# Final Report

Kent State University High-Power Rocket Club

Kent State University


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# *Aerotech* J-415-WL Performance: Predicted v Actual

## Predicted Values

Predicted J-415-WL performance, utilizing *MATLAB*, shows a maximum altitude of approximately 3,600 feet above ground level (AGL), shown in *Figure 1*. Predicted velocity of the J-class motor, shown in *Figure 2*, projected a maximum velocity of near 625 feet-per-second at the end of the motor burn. These predictions were made using two first-principle equations:

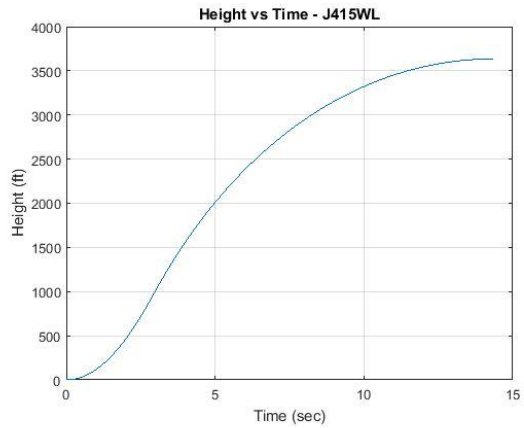


*Figure 1: Aerotech J-415-WL; Predicted Altitude*

$D = \frac{1}{8}\rho\pi d^2 V^2 C_D$ , *Where d is the diameter of the rocket body* **[Eqn. 1]**

$F = m\alpha$ **[Eqn. 2]**

The prediction models were then verified using *RockSim*. They assumed a total rocket weight of 12 pounds. This process revealed satisfactory flight stability results.

Actual performance met with expected accuracy to the predicted values mentioned above. The rocket, with an actual total weight of 13.6 pounds for the J-class motor, was flown with a primary and secondary *StratologgerCF* as well as a team *Altimeter 2* and a competition provided *Altimeter 2*.

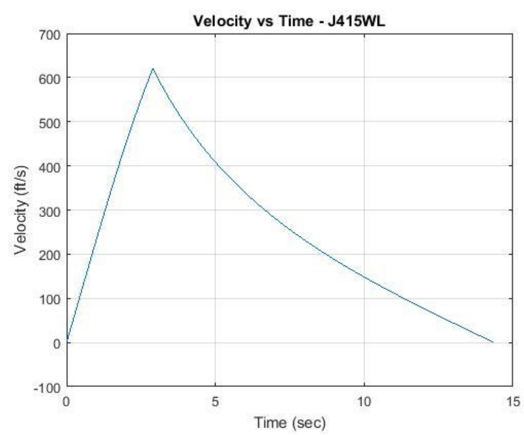


*Figure 2: Aerotech J-415-WL; Predicted Velocity*

## Actual Altitude Values

The primary *StratologgerCF*, *Figure 3*, shows a maximum altitude of 3,516 feet AGL for the J-415-WL motor. This is a difference of 82 feet, or 2.4%, compared to the predicted altitude. The secondary *StratologgerCF*, *Figure 4*, measured a maximum altitude of 3,508 feet AGL. A difference of 8 feet, or 0.23%, from the primary *StratologgerCF*, and 92 feet, or 2.6%, when compared to the predicted altitude. Each *Altimeter2* verifies the altitude data measured by each *StratologgerCF*, with the team's *Altimeter2* reading 3,506 feet AGL and the competition provided *Altimeter2* measuring 3,512 feet AGL.

### Actual Velocity Values

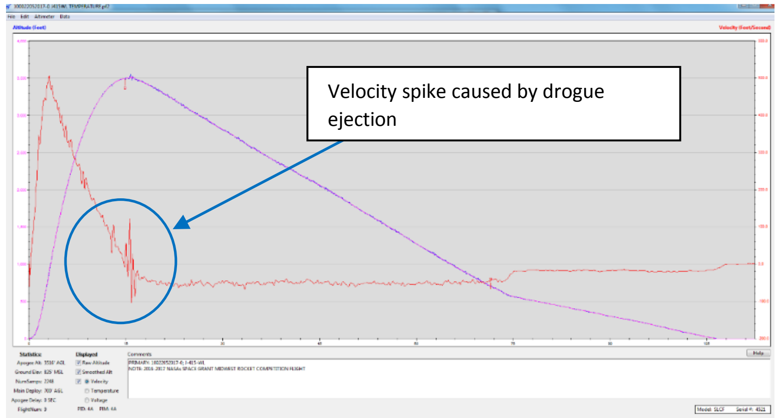


Figure 3: Primary StratologgeCF; Aerotech J-415-WL Actual Velocity & Altitude

Actual velocity for the J-class motor also matched our predictions closely, though with a bit more error than the altitude. The primary StratologgerCF, *Figure 3*, measured a maximum velocity of approximately 510 feet-per-second. A difference of 115 feet-per-second, or 22.5%. The secondary StratologgerCF, *Figure 4*, measured around 515 feet-per-second: a difference of 5 feet-per-second from the primary and 120 feet-per-second from the predicted velocity. The Team's Altimeter2 measured a maximum velocity of 554 feet-per-second, while the competition provided Altimeter 2 showed a maximum velocity of 525 feet-per-second, a 12.8% and 19%, respectively, difference from the predicted value of 625 feet-per-second.

