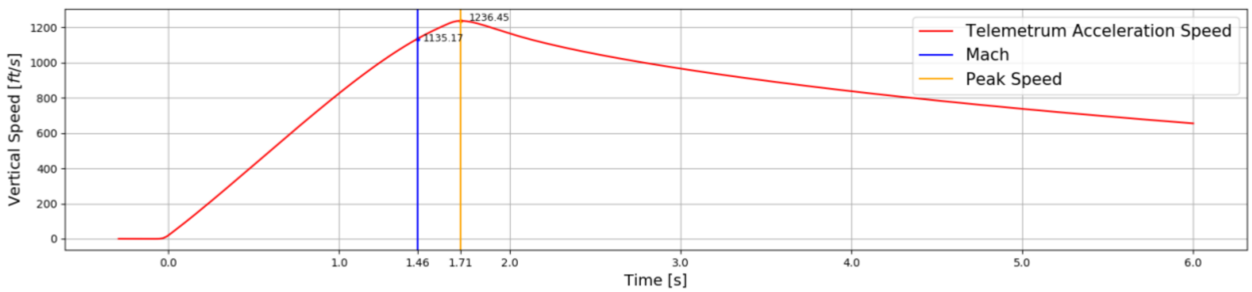


Figure 12: Vertical Speed vs Time data recorded by the Telemetrum

The StratoLogger recorded a peak velocity of 944.88 m/s, which was measured 3.50 seconds after launch was detected. This value is not deemed to be accurate. Further analysis is explained in 4.3.2.

4.2 Non-Commercial Evidence of Supersonic Flight

Unfortunately, the non-commercial sensor suite failed to record data during the supersonic flight. Although the non-commercial system was operational and recording data up until launch, the system ceased recording data at the moment of launch.

The flight software is configured to record Unix timestamps until launch is detected, after which the software records timestamps relative to launch. The last data point recorded by the non-commercial system has a Unix timestamp of 1565469801.596686, which when converted to a date and time, yields August 10, 2019 3:43:21.596 PM. This final timestamp matches very closely to the exact moment launch occurred. After this final data point, the data log file contains two additional lines of corrupted data.

This post flight analysis leads the team to believe that the cause of failure was the vulnerability of the SD card reader on the Raspberry Pi flight computer from vibrations and high acceleration. Although the non-commercial system functioned during the subsonic flight, the heightened acceleration and vibrations in the second flight likely caused the SD card to lose electrical contact within the SD card slot on the Raspberry Pi flight computer. This is believed to have caused the flight computer to crash at the moment of launch, or soon after the moment of launch.

4.3 Data Interpretation and Comparison to Expectations

The StratoLogger recorded a peak velocity of 1338 ft/s (Mach 1.19, 65.4% error) during the first flight and 3100 ft/s (Mach 2.75, 150.6% error) during the second. One factor that contributed to the discrepancy was the pressure due to the drogue charge since the StratoLogger records data from pressure-based measurements. After a drogue charge is ignited, pockets of high pressure are created. The team believes the StratoLogger picked up on, and falsely recorded these pockets, because the recordings showed a rapid dive at apogee and then returned to a correct altitude. In turn, this motion would be an inflated interpretation of peak velocity. Peak acceleration was not derived from the StratoLogger, because the initial pressure-based velocity data was so poor.

The pitot tube sensor in the non-commercial sensor suite recorded a peak velocity of 683.45 ft/s (Mach 0.59, 15.5% error) during the first flight. The error in the measurement is believed to be due to the team's limited resources which inhibited an accurate calibration of the sensor. In order to calibrate the pitot sensor, the upper avionics assembly and nosecone were held out of a vehicle at speed. Measurements from the pitot sensor and the vehicle's speedometer were used to calibrate the pitot sensor's raw measurements to reflect airspeed. A more controlled calibration method that would simulate higher airspeeds would have allowed for a more accurate calibration of the sensor.

4.3.1 Flight One Analysis

During its first flight with the I-218 motor, the rocket flew lower than expected altitude. There are a couple of factors that could have caused a difference between the simulated and actual altitude. Weather conditions on launch day likely had a very strong effect on the rocket's altitude. The predicted flights were simulated with an average windspeed of 6.56 ft/s from the East. However, during the first flight, the wind speed was 12 ft/s coming from southwest. Additionally, there was a significant amount of friction between the launch rail and the rocket as described in 2.1.3 Flight Trajectory Assessment. This friction may have had an impact on the peak altitude of the rocket as well. The I-218 burn time discrepancy is within the 10% error bounds, likely due to manufacturing of the motor casing as detailed by the motor casing company.

4.3.2 Flight Two Analysis

During its second flight with the J-430 motor, the rocket was expected to achieve a peak velocity of 1237 ft/s. The rocket flew at supersonic speed during this flight. This is evidenced by an anomaly in the barometric-based TeleMetrum data near the time the rocket approached Mach 1. As explained in 4.1, the maximum velocity occurs around 1.71 seconds, about when the barometric-based TeleMetrum data experiences an unexpected jump in velocity in Figure 9. On the other hand, it is observable that the accelerometer-based data does not have any anomalies.

Since barometric data uses pressure-based readings from the static ports on the upper body tube, the flow around the air begins to act differently approaching supersonic speeds. The flow around the rocket becomes compressible instead of incompressible therefore indicating that the rocket did approach supersonic speeds. The accelerometer-based data confirms that the speed barrier was broken as it achieved supersonic speeds during the time of anomalies in the pressure-based data.

The rocket reached apogee at a lower altitude than simulated and experienced slightly lower peak velocity and acceleration. The discrepancies between the simulated and the actual flight could be due to a couple of issues. As stated in 4.3.1, the simulation was performed with a windspeed of 6.56 ft/s from the east. During the second flight, there was a stronger wind of 9 ft/s from the north. Again, the friction between the launch rail and the rocket may also have had an impact on performance.