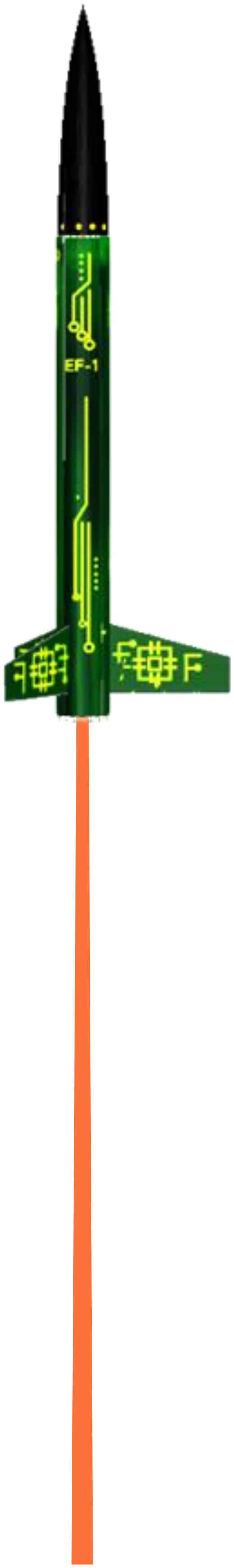

EF-1 Rocket

High Power Certification Level 1 Design Report

University of Florida

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Executive Summary

Abstract

The EF-1 rocket was built primarily to experiment and validate passive roll control through canted fins and attain the level 1 high power rocketry certification with an H-class impulse motor from the National Association of Rocketry. Its design achieved a crucial balance between high performance, affordability with a $200 budget, and visual appeal. With an abundance of options and design choices, weighted decision matrices and trade studies were employed to finalize the design. After a design was created in Fusion 360, the result was simulated in OpenRocket, a numeric simulation software, to fix and verify parameters such as stability margin and the ejection charge delay to ensure successful flight. The EF-1 launched with no issues and was recovered after successful parachute deployment at a simulated apogee of 2,288 feet. Although the mission was successfully completed, certain simulated results such as the spin stabilization, stability margin, and apogee were unverifiable without an avionics bay. Future iterations of the rocket, or more notably an EF-2 rocket, should aim to verify these constraints by incorporating a GPS sensor, camera, and an inertial measurement unit.

Table I: Launch Vehicle Summary	
Parameter	Value
Rocket Name	EF-1
Predicted Apogee	2,288 ft
Motor Selection	H135W-14A
Max Diameter	2.68”
Length	35.8”
Wet Mass	35.3 oz
Dry Mass	31.0 oz
Launch Date	January 11, 2026
Parachute Shroud Line Length Diameter	48”
Parachute Shape	Hexagon

Changes Since Preliminary Design Review

Since the Preliminary Design Review (PDR), the fins have been modified to improve performance, stability, and manufacturability. Originally, aluminum sheet metal was selected for the fin material due to its heat tolerance and ease of availability. However, it is susceptible to bending and detachment because of epoxy bond failure. Aluminum naturally forms a thin layer of aluminum oxide (Al_2O_3) on its surface, which impedes adhesion unless properly abraded or sandblasted. Fiberglass offers greater durability and stiffness, is easier to bond with epoxy, and provides comparable thermal resistance while reducing mass by approximately half. The fin geometry was adjusted accordingly to raise stability to a safe margin of approximately 2.0 calibers. Rather than a delta fin with zero leading-edge sweep angle, a trapezoidal planform was adopted as detailed in *Design Methodology*. Lastly, the position of the aftmost centering ring was shifted 0.25 inches forward to provide sufficient clearance for an epoxy fillet during assembly. This manufacturing requirement was not identified in the original PDR.

Introduction

Mission Statement and Purpose

The EF-1 rocket is being developed primarily to experiment with and validate passive roll control, achieved through the addition of carefully canted fins. Its design is a thoughtful optimization, achieving a crucial balance between high performance, affordability, and visual appeal. The rocket is being constructed using a variety of structural materials, from aluminum and engineered plywood for core strength to various durable plastic components.

The rocket is named after my initials followed by the number 1, EF-1, reflecting the iterative nature of engineering design. The designation signifies there is more to come in a sequence of improvements in advancing performance and reliability of the rocket.

Project Background

High Power Rocketry Certification

The purpose of this project is to attain the Level 1 High Power Rocketry Certification from the National Association of Rocketry (NAR), as noted in [1]. This is a requirement for buying an H and I motor and is necessary for more advanced certification levels. The motor must be within 160.01 to 640 Newton-seconds of impulse (classified as H to I motors), and the rocket must weigh below 53 ounces to abide by FAA regulations. In addition, it must contain a standard parachute recovery system and pass inspection by a certification team. The rocket will be evaluated for stability during ascent, recovery system deployment, and safe recovery. If successful, NAR is to sign and approve the paperwork necessary for certification.

The achievement of this certification demonstrates the ability to develop and demonstrate that the engineer has the necessary knowledge and skills to safely construct, prepare, and launch rockets using mid-power motors.

Motor Nomenclature

The rocket motor designation for disposable single-use solid-state boosters follows a predictable structure. The motor employed in the EF-1 is the HP-135W-14A. The first two letters immediately designate whether it is a low-power or high-power rocket, where HP stands for high power. The next letter is separated by a dash with the impulse class listed. Measured in newton seconds (Ns), an H impulse class motor has 160 Ns to 320 of thrust [2]. The number after the impulse class designates the nominal average thrust of 135 newtons. The final letter, W, indicates the propellent which is white lightning in this case. White Lightning propellant is from AeroTech and produces a smoky white trail [3]. The suffix portion of the name dictates the ejection charge information. The number 14 is the number of seconds the ejection charge can wait until firing. The A is for adjustable, as the charge is adjustable using a tool to shave off time.

Passive Roll Control

Passive Roll Control through canting fins for fin stabilization is a concept harnessed by the EF-1 rocket by canting fins. Passive roll control in this context refers to an intentional slight spin in a controlled direction and rate. This effectively negates thrust misalignment by rotationally averaging the thrust direction. This prevents the rocket from thrusting too much into one direction, helping to resolve small asymmetries.

This functions through canted fins, which generate aerodynamic torque that allows the rocket to spin. The airflow surrounding each canted fin produces a side force on each fin, which causes the rocket to roll according to (1). The roll torque is weak at liftoff but is expected to rise rapidly during powered ascent and descent as the rocket slows according to (2).

$$\tau_{\text{roll}} \approx \sum r_i \, F_{\text{side},i} \tag{1}$$

$$q = \frac{1}{2}\,\rho V^2 \tag{2}$$

Stability Margin

The stability margin, also known as the static margin, describes how well a rocket can correct itself and flight straight after being disturbed by wind or an off-nominal launch. It's calculated as the distance between the rocket's center of gravity (CG) and center of pressure (CP), divided by the rocket's body tube diameter, giving a result expressed in "calibers" (3), where D is the diameter of the rocket.

$$\text{Stability margin} = \frac{x_{\text{CP}} - x_{\text{CG}}}{D} \tag{3}$$

The CG is the point where the rocket's mass balances, which describes the points where the rocket pivots during flight. A CP below the CG is considered stable because it allows a restoring torque to reorient the nose back into the direction of airflow. An unstable rocket would amplify any wobble instead of dampening or correcting it. A stability margin of two is desired, as going lower would be unstable, while going higher would cause excessive weathercocking [4].

Black-powder Ejection Charge Sizing

Black powder is the explosive powder responsible for stage separation by creating an area of high pressure that pushes against the bottom of the nose cone and causes it to eject outwards. The amount of black powder to insert is dependent on the ideal gas law, with the weight of powder needed, W_p, isolated. The other parameters include the target ejection pressure (P) which was selected to be 10 psi. The internal volume (V) of the cavity that will be pressurized, the specific gas constant (R) at about 22.16 ft·lbf/(lbm·°R) and the combustion gas temperature (T) at approximately 3307 °R.

$$W_p = \frac{P \times V}{R \times T} \tag{4}$$

The volume of the cavity can be approximated as a cylinder, as the internal portion of the airframe is almost a perfect cylinder aside from the top and bottom edges.

$$V = \frac{\pi}{4} \times D^2 \times L \tag{5}$$

Report Organization

The following report reviews the design requirements in depth by going over a comprehensive list of both functional and performance requirements based on the NAR certification standards and personal project goals. An overview of constraints is included to ensure the project remains reasonable and possible to execute. Following the design requirements, the design methodology outlining the design process, analysis tools, component selection approach, and safety considerations is found before the final design description. The final design description provides in-depth context of the final design before manufacturing. The final design is manufactured and verified in the next section through simulations and the physical launch. Finally, conclusions and recommendations are to be drawn based on the results of the design.

Design Requirements

Eligibility and On-site Requirements

To attain the NAR HPR L1 certification the candidate must be at least 18 years old with a government issued identification. The candidate must also be in good standing in NAR with a membership. The candidate must launch a high-power rocket (impulse over 320 N-sec) and pass a preflight safety inspection where the candidate verbally explains their design technically [1]. This inspection includes how the center of gravity, center of pressure, and stability margin was found to ensure safe deployment. The candidate must demonstrate an understanding of the performance characteristics of the rocket and the motor nomenclature. The certification is given if there are two level two NAR certified witnesses, or one level two witness [1].

Functional Requirements

To attain the certification, the model rocket must function like a conventional rocket with no shapes (e.g., pyramids, saucers, etc.) [1]. The motor must be an H- or I-impulse class motor which does not exceed 640 N-sec without stacking lower-impulse motors. The motor can be any nonexperimental motor including but not limited to single-use, reloadable, or hybrid motor technologies. The rocket must contain an active recovery system like a parachute with nonstandard recovery methods (e.g., tumble, helicopter, gliding, etc.). An avionics bay with electronics is not required nor prohibited for the flight [1].

Performance Requirements

Several performance requirements related to safety and stability are present. For powered ascent, the rocket must fly straight up without tumbling, excessive weathercocking, veering off the pad, or in an unpredictable manner. The parachute must deploy properly at apogee and safely decelerate the rocket for landing. If a dual deploy drogue parachute is chosen, the landing must end with the main parachute. Upon landing, the rocket must be intact with only minor cosmetic damage. Any structural breakup or detached fins count as failure.

Constraints

The functional constraints overlap with the functional and performance requirements, but personal constraints involve cost and time. This project is funded and must not exceed an allocated budget of over $200. In addition, this project is to be completed within one university school semester, or within four months' time. Although there are no explicit apogee requirements, an apogee of at least 2000 feet as well as testing passive roll control is a realistic goal set for the EF-1 project.

Design Methodology

Overall Design Process

The design process started with defining objectives. The objectives are based on the requirements for the L1 HPR NAR certification with the added apogee goal of at least 2000 feet and test of passive roll control. This is also where the conceptualization stage occurred with the name of EF-1 given to the rocket, as well as the theming of looking like a PCB board. Afterwards, a research stage was conducted where more fundamental physics was reviewed and typical L1 rockets were investigated to get an idea of the general form factor. This led to material selection stage where all critical materials were chosen. Lastly, the design was conceptualized using parametric 3D modeling software like Fusion 360. This prototype was then simulated in OpenRocket. Although these are separated into multiple design stages, the design process was more fluid in that a previous stage could be revisited if any of the constraints and requirements were not met with the current prototype (Fig. 1).