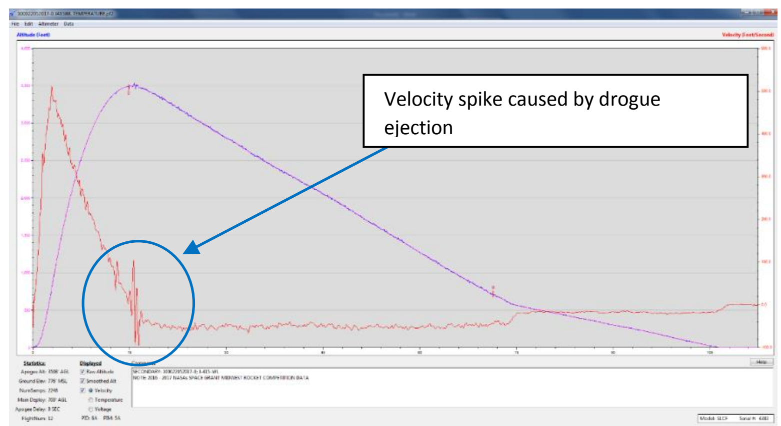


Figure 4: Secondary StratologgerCF; Aerotech J-415-WL Actual Velocity & Altitude

The four separate altimeter readings reveal that the rocket was slowed compared to our team's predictions. This is likely due to the excess drag caused by the cameras, pitot system, and drag system hardware that were unable to be accounted for with reasonable accuracy in *MATLAB*

The reduction in altitude was also likely caused by the excess weight of 1.6 pounds caused by the pitot tube, cameras, and paint.

The velocity for the J-class motor was also recorded by the pitot system. The microsensor used, however, has a maximum calibration speed of 350 miles-per-hour or 513 feet-per-second. *Figure 5* reveals the error once the microsensor approaches this velocity. Our team also noticed this phenomenon in the test flights.

The sensor will either show a linear transient to zero, or, as in this case, spike to an unreasonable value. In either case, the sensor will reset once the velocity decreases to below its maximum calibration speed. It is apparent though that this graph reveals an approach to a value close to those measured by the four altimeter values: between 510 to 554 feet-per-second as represented by the green line. This supports the validity of the four altimeter velocity values.

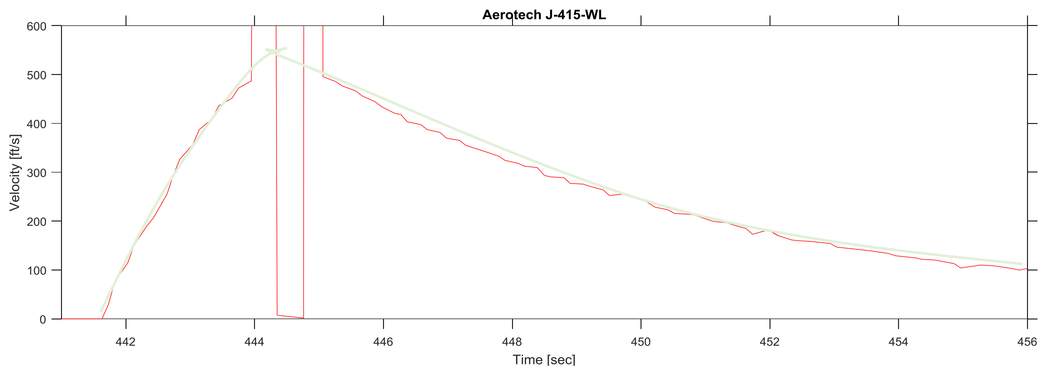


*Figure 5: Pitot Sensor; Aerotech J-415-WL Actual Velocity*

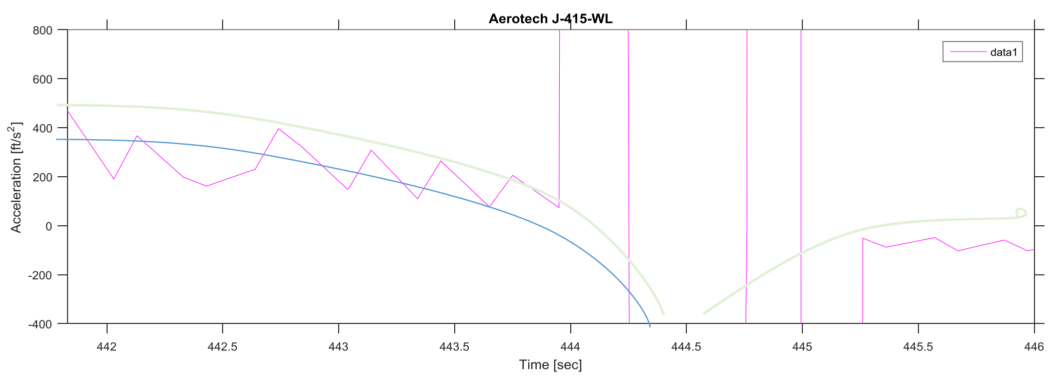


*Figure 6: Pitot Sensor; Aerotech J-415-WL Actual Acceleration*

**Actual Acceleration Values**

Acceleration can also be graphed using the velocity values gathered from the pitot system and Equation 3.

