Quick Link: A NAR Level 2 Certification Rocket

Nathan Tardy*
Florida Institute of Technology, Melbourne, Florida, 32901, USA

In the United States, there are primarily two organizations that facilitate the high-power rocketry (HPR) certification process: the National Association of Rocketry (NAR) and the Tripoli Rocketry Association (TRA). While there are slight differences between these two organizations in terms of certification and membership, the *general* certification requirements are comparable. Within these organizations, there exist three levels of certification, with 'level 1' being the least technically challenging and 'level 3' being the most involved. While there are benefits that ensue at each level of certification (namely, in the form of being permitted to purchase more powerful rocket motors), perhaps the greatest incentive for obtaining certification lies with the educational aspects of the engineering process. This manuscript details the design, construction, and test processes involved with preparing a NAR level 2 (L2) certification rocket for flight. Design topics of discussion will include the custom 3D-printed avionics bay and its components. Construction topics will include material selections and assemblage methods. Lastly, tests performed include ground-based ejection charge tests for each section of the rocket's dual-deployment-capable assembly, and the results of the flight attempt will be discussed. While the preliminary objective of this project was to obtain a NAR L2 certification, it was subsequently desired to present this work to an appropriate community to afford the reader the opportunity to learn from the author's hardships as well as to provide a foundation for assisting Florida Tech AIAA members with their NAR L2 certifications.

I. Introduction

The National Association of Rocketry (NAR) and the Tripoli Rocketry Association (TRA) are, arguably, the two largest organizations involved with model and high-power rocketry (HPR) in the United States. Each organization offers its members three levels of certification, and the higher the level of certification a member obtains, the higher the 'power' of rocket motors they are allowed to purchase.

The word 'power' is placed in quotes here to emphasize that it is not a *completely* accurate descriptor; commerical-off-the-shelf (COTS) solid rocket motors are primarily measured via their total installed impulse (in Newton-seconds), which is not the same as power (typically measured in watts (Joules per second)). However, the amateur rocketry community tends to refer to motors with a greater installed impulse as 'more powerful'; thus, such terminology will also be employed here.

Each level of HPR certification comes with its own unique requirements, and the general requirements for each level of certification are comparable (if not identical) between the NAR and the TRA. Since the rocket discussed here was built and flown for a NAR L2 certification attempt, the certification requirements of that organization will be detailed. Although the particular level of certification attempted was level two, general requirements for each level of potential certification will be provided to aid in understanding the required process for certification.

*Undergraduate Student, Department of Aerospace, Physics, and Space Sciences, and AIAA Student Member (1401603)

II. Levels of Certification

<table>
<tr><th colspan="4">Hobby Rocket Motor Information</th></tr>
<tr><th>Classification</th><th>Impulse Range</th><th>Impulse Limit</th><th>Category</th></tr>
<tr><td rowspan="11">Model Rocket</td><td>1/8A</td><td>0.3125</td><td>Micro</td></tr>
<tr><td>1/4A</td><td>0.625</td><td rowspan="6">Low Power</td></tr>
<tr><td>1/2A</td><td>1.25</td></tr>
<tr><td>A</td><td>2.5</td></tr>
<tr><td>B</td><td>5</td></tr>
<tr><td>C</td><td>10</td></tr>
<tr><td>D</td><td>20</td></tr>
<tr><td>E</td><td>40</td><td rowspan="3">Mid Power</td></tr>
<tr><td>F</td><td>80</td></tr>
<tr><td>G</td><td>160</td></tr>
<tr><td rowspan="8">High Power</td><td>H</td><td>320</td><td rowspan="2">Level 1</td></tr>
<tr><td>I</td><td>640</td></tr>
<tr><td>J</td><td>1280</td><td rowspan="3">Level 2</td></tr>
<tr><td>K</td><td>2560</td></tr>
<tr><td>L</td><td>5120</td></tr>
<tr><td>M</td><td>10240</td><td rowspan="3">Level 3</td></tr>
<tr><td>N</td><td>20480</td></tr>
<tr><td>O</td><td>40960</td></tr>
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Fig. 1 A tabular view of the various amateur rocket motor impulse classes. [1]

