10K CDR - Aerodynamics Notes

Aerodynamics Team:

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Overview:

Objective: Design main profiles considering stability, performance, and manufacturability. Perform analysis of profile designs and projects in order to gauge flight performance through simulation and research.

Main Updates From PDR:

- Detailed flight trajectory estimates with further accuracy
- Clearer design choices and drawings
- Full manufacturing and integration plan of profiles

Topics:

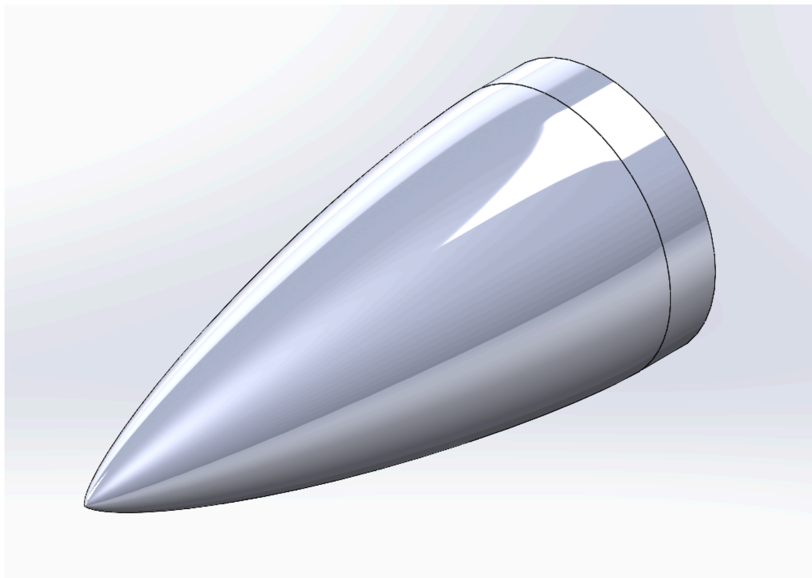
1. Flight Performance & Simulations
    - Flight Performance Goals
    - Motor
    - Star-CCM+ Model
    - MATLAB Model
    - OpenRocket Model
    - RASAero Model
    - Simulation Results
    - Mass Estimation
    - Wind Analysis
    - Next Steps
2. Profiles Manufacturing
    - Composites
    - Surface Finish
    - Shear Modulus
    - Compressive Strength
    - Material Choices
    - Manufacturing Overview
    - Vacuum Bagging
    - Note On Molds
    - Next Steps

Overall Model

Nose Cone

Summary: Von Kármán was chosen over the other nose cones because it had a high apogee low coefficient of drag, and performs well at speeds above Mach 0.9. After many simulations with different dimensions, the length was chosen as a compromise between low drag and high apogee.

Material Choice: Carbon Fiber Prepreg



NOTE: Original Plan → Wet Layups for the Nose Cone. Have since changed to prepregs (More on this after the "Profiles" Section))

Notes on Wet Layups:

Questions to answer:

1. How can we ensure that the resin is evenly distributed throughout the carbon fiber weave?

    Use squeegee first to quickly spread over surface, work out trapped air and wrinkles by stippling with cut-bristle brush and/or soft rollers

    $$\frac{Specific\ gravity\ of\ epoxy\ (g/cm^3) \times 16.39 \times 144}{100} = grams\ per\ foot\ at\ 0.01\ inch\ thick$$

    Use the equation to find the correct mass of needed epoxy

    Thinner the coats, easier to remove trapped gas, less susceptible to shrinkage, cracking, crazing

    Roller can also be used to get rid of excess and air bubbles

    Use fingers to get out air bubbles and remove excess

    https://www.compositesworld.com/articles/fostering-best-practices-for-wet-layup-procedures

2. Are there certain types of resin that work better with carbon fiber?

Epoxy v.s. Polyester v.s. Vinyl Ester

Epoxy: high strength-to-weight ratio, good tensile strength, vibration dampening, temp resistance up to 500 degrees F (dependent on brand). 3 times stronger than the next strongest resin type. Most expensive, sensitive to mix ratio and temperature variations. Uses specific hardener (two-part system), some require heat

Polyester: Easy to use (popular), UV resistant, lowest cost. Low strength and corrosion resistance. Cures with catalyst

Vinyl Ester: mix of performance from epoxy and polyester, best corrosion, temp resistance, and elongation. Lower strength than epoxy and higher cost than polyester. Limited shelf life.

