NC STATE UNIVERSITY

Tacho Lycos
2019 NASA Student Launch
Flight Readiness Review Addendum

High-Powered Rocketry Club at NC State University
911 Oval Drive
Raleigh, NC 27695

March 25, 2019

Common Abbreviations & Nomenclature

AGL	=	above ground level
APCP	=	ammonium perchlorate composite propellant
ARRD	=	advanced retention and release device
AV	=	avionics
BP	=	black powder
CDR	=	Critical Design Review
CG	=	center of gravity
CP	=	center of pressure
EIT	=	electronics and information technology
FAA	=	Federal Aviation Administration
FMECA	=	failure mode, effects, and criticality analysis
FN	=	foreign national
FRR	=	Flight Readiness Review
HEO	=	Human Exploration and Operations
HPR	=	High Power Rocketry
HPRC	=	High-Powered Rocketry Club
L3CC	=	Level 3 Certification Committee (NAR)
LCO	=	Launch Control Officer
LRR	=	Launch Readiness Review
MAE	=	Mechanical & Aerospace Engineering Department
MSDS	=	Material Safety Data Sheet
MSFC	=	Marshall Space Flight Center
NAR	=	National Association of Rocketry
NCSU	=	North Carolina State University
NFPA	=	National Fire Protection Association
PDR	=	Preliminary Design Review
PLAR	=	Post-Launch Assessment Review
PPE	=	personal protective equipment
RFP	=	Request for Proposal
RSO	=	Range Safety Officer
SL	=	Student Launch
SLS	=	Space Launch System
SME	=	subject matter expert
SOW	=	statement of work
STEM	=	Science, Technology, Engineering, and Mathematics
TAP	=	Technical Advisory Panel (TRA)
TRA	=	Tripoli Rocketry Association

Table of Contents

List of Tables

List of Figures

1. Flight Readiness Review Addendum Summary

1.1 Team Summary

1.1.1 Team Name and Mailing Address

Team Name: High-Powered Rocketry Club at NC State
Mailing Address: 911 Oval Drive, Raleigh, NC 27695
Primary Contact: Harvey Hoopes IV (Email: hwhoopes@ncsu.edu; Phone 910-389-3757)

1.1.2 Mentor Information

Name: Dr. Charles "Chuck" Hall
Email: chall@ncsu.edu
TRA Certification Number/Level: 14134, Level 3
Name: Alan Whitmore
Email: acwhit@nc.rr.com
TRA Certification Number/Level: 05945, Level 3
Name: James "Jim" Livingston
Email: livingston@ec.rr.com
TRA Certification Number/Level: 02204, Level 3

1.2 Purpose of Flights

The purpose of the demonstration flight discussed in this document was to qualify both the launch vehicle and payload.

1.3 Flight Summary Information

Table 1-1 Launch Conditions and Predictions

Detail	Remarks
Date of Flight	March 23, 2019
Location	Bayboro, NC
Launch Conditions	Winds 10-15
Motor Flown	Aerotech L1150R
Ballast Flown	1.25 lbs
Final Payload Flown (Y/N)	Yes
Airbrake System Status	N/A
Declared Target Altitude (ft.)	4090
Predicted Altitude (ft.)	4136
Measured Altitude (ft.)	3192/3195

Table 1-2 List of Off-Nominal Events

System	Event
Launch Vehicle	Apogee of 3192 ft AGL
Payload	Eye bolt separated from pod during launch
Payload	Pusher broke during launch

Payload	Payload deployment electronics did not activate at launch field
Payload	UAV Failed to arm when commanded by the RTX

1.4 Changes Made Since FRR

Table 1-3 Changes made to Vehicle Criteria

Change	Reason for Change
Fin Can Ballast	Stability margin exceeded team derived requirement 6.9 during launch on February 9th. Ballast in Fin Can moved the CG further aft.
GPS no longer controlled by a power switch	Circuitry for switch interfered with GPS functionality. Testing in FRR confirmed GPS fulfilled endurance requirements without the use of a switch