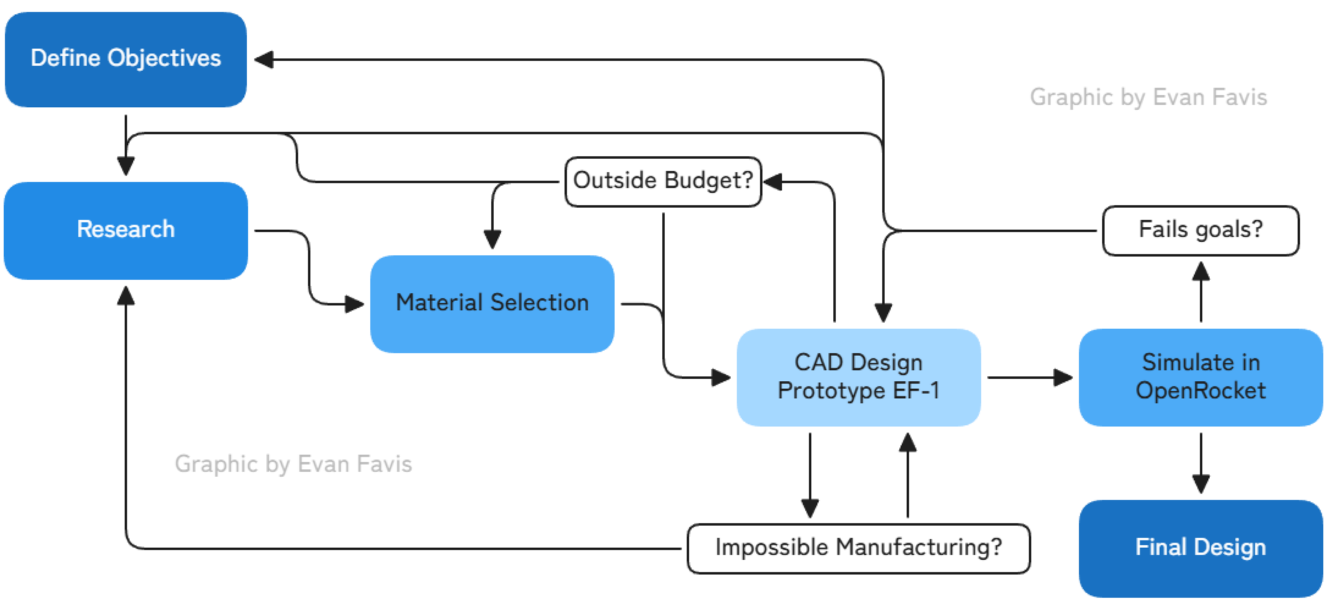


Figure 1 Design Stages for EF-1 Rocket

Materials and Component Selection Approach

Due to the abundance of options, weighted decision matrices were employed to finalize the material selection process. Weighted decision matrices provide a structured quantitative way to defensively and systematically choose materials while maximizing objectivity and minimizing bias. A weighted decision matrix contains an objective characteristic being compared across all materials, along with a weighting factor to account for its importance on the overall decision. The magnitude is given for each material in its corresponding unit which is shown in the parameter column. The objectives characteristics were chosen to be important factors required for performance and assembly. Density is included to account for differences in weight. Cost is included due to a limited budget. Ultimate tensile strength (UTS) and young's modulus (E) serve to ensure the rocket has sufficient structural integrity to survive the harsh aerodynamic conditions. Manufacturability was also considered and ranked from one to three where one is the worst manufacturability, two is better, and three is best. Codes start with M and a number were used to denote the manufacturability score due to the space constraints on the table. M1 refers to ease of manufacturability in cutting. M2 refers to how it can easily the material can be epoxied. Some materials cannot be glued well, while others require significant sanding to work. Lastly, M3 refers to safety and how dangerous it is to work with sanding.

A score from zero to ten ranks each objective proportionally where ten is the best score. The formula for the maximizing and minimizing cases are summarized in (6) and (7). Density and cost are minimizing factors, because ideally a lighter rocket with lower cost is better. On the other hand, the ultimate tensile strength, Young's modulus, and manufacturing rankings are maximizing objectives because we want these to be as high as possible.

$$\text{score} = \frac{10 \times \text{design magnitude}}{\text{highest magnitude}} (\text{Maximizing Parameter}) \tag{6}$$

$$\text{score} = \frac{10 \times \text{lowest magnitude}}{\text{design magnitude}} (\text{Minimizing Parameter}) \tag{7}$$

The value multiplies each score by a weighting factor (WF) to account for the set importance of each parameter. Density has the lowest WF at 5%, while other parameters unrelated to manufacturing are at 10%. Manufacturing parameters are set greater than or equal to 20% because we are limited by time and equipment. Density was put at the lowest weighting factor of 5% because apogee is not a main priority for this flight.

$$\text{value} = \text{score} \times \frac{\text{weighing factor}}{100} \tag{8}$$

The overall value sums all the values in the column and is the final number examined for the material selection assessment.

$$\text{overall value} = \sum_{i=1}^{n} \text{value}_i \tag{9}$$

An example decision matrix for the airframe will be presented in depth to ensure clear understanding (Table II). The young's modulus of BlueTube was treated as higher than cardboard but lower than fiberglass as described in [5]. Although no value is given, 10 MPa is a reasonable and conservative guess closer to that of cardboard. BlueTube has the highest overall value, balancing mass, cost, strength, and manufacturability. BlueTube is a vulcanized paper phenolic composite material.

Table II: Decision Matrix for Airframe Material														
Airframe Material			Aluminum [6]			Cardboard [7]			BlueTube [5]			Carbon Fiber		
Objective	WF	Parameter	Mag.	Score	Val.	Mag.	Score	Val.	Mag.	Score	Val.	Mag.	Score	Val.
Density	5%	g/cm^3	2.7	2.6	0.1	0.7	10.0	0.5	1.1	6.4	0.3	1.6	4.4	0.2
Cost	10%	USD	53.8	1.9	0.2	10.3	10.0	1.0	35.7	2.9	0.3	300.0	0.3	0.0
UTS	10%	MPa	90	1.8	0.2	15	0.3	0.0	115	2.3	0.2	500	10.0	1.0
E	10%	GPa	70	6.7	0.7	4	0.4	0.0	10	1.0	0.1	105	10.0	1.0
M1	25%	Rank	1	3.3	0.8	2	6.7	1.7	3	10.0	2.5	1	3.3	0.8
M2	20%	Rank	2	6.7	1.3	3	10.0	2.0	3	10.0	2.0	2	6.7	1.3
M3	20%	Rank	2	6.7	1.3	3	10.0	2.0	3	10.0	2.0	1	3.3	0.7
Overall value					**4.7**			**7.2**			**7.4**			**5.1**

Analysis Methods and Tools

OpenRocket was the simulation software of choice due to its sizable community and open-source nature. OpenRocket is a physics-based time-stepped six-degrees-of-freedom flight simulator by simulating a rocket's translation and rotation in three dimensions. By numerically calculating forces and moments with a fourth-order Runge-Kutta, it is an effective tool for characterizing the flight [9]. As OpenRocket is a numeric solver, it is highly dependent on the starting conditions which include atmospheric variables, gravity, launch site conditions, and wind. The selected wind will be expected wind parameters, which is 10 mph, the average between no wind and the maximum of 20 mph winds.

Information about aerodynamic loads, propulsion and mass effects, translational and angular acceleration, and stability margin will be accounted for to ensure the structural integrity of the rocket as well as safe recovery and descent. More specifically, the altitude, apogee, velocity, Mach number, acceleration, dynamic pressure, position, downrange drift, orientation, angular velocity, angle of attack, motor burnout, deployment, descent, landing behavior, CG, CP, stability, drag, and component level aerodynamic contributions will be analyzed.

As OpenRocket simulation results are highly dependent on initial conditions, the predicted initial conditions will be replaced with the actual values as they are measured. For example, the nominal mass of the fins will replace the predicted mass once manufacturing is completed. This is to ensure and compensate for any incorrect predictions.

Final Design Description

System Overview

The concept of operations of the EF-1 rocket is similar to that of a missile but simpler and shorter. After the preflight safety inspection, the rocket is placed on the pad where the rail buttons are aligned with the 10-foot rail to guide it straight upwards or slightly against the wind. During the prewarm stage, the igniter is installed without the safety key, and a continuity check is confirmed on the controller. Once the atmospheric conditions are deemed safe and after proper clearance, the ignition is pressed from a distance, and the rocket launches up to enter the boost phase. This powered ascent is thrust-dominated and lasts about 2.1 seconds before motor burnout. Due to the high momentum and inertia of the rocket, the rocket continues flying upwards after motor burnout in coast phase until it reaches the highest point at apogee. The delay grain is still burning during the ballistic portion. Once burnt out, the black powder ejection charge is ignited, which blows the nose cone off and pushes out the parachute. The parachute slowly brings the rocket down in a descent stage where the rocket slowly drifts downwards. Upon touchdown, the rocket is located and recovered for a post flight analysis.

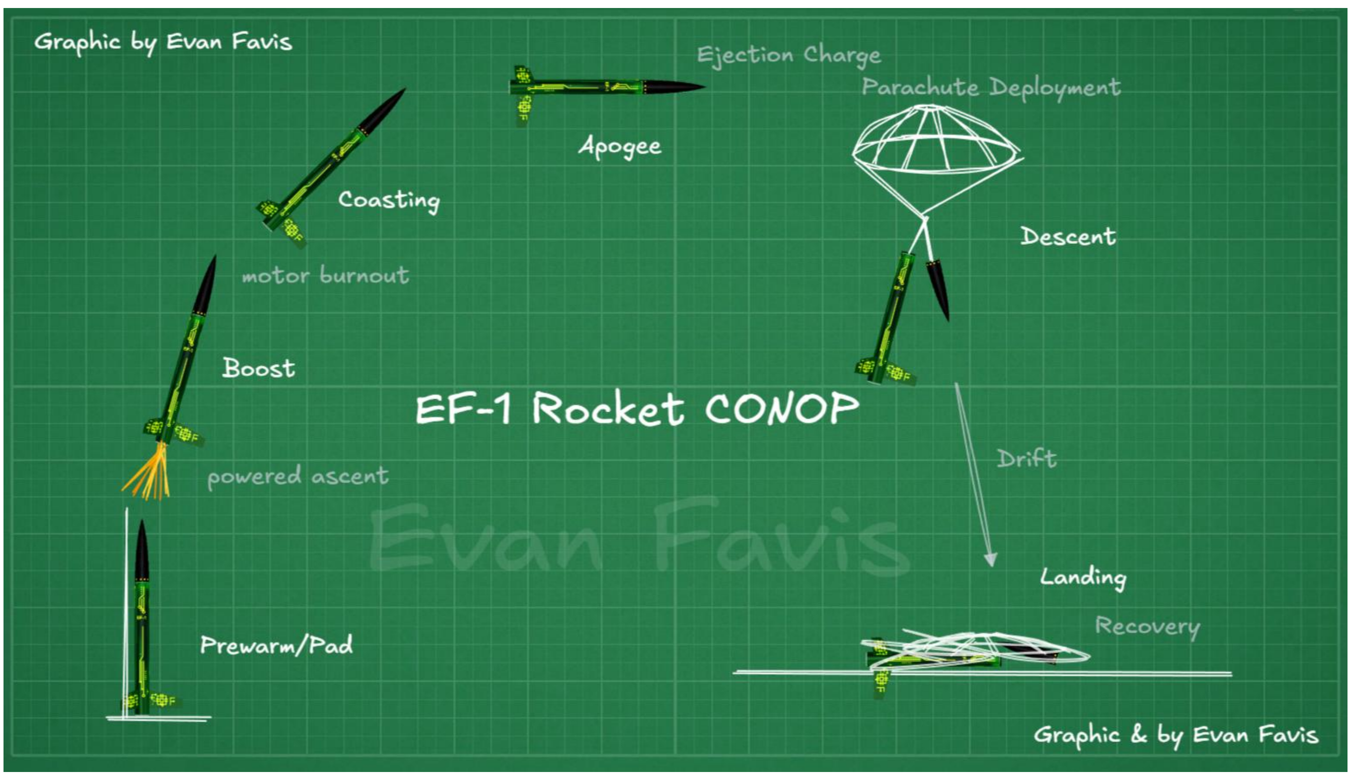


Figure 2 Concept of Operations (CONOP) of EF-1 Rocket.

To attain an apogee as high as 2,288 feet, the rocket had to be optimized for mass efficiency. For this reason, it was kept down to a total of three feet with a relatively small diameter of 2.68" to ensure the mass was kept as low as possible. Accordingly, a smaller three-foot parachute was chosen, and all materials were selected based mainly on mass and cost. Overall, the rocket ended up costing $198. Each component is described in detail under *Architecture, Components, and Rationale,* with their drawings included in *Appendix A*.

Table III: Launch Vehicle Summary	
Parameter	Value
Rocket Name	EF-1
Predicted Apogee	2,288 ft
Motor Selection	H135W-14A
Max Diameter	2.68"
Length	35.8"
Wet Mass	35.3 oz
Dry Mass	31.0 oz
Parachute Shroud Line Length Diameter	48"
Parachute Shape	Hexagon

Table IV: Component Mass Table		
Item	Mass (oz)	Additional Information
Parachute	2.2895	Scale
Eyebolt	0.643	Scale
Swivel	0.579	Scale
Shock Chord	1.2	[10]
Rail Button	0.07	[11]
Nose Cone	3.4595	Scale
Airframe	9.206	[12]
Inner Tube	2.3	[13]
Centering Rings (forward)	0.549	Scale
Centering Rings (aft)	0.559	Scale
Fins	1.88	Scale

Architecture, Components, and Rationale

Recovery System

The recovery system deployment is initiated upon motor burnout via the certified motor's internal ejection charge. This charge is blown after a set time of 12 seconds after the motor is initially lit. The ejection charge generates a rapid pulse of hot, high-pressure gas that is directed into the airframe cavity. This pressure vessel increases pressure once the charge is lit, acting against the nosecone's base to drive it out of its retention shoulder and simultaneously extract the bundled recovery system, allowing the parachute to deploy for descent. The ejected nosecone is connected via a Kevlar cord that holds the airframe and nosecone as the parachute slows down the fall (Fig. 3).

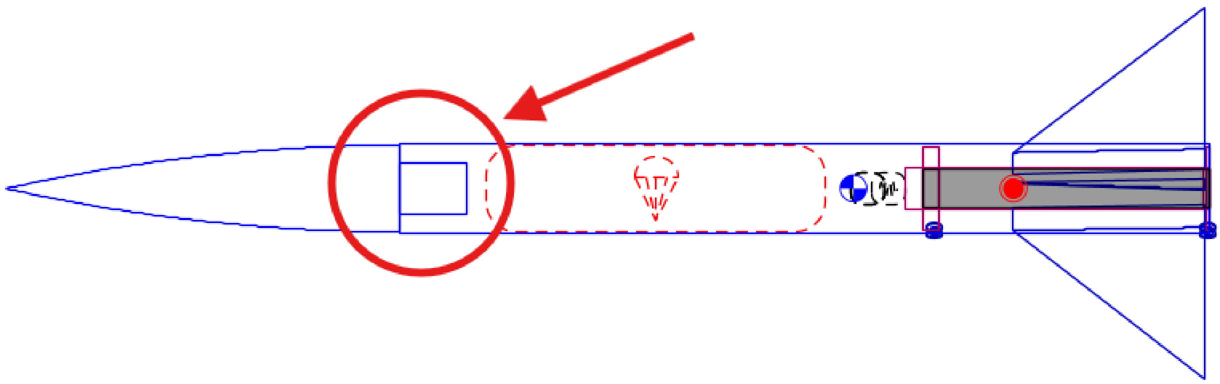


Figure 3 The Marked Separation Point is circled.

A bright parachute connected to a Kevlar shock chord designed to withstand 700 pounds of force deploys, being connected by several anchor points. These anchor points are as follows: two eyebolts, a swivel, and a D-Link. The parachute is three feet in diameter, which allows for an impact landing velocity of less than 20 ft/s, making this a valid choice for a small rocket with a relatively low mass of 35.3 oz. While using a larger parachute may appear as a safer choice, a larger parachute risks larger drift during descent. Thus, the smallest possible parachute with the given coefficient of drag was chosen while ensuring a safe impact velocity.

Table V: Parachute Summary

Parameter	Value
Mass	2.2895
Shape	Hexagon
Shroud line length	36”
Coefficient of Drag	0.75

Nose Cone

The nose cone features an Ogive shape, which is highly desirable for its low overall drag performance. The LOC Precision plastic nose cone was selected primarily for its cost-effectiveness and its lightweight nature. The hollow plastic material keeps it lightweight and is not susceptible to melting due to the flight's subsonic speeds. Thus, the nose cone experiences only minimal aerodynamic loading and does not require costly thermal protection. Structurally, the plastic is sufficient for the forces encountered. While the ideal design requires the nose cone's base diameter to perfectly match the airframe's outer diameter, the selected part has a 0.12" mismatch due to the unavailability of a perfect-fit component. This deviation is justifiable because the required dimensional correction can be easily achieved by sanding parts to fit for a close running or loose fit to ensure successful parachute deployment. The dimensions are summarized in Table VI.

Table VI: Nose Cone Summary

Parameter	Value
Shape	3.45"
Base diameter	2.56"
Length	11.62"

Airframe

The airframe, or body tube, is made up of Blue Tube, a proprietary material manufactured from recycled tank ammunition by Always Ready Rocketry LLC. This material is Mach-capable and able to withstand strong g-forces, making it overqualified for the EF-1. Although materials like carbon fiber are both strong and light, carbon fiber is considerably more expensive, while Blue Tube is comparatively cost-effective.

The rocket's airframe is designed with a 24-inch length and a 2.56-inch inner diameter. This relatively short length was chosen to minimize mass and, consequently, maximize apogee (peak altitude). However, this shorter design inherently reduces stability, necessitating a larger or more effective fin design to ensure a straight flight. The small 2.56-inch diameter is sufficient to house the motor and recovery parachute, though its narrowness may require the use of a loading stick to properly insert the parachute into the body tube. The airframe is to be bought directly from [12] and cut to exactly two feet in length using a band saw. Then, fit slots are to be cut at the 2-degree angle using a mill machine. The 2-degree angle will be executed with an airframe mount to hold it in place at the desired angle while in the vice of the mill.

Centering Rings

The centering rings ensure that the motor remains properly aligned within the airframe so that thrust is directed straight aft, preventing unintended vehicle maneuvers. Because the motor is housed inside the motor tube, the inner diameter of the centering rings must match the outer diameter of the motor tube, while their outer diameter must fit the inner diameter of the airframe. As detailed in the *Dimensions* section, the centering rings have an inner diameter of 1.207" and an outer diameter of 2.5".

The aft centering ring is positioned 0.25" forward of the airframe end to provide clearance for epoxy fillets during assembly. The rings also clamp the fins against the motor tube, increasing structural rigidity. Two centering rings were selected due to the short length of the motor tube, and plywood was chosen as the material for its availability, low cost, and favorable strength-to-weight ratio.

Fins

Fins are vital for rocketry as they provide aerodynamic stability by lowering the center of pressure. This stability is maximized if passive roll control through canted fins is added. In accordance with the mission objective, the fins are canted at a 2° angle. This slight angle deliberately induces a slow, stabilizing roll in the vehicle. This spin provides gyroscopic stability, enabling passive roll control throughout ascent. 2° was chosen as anything over 3° may cause a rocket to spin out of control and may induce more drag than necessary. A more conservative 2° was therefore chosen as a factor of safety.

The EF-1 rocket is relatively short with a total length of 35.8 inches to maximize apogee. This short height is responsible for less-than-optimal stability numbers. To counteract the short height, trapezoidal fin geometry was chosen because it offers an excellent balance of aerodynamic stability and structural integrity. Trapezoidal fins shift the center of pressure rearward without requiring excessively large surfaces and remain straightforward to manufacture. While aft-swept fins could further increase stability, they are more susceptible to damage on landing and were therefore not chosen.

The fins are constructed from fiberglass due to its high strength-to-weight ratio, stiffness, and durability. This material selection minimizes bending under aerodynamic loading and provides sufficient resilience for repeated flight conditions. Three fiberglass fins are to be cut via a waterjet machine for precision. The fin dimensions without the fin tabs are included in Table VII. As the fin parameters may be difficult to visualize, a drawing is included in *Appendix A*.

Table VII: Fin Summary	
Parameter	Value
Root Chord	Ogive
Tip Chord	4.7”
Sweep Length	4.06”
Height	15.3”
Mass	1.88 oz

Motor

The EF-1 uses an H135W-14A motor, an H-class choice that provides enough thrust to clear our 2,000-foot apogee target while testing the passive roll control system. The I-class motor was ruled out early on as it would have doubled our motor budget without offering a practical performance advantage for this specific mission profile. To fit inside the rocket's narrow airframe and minimize overall mass, a slim, elongated motor configuration was selected. The motor is bought from [3] and will simply be inserted into the Rocket. Since it is an exact fit, grease and lubricant will be required to insert the motor into the Inner Tube. Equations (4) and (5) are applied to find the weight of black powdered required.

Performance specifications for the selected motor are detailed in Table VIII below: total impulse of 226 N·s, average thrust of 135 N (peaking at 152 N), and a 1.7-second burn time. The adjustable delay timer (up to 14 seconds) gives us plenty of room to fine-tune the parachute deployment timing. Total motor weight is 7.48 oz, which includes 4.27 oz of solid propellant. The simulated thrust curve is presented in Figure 4. Figure 4 has slightly different statistics due to differences in simulation and the cataloged specifications. The cataloged specifications will be taken as it was experimentally found despite.

Table VIII: Disposable Motor System (DMS) H135W-14-A White Lightning	
Parameter	Value
Total Impulse	50.8 lb-second
Burn Time	1.7 seconds
Peak Thrust	34 lbs
Delay Time	14 seconds max (adjustable)
Propellant Weight	4.27 oz
Loaded Weight	7.44 oz
Dimensions	1.13” x 8.00”
Motor Diameter	1.125”
Casing Length	8.00”

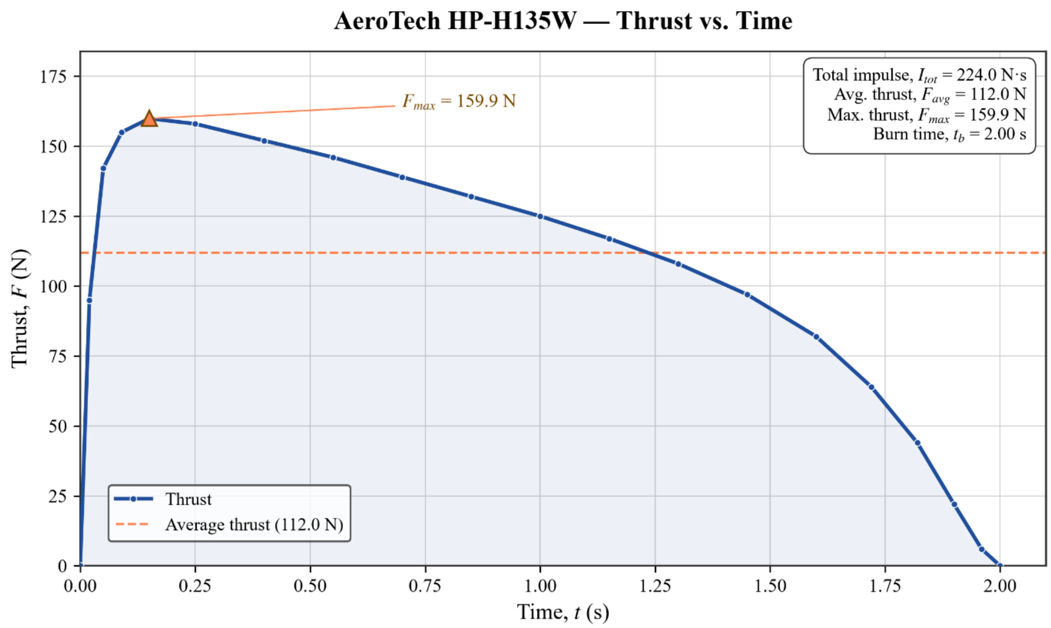


Figure 4 Simulated Thrust curve for HP-H135W motor. This differs slightly from the cataloged data in Table VIII.

Airframe Mount

The airframe mount holds the airframe at the correct angle during the milling process to manufacture the canted fin slots. The mount will hold the airframe at a 2-degree angle and additive manufacturing was executed using polyethylene terephthalate glycol (PETG), which is a glycol-modified thermoplastic polyester. This material offers superior strength compared to other similarly priced and commonly used filaments such as Polylactic Acid (PLA). The airframe mount is essentially a rectangle with a cylindrical extrude cut through it to firmly hold the airframe at the correct angle. The rectangular shape is to ensure it can be easily installed into a milling machine. Its dimensions are summarized in *Appendix A*.

Inner Tube

The inner tube holds the motor and, accordingly, has an outer diameter that matches the inner diameter of the centering ring. This exact match is a tight fit that requires a lubricant to push through. This design choice is intentional to ensure the inner tube does not fall out of the rocket while on the launch pad. It is made up of a lightweight phenolic heat-resistant cardboard-like material to save on cost.

Centering Rings

The centering ring ensures the motor tube is perfectly centered for thrust stability. The outer diameter matches the inner diameter of the airframe, and the inner diameter must be equal to the outer diameter of the motor tube. The centering ring mass closer to the tip of the rocket has an eye-bolt drilled into it, hence the lower mass value displayed.

Table IX: Centering Rings Summary	
Dimension	Value
Outer diameter	2.5”
Inner diameter	1.207”
Thickness	0.5”

Motor Retainer

The motor retainer is screwed onto the bottom of the rocket after the motor is installed. It helps to retain the motor and prevent it from falling out. A thin sheet of steel was selected for heat resistance as it is directly along the path of the exhaust of the motor

Table X: Motor Retainer Summary	
Dimension	Value
Outer diameter	2.5”
Inner diameter	0.99”
Thickness	0.1”

Heat Shield

The heat shield is to be wrapped around the parachute to protect the parachute from the intense burst of heat from the ejection charge delay. The heat shield blanket is to be wrapped in such a way as to prevent tangling within the parachute.

Table XI: Heat Shield Blanket Summary [8]	
Parameter	Value
Shape	Square
Area	144 in^2
Mass	0.4750 oz

Shock Chord

A 9’ long shock chord with a 1/8” diameter thickness and 0.104 oz/ft mass Kevlar shock chord was selected for the recovery system. The shock chord is approximately three times the overall length of the rocket to reduce peak loads and avoid mid-air collisions between components. Limiting shock loads is vital for mitigating damage like zippering, which is when the airframe unzips and tears apart after the charge fires and the parachute snaps open. An elastic shock chord was chosen to dissipate kinetic energy along the cord through elasticity through successive spring-like behavior to help prevent zippering. A 9-foot cord also minimizes the risk of mid-air collections, which occur because once the parachute deploys, the body will be hanging like two masses on a tether. These components may swing and damage the nose cone or airframe upon descent and recovery. Increasing the shock cord length to three times the body length reduces angular acceleration and impact forces. Kevlar material was selected because it offers high tensile strength and excellent heat resistance at a relatively low mass. While materials such as nylon or rubber provide greater elasticity, Kevlar's superior strength-to-weight ratio and thermal robustness make it more suitable for withstanding ejection charge temperatures and repeated recovery loads.

Off The Shelf Parts

The following items are off-the-shelf (OTS) parts ordered or bought from a third-party source. These are generally smaller pieces that are widely accessible at low cost and would be more expensive to make manually. No extra manufacturing will be done aside from epoxying or attaching the items as needed.

This includes the parachute, eyebolt, swivel, shock chord, rail buttons, and heat shield blanket. The eyebolt needs to be attached to the nosecone but there is no pre-designed method for this task. Instead, the eyebolt will be epoxied to the nose cone. The swivel is attached to the eyebolt and allows a rotational degree of freedom to prevent the shock chord from tangling. The rail buttons exist as a small protrusion to slide on the rail on the launch pad, so it is guided straight up or slightly towards the wind. For the rail button to be screwed through, a hole would have to be drilled through the airframe.

Engineering Analysis and Verification

Calculations and Models

OpenRocket was the physics-based simulation selected for the EF-1 rocket. It functions by numerically calculating forces and moments with a fourth-order Runge-Kutta to find flight characteristics. OpenRocket employs the International Standard Atmosphere (ISA) model for calculations but gives the option to set your own pressure and temperature at seal level or your given altitude for a more accurate calculation [9]. The default model will be simulated until the empirically measured information is available.

This analysis was conducted with intentionally suboptimal conditions to encapsulate realistic launch scenarios. The modified launch conditions were set as follows. An average windspeed of 10 mph at 90° is used. Note that according to [1], the maximum allowed wind for launch is 20 mph. The launch rod was sent to a 7° angle and is 10 feet (120") long. Information about aerodynamic loads, propulsion and mass effects, translational and angular acceleration, and stability margin will be accounted for to ensure the structural integrity of the rocket as well as safe recovery and descent. More specifically, the altitude, apogee, velocity, Mach number, acceleration, dynamic pressure, position, downrange drift, orientation, angular velocity, angle of attack, motor burnout, deployment, descent, landing behavior, CG, CP, stability, drag, and component level aerodynamic contributions will be analyzed.

Simulation Results

The simulated results are summarized in Table XII and elaborated upon in their respective sections. The simulation yielded a stability margin within the 1-2 range during ascent, a vertical acceleration peak of 394ft/s^2 at lift off and vertical velocity maximum at 381 ft/s. After reaching an apogee of 2288 ft at 11.21 seconds, the rocket descends for 173.7 seconds with a landing velocity of 18.1 ft/s, only drifting up to 1472 ft from the launch pad with 10 mph winds. The profile of the thrust to weight ratio and mass against time also looks favorable and is within safe bounds. The simulated results confirm the flight readiness of the EF-1 rocket as all results are acceptable for the real flight.

Table XII: Simulation Results Summary

Metric	Value
Apogee	2288 ft
Max velocity	497 ft/s
Max vertical velocity	481 ft/s
Max acceleration (motor burn)	398 f/s^2
Max acceleration (overall incl. chute shock)	880 ft/s^2
Rail-exit velocity	88 ft/s
Burnout velocity	458 ft/s
Velocity at recovery deployment (total)	61.5 ft/s
Velocity at recovery deployment (vertical)	28.5 ft/s
Ground-hit velocity (total)	20.6 ft/s
Ground-hit velocity (vertical)	13.9 ft/s
Terminal descent rate (under canopy)	13.9 ft/s
Expected drift from pad	1477 ft
Stability margin (rail exit)	1.65 cal

Table XII (Continued)	
Metric	Value
Stability margin (min powered ascent)	1.65 cal
Stability margin (max powered ascent)	2.19 cal
Max thrust-to-weight ratio	13.4
Thrust-to-weight at rail exit	12.6
Liftoff mass	43.08 oz
Burnout mass	40.19 oz
Propellant burned	2.89 oz
Motor burn time	2.04 s
Time to apogee	11.21 s
Descent time (apogee to landing)	162.5 s
Total flight time	173.7 s
Max thrust	159.8 N

Stability Margin

Stability margin is important to maintain aerodynamic stability and ensure a safe flight trajectory. The stability margin should be within 1-2 calibers until the descent stage. Although the stability margin upon ignition is lower at 1.65 calibers, this is still within the 1-2 caliber range. The EF-1 rocket successfully remains around 2 calibers of stability margin for the duration of the flight until descent, passing the rocket in terms of stability analysis for stability margin against time (Fig. 5).

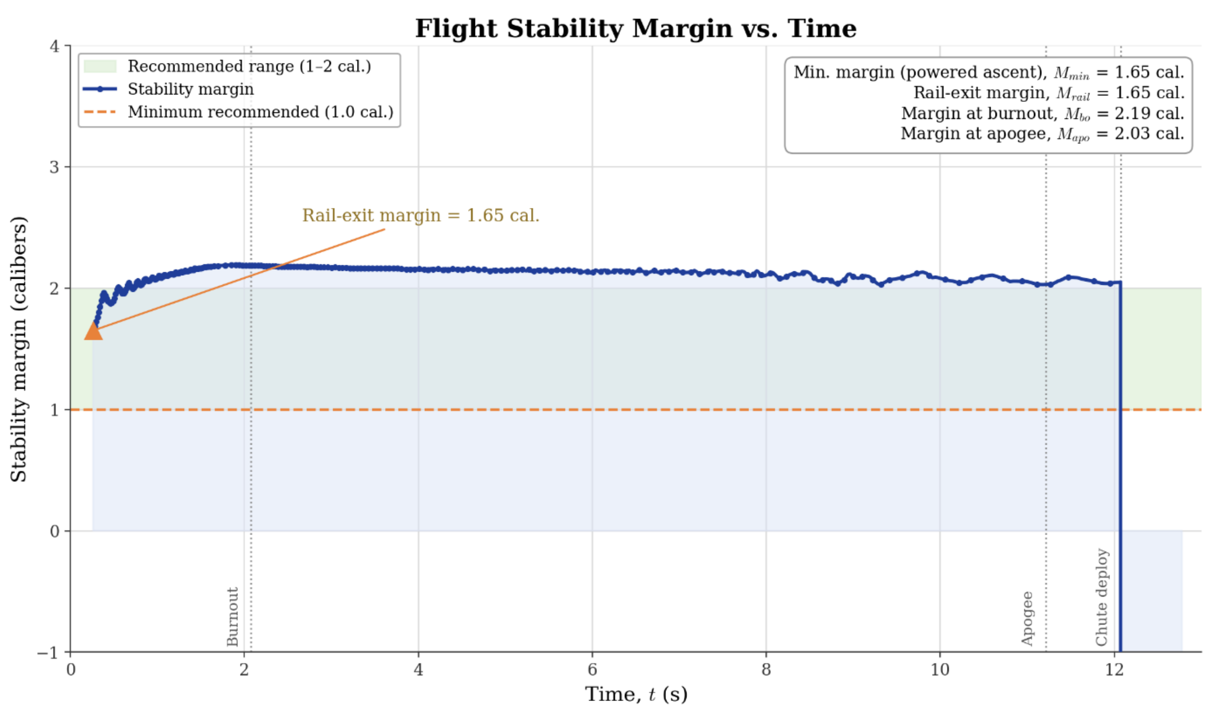


Figure 5 Plot of Stability Margin vs. Time. The value remains near two until the descent stage.

Altitude, Vertical Velocity, Vertical Acceleration, and Time

The flight profile shows three distinct phases. During powered flight (0 to 2.07 s), vertical acceleration peaks near 394 ft/s² shortly after liftoff as thrust is highest and propellant mass is still being burned off, then tapers as the motor thrust curve decays toward burnout. Vertical velocity continuously rises during the boost phase as expected with a maximum of 481 ft/s until burnout. As gravity decelerates the rocket during the coasting phase, the vertical velocity decreases until it reaches zero at apogee at 11.21 seconds. After this point, the magnitude of acceleration begins to rise as the rocket enters free fall with a sharp spike indicating the velocity dropped quickly due to the parachute deployment. The vertical acceleration remains at a slower negative value as the rocket slowly descends for 173.7 seconds (Fig. 6). Due to the lightweight nature of EF-1, the rocket achieves an apogee of over 2,200 feet and experiences acceleration within safe bounds. The landing velocity of 18.1 ft/s is slow enough to have no structural damage, but fast enough to not drift too far.

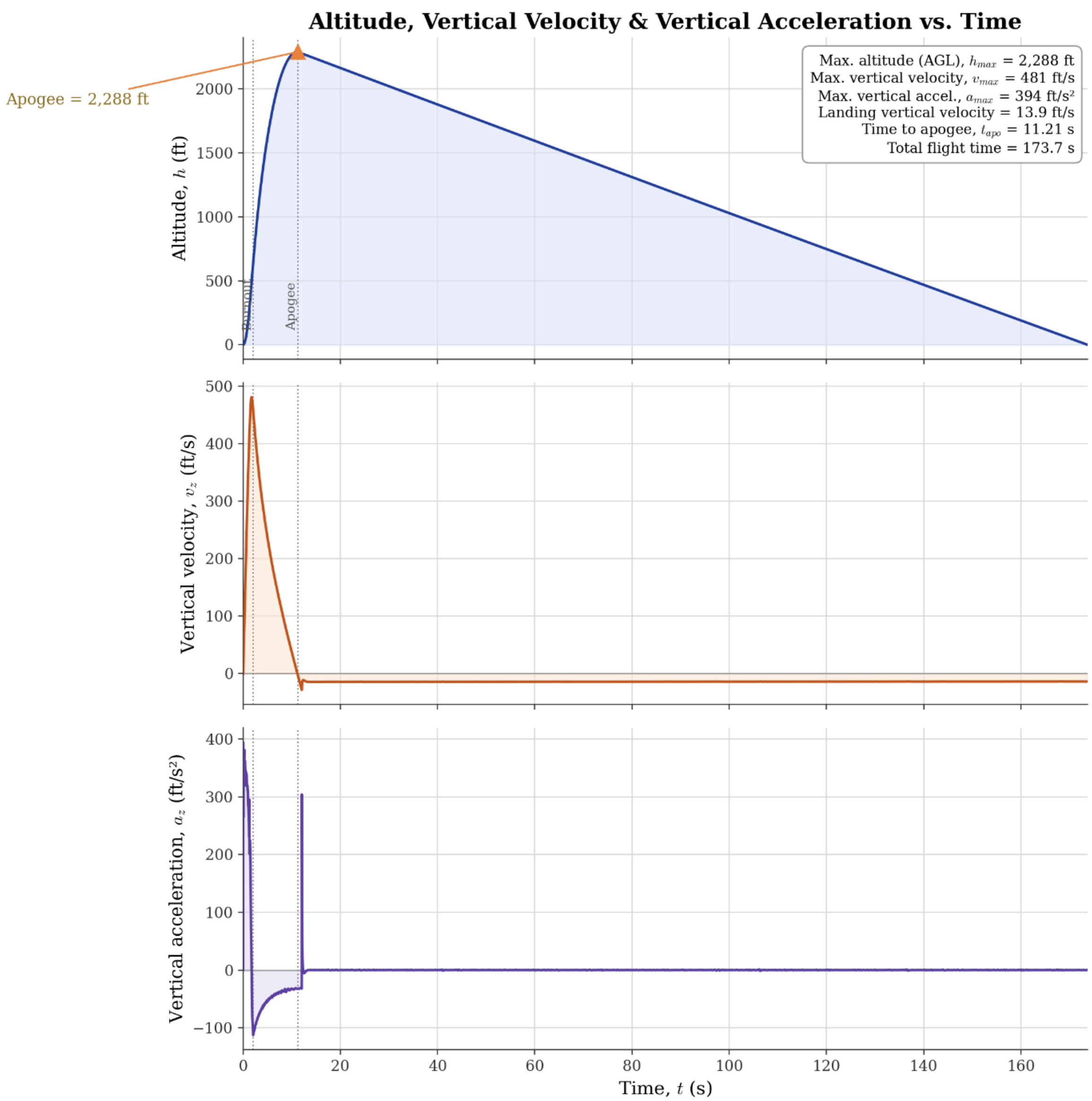


Figure 6 Altitude, Vertical Velocity, Vertical Acceleration vs Time. All are within safe limits.

Vertical Velocity against Altitude

The vertical velocity against altitude is also plotted which each stage (powered ascent, coast, free-fall, descent) color coded. The maximum velocity is found to be $v_{max} = 481$ ft/s which is within the operating range of the rocket given its structure (Fig. 9). The strong BlueTube airframe material does not have a specific stated operating range, but is stated to be Mach capable, making the speed well within its operating range [14]. The plastic nose cone would also be unaffected because at 481 ft/s, aerodynamic heating is negligible. One possible issue is fin flutter, because the fins are long to compensate for the short height of the rocket. This, however, is mitigated by having the fins thicker to help reduce the possibility of catastrophic flutter. As long as the recovery system is timed to deploy at or near apogee and not during the fast velocities, the rocket will be in good condition. The freefall speed of 28 ft/s before the parachute fully deploys is favorable, corroborating the use of a single deploy parachute rather than a more expensive dual deploy drogue and main parachute system. Lastly, the terminal descent of 13.90 ft/s is slow enough to have safe landing but fast enough as to not cause more than 1500 ft worth of drift.

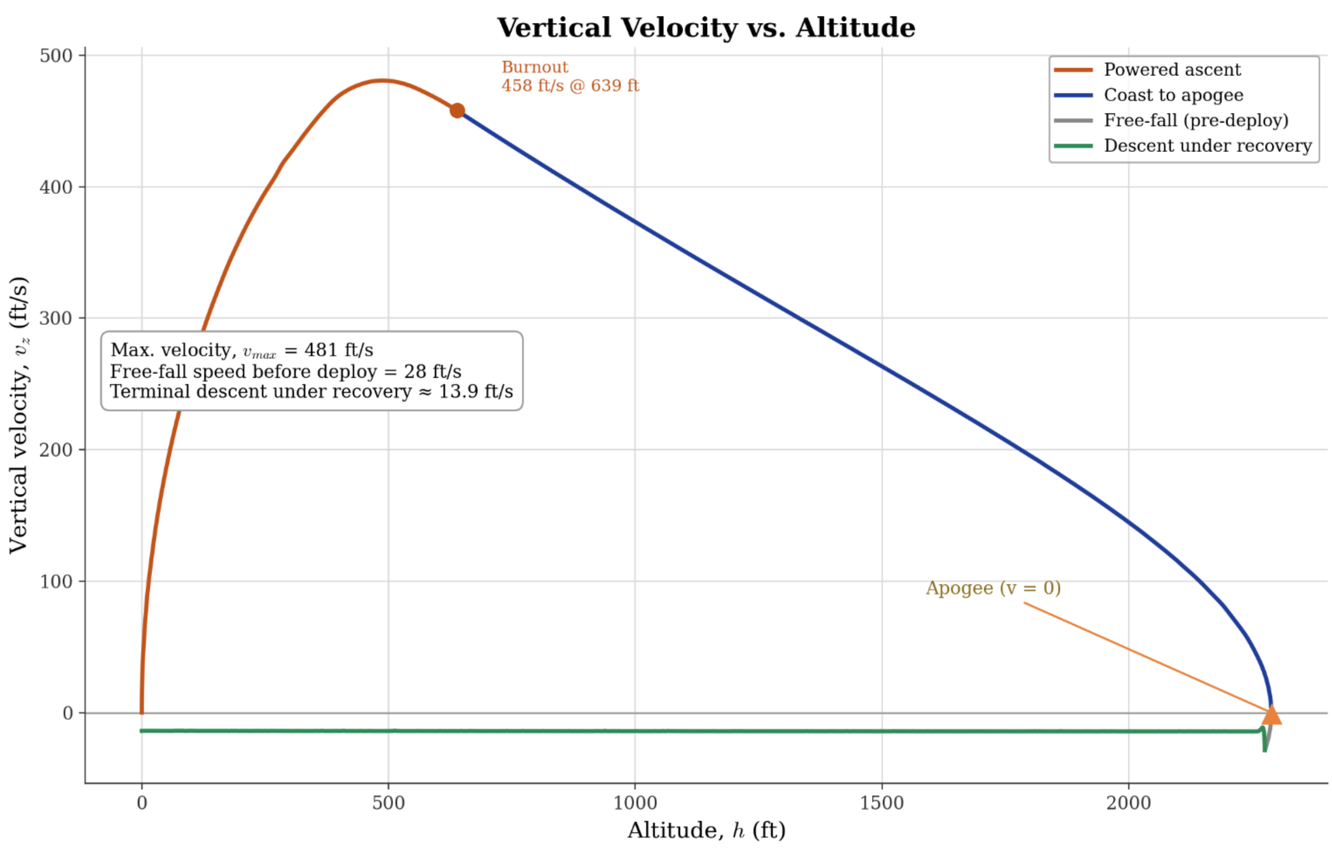


Figure 7 Vertical Velocity vs. Altitude plot presents a highly favorable flight profile.

Flight Drift

To verify the parachute was not too wide to allow the rocket to drift too far, the flight trajectory was graphed with altitude against position east of launch. East was selected as that was apart of the initial condition for the direction and speed of the wind. Relative to the launch pad, the rocket lands approximately 1472 feet west. From the launch site, the tree line varies but is not less than 2000 feet, making this magnitude of drift within acceptable bounds for a successful recovery. Theoretically, the rocket is to land within the open field with winds of 10 mph.

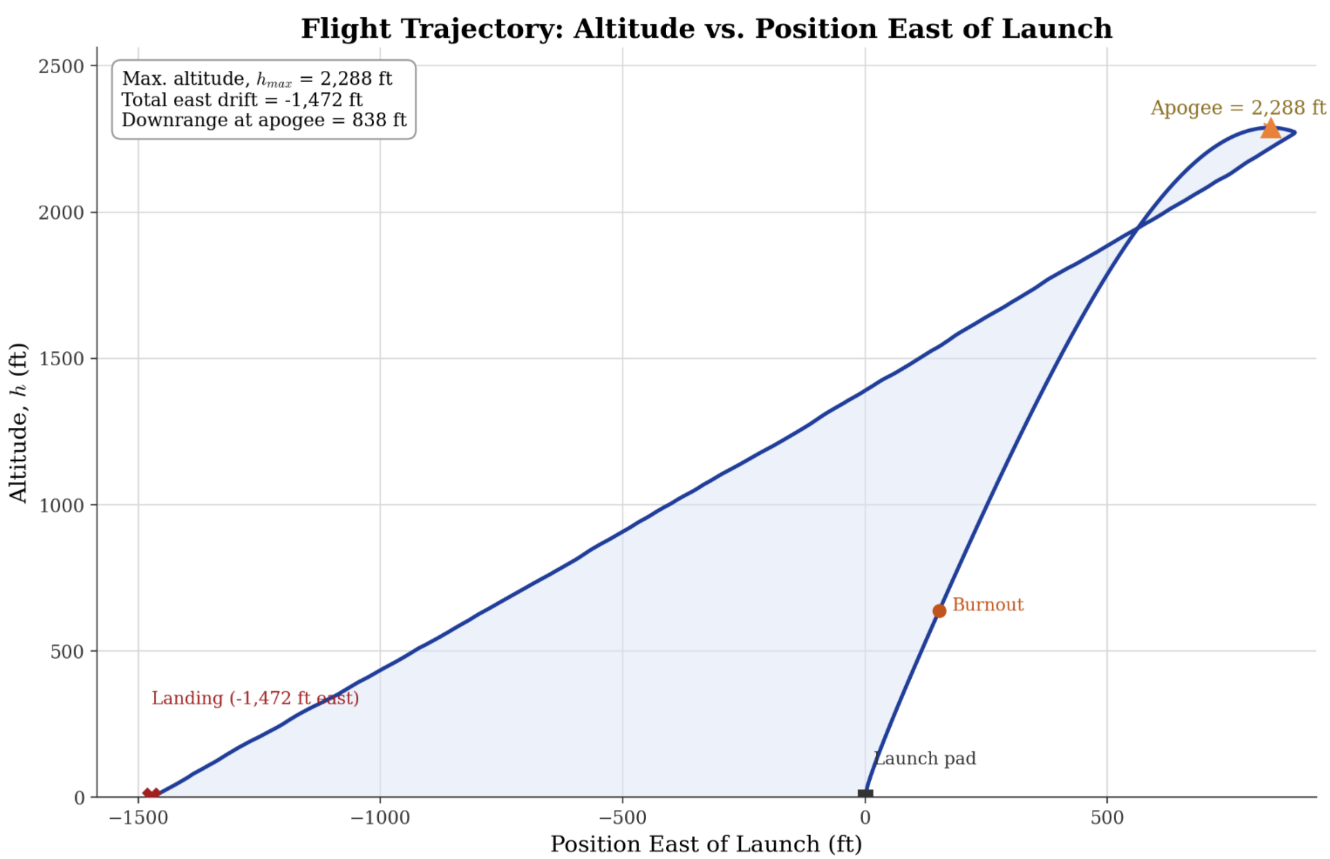


Figure 8 Altitude vs. Position East of Launch plot. The rocket lands within the 2000 ft radius of where parts of the tree line start.

Top-Down Flight Trajectory

Although the winds in the simulation were westward, making the position east of launch a useful metric for drift, the north-south side is plotted alongside the east-west directions to ensure there is no significant drift in the north-south direction (Fig. 9). Figure 9 also helps visualize the information from Figure 8 but without altitude and from a top-down map view. The rocket only drifts about 100 feet north, verifying the rocket is unlikely to drift out of bounds in the north-south direction or direction perpendicular to the direction of wind.

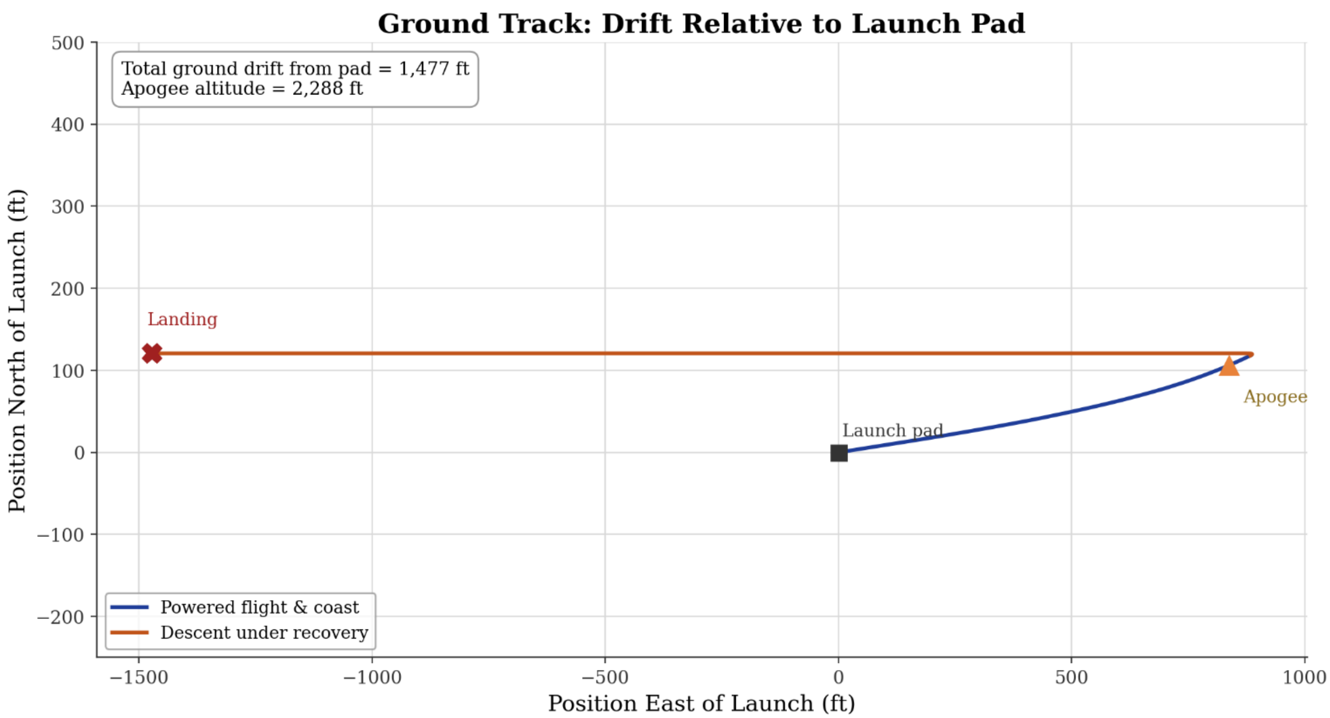


Figure 9 Drift relative to launch pad. No significant drift in north-south direction.

Thrust-to-Weight Ratio and Mass against Time

The plot in figure 10 displays the thrust-to-weight ratio and mass against time for the powered flight section. Motor burnout occurs at approximately 2.1 seconds with the mass being completed at burnout out. The thrust to weight ratio spikes to about 13.4:1 in the first fraction of a second (thrust ramps up faster than the rocket has moved), dips as the motor's thrust curve wobbles through its initial peak, climbs back over 12:1 through the early-to-mid burn, then decays steadily as thrust tapers off approaching burnout, hitting zero right at 2.07 s. The jaggedness reflects the motor's actual thrust curve, irregular grain burn, not vehicle behavior. At the rail exit, there is a thrust-to-weight ratio of about 12.6:1 which is well above the common 5:1 rule of thumb, meaning the rocket left the rod at a safe, controllable speed rather than wobbling off with marginal thrust. The total mass falls smoothly and almost linearly from 43.08 oz at liftoff to 40.19 oz at burnout. This continuous curve is smooth due to its cumulative nature. This confirms the use of the HP-H135W motor was an adequate choice.

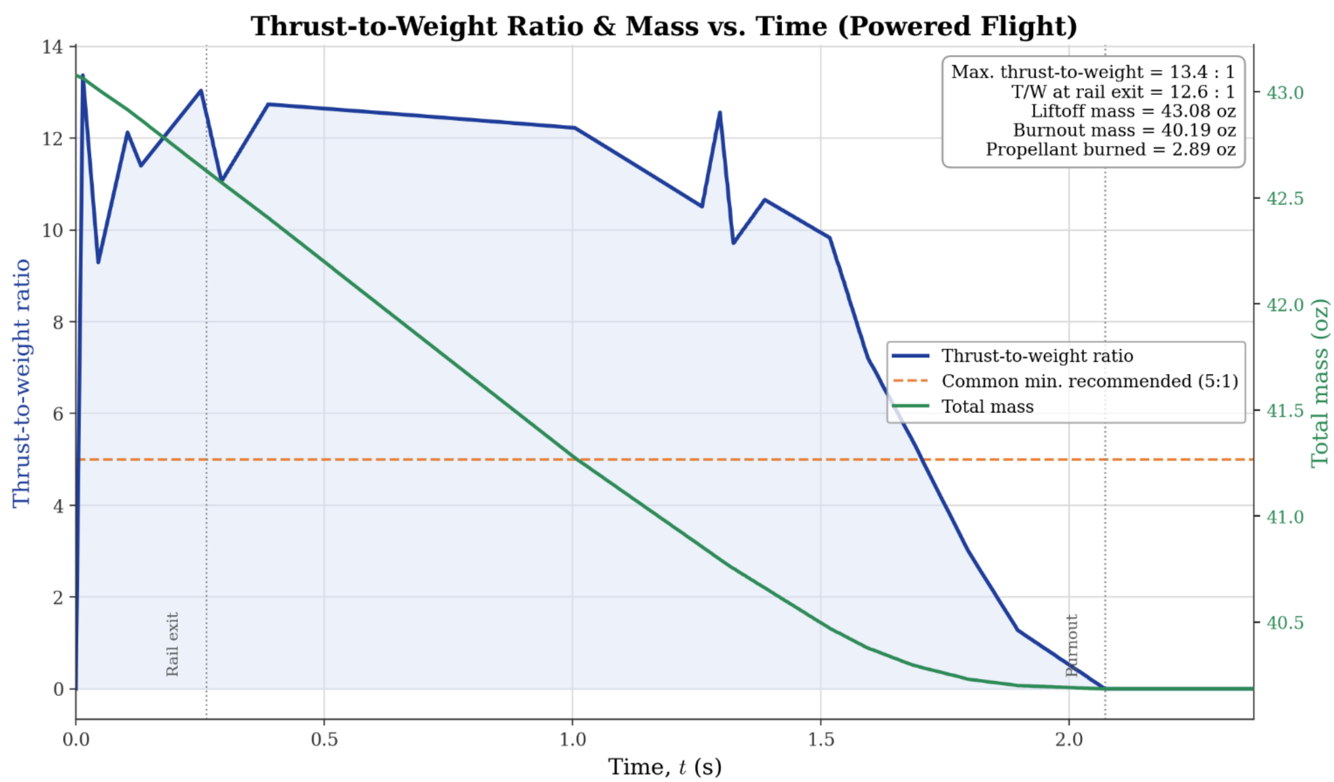


Figure 10 Thrust-to-Weight Ratio & Mass vs. Time plot during powered ascent confirms the selection of the HP-H135W motor.

Flight Results

The flight encountered no noticeable problems with successful launch and parachute deployment at apogee. The EF-1 rocket landed within the tree line and was recovered with no functional damage. As there is no onboard GPS or position system on the rocket, the distance drifted was verified by taking GPS coordinates at the launch location and at the rocket's touchdown location. The distance between these coordinates was 1,535 feet, close to the simulated drift of 1,472 feet calculated using the haversine formula. The certification was successfully awarded with no stability issues from afar. Against all flight constraints, the rocket succeeded and, without tax, was under $200.

Figure 11 EF-1 Powered Ascent in first second.

Conclusions and Recommendations

Limitations

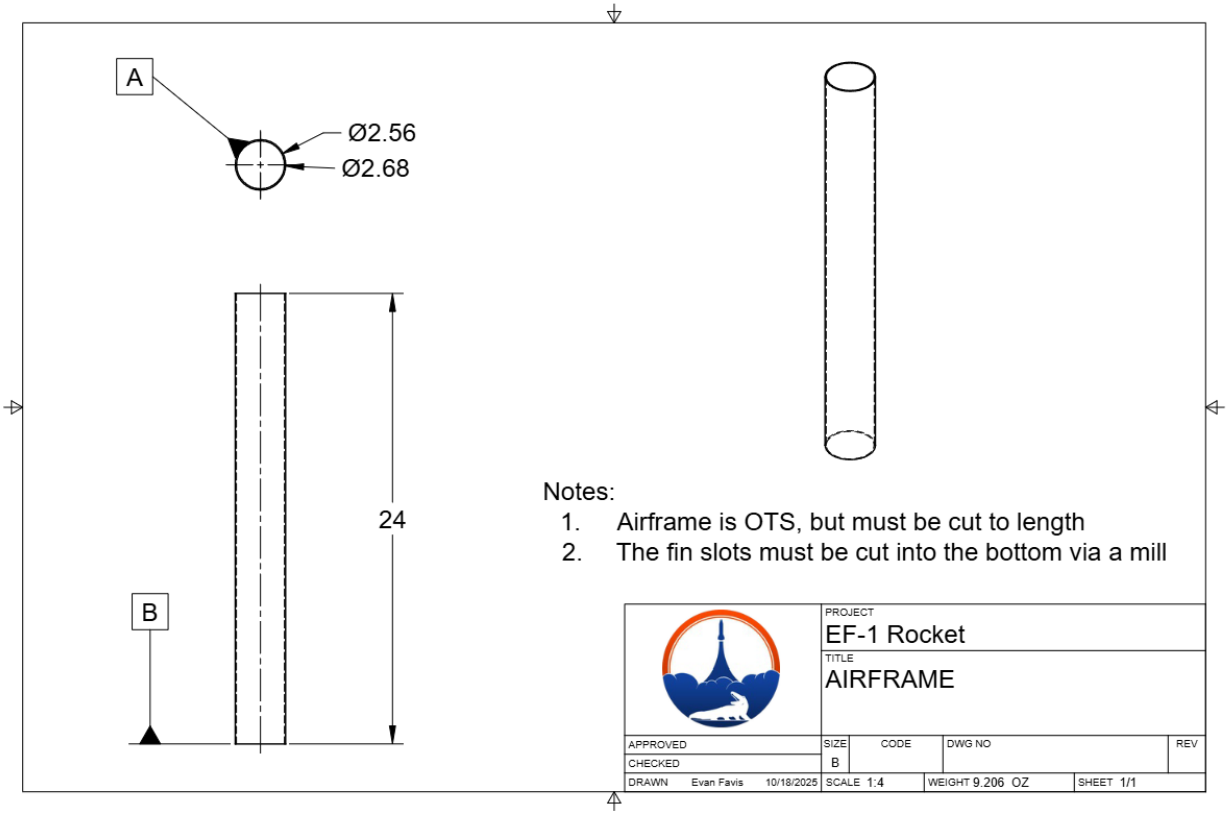
Although it can be assumed that the passive roll control was successful as the rocket appeared stable in the video recording of it launching, it is unclear if the rocket truly had a slow stabilizing spin due to the rocket flying far out of view after the first few seconds. Similarly, there was no way to verify the exact altitude due to a lack of an altimeter or avionics bay.

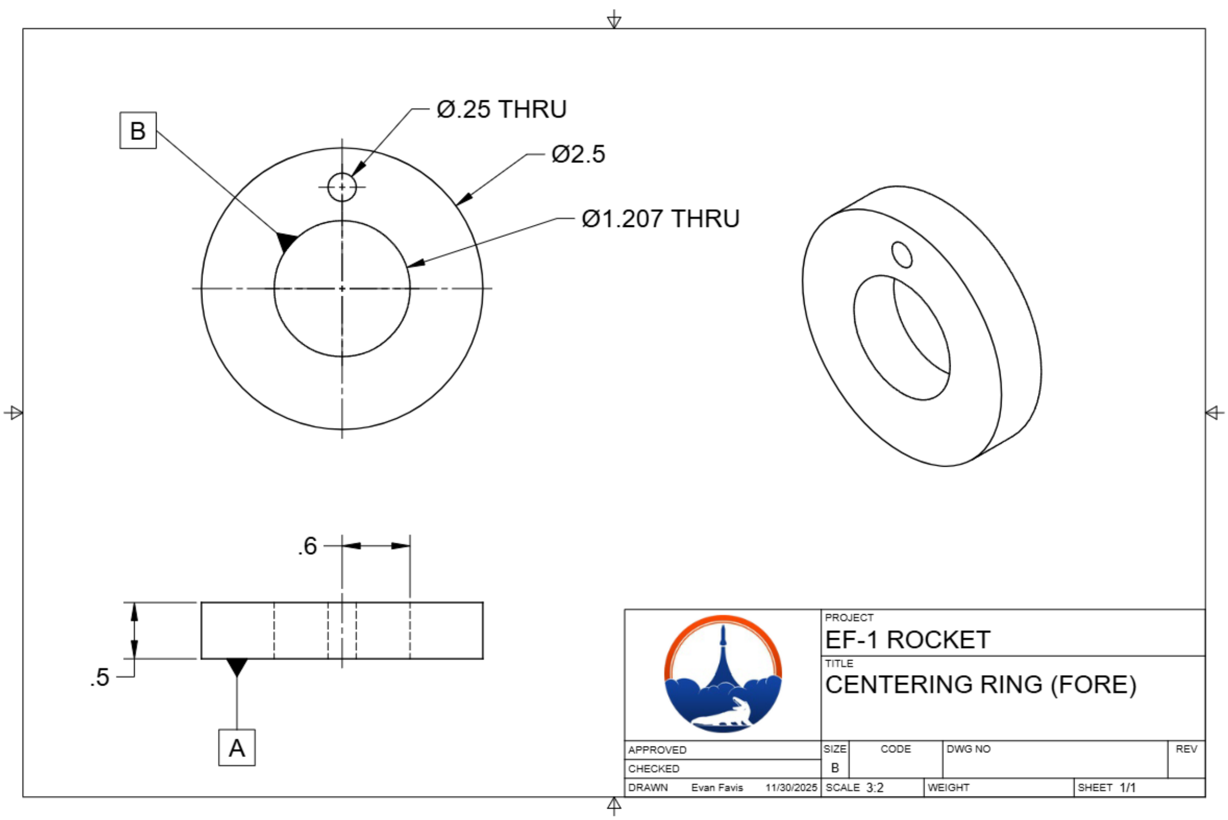
The simulation was accurate in the predicted drift but deviated by 63 feet with a percent error of 4.1%. This deviation was likely due to the assumption of predictable wind speeds. Unlike the simulation, the wind speed at the launch site was constantly changing moment to moment.

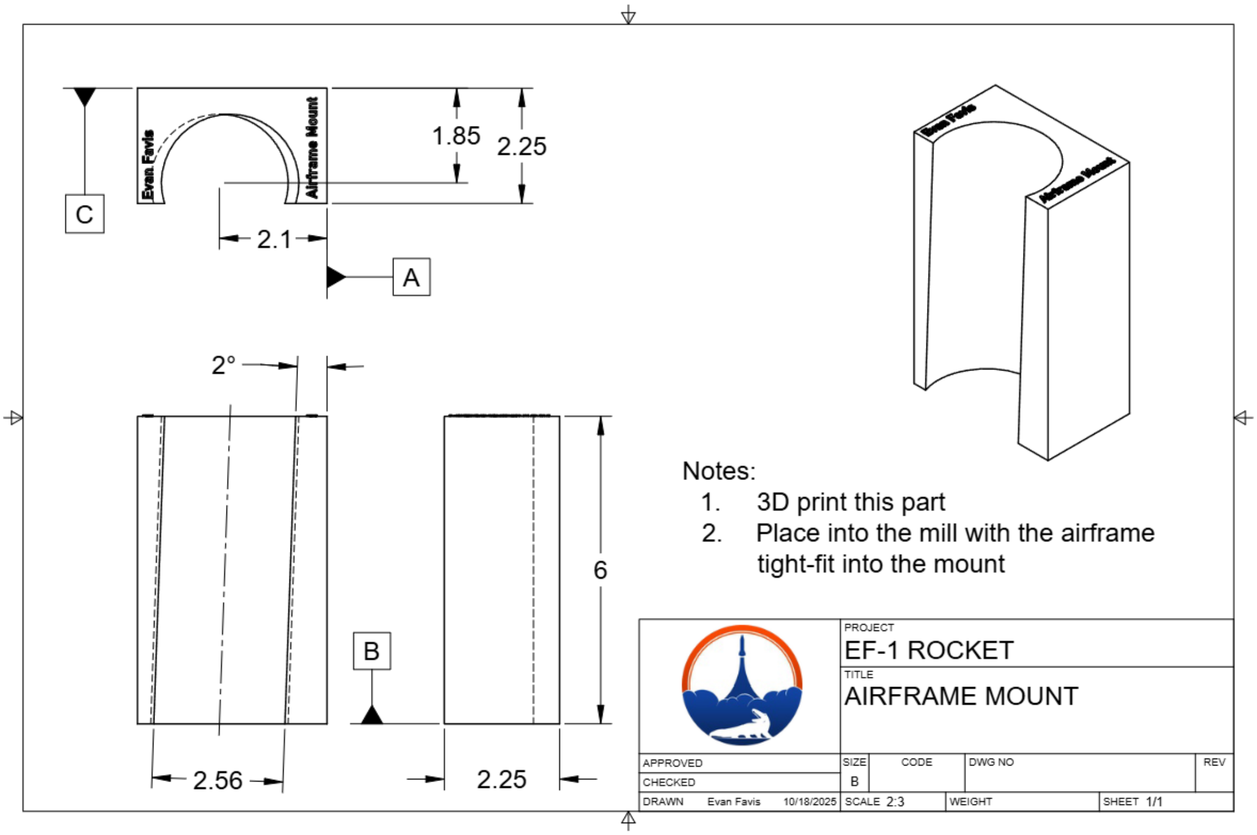
Recommended Next Steps

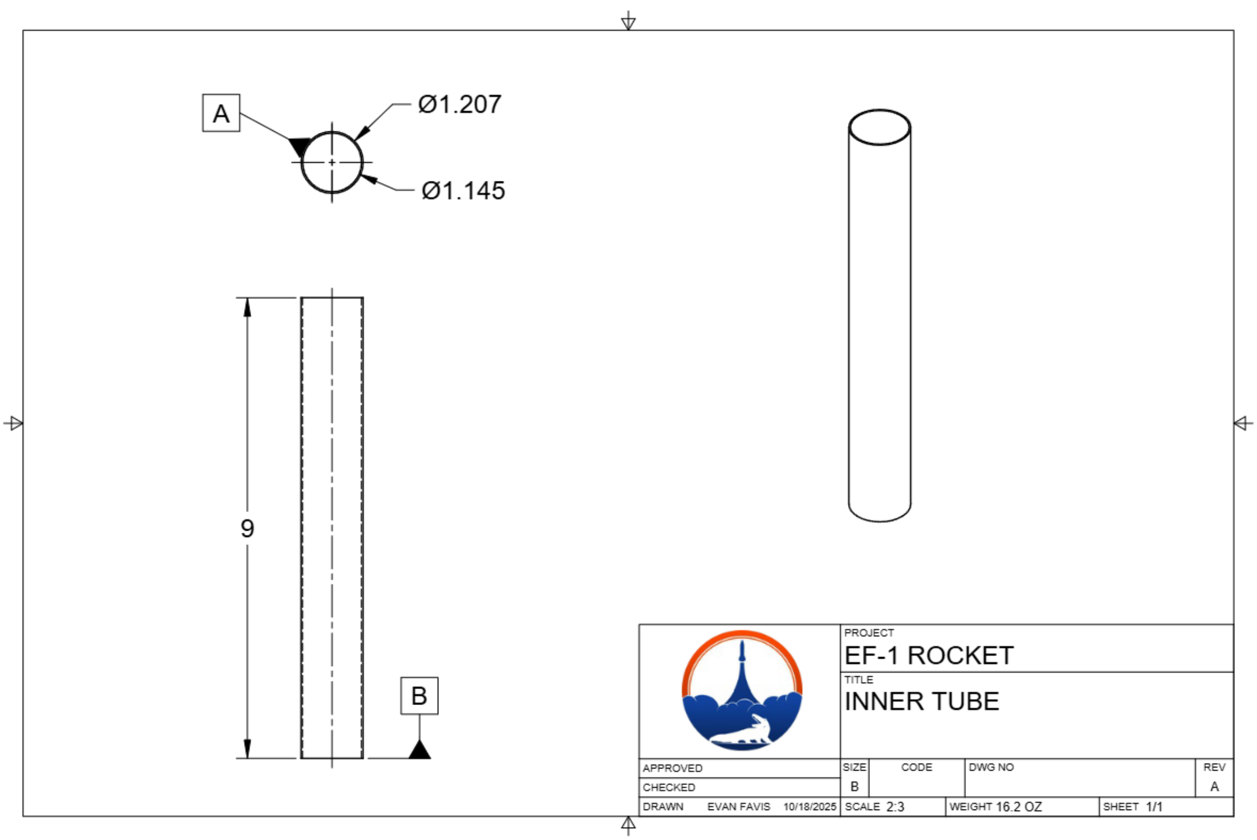
The next step would be to attain the level 2 certification with a bigger EF-2 rocket, which would include an avionics bay. This electrical system would include sensors that verify unverifiable simulated results from EF-1. These sensors would include an altimeter, GPS sensor, a camera, and an inertial measurement unit (IMU). The altitude would be used to verify apogee along with the GPS system as redundancy. The GPS could also help recovery by broadcasting its location from launch to touchdown. The camera, which would point downwards, would help to verify the passive roll control with data on how fast the rocket is spinning. The camera could double as a third redundant system for estimating altitude using information on the camera's specifications and geometry. Lastly, the IMU could be used to give data on the rocket's acceleration and orientation to help verify stability.

Appendix A – Drawings






Evan Favis
Airframe Mount
1.85
2.25
C
2.1
A
2°
6
B
2.56
2.25
Notes:
1. 3D print this part
2. Place into the mill with the airframe tight-fit into the mount
PROJECT
EF-1 ROCKET
TITLE
AIRFRAME MOUNT
APPROVED
CHECKED
DRAWN Evan Favis 10/18/2025
SIZE B
CODE
DWG NO
REV
SCALE 2:3
WEIGHT
SHEET 1/1


A
Ø1.207
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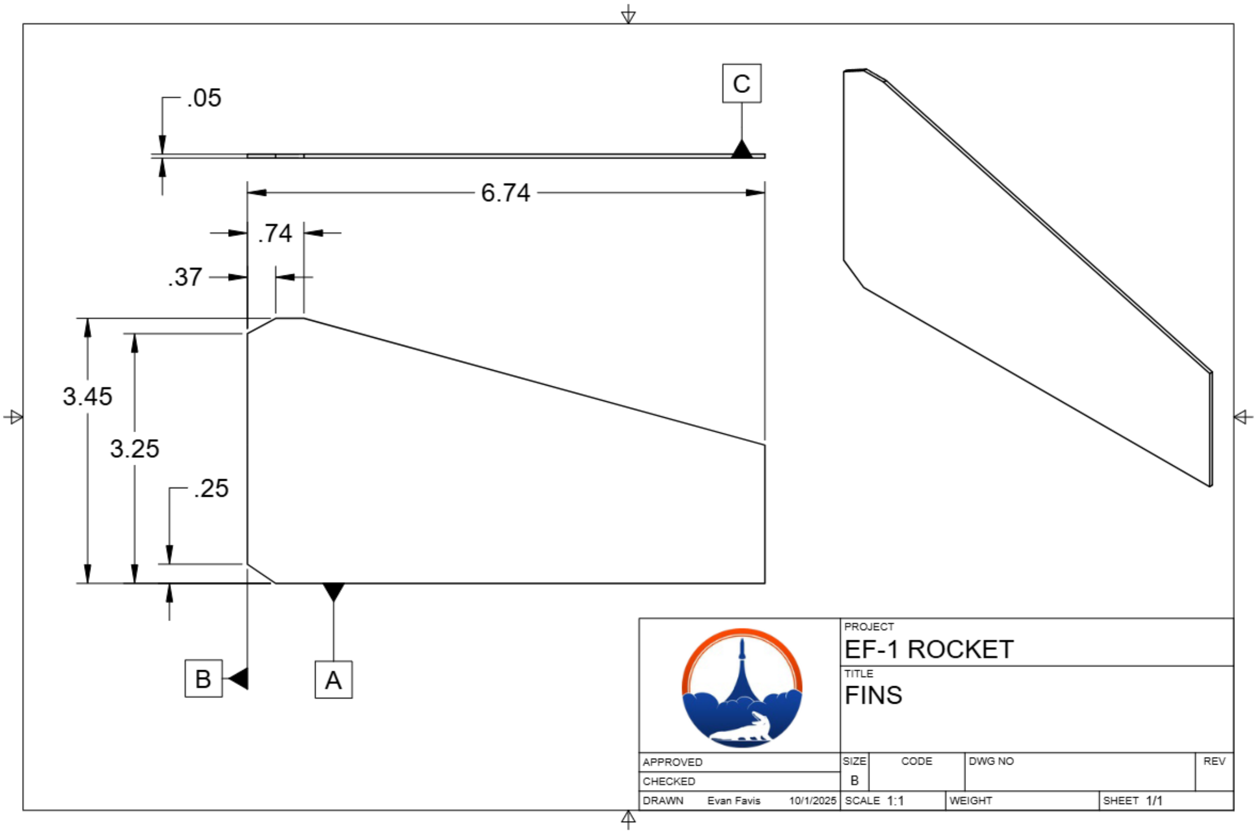
9
B
PROJECT
EF-1 ROCKET
TITLE
INNER TUBE
APPROVED
CHECKED
DRAWN EVAN FAVIS 10/18/2025
SIZE B
CODE
DWG NO
REV A
SCALE 2:3
WEIGHT 16.2 OZ
SHEET 1/1


.05
C
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PROJECT
EF-1 ROCKET
TITLE
FINS
APPROVED
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DRAWN Evan Favis 10/1/2025
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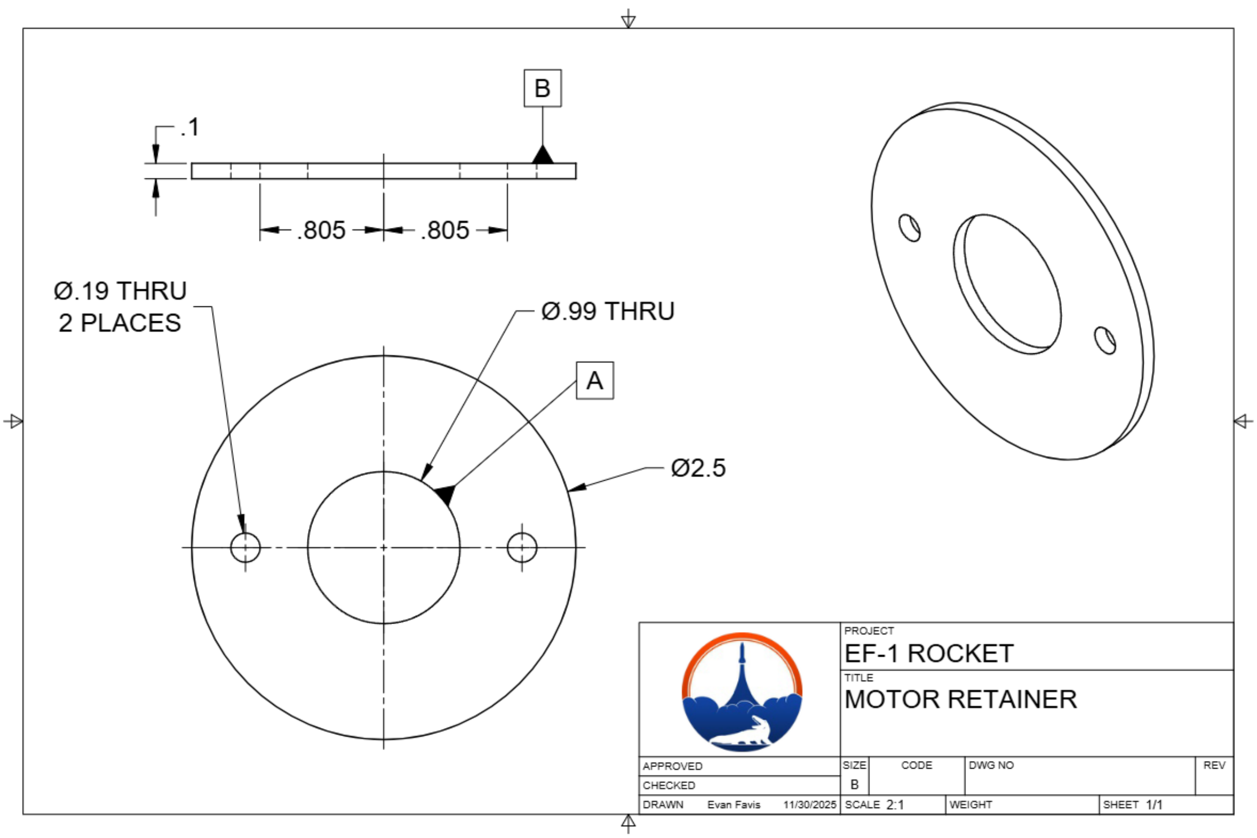
B
.1
.805
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Ø.19 THRU
2 PLACES
Ø.99 THRU
A
Ø2.5
PROJECT
EF-1 ROCKET
TITLE
MOTOR RETAINER
APPROVED
CHECKED
DRAWN Evan Favis 11/30/2025
SIZE B
CODE
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REV
SCALE 2:1
WEIGHT
SHEET 1/1

References

[1] "L1 Certification," Stanford Student Space Initiative Wiki. Accessed: Nov. 15, 2025. [Online]. Available: https://ssi-wiki.stanford.edu/L1_Certification

[2] "AeroTech HP-H135W Rocket Motor Data," ThrustCurve.org. Accessed: Nov. 16, 2025. [Online]. Available: https://www.thrustcurve.org/motors/AeroTech/HP-H135W/

[3] "Aerotech H135W-14A White Lightning Rocket Motor." https://www.csrocketry.com/rocket-motors/aerotech-rocketry/motors/29mm/dms-rocket-motors/aerotech-h135w-14a-white-lightning-rocket-motor.html

[4] "Rocket Stability," NASA Glenn Research Center. Accessed: Nov 10, 2025. [Online]. Available: https://www.grc.nasa.gov/www/k-12/VirtualAero/BottleRocket/airplane/rktstab.html

[5] Always Ready Rocketry, "Blue Tube 2.0," Always Ready Rocketry. Accessed: Nov. 2, 2026. [Online]. Available: https://alwaysreadyrocketry.com/blue-tube-2-0/

[6] "McMaster-Carr," Mcmaster.com, 2025. https://www.mcmaster.com/89965K871/ (accessed Dec. 21, 2025).

[7] "Cardboard Airframes," LOC Precision / Public Missiles Ltd., 2015. https://locprecision.com/collections/components-airframes/products/cardboard-airframes?variant=39778656092351 (accessed Dec. 21, 2025).

[8] Apogee Components, Inc, "Apogee 12in Parachute Protector," Apogeerockets.com, 2024. https://www.apogeerockets.com/Building-Supplies/Parachute-Protection/Cloth/Apogee-12in Parachute-Protector (accessed Dec. 19, 2025).

[9] S. Nkka, "OpenRocket technical documentation," OpenRocket, Tech. Rep. v13.05, May 2013. [Online]. Available: https://github.com/openrocket/openrocket/releases/download/OpenRocket_technical_documentation-v13.05/OpenRocket_technical_documentation-v13.05.pdf

[10] "Kevlar / Shock Cords | Mach 1 Rocketry," *Mach 1 Rocketry*. https://www.mach1rocketry.com/product-page/kevlar-shock-cords

[11] Apogee Components, Inc, "Standard Rail Button (fits 1" Rail - 1010)," Apogeerockets.com, 2015.

[12] "Airframes – always ready rocketry." https://alwaysreadyrocketry.com/product/1-15-29mm-x-062-wall-x-48-airframe-mmt/

[13] "Phenolic Motor Mount Tubing," LOC Precision / Public Missiles Ltd. https://locprecision.com/products/phenolic-airframe-tubing-1?variant=40827427946687

[14] C. Rogers, "On high speed aerodynamics and heat transfer," *Ex-Rocketman*, Jan. 01, 2020. [Online]. Available: https://exrocketman.blogspot.com/2020/01/on-high-speed-aerodynamics-and-heat.html. [Accessed: Aug. 16, 2025].