EL2 Epoxy laminating resin, AT30 fast epoxy hardener (example used in youtube video: https://www.youtube.com/watch?v=bLyjhLBTcFw

Epoxy resin with amine hardener, correct ratio essential for correct binding of epoxy and hardener

Type of epoxies:

Cyanoacrylate: Known to many manufacturers as "instant adhesive," this is excellent for bonding carbon fiber reinforced polymers.

Single component epoxies: High-level single component epoxies are specifically designed to work with carbon fiber. These solutions can offer color match aesthetics, as well as exceptional strength.
Two-component epoxies: Some two-component epoxies have also been carefully developed to encapsulate the fibers in carbon fiber projects.
Structural acrylic: MMA-grade acrylics offer excellent carbon fiber bonding.
Polyurethane adhesives: Most Permabond polyurethane adhesives offer good impact resistance and strength.

Choosing hardener allows one to control rate of reaction

Choosing viscosity of resin

Low: wets fabric well but slippery and makes plies sag on vertical surfaces (won't be an issue when using mold of nose cone)

Choosing calcium carbonate filled laminating resin minimizes slipping and kee[s resin from running out of layers

High strength-to-weight ratio, good tensile strength, vibration dampening, temp resistance up to 500 degrees F (dependent on brand). 3 times stronger than next strongest resin type

Laminating resin? Pre-preg?

https://compositeenvisions.com/document/resin-selection/

https://plasticmaterials.net/blog-epoxy-resin-for-carbon-fiber/#:~:text=Some%20of%20the%20available%20epoxy,to%20work%20with%20carbon%20fiber.

https://www.sollercomposites.com/EpoxyResinChoice.html

https://formlabs.com/blog/composite-materials-carbon-fiber-layup/

https://www.easycomposites.co.uk/learning/introduction-to-out-of-autoclave-prepreg-carbon-fibre

Pre-preg: solvent drip process vs. hot melt

Solvent: dip fabric into resin, wrap fabric around object to give it shape

Vacuum treatment/bagging to enhance properties → pressure chambers before, during, or after curing

Hot melt: spread resin on metal sheet, sheet heated up in oven to melt rein, fabric laid over metal sheet and pressed into it

Fabric cools, absorbs resin from being sandwiched between the two

More pressure applied = more resins absorbed by composite material

3. What sort of equipment do we need to optimize our process?

Epoxy-compatable polyester gelcoat (some type of primer), will allow easy removal

Brushes, squeegees, rollers, masks, gloves

Body Tube

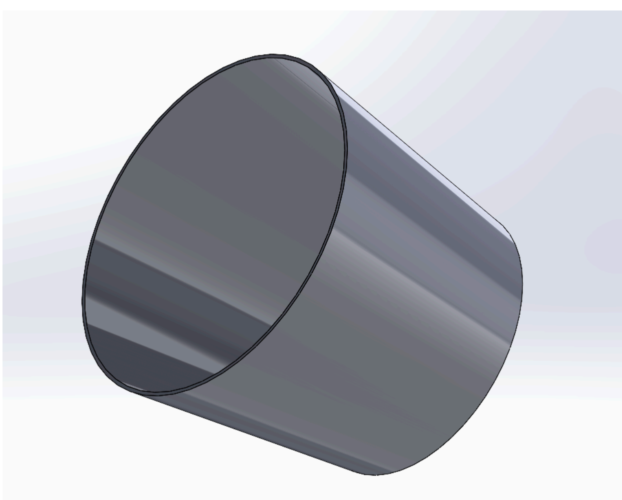
Summary: The body tube dimensions were chosen with the other subsystems in mind.

Material Choice: Carbon Fiber Prepreg for Recovery and Motor Body Tubes, Fiberglass Prepreg for Avionics Body Tube.