A level 1 certification is required to fly rockets "containing multiple motors with a total installed impulse of [greater than or equal to] 320.01 Newton-seconds" or "containing a single motor with a total installed impulse of [greater than or equal to] 160.01 Newton-seconds." [2] This tends to be the primary goal or objective of an L1 flight attempt: the flyer must use an H or I impulse class (range) motor (which, as shown in Figure 1, fall within the 160.01 Newton-second to 640 Newton-second impulse limits) or a combination of H and I motors not exceeding 640 Newton-seconds of combined impulse and, upon successful certification, is permitted to use motors of similar impulse class for future flights. [2] Furthermore, it is also required to 1) "launch rockets that weigh more than 53 ounces (1500 grams)" or 2) launch rockets containing motors that produce a) an "average thrust in excess of 80.0 Newtons"; b) "contain in excess of 125 grams of propellant"; or c) are classified as a "hybrid" rocket motor. The numerous preceding qualifiers essentially establish the boundary between model and high-power rocketry; the former exclusively uses lower-power motors and, as a result, does not require any special certifications, while the latter does. [2] For a comprehensive list and breakdown of the requirements for NAR HPR L1 certification, see [2].

Moving along, a level 2 certification "allows the purchase and use of J, K, and L impulse class motors," which, as shown in Figure 1, fall within the limits of 640.01 Newton-seconds and 5120 Newton-seconds of impulse. [3] The flyer must use one of these motor classes for their certification attempt. Additionally, to attempt a level 2 certification, the flyer must currently be level 1 certified and "in good standing" with the NAR. [3]. Furthermore, unlike the procedures for an L1 certification, a level 2 certification requires a passing score (35/40) on a 40-question multiple-choice exam, which must be administered and successfully completed before the flight attempt. See [3] for an extensive list and breakdown of the process and requirements for a NAR HPR L2 certification.

Lastly, the highest level of certification that the NAR offers is level 3, which requires flying a rocket containing a motor with greater than 5120 Newton-seconds of impulse (which falls into the M, N, and O impulse classes, as shown in Figure 1). The process for obtaining an L3 certification is significantly more involved than that of L1 and L2 certifications, primarily due to the significantly increased power of the motors that L3-certified flyers are permitted to use and the associated safety concerns. Although L3 certification attempts do not require a written exam as the L2 process does, flyers wishing to become L3-certified must work in conjunction with "a member of the Level 3 Certification Committee (L3CC)," who will ensure that the flyer has sufficient experience successfully flying high-power rockets and that their L3 certification rocket will meet the requirements set forth by the NAR. [4] For purposes of brevity, the previous description only scratches the surface of the requirements and process for obtaining an L3 certification; a more complete list can be found at [5].

III. Vehicle Design

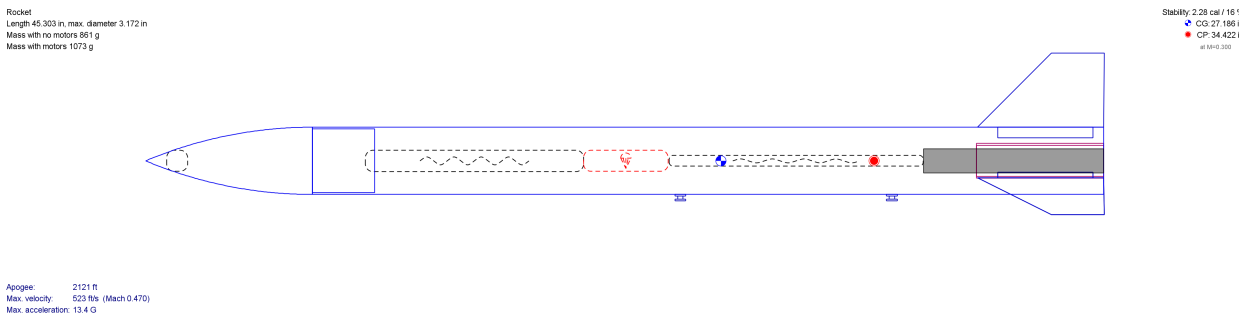

Fig. 2 A 2D, wireframe depiction of the level 1 certification rocket in OpenRocket.