Table 1-4 Changes Made to Payload Criteria

Change	Reason for Change
Hooks Installed on Pod Flaps	Hooks redirect shock cord away from flight path of drone after flaps open.
New VTX installed	New VTX transmits at 200mW of power throughout the whole flight regime.
New antennae for video transmission circuit	Improved video quality and range.
Extension added to end of payload pod	Increases distance between pod and payload bay at deployment. This enables the hooks to better redirect shock cord out of the flight path of the drone.
Payload Pod flaps thickened	Added robustness to counter outward force produced by UAV in closed state. Thicker walls also provide better adhesion for modular parts.
9V to power latch	Weight reduction in the nosecone section to comply with team derived requirement ___.
5:1 gearbox added to drivetrain	Increased torque to overcome friction during payload deployment events
Guide rod reinforced with carbon fiber rod	A stiffer guide rod reduces friction due to misalignment of guide rod and lead screw during payload deployment.
Lead screw changed to steeper pitch	Used to increase the speed of the payload deployment event.

2. Payload Demonstration Flight Results

2.1 Payload Retention Performance

2.1.1 Design Summary

The UAV itself is retained in all directions by the payload pod. The pins in the floor of the pod hold the UAV laterally, the carbon fiber rod holds it vertically, and the pins in combination restrict all rotation. The pod is held in the payload bay by the centering rings, which hold it in 5 degrees of freedom. Axially, the pod has an eye bolt which is latched to an electronic latch. Should a latch wire disconnect, the latch would be unable to unlock, continuing to retain the payload.

2.1.2 Successes

The latch, having been tested between the CDR and FRR document dates, continued to prove its reliability. The connections between the bulkhead and latch also withstood full flight forces. Finally, the overall design and placement of the payload ensured that a retention failure would not result in a free-falling pod.

2.1.3 Failures

During the flight, the loading placed on the connection between the pod and latch was enough to break the eye bolt free from the pod. This left the pod secured by the friction of the centering rings, friction along the carbon fiber rod, and gravitational force directed by the vertical orientation of the payload bay. Additional flight or recovery event loading cause the pusher to break in shear, across the layers. This indicates that the loading was impulsive, as longer times would have allowed for delamination. The pusher and cantilevered carbon fiber rod remained attached and through the pod, and the pod was recovered while still present in the payload bay. On recovery, the pod extended from the aft most centering ring by 0.5 inches, which would not have been possible had the pod been attached to the latch.

While the pusher breaking has an impact on payload retention. The removal of the eye bolt due to flight loading is what ultimately frees the pod axially. Upon inspection after recovery, the eye bolt was still attached to the perimeter layers of the 3-D printed pod. This leads to the conclusion that the ultimate point of failure was the infill percentage of the pod. In a subsequent 3D print from the one tested, the infill percentage was lowered. While the overall material properties were considered, the effects of localized forces were not.

Upon landing, the Payload Communications Subteam lead initiated the payload deployment process by transmitting a 433 MHz radio signal to the payload bay electronics. This signal was not successfully received by the payload deployment electronics system. As a result, the latch did not disengage from the now severed eye bolt and the stepper motor did not begin turning. Attempts were made to send the deployment signal from progressively closer distances. None of these attempts were successful.

2.1.4 Status of Damaged Hardware

The eye bolt connecting the payload bay pod to the latch was severed completely from the pod. This damage, shown in Figure 2-1 requires that a new pod base be printed and attached to the pod. Additionally, the pod and eye bolt would be tested in accordance with section 6.1.5 of the FRR document.

Figure 2-1 Damage to Payload Retention System

2.1.5 Lessons Learned

The retention of the payload pod is a safety concern for personnel and spectators on the ground, which makes it an utmost focus for design. The payload pod has gone through many small design improvements, calling for it to be reprinted. The payload retention test was performed on the most updated pod at the date it occurred, which was not the same 3-D print as the one flown on the March 23rd launch. A change in infill percentage may have impacted the ability of the eye bolt and pod to withstand flight loads. The key takeaway for the team is to put into place administrative controls which ensure that a change in flight hardware calls for a re-test of related requirement verification tests. This lesson learned is echoed in the discussion of the payload electronics in Section 2.2.5.

2.2 Payload Mission Performance

2.2.1 Design Summary

The steps of the designed payload mission are as follows:

- If the main parachute is inflated upon landing, it will be restrained by a member of the recovery team.