Boat Tail

Summary: The boat tail minimizes drag which indirectly increases apogee, but it significantly reduces stability and it is more difficult to manufacture.

Material Choice: Carbon Fiber Prepreg



Fins

Summary: The fins will make up for the boat tail's stability offset. The tapered swept fin was chosen because of high stability to apogee ratio and lower variation between different dimensions. 4 fins were chosen rather than 3 because 4 fins had significantly higher stability. The fin boundary equation determined that the rocket's estimated maximum velocity is within the safety margin for fin flutter velocity.

Material Choice: Sandwich Layup with carbon fiber prepreg and aramid honeycomb core

FLIGHT PERFORMANCE & SIMULATIONS

Flight Performance Goals

Overview: Design of rocket aimed to maximize flight performance and apogee within the manufacturing constraints.

- Target Apogee: 10,650 feet | 3246 meters
- Apogee Range: +/- 650 feet *(~10,000-11,300 ft)* | +/- 198 meters *(~3048-3444 m)*
- Maximum Velocity: 1013 ft/s | 309 m/s (Mach .9)
- Target Stability: 1.5 - 2.5 cal

Objectives:

- Target Apogee: The target apogee represents the absolute desired maximum altitude of the rocket during launch.
- Apogee Range: The apogee range represents the range of desired outcomes for the maximum altitude of the rocket during launch. Having an apogee during the launch within the range would be considered a "success". Having an apogee outside of the range would indicate that the simulation models did not accurately depict the flight trajectory of the rocket and was not considered a key factor.
- Maximum Velocity: Set to avoid transonic flow, which induces more drag and pressure forces.
- Target Stability: Stability targets set to maintain a consistent flight trajectory.

Considerations:

→ Competition Placement:

One of the primary goals is to place well in the competition, which requires the rocket to have a maximum altitude of 10,000 feet. Every foot under/over leads to a reduction to the total score, and the goal is to get the highest score possible; thus apogee is a critical component to achieving success in the competition.

The target apogee range reflects the goal set in PDR of having the apogee come within 1,250 feet of 10,000 feet, which would have placed the rocket within the top two in its class in the previous competition assuming successful recovery.

→ Manufacturing & Launch Site Conditions:

It was considered that simulation models can tend to overestimate the apogee and flight trajectory of a launch vehicle. This can be due to manufacturing imperfections and wind conditions during launch, which lowers apogee during flight. Thus, the apogee range was set to only include values over 10,000 feet because of the consideration.

→ Future Project Implementation:

Another key detail in determining the target apogee was the consideration of future competitions and projects. The current design would not need a major overhaul if CPSS were to compete in the FAR 10k competition again in future years in terms of its flight performance because of the high apogee range. Because the current design can be optimized to travel well above 10,000 feet, the rocket can also maintain more projects if desired. For example, the rocket could handle the addition of mass from a drone in the future, which is one of the bonuses of the FAR competition.

Updates From PDR:

- Removal of Simulated Windows: The following simulations have gained accuracy from PDR, thus it was deemed that there was no need for a separate simulation range.
- Updated Target Apogee Window: The range no longer includes apogees below 10,000 feet. The reasons for the removal are discussed in further detail below.
- Lowered Maximum Velocity: The maximum velocity of the rocket was lowered from Mach 1 to Mach .9. This decision was made because some of the flow becomes transonic before Mach 1, as seen by the CFD results. The presence of this flow increases the drag of the rocket on ascension from the shock waves, which is seen by the increase in drag coefficient at values close to Mach 1.