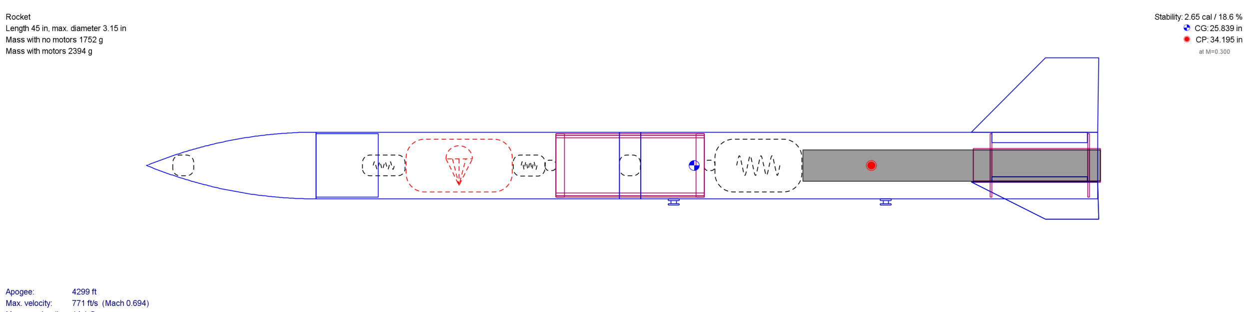

Fig. 3 A 2D, wireframe depiction of the level 2 certification rocket in OpenRocket.

The previously-flown L1 certification rocket, shown above in Figure 2, was mostly repurposed for the L2 certification attempt; the same airframe, fins, and motor mount assembly were used. However, modifications related to the increased power and weight of the larger motor required for the L2 certification attempt were performed and will be further discussed below. In Figure 2, note that the red dot along the longitudinal axis of the vehicle and positioned near the aft of the vehicle denotes the center of pressure (CP) or the location at which the total resultant aerodynamic forces can be considered to act. Furthermore, note that the blue and white 'checkered' circle near the vehicle's center and along the longitudinal axis represents the vehicle's center of gravity (CG). For the vehicle to be stable in flight, the center of gravity **must** be closer to the nose of the vehicle than the center of pressure. Traditional practices involve placing the CG about 2-3 airframe diameters (denoted as 'calibers,' or 'cals' for short) ahead of the CP. In the above design, the vehicle's stability was roughly 2.65 cals with the motor installed. The stability is aided by having 100 grams of ballast located in the tip of the nose cone (shown as a black dashed circle in Figure 2) and held in place with epoxy, although, as will be discussed, this was not sufficient for the larger motor required for the L2 certification flight.

A. Motor Choice

A J270-14A *Aerotech* motor was the intended motor to be used for this L2 certification flight, which was considerably more powerful and heavier than the H135-14A* *Aerotech* motor used for the previous L1 certification flight. This motor was chosen primarily because it was one of only a few J-class *Aerotech* motors that would fit into the 38mm-diameter motor tube installed in the rocket. This was the main reason that the L1 certification rocket was repurposed for this L2 flight: it was *capable* of holding a J-class motor that would suffice for the certification attempt. If a smaller motor tube had been used for the L1 rocket, this cross-capability would not have existed, and the vehicle could not have been reused in the manner it was. Another benefit of using the chosen motor was that its installed impulse was only 703 Newton-seconds, which, as shown in Figure 1, is less than 100 Newton-seconds greater than the most powerful I-class motors (the next lowest class). Since rocket motor costs tend to be proportional to their impulse, this helped keep the cost of the motor to a minimum by keeping it toward the lower limit of the required impulse for the certification flight.