- Upon verification that the launch vehicle has settled, the signal will be sent to the deployment radio receiver, beginning the Arduino program.
- The Arduino will trigger the latch to unlock
- The Arduino will, through the shield attachment and motor controller, begin the stepper motor.
- The stepper motor drives the pusher, which drives the pod from the payload bay
- The pod self-orients heavy side down
- The Arduino drives the motor in reverse, pulling the cantilevered rod out of the pod.
- When the rod is clear, the elastic potential of the folded UAV arms will open the flaps of the pod. This leaves the UAV able to lift vertically with no obstacles in the path of the rotor blades.
- Within line of sight of the UAV, turn on and verify that video receiver is receiving a video signal from the UAV.
- Once video signal has been confirmed, turn on and arm the UAV using the RTX.
- The UAV pilot lifts the UAV up out of the pod and flies to an altitude where the UAV is easily visible above any existing tree line.
- The UAV is then piloted to a predetermined target or future excursion area (FEA).
- Once the position of the UAV over the FEA has been visually confirmed, the pilot then lowers the altitude of the UAV, deploying the simulated navigational beacon onto the FEA, before landing safely in a pre-determined landing area.
- The UAV is then disarmed and power off the RTX and video transmitter leaving the UAV safe to approach.

2.2.2 Successes

The UAV was able to take off, from the open payload pod, achieving stable and level flight in turbulent wind conditions. It was able to be flown, both by line of sight and camera, and landed safely. The simulated navigational beacon (SNB) was deployed, though a test of the UAV's ability to accurately drop the SNB was not tested at the March 23rd launch.

2.2.3 Failures

As described in section 2.1.3 above, the pusher, designed to use the spinning lead screw to deploy the pod, was sheared into 3 parts, making it incapable of completing its mission. The shock cord may have interfered with the pod opening, but as the pod had to be removed manually, this was not tested on launch day.

Section 2.1.3, describes how the payload retention system failed to disengage after being sent a signal to initiate the payload deployment sequence. In addition to this failure, the subsequent steps of the payload deployment process also did not occur. This includes the activation of the stepper motor to drive the lead screw and pod out of the body tube. These components were inspected at the launch field as the team suspected a severed power connector was to blame for this failure. The Payload Communications Subteam lead was unable to find evidence of any loose or disconnected wires and then elected to reattach the nosecone and payload bay and transport them to the team's lab facility, intact, for further inspection. The results of this inspection are discussed in section 2.2.5.

Once the payload pod had been manually deployed, the arming mechanism on the radio transmitter (RTX) failed to arm the UAV at approximately 0.32 miles away. This distance had been previously tested and was known to be within the range of the RTX. The RTX was restarted two times and the arming The UAV was observed to be producing the beep code for indicating no detection of the RTX. The UAV was approached, and the arming procedure was repeated from 3 feet away with no success. The UAV was then restarted via disconnecting and subsequently reconnecting the power supply. After the UAV rebooted, it armed properly and then performed a nominal flight maintaining connection to the RTX.

2.2.4 Status of Damaged Hardware

After a visual inspection of the UAV, it was determined that no hardware sustained damage during the flight of the launch vehicle.

The pusher was the only part of the payload that was damaged in a way that requires replacement. Figure 2-2 shows the damage to the pusher. The pusher is constructed of 3D printed PLA plastic with a carbon fiber rod press fit into the center and a plastic nut for interfacing with the lead screw, press fit into its lower portion. Replacement consists of reprinting the plastic portion and pressing a new carbon fiber rod into place. This would be followed by testing of the payload deployment process to confirm proper functionality of the new pusher.