$$\frac{V_1 - V_0}{t_1 - t_0} = \frac{\Delta V}{\Delta t} \qquad \textbf{[Eqn. 3]}$$

This yields the graph in *Figure 6*. This graph also shows the error similar to *Figure 5* however. The green line represents a typical smoothed acceleration curve. The figure reveals a maximum acceleration of approximately 450 ft. /s$^2$. However, each *Altimeter2* measured a maximum acceleration of 8.2 to 8.5 G's. This is about 264 to 273 ft. /s$^2$ respectively. These numbers are very close to our predicted value of 240 ft. /s$^2$ shown in *Figure 7*. There could be some error within the pitot system however. If we take the average of the values, represented by the blue line in *Figure 6*, we see a value closer to that of the predicted value and the values measured by each of the *Altimeter2*'s.

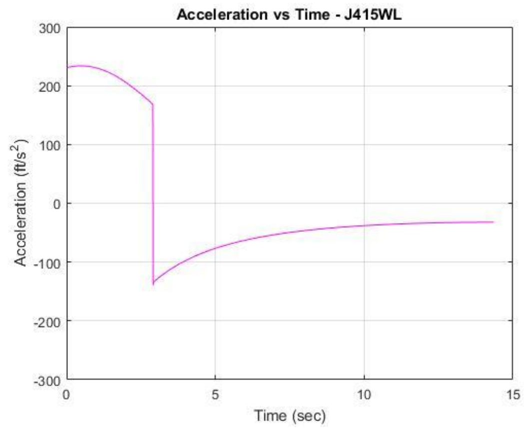

*Figure 7: Aerotech J-415-WL; Predicted Acceleration*

## *Aerotech* K-550-WL Performance: Predicted v Actual

### Predicted Values

Much the same as the J-class motor, the K-550-WL predicted performance was proven accurate with the competition flight. Altitude for a 12- pound rocket was predicted to be approximately 3,700 feet AGL (*Figure 8*), while the predicted velocity was around 700 feet-per-second (*Figure 9*). The actual weight of the rocket with the K motor was 14.3 pounds.

### Actual Altitude Values

*Figure 10* shows the actual performance of the K-class motor, as measured by the primary *StratologgerCF*, reached an altitude of 3,552 feet AGL. This is 148 feet short of the predicted value. Like the J-class motor, this

*Figure 8: Aerotech K-550-WL; Predicted Altitude*

is likely due to the excess weight, 2.3 pounds, from the paint and cameras as well as the drag from

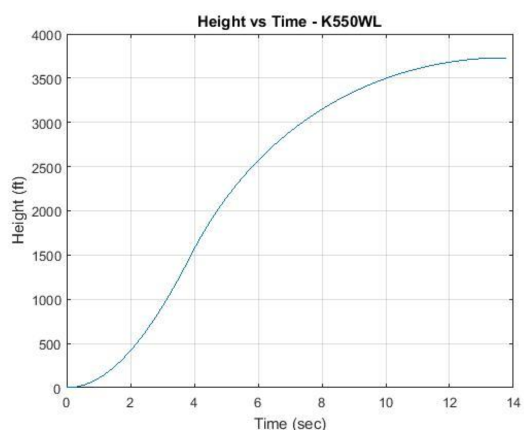

*Figure 8: Aerotech K-550-WL; Predicted Altitude*

the cameras and pitot system. This value is confirmed by the secondary *StratologgerCF* that measured 3,546 feet AGL; a 154 feet difference from the predicted altitude. Each *Altimeter2* further confirms these numbers with one measuring 3,554 feet and the competition provided *Altimeter2* measuring 3,557 feet AGL.

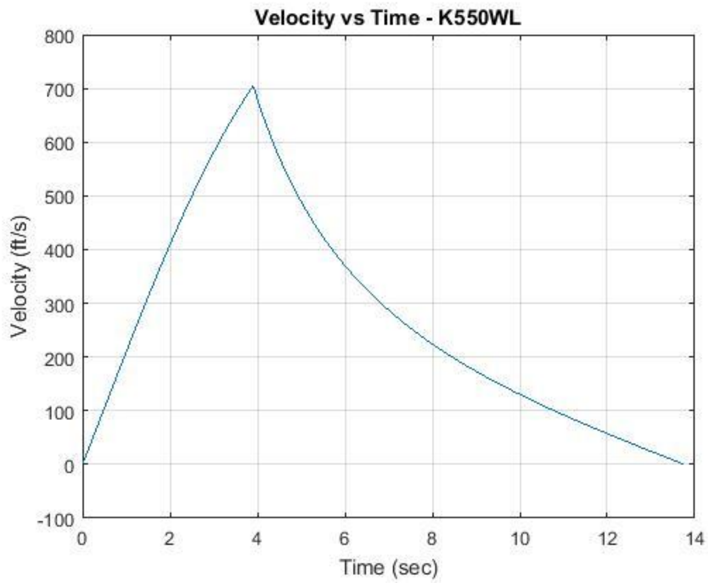

*Figure 9: Aerotech K-550-WL; Predicted Velocity*

**Actual Velocity Values**

The primary *StratologgerCF*, *Figure 10*, recorded a maximum velocity of 660 feet-per-second. This is only a 40 feet-per-second difference from the predicted value, or a 6% difference. The secondary *StratologgerCF*, *Figure 11*, confirms the primary value by recording a maximum velocity of approximately 680 feet-per-second: a 20 feet-per-second difference, or a 3% difference. Each Altimeter2 also confirms these values with maximum velocity values of 689 feet-per-second, and 657 feet-per-second (competition provided *Alt2*).

The pitot tube reveals a similar maximum velocity of around 650 feet-per-second in *Figure 12*. This graph, however, shows the pitot sensor's error as it did for *Figure 5*. The green line represents a typical velocity curve and proves the maximum velocity similar to those measured by the

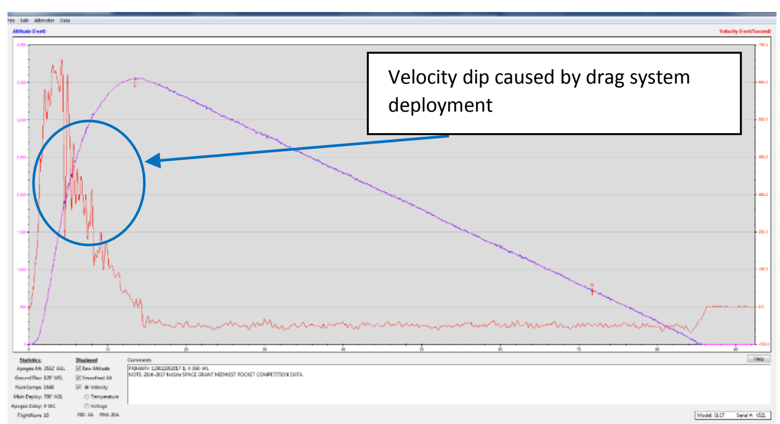

*Figure 10: Primary StratologgerCF; Aerotech K-550-WL Actual Velocity & Altitude*

four altimeters and the predicted value. This is approximately an 8% difference.

As we did with the J-class motor pitot data, we can use the data collected, with Eqn. 3, and create an acceleration graph for the K-class flight *Figure 13* shows the actual acceleration curve and reveals a maximum acceleration of approximately 750 ft. / s$^2$. The green line represents a smoothed acceleration curve. The blue line represents an average of the values, bringing the values closer to that of the predicted value of around 215 ft. /s$^2$, *Figure 14*. The values for maximum acceleration captured by each of the Altimeter2's are 383 to 408 ft. /s$^2$. These values are much closer to the pitot sensor averaged value but do not fairly represent the predicted value. This could be due to a poorly represented reduction due to the drag system in our *MATLAB* code.

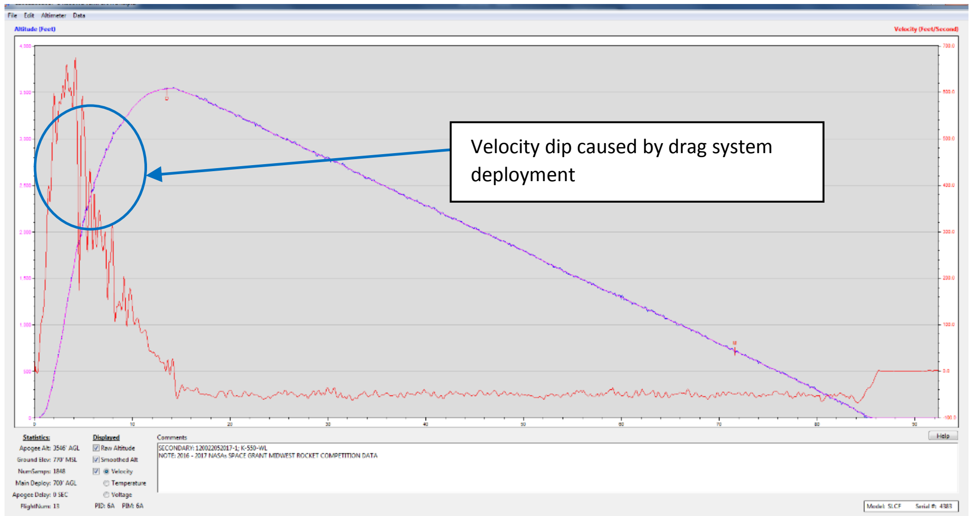


*Figure 11: Secondary StratologgerCF; Aerotech K-550-WL Actual Velocity & Altitude*

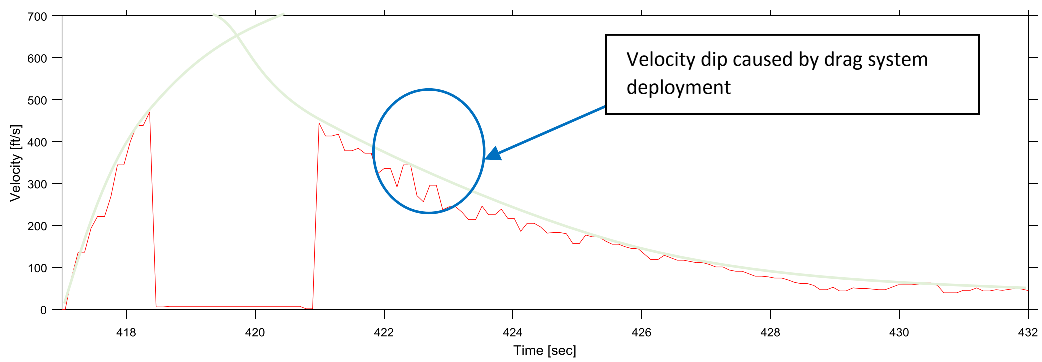


*Figure 12: Pitot Sensor; Aerotech K-550-WL Actual Velocity*

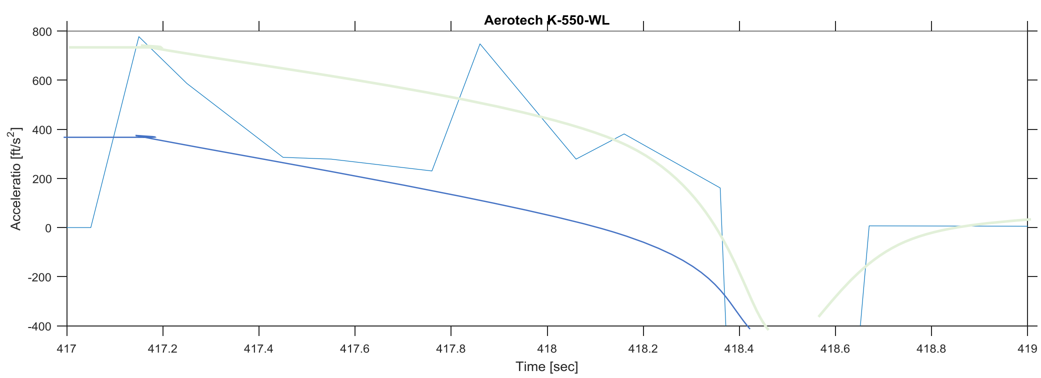


*Figure 13: Pitot Sensor; Aerotech K-550-WL Actual Acceleration*

# Flight Trajectory & Recovery System Assessment

**Flight 1: J-415-WL**

The rocket's flight for the J-class motor went as expected. The flight was nearly vertical and the drogue chute opened at apogee as seen in *Figure 3* and *Figure 4*. The main parachute opened at 700 feet AGL post-apogee as anticipated: also shown in *Figure 3* and *Figure 4*. The primary and secondary *StratologgerCF* were both programmed to deploy the drogue and main parachutes at the same altitudes. *Figure 15* shows a dip in battery voltage for the primary *StratologgerCF* at both the drogue deployment and the main deployment. This means it was operating normally and as predicted, resulting in a successful deployment of each parachute. *Figure 15* shows a voltage dip only in the main deployment. This may mean the secondary *StratologgerCF* was not functioning normally. However, the redundancy of the system worked. The rocket landed within approximately 500 yards from the launch pad indicating that our team's decision to deploy the main chute at 700 feet AGL post-apogee rather than at a higher altitude was a good one that led to easy and successful recovery of the rocket.

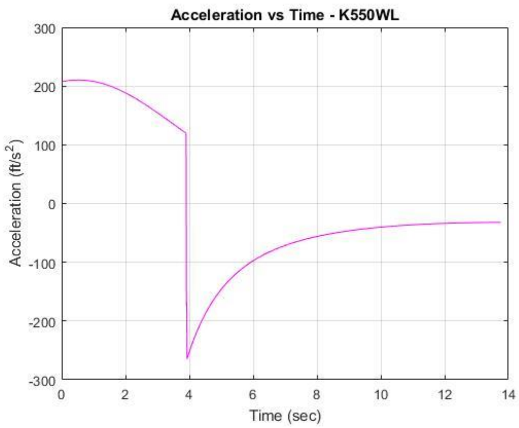

*Figure 14: K-550-WL; Predicted Acceleration*

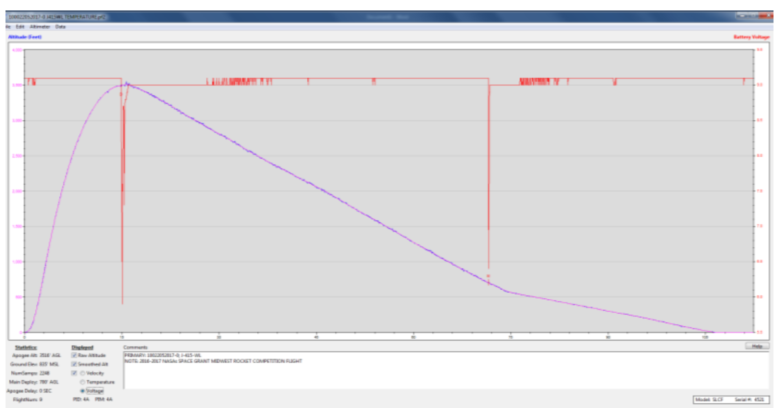
*Figure 15: Primary StratologgerCF; J-415-WL Actual Voltage & Altitude*

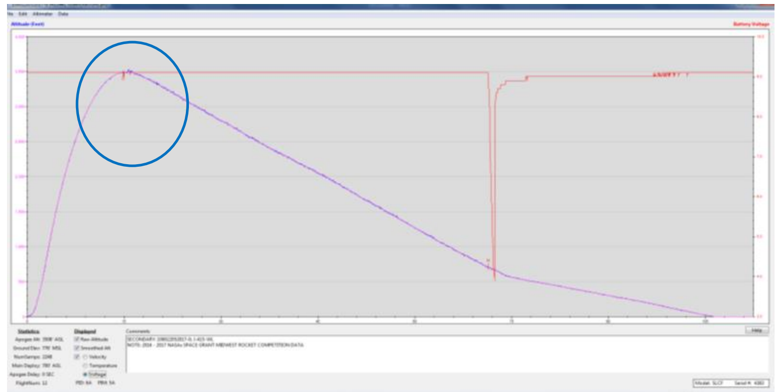

*Figure 16: Secondary StratologgerCF; J-415-WL Actual Voltage & Altitude*

**Flight 2: K-550-WL**

The K-class motor flight performed very similarly to the J-class motor flight. The flight was again nearly vertical, pushed slightly by the wind. The drogue chute opened normally and at apogee as can be seen in *Figure 10* and *Figure 11*. However, the main parachute failed to deploy. The charge was ignited and the audience could hear an audible 'pop', but the parachute failed to deploy. Reviewing *Figure 17* and *Figure 18*, one can see that the secondary *StratologgerCF* failed to send voltage to the main chute charge. This, however, was accomplished successfully by the primary *StratologgerCF*.

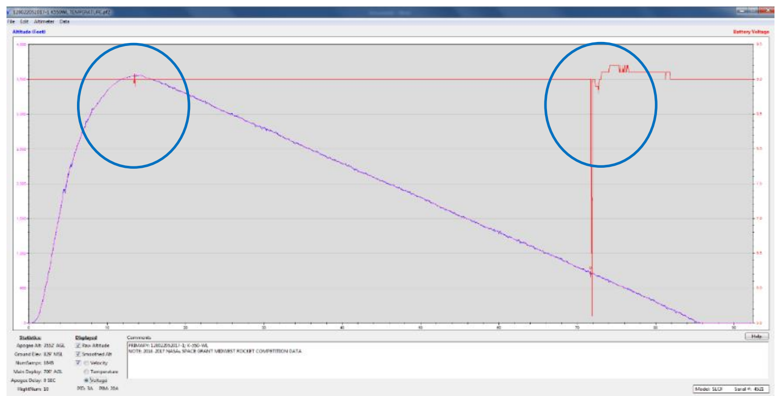

*Figure 17: Primary StratologgerCF; K-550-WL Actual Voltage & Altitude*

Upon further analysis, the team found that the only cause could be a low black powder weight within the charge. Upon the decision to use both *StratologgerCF's* to ignite the upper and lower charges, the team failed to re-weigh the charges to ensure the appropriate amount,1.5 grams, was present.

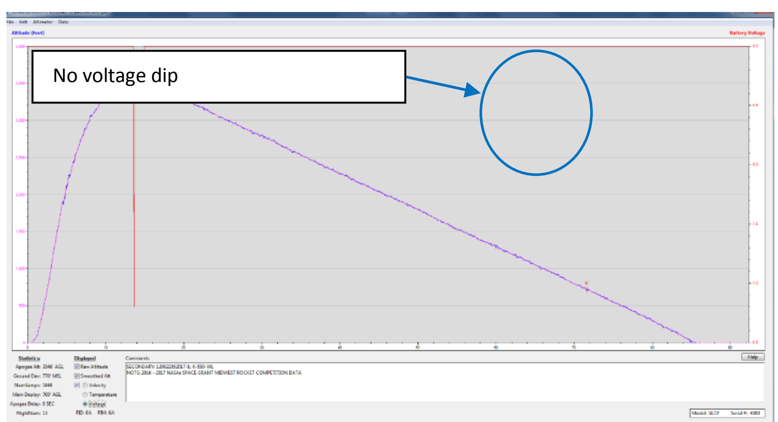


*Figure 18: Secondary StratologgerCF; K-550-WL Actual Voltage & Altitude*

**Descent Rates**

The descent rates, in accordance with the *Altimeter2*'s, were slightly high. The J-class motor was recorded at a descent rate of 37 to 38 feet-per-second.

This still allowed for a reasonably safe descent of the rocket and a successful recovery. The descent rate of the K-class motor was slower, despite suffering a main chute deployment failure. The *Altimeter2*'s measured a descent rate of 13 to 16 feet-per-second. With both altimeters measuring so closely, it is difficult to ascertain why they read the descent rate so low. Analysis of Figures 16 & 17 reveals a slower descent rate with the J-415-WL after main chute deployment when compared to that of the K-550-WL.

## Pre-Launch, Flight Pad & Arming, and Recovery Procedures Assessment

Our team's pre-launch, flight pad & arming, and recovery checklists were extremely useful. We used these checklists during most of the nine test flights and edited as necessary each time to ensure they were up-to-date and in correct order. These test flights and the two competition flights went as expected as a result. Our checklists also included a *safety checklist*, *safety briefing*, *club launch standard operating procedure (SOP)*, and many appendices that contained information about the competition rocket. We utilized this checklist for model rocket flights as well, both for the educational outreach with the Boy Scouts of America and for the team's familiarization flights.

## Drag System Evaluation

The drag system worked close to as expected though did show a failure in one tab. The tab opened during motor burn. Analysis of the failure showed the elastic band allowed the tab to lean forward slightly and the wind caught the tab and forced it to fully open, *Figure 19*. This force bent the pivot pin which did not allow the tab to fully return to stowed position at apogee as shown in *Figure 20*. The second drag tab however worked exactly as expected. It remains stowed during motor burn, as seen in *Figure 19*, and deploys just after motor burn-out, *Figure 21*. The tab then returns to its stowed position at apogee, just prior to drogue chute ejection *Figure 20 – left tab*. This drag tab is a proof-of-concept and can clearly be seen working as such in the video (refer to https://youtu.be/o1Xb6Gkw9CI for the video). *Figure 22* shows the current schematic for the drag system. As a solution to the tab's early deployment, a shroud could be placed over top of each tab on the rotational side of the tab as shown in *Figure 23*. This shroud will redirect the wind around the tab itself but leave the wind catch within the wind sream.

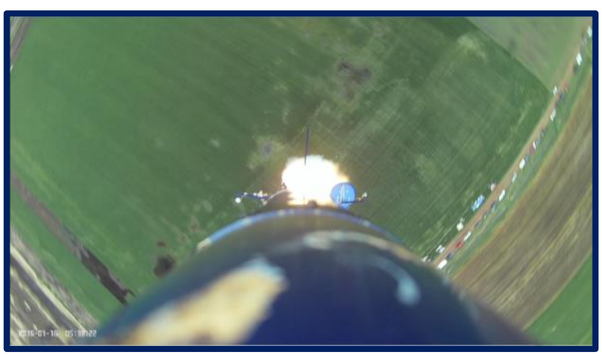

*Figure 19: Drag Tab (Right) Forced to Deploy During Motor Burn*

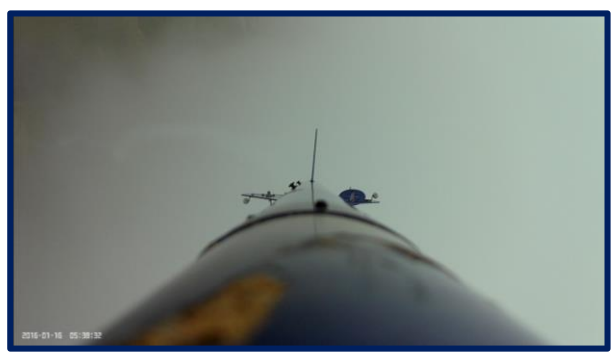

*Figure 20: Drag Tab (Right) Unable to Fully Stow at Apogee*

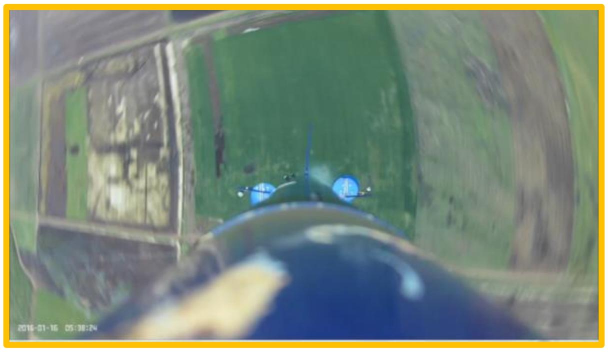

*Figure 21: Drag Tab (Left) Deployed at Motor Burn-Out*

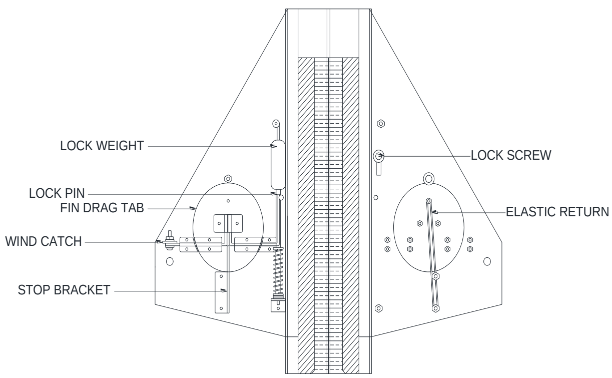


*Figure 22: Current Drag System Schematic*

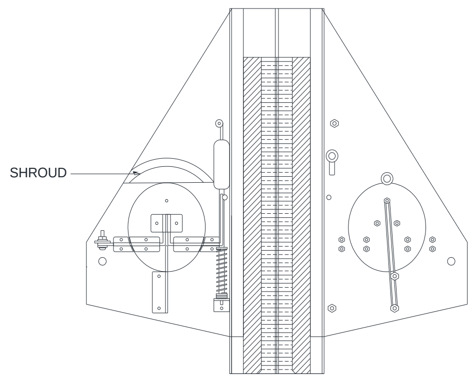


*Figure 23: Drag System with Proposed Shroud*

## Rocket Operational Assessment

Overall, the rocket operated as expected and functioned normally. The drag system worked very well to allow us to reach 45 feet difference in apogees between the two motors. The flight paths were normal and the rocket stayed within view at all times. The base height set by the J-class motor was nearly as predicted and allowed us to reach objective fruition.

### Flight Anomalies

There were three flight anomalies that occurred:

1. Main parachute deployment failure, flight number two, K-550-WL.
2. One camera failure on each of the two flights.
3. One drag tab of the two opened early during K-550-WL flight.

The main parachute deployment failure, as well as the drag tab early deployment have already been analyzed and discussed in previous sections. The camera failures will be analyzed next.

The cameras, *Mobius Mini ActionCam*, were charged the evening prior to the competition event. During the J-class motor flight each of the two cameras did power on. However, the down camera turned off prior to the launch. The up camera operated normally and captured the main parachute deployment, (refer to https://youtu.be/wYBNb6XBig4 for part 1 and https://youtu.be/28HmvRnlan8 for part 2 that shows chute deployment). The down camera for this flight was not critical as the drag system was locked in its stowed position. We decided to switch the up camera to the down camera position for the second flight as we would be deploying the drag system and needed to ensure it was captured on film. We also tested a third camera that was not in use for the previous flight and it tested fine and was placed in the up camera position. This camera failed to power on during the flight arming procedure. Fortunately, the down camera continued to function properly and the drag system deployment was captured on film. Upon further assessment, we found that the two cameras that failed will no longer power on even with a full charge. Either they suffered damage during the flights caused by the forces acting upon them, or they failed due to manufacturing specifications.

## Propulsion System Assessment

The J-415-WL and K-550-WL were good choices for our team. They provided enough of a difference to ensure we were meeting the spirit of the challenge, yet were not so different as to demand a more complicated solution to reaching identical apogees. This being our team's first year with rockets and our first competition, these motors were a great choice.

*Table 1: Comparison of Predicted v Actual Performance*

| General Values | | |
|---|---|---|
| | J-415-WL | K-550-WL |
| Actual Total Weight [kg] | 6.17 | 6.49 |
| Predicted Total Weight [kg] | 5.44 | 5.44 |
| Total Impulse [N-s] | 1201 | 1594 |
| Average Thrust [N] | 343 | 456 |
| Peak Thrust [N] | 552 | 853 |
| Burn Time [s] | 3.5 | 3.5 |
| Propellant Mass [kg] | 0.66 | 0.88 |
| Motor Mass [kg] | 1.199 | 1.515 |

| Performance Values | | | | |
|---|---|---|---|---|
| | | J-415-WL | K-550-WL | Difference [ft] |
| Actual Altitude [ft] | Primary StratologgerCF | 3516 | 3552 | 36 |
| | Secondary StratologgerCF | 3508 | 3546 | 38 |
| | Team Altimeter2 | 3506 | 3554 | 48 |
| | Competition Altimeter2 | 3512 | 3557 | 45 |
| Predicted Altitude [ft] | | 3600 | 3600 | |
| Actual Velocity [ft/s] | Primary StratologgerCF | 510 | 660 | |
| | Secondary StratologgerCF | 515 | 680 | |
| | Team Altimeter2 | 554 | 689 | |
| | Competition Altimeter2 | 525 | 657 | |
| | Pitot System | 510-554 | 650 | |
| Predicted Velocity [ft/s] | | 625 | 700 | |
| Actual Acceleration [$ft/s^2$] | Team Altimeter2 | 273 | 408 | |
| | Competition Altimeter2 | 264 | 383 | |
| | Pitot System | 400 | 750 | |
| Predicted Acceleration [$ft/s^2$] | | 240 | 215 | |