B. Nose Cone

The same nose cone design was used for both the L1 and L2 certification rockets. It was 3D printed from black PLA material and featured an ogive shape. It also included a shoulder section that was roughly 3in long and 3in diameter; this portion fit *into* the top of the airframe and helped hold the nose cone in place via a simple friction fit during the vehicle's ascent.

For the L1 rocket, 100 grams of ballast (scrap nuts and bolts) were internally added to the tip and secured with epoxy to give the vehicle greater aerodynamic stability. This pulled the CG closer to the tip of the vehicle and increased the static margin.†

For the L2 nose cone, the ballast mass was increased to 200 grams to compensate for the increased weight of the larger motor. This required obtaining a new nose cone, which had already been 3D printed and would have been necessary anyway, given that the L1 nose cone was accidentally knocked off of a workbench after the certification flight, causing the tip to crack off and render it unfit for further flight.

After the ballast was secured in place, the shoulder of the nose cone was sanded down to eliminate a small lip created by the 3D printer to make it fit easier into the airframe. The nose cone was intentionally 3D printed with a slightly larger-than-optimal shoulder diameter, with the understanding that it would need to be sanded down. These nose cones are often printed in batches for L1 rocket certification build workshops hosted by the Florida Institute of Technology AIAA chapter for its members, and printing them with a larger shoulder allows each flyer to tailor the friction strength between the nose cone and the airframe as desired.

The nose cones are printed with a cross-piece at the base of the shoulder, which serves as a connection point for the shock cord.

C. Airframe

1. Body Tube

As previously mentioned, the airframe from the L1 certification rocket was reused for the L2 rocket, albeit with some necessary modifications. Firstly, using a larger motor meant an increased apogee for the rocket's flight, and this all but necessitated that the rocket be flown with onboard avionics (which will be discussed in great detail subsequently). To accommodate this, the airframe was cross-sectionally cut into three sections; the lower section stretched roughly 21.5in from the tail of the rocket, the middle section consisted of a 1in band that was epoxied to the avionics bay, and the upper section connected the previous band to the nose cone.

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*In amateur rocket motor names: 1) the leading letter refers to the impulse range of the motor; 2) the number following the leading letter is the average thrust of the motor (in Newtons); 3) the number following the dash is the pre-installed default delay (in seconds) between the ignition of the motor and the ejection charge; and 4) the final letter is a code that refers to the appearance of the motor's exhaust. For the H135-14A, the motor belonged to the 'H' impulse range, produced 135 Newtons of average thrust, and had a default ejection charge delay of 14 seconds.

†The static margin measures the vehicle's stability and can be calculated by measuring the distance between the CG and CP and dividing by the diameter of the vehicle. Positive values indicate that the CG is closer to the nose than the CP and, thus, that the vehicle is longitudinally stable. Conversely, negative values indicate that the CP is closer to the nose than the CG, meaning the vehicle is unstable.

2. Fins and Motor Mount Assembly

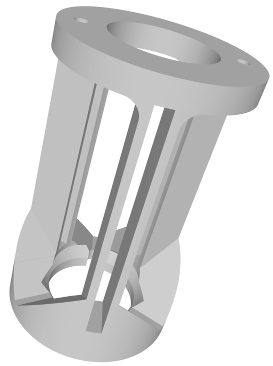


Fig. 4 An image of the 3D printable motor tube holder and fin aligner. A previous member of the Florida Tech AIAA rocket team designed this piece.

As previously mentioned, the aft of the vehicle was kept nearly identical to its configuration for the L1 flight; the same fins and motor mount assembly were used. The primary design change involved the addition of fillets to the connection seams between the fins and the airframe. While there were neither structural concerns for the fins before the L1 flight nor afterward, adding the fillets was desired to give the fins a qualitative 'factor of safety.' The motor mount assembly included a 3D-printed, combined motor tube holder and fin aligner, which a previous Florida Tech AIAA member designed. This assembly is shown in Figure 4. The part is pictured upside-down, which is to say that the top ring with two symmetric screw holes[‡] belongs at the bottom of the rocket. In this image, the fin tab slots can be seen running tri-symmetrically along the longitudinal axis of the part. These slots were designed to be the same size as the tabs of the fins cut via a laser cutter at the Florida Tech L3Harris Student Design Center (L3HSDC). (A previous Florida Tech AIAA rocket team member, who was laser-cutter certified and has since graduated, assisted with cutting the fins.)