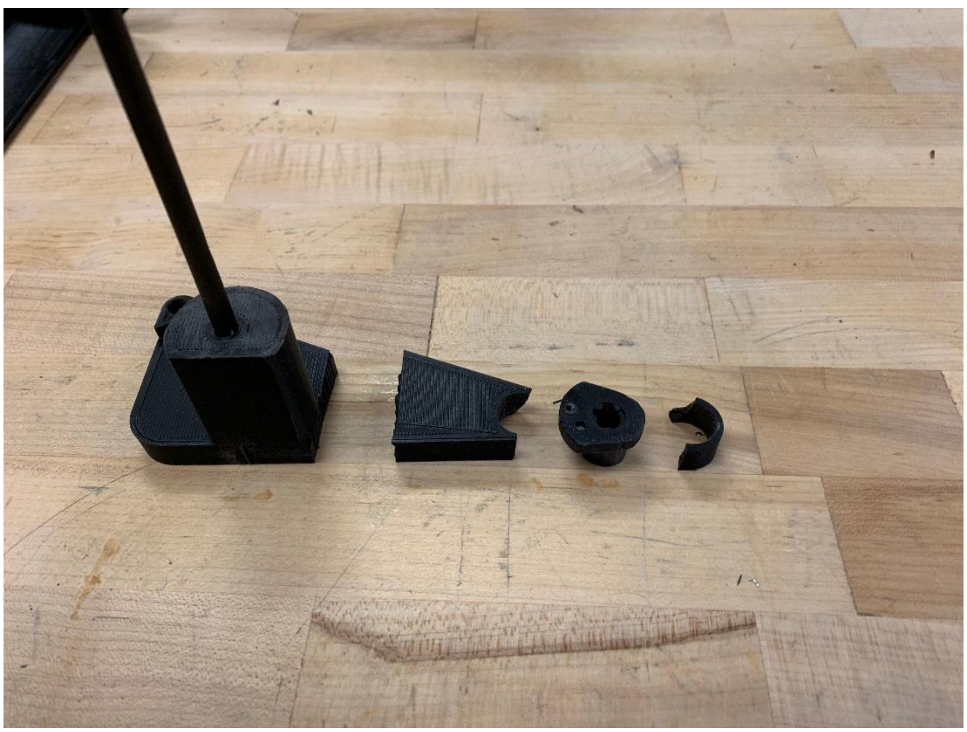

Figure 2-2 Damage to Payload Pusher

2.2.5 Lessons Learned

The fractured state of the payload pusher caused the team to question its design and construction; though without further testing, the following claims are merely conjecture. The nature of the press fit between the plastic nut and the pusher likely subjected the plastic in that area to some amount of preloaded tension. The fractures in this region, shown on the right side of Figure 2-2, suggest that the payload pod was forced towards the aft end of the payload bay; an event that is associated with the firing of the main parachute ejection charge. With the eye bolt connection severed, this would have exposed the region of the pusher around the lead screw to a bending moment. This, coupled with the preloading associated with the press fit, is likely the failure mechanism that compromised the pusher. For future projects involving 3D printed parts, the team shall exercise caution when using construction techniques such as press and interference fits. The team shall use finite element analysis to better understand the internal stresses imposed by these techniques and, where able, use chemical adhesives that better exploit the strengths of 3D printed building materials.

After returning to the lab, the Payload Communications Subteam Lead and Payload deployment Subteam Lead inspected the nosecone and payload bay assembly in greater detail. After taking photos to document the condition of the article after transport, the Payload Communications Subteam Lead again attempted to initiate the payload deployment process. With the transmitter with 2 feet from the body tube, the payload electronics responded immediately and the payload deployment sequence was executed as designed. An attempt to initiate the deployment process was not done at this distance at the launch field. This is because the payload pod had already been manually removed from the body tube by the time the Payload Communications Subteam Lead and UAV pilot had arrived at the landing site to address the issues with UAV connectivity. The payload electronics had been on for over 8 hours at the time of this test which suggests they had ample power at the launch site.

A test of the range capability of the payload electronics was conducted prior to the first payload demonstration flight on February 9th and is discussed in section 6.1.4 of the FRR document. In this test, the onboard electronics were not enclosed in fiberglass as they were on launch day. The team recognizes that not testing the electronics in their launch day configuration may have skewed the results of this test. From this result the team has learned that all testing of flight components should be conducted, when possible, with the components in their flight ready configurations. Doing so will ensure that the results of a test are reflective of launch day conditions. Regardless of the outcome of this payload demonstration flight, the team has plans to test the range of the payload deployment electronics in their flight ready configuration in the coming week.

In an effort to determine why the UAV was not able to reestablish connection to the RTX without being restarted, an additional test of the connectivity was conducted. The UAV was powered on with the RTX. The UAV was then armed to verify that the RTX was properly connected. Once the connection had been verified the RTX was powered off and the UAV was left to sit for 2 hours (similar to 3/23/19 launch day conditions). The RTX was then powered on and successfully armed the drone without issue. This test was done to see if the UAV would stop trying to connect to a controller after a certain amount of time. The preliminary results of this test suggest that the length of time during which the UAV was disconnected was not a factor in its failure to arm after launch. The only difference from the test and the launch that could reasonably be attributed to the failure observed were the loads experienced during flight. The UAV Subteam Lead is currently reviewing the UAV's flight controller documentation to determine if high accelerations can cause the controller to enter an unresponsive state.

3. Vehicle Demonstration Flight Results

3.1 Launch Vehicle Performance

3.1.1 Successes

3.1.1.1 Structure of Launch Vehicle

All systems of the structure of the launch vehicle performed as intended during the vehicle demonstration flight. The launch vehicle was able to be recovered on the field with no signs of damage to any bulkheads, body tubes, or fins upon inspection. The t-nut inserts which were used to secure sections that were attached permanently during flight performed as designed and held the applicable sections during all stages of flight. They also did not separate from the coupler sections within the launch vehicle and no damage was sustained to them from flight.

In addition, the increased amount of shear pins used at the main parachute separation point was sufficient to secure the sections together during flight and drogue parachute deployment, while not hindering main parachute deployment or causing damage to the vehicle.

3.1.1.2 Recovery Subsystem

The recovery system functioned as designed. The drogue parachute deployed at apogee as designed. The drogue deployed and opened fully with no tangled shroud lines. The main parachute deployed after the launch vehicle descended below 600 feet AGL. The main parachute opened fully with no tangled or twisted shroud lines. The deployment bag and all Nomex cloths used to protect the parachutes from thermal conditions during the deployment events were successfully retained by the recovery harness. Neither parachute sustained any damage requiring repair or replacement.

3.1.2 Failures

No aspect of the launch vehicle's performance failed to meet the criteria of the launch vehicle demonstration flight requirements. However, some of the results of the flight were off-nominal; these results will be discussed here.

Figure 3-1 Launch Vehicle Flight Path Shortly After Takeoff

Despite the team's efforts to prevent weathercocking, the launch vehicle still exhibited severe weathercocking in the moments shortly after rail exit. The launch rail was angled 3 degrees away from the wind. Figure 3-1 shows the launch vehicle pointing into the wind at an angle of 33 degrees with respect to vertical. The launch vehicle was launched from a 10 ft launch rail mounted to a launch pad of sturdier construction than the one used previously. This was done to prevent weathercocking due to a low rail exit velocity. It is clear that these measures were insufficient to prevent weathercocking. However, the results of this launch suggest that this trajectory does not inhibit the launch vehicle's ability to be launched and recovered safely.

3.1.3 Altimeter Data

Figure 3-2 shows the data extracted from the primary altimeter. Apogee was recorded at 3192 ft AGL. Top speed was recorded at 480 fps. This data also shows that the launch vehicle descended under drogue at a speed near the estimated 71.5 fps. Additionally, the descent rate under main was found to be near the previous result of 17 fps.

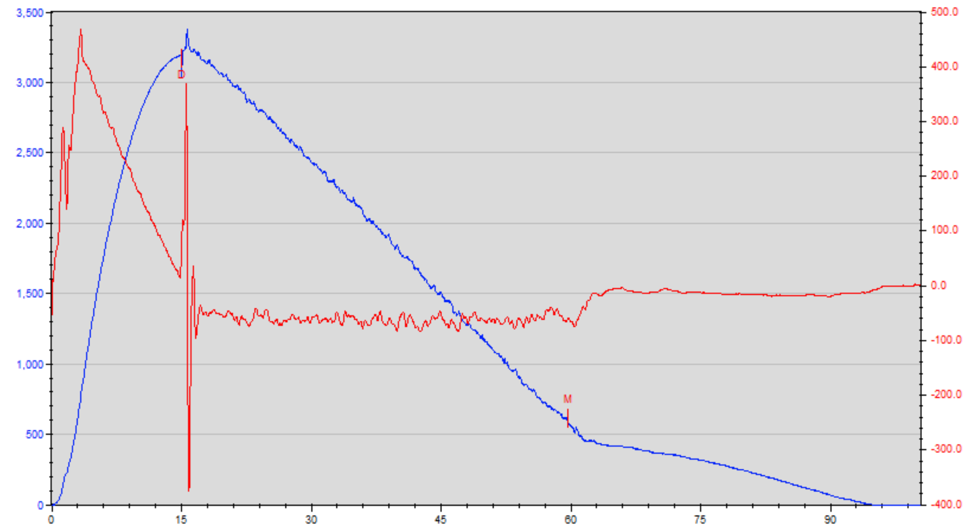

Figure 3-2 Flight Data from Primary Altimeter

3.1.4 Flight Analysis

The launch vehicle left the rail at a velocity of approximately 69.25 feet per second which is comparable to the RockSim model of 64.45 feet per second. After exiting the launch rail, the launch vehicle weathercocked into the wind at approximately 33 degrees off vertical in a span of approximately 2 seconds. After picking up speed, the launch vehicle traveled along a straight trajectory towards its final apogee of 3192 ft. Wind conditions at launch were measured as 10-14mph on the ground. At the time of launch, the Coastal Carolina Regional Airport in New Bern, NC report a density altitude of –75 feet MSL on its Automated Weather Observing System (AWOS). These observations were used to create a post-flight simulation in RockSim. Figure 3-3 shows the results of this simulation.

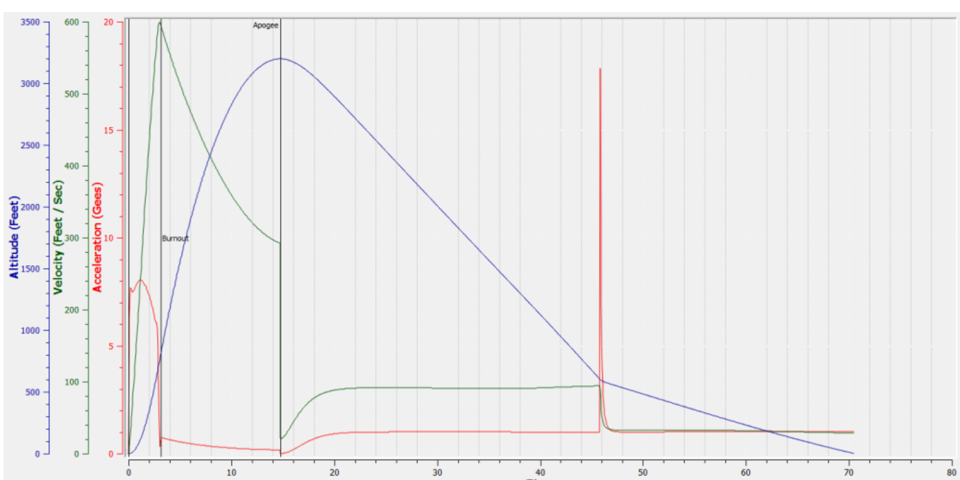

Figure 3-3 RockSim Post Launch Flight Analysis

3.1.5 Drag Coefficient Estimation

The data in Figure 3-3 was generated after first adjusting the drag coefficient of the launch vehicle to reflect the flight data in Figure 3-3. The drag coefficient was found to be 0.365.

This is lower than the previous estimate of 0.55 in the FRR. This change is due to the team's increased confidence in the early flight conditions of the launch vehicle. Specifically, the team is confident in the accuracy of the measured wind conditions, the launch rail exit velocity and the angle of the launch vehicle shortly after takeoff.

3.1.6 Status of Damaged Hardware

After inspecting the launch vehicle, it was determined that no components of the launch vehicle require repair or replacement. However, inspection of the motor casing after launch revealed an indentation in the forward closure that was not present before launch. Shown in Figure 3-4, this indentation extends into the area normally occupied by the forward seal O-ring. This O-ring is necessary for maintaining stable pressure within the casing during the motor burn. After consulting with the team's advisor and mentor, the team has elected to replace this forward closure with an identical, but undamaged, forward closure for any future flights. Furthermore, the damaged flight article has been marked inoperable and shall not be used in any future launches.

Figure 3-4 Damage to Motor Casing Forward Closure

3.1.7 Lessons Learned

The results of this launch suggest that the rocket, in its current configuration, will weathercock dramatically in windy conditions. This will greatly impede the team's chances of achieving the apogee goal of 4090 ft. Based on the results of this flight and the team's first flight, even light winds will result in the launch vehicle failing to reach a scorable apogee. The team's mentors have advised that in the future, the team opt for larger fins as well as a motor that provides a higher thrust to weight ratio to prevent this issue. While these changes cannot be applied to the current launch vehicle design, the team intends to implement them as best practices in future years. Additionally, the team is exploring the possibility of acquiring another motor for testing by the team's mentors who are both members of the Technical Advisory Panel of TRA. Due to the limited availability of L-class motors at this stage of the competition cycle, the team is unable to pursue such testing at this time.