Motor

Aerotech M1939W

Summary:

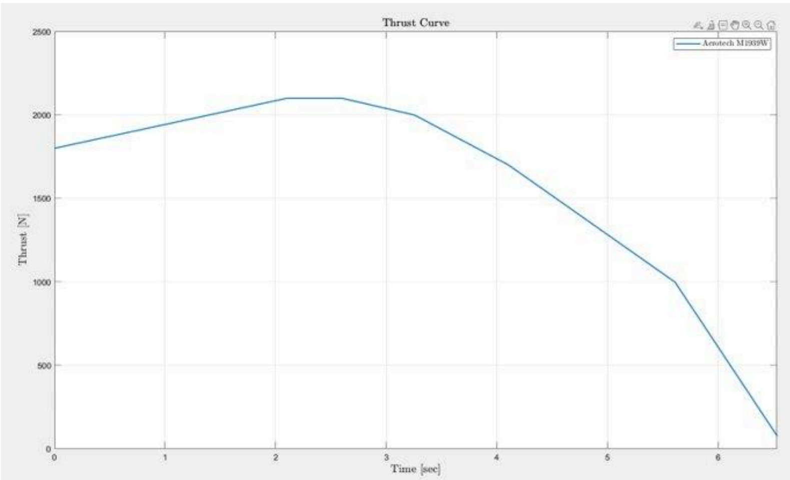
- High thrust, low burn time
- Chosen because of the consistent flight performance results because of the motor, given the lack of control systems on the rocket. The motor also meets the dimensional constraints of the rocket, as well as the apogee and maximum velocity ranges.

Specifications:

1. Average Thrust: 1582 N

2. Max. Thrust: 2084 N
3. Burn Time: 6.52 s
4. Launch Mass: 8844 g
5. Empty Mass: 3524 g
6. Length: 75.1 cm

Thrust Curve:



Motor Preparation: The motor will be shipped directly to the launch site at FAR. Before the launch, the bottom of the rocket will contain a motor sleeve that the motor can slide into before the launch. The motor will cost around $870 to order online.

Star-CCM+ Model

Summary:

- Implements computational fluid dynamics and Navier Stokes equations.
- Generates drag data and pressure gradient of the rocket during flight.
- Used to generate coefficient of drag versus mach curve, adding another estimate of rocket launch trajectory.
- Also used to identify key points of pressure on launch vehicle during most critical points of launch.

Process:

- Assumptions: Compressible flow, turbulent flow, ideal gas, flow parallel to direction of rocket, standard atmosphere.
- Analyzes flow across vehicle in two-dimensions, providing fairly accurate values of drag and pressure.
- 20 representative mach values were picked between launch and maximum predicted airspeed. CFD was run at those 20 mach values and corresponding projected altitudes.
- Altitude at mach levels was considered for air pressure and density at these mach levels, using the Standard Atmosphere model. Altitude data at mach levels taken from OpenRocket Data.

MATLAB Model

Summary

- Simulation model using MATLAB to estimate full flight trajectory using ordinary differential equations based on different drag data.
- Drag Data: OpenRocket, RASAero, Star-CCM+
- Three Phases: Burn Phase, Coast Phase, Recovery Phase

Updates from PDR:

1. Accurate Thrust Curve
   a. No Ejection Charge considered with new recovery system in place
   b. Rough estimate of thrust of the Aerotech M1939W motor over its burn
2. Adjustable Cd vs. Mach
   a. Previous Estimate: Cd = .4 across all velocities of the rocket.
   b. OpenRocket: Higher drag values for transonic flow.
   c. RASAero: Higher drag values for low mach values, lower drag values for upper subsonic and transonic flow.
   d. Star-CCM+: Similar trend as Openrocket; higher increasing drag from subsonic to transonic
3. Accurate Initial Conditions
   a. FAR Launch Site: Initial altitude of 600 meters taken into account in standard atmosphere model.
4. Recovery System
   a. The recovery system was added to the Matlab simulation in order to accurately depict the trajectory of the rocket during its recovery phase. This includes the drogue chute, which deploys at apogee, and the main chute, which deploys at 1000 feet. This addition has made the recovery phase portion of the simulation model accurate in terms of landing time and total launch time.