D. Avionics

The largest change to the vehicle's design was the addition of an avionics bay. This included a custom avionics sled, two bulkheads, and a cylindrical fiberglass-wrapped tube coupler, all 3D-printed.

[‡]The screw holes are for screws that mount a retaining ring that helps hold the motor in the rocket after burnout and during the firing of the ejection charge. Somewhat funnily, for the L1 flight, the friction fit between the motor and the cardboard motor tub was so extreme that the retaining ring was unnecessary and not used. However, it could have served as a redundant method of motor retention.

1. Structural Design

(a) The avionics sled and bulkheads that sealed the ends of the avionics bay.

(b) The tube coupler with the bulkheads sealing each end.

Fig. 5 Images from Fusion360 of the avionics assembly.

The avionics sled (Figure 5a) was designed with mounting holes for the COTS altimeter and GPS on one side and holes for zip ties to secure the necessary batteries on the other. The bulkheads included shoulders that were designed to fit flush into the tube coupler (Figure 5b), and each had one centrally-located hole for the threaded rod and one off-center hole for the ejection charge wire.

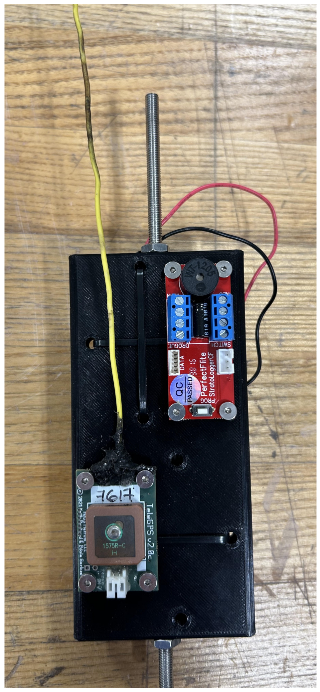
(a) Top view of the tube coupler.

(b) Side view of the tube coupler.

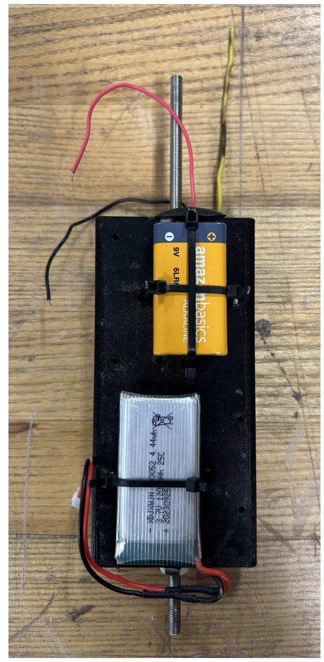
(c) The assembled avionics bay.

Fig. 6 Images of the avionics tube coupler and the assembled avionics bay.

The tube coupler was 3D-printed and then wrapped in roughly five layers of fiberglass cloth. The black inner plastic coupler and outer fiberglass layers can be best observed in Figure 6a. The aforementioned 1in band cut from the airframe was epoxied around the middle of the tube coupler, as shown in Figure 6.



(a) The front of the avionics sled with the altimeter and GPS.



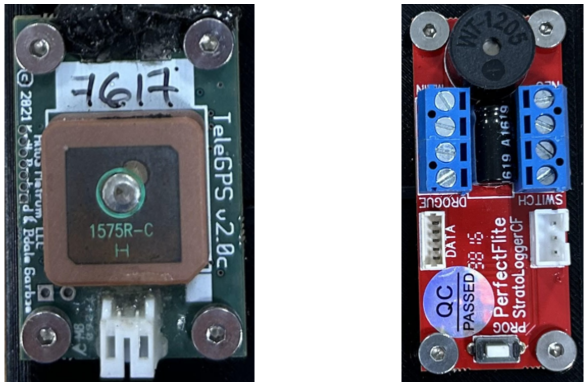
(b) The back of the avionics sled with the batteries to power the altimeter and GPS.

Fig. 7 Images of the avionics sled and its components.

The avionics sled, shown in Figure 7, has an M5 threaded rod through its center along its longitudinal axis and two $\frac{10}{32}$ nuts securing it, one on each end. The threaded rod fitted through printed holes in the bulkheads (visible in Figure 5a) and connected with M5 eye nuts (visible in the top and bottom of Figure 6c). To accommodate the antenna of the GPS (visible as the yellow wire in Figure 7), an extra off-center hole was drilled out of the bottom bulkhead.

2. Components

From an electronics perspective, the avionics bay included a COTS *PerfectFlite Stratologger CF* altimeter and an *Altus Metrum TeleGPS*, shown in Figure 8. These were chosen because the Florida Tech AIAA rocket team had previously used them for project rockets, and they were temporarily available for use. The altimeter and GPS were powered by a 9-volt battery and a 3.7-volt LiPo battery, respectively.



(a) The front of the *Altus Metrum TeleGPS*.

(b) The front of the *PerfectFlite Stratologger CF* altimeter.

Fig. 8 Images of the electronic avionic components.

The altimeter, shown in Figure 8b, is capable of managing a dual-deployment recovery system, which includes a drogue parachute that deploys at the apogee of the flight (typically) and a main parachute that deploys at an arbitrary lower altitude. While the rocket flown for the L2 had a dual-deployment *capable* assembly, no drogue parachute was used to minimize the lateral drift of the vehicle on the descent. However, the vehicle still used two ejection charges; one to separate[§] the booster section from the top portion at apogee (thus increasing the drag on the airframe and slowing its descent rate), and another to deploy the main parachute at 700 ft.

IV. Vehicle Construction

As mentioned, most of the vehicle was constructed for the L1 certification flight. However, for completeness, this process will also be included here.

A. Motor Mount and Fins

A dremel was used to cut fin slots out of the body tube, and since a three-fin design was employed, these slots were cut 60° apart with respect to the longitudinal axis. The Kevlar shock cord was fitted through the motor mount's upper portion (the bottom circular opening of Figure 4) and epoxied to the cardboard motor tube. Then, the motor mount assembly was inserted into the bottom of the rocket, the fin tabs and slots were coated in epoxy, and the fins were inserted into the slots. (It should be noted that the *actual* process involved much more trial-and-error than was described here. Very rarely do the fin tabs perfectly align with the slots in the body tube *and* those in the motor tube holder on the first attempt.) To ensure structural soundness, a very generous amount of epoxy was applied to the motor mount assembly and fins, and the result was (fortunately) very rigid. Lastly, fillets were added to the fins for the L2 flight to increase the structural rigidity further.

B. Nose Cone

The ballast for the nose cone was scrap nuts and bolts that were freely available at the Florida Tech L3HSDC and were weighed out on a digital scale. To ensure adequate stability for the vehicle, 100 grams were added inside the nose cone tip and epoxied in place. As previously mentioned, this weight was increased to 200 grams for the L2 attempt, necessitating a new cone.

C. Shock Cord

A Kevlar shock cord was used for the portions exposed to an ejection charge. For the L1 flight, this included the portion of the shock cord between the motor and the Nomex fire blanket protecting the parachute. For the L2 attempt, this included the shock cord for the entire booster section and the portion in the upper section between the avionics bay and the Nomex fire blanket. Any portions of the shock cord that would not be (intentionally) exposed to an ejection

[§]The two portions were still connected via a shock cord.

charge were braided Nylon cords. ‘Figure-eight follow loop’ knots were tied to connect the shock cord to the nose cone crosspiece, to connect the Kevlar cord to each side of the avionics bay, and to connect the Nylon and Kevlar shock cords (although a simpler knot, such as a ‘square knot,’ would have likely sufficed). An ‘overhand loop knot’ was tied in the Nylon cord to connect to the parachute’s quick link.

D. Avionics Bay

The 3D-printed tube coupler was wrapped in 4-5 layers of fiberglass cloth, which were coated in epoxy as they were wrapped. This greatly increased the stiffness of the coupler, which was important given that the coupler would be one of the exposed pieces of the vehicle upon landing. Once the epoxy applied to the fiberglass cloth had cured, the 1in band cut from the airframe was epoxied to the center of the tube coupler and allowed to cure. Lastly, the excess fiberglass cloth was cut off the ends of the tube coupler, and the coupler was sanded down to help it fit better into the airframe.

E. Aesthetics

Finally, the vehicle (except the nose cone) was spray-painted blue, and the fin section was further covered in matte grey. Additionally, matte grey lettering spelling ‘Quick Link’ was spray painted to the upper section using a hand-cut paper stencil and a generous amount of masking task. All this is shown in Figure 9.

(a) Positioned horizontally on a workbench. **(b) Leaning vertically against a workbench.**

Fig. 9 The vehicle fully assembled (no motor) and painted.

V. Testing and Simulation

The flight attempt was intended to occur at the *Spaceport Rocketry Association* (SRA) site on one of their scheduled launch days. There were three separate instances (launch days) when the vehicle was intended to be flown: November 18, 2023, January 20, 2024, and February 24, 2024. In November, it was first necessary to help other Florida Tech AIAA members with their NAR L1 certifications before the L2 flight could be attempted. Unfortunately, by the time all the L1 certifications had been completed, there was not enough time remaining to complete the L2 flight. Instead, this was used as an opportunity to perform an ejection charge test of both sections of the vehicle. Another ejection charge test was performed before the January launch day. The following figure (Figure 10) shows still images taken from videos of these ejection charge tests.

(a) Ejection charge test of the upper section. **(b) Ejection charge test of the bottom section.**

Fig. 10 Ejection charge tests of the vehicle's upper and lower sections.

The January launch day yielded a similar result; an emphasis was placed on assisting other members with their NAR L1 certifications, so there was not enough time for the L2 certification attempt. Lastly, the February launch day yielded the same result as the January launch day; a flight could not be attempted.

A. Simulation and Simulated Results

In the absence of a flight attempt, the next best method for quantifying the (theoretical) performance of the vehicle was via computer simulation. The free rocket software *OpenRocket*, which was used to create the wire-frame models shown in Figures 2 and 3, was used to model the vehicle and simulate its performance.

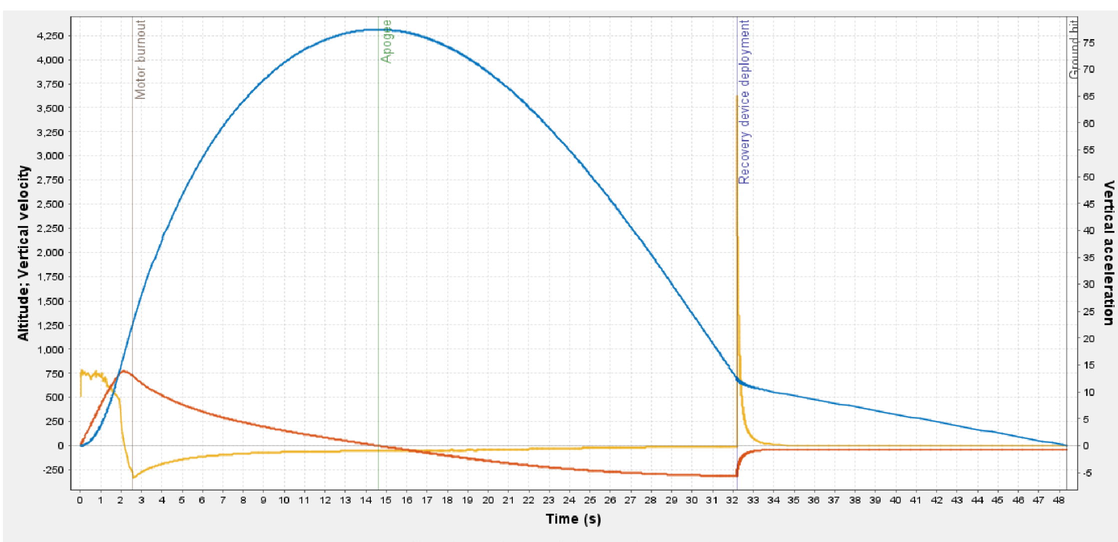


Fig. 11 OpenRocket simulation of the vehicle's performance.

Figure 11 above shows the simulated performance of the vehicle based on the motor intended to be used and the wind conditions on the February launch day. According to this simulation, the apogee of the flight was predicted to be about 4312ft, the vehicle would experience a maximum velocity of about $772\frac{\text{ft}}{\text{s}}$ (M = 0.694), and the vehicle would experience a maximum acceleration of about 14.1 G $\left(454.02\frac{\text{ft}}{\text{s}^2}\right)$.

While the predicted apogee and maximum velocity can be taken as acceptably accurate, the predicted maximum acceleration is likely a gross overestimate. Despite its multitudinous capabilities, *OpenRocket* does not simulate drag on the airframe. Therefore, due to the lack of a drogue chute, it cannot appropriately simulate the descent rate of the vehicle between apogee and the main parachute ejection; it treats the vehicle's behavior as ballistic, which results in an obscene predicted acceleration at the moment of main parachute deployment. If the vehicle had flown, this would not have been the case; the drag on the airframe would have slowed it down to a reasonable descent rate, and while the ejection of the main parachute *would* have caused a sizeable acceleration for the vehicle, it would not have been on the order of 10+ Gs.

VI. Conclusion

A NAR Level 2 certification rocket was fully constructed, which included a custom 3D printed and fiberglass-wrapped avionics bay. Ejection charge tests of both sections of the vehicle were performed successfully, which, when combined with the positive stability of the vehicle, indicated that the design is fit for flight. Time constraints prohibited a flight attempt numerous times; accordingly, computer simulations were used to predict the vehicle's performance using the wind conditions on the date of the last launch day. The vehicle had a simulated maximum altitude, velocity, and acceleration of 4312ft, $772\frac{\text{ft}}{\text{s}}$, and 14.1 G $\left(454.02\frac{\text{ft}}{\text{s}^2}\right)$, respectively. The validity of these results has been discussed, and the probable inaccuracy of the predicted maximum acceleration has been addressed.

There are a few areas for improvement of the vehicle's design. Firstly, the length of the upper section is *barely* adequate for holding the parachute and shock cord while also accommodating 3 inches (roughly half) of the avionics bay. In several ejection charge tests, this volumetric limit caused the charge to 'vent' out the gap between the avionics bay and the airframe instead of separating the vehicle. To mitigate this issue, the length of the vehicle's upper section could be increased using an extra section of airframe and a tube coupler. While there is no analysis to substantiate these estimates, from intuition, 6-12 inches of added length should be more than sufficient.

Another area of improvement also lies with spatial limitations; the avionics bay should be redesigned longer. Since it must fit into a 3in airframe and cannot be made any radially larger, a longer avionics bay would allow for much neater and easier wire management. On the February launch day, the avionics bay was fully assembled with all battery connections and ejection charges, and there was *barely* enough room for all the necessary wires.

Lastly, the size of the main parachute should be increased. The descent rate under the current parachute is roughly $38.5\frac{\text{ft}}{\text{s}}$, which is faster than optimal. General amateur rocketry guidelines suggest a ground-impact velocity of 15-20$\frac{\text{ft}}{\text{s}}$, however, this can be varied based on the flyer's confidence in the strength of their external components. While the vehicle constructed is more than strong enough to survive a ground-impact speed of roughly $40\frac{\text{ft}}{\text{s}}$, a slower descent rate would increase the safety, reliability, and reusability of the vehicle.

Acknowledgments

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