Flight Trajectory Simulation Block Diagram

- Environment
  - Standard Atmosphere Model
    - Gives pressure, density, temperature data at given altitude
- Force & Moments
  - Aerodynamics
    - Mach versus coefficient of drag data
    - Recovery Phase: Increased drag effect from parachute
  - Propulsion
    - Burn Phase: Thrust in direction of motion according to thrust curve
    - Coast & Recovery Phase: No effect
  - Gravity
    - Burn & Coast Phase: Opposing motion
    - Recovery Phase: In direction of motion
- Mass Properties
  - Change in Mass
    - Burn Phase: Linear burn of wet motor mass
    - Coast & Recovery Phase: No effect
- ODE
  - Initial States
    - Initial Conditions of FAR launch site

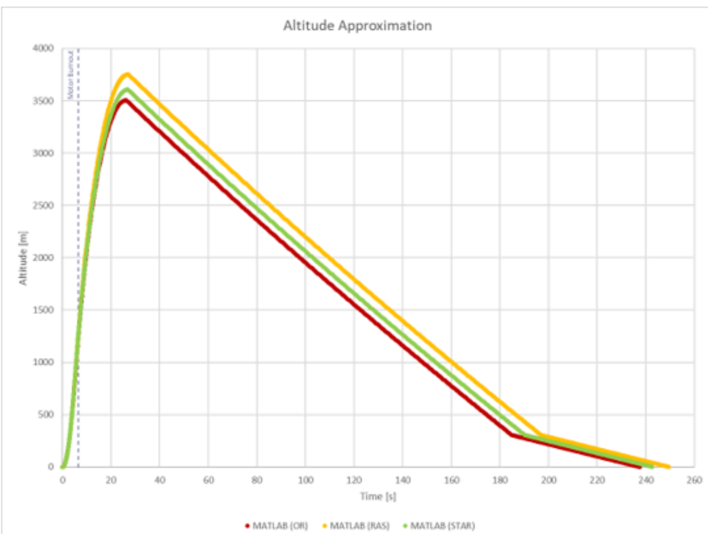
    - Equations of Motion (EOM)
        - For altitude, velocity, acceleration, mass
    - Solver (ODE)

Notes:

- This simulation does not consider the effect of wind upon the launch trajectory.
- The rotational motion of the rocket is also not considered (roll, pitch, and yaw) in this simulation.

Results:

- Flight trajectory is similar but slightly lower in Matlab than it is in other programs, even when using the same drag data of those respective programs.



Results with no additional mass added:

OpenRocket Data
Max Altitude: 11496.4846 ft
Max Velocity: 981.6586 ft/sec
Highest Mach Number: 0.88958
Max Acceleration During Burn: 231.1896 ft/s^2
Motor Burn Time: 6.53 sec
Time of Apogee: 26.2771 sec
Flight Time: 237.7741 sec

RASAero Data
Max Altitude: 12309.3008 ft
Max Velocity: 1013.0521 ft/sec
Highest Mach Number: 0.91845
Max Acceleration During Burn: 230.7438 ft/s^2
Motor Burn Time: 6.53 sec
Time of Apogee: 27.0865 sec
Flight Time: 249.7415 sec

Star-CCM+ Data
Max Altitude: 11833.5829 ft
Max Velocity: 984.9588 ft/ sec
Highest Mach Number 0.89261
Max Acceleration During Burn: 234.401 ft/s^2
Motor Burn Time: 6.53 sec
Time of Apogee: 26.9285 sec
Flight Time: 242.9687 sec

OpenRocket Model

Summary/Results:

- OpenRocket uses the Extended Barrowman calculation method to simulate the flight trajectory.

Updates from PDR:

- Surface Finish: The surface finish of the rocket was increased in roughness. This lowered our apogee due to the increase in drag during flight.
    - Full Surface Finish Trade Study: https://docs.google.com/spreadsheets/d/1sL8eY2Mc7pzxnnXm0w8iXI9iKNx1NRDl1xkeOXSuJxw/edit?usp=sharing
- Mass:
    - Mass was added to the rocket from the increase in weight of the couplers. The mass of the payloads/avionics section of the rocket also decreased.

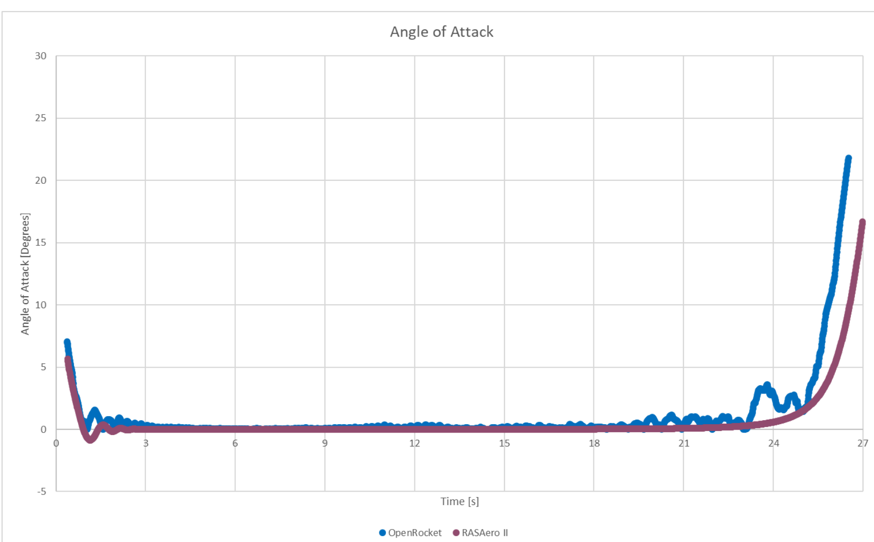
RASAero Model

Summary/Results:

- RASAero II uses the Rogers Modified Barrowman calculation method to simulate the flight trajectory.

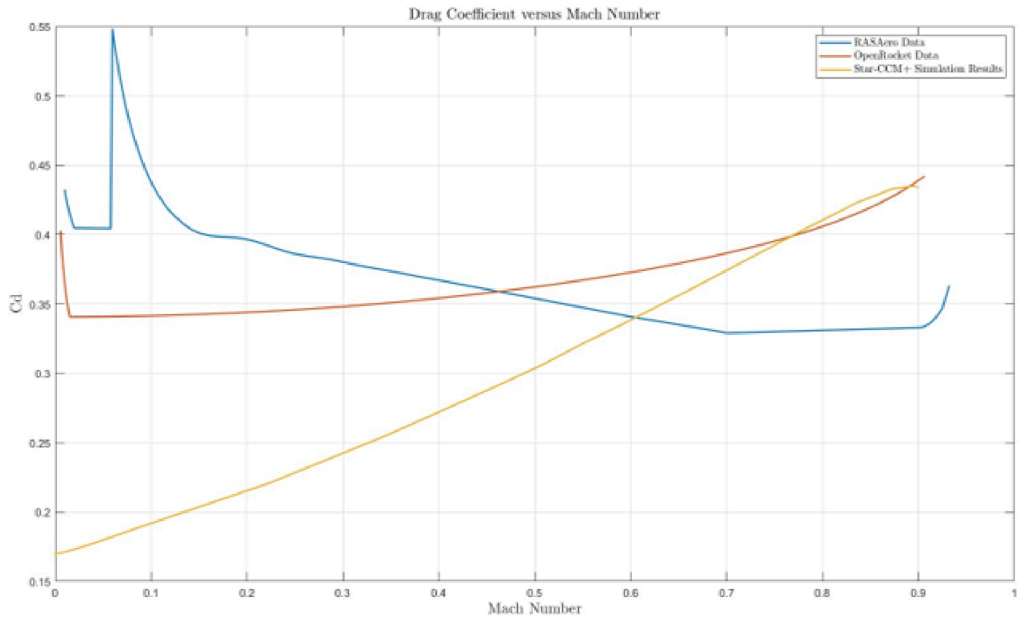
Updates from PDR:

- Previously, RASAero II was used only for the coefficient of drag estimation. For CDR, the program's flight simulation was used to predict the trajectory.
- Higher Apogee: The RASAero Model produced a higher apogee than other models.
    - Mach vs. CD: RASAero outputs a Mach vs. CD with much higher drag values at lower mach levels but lower drag values at higher mach levels (approaching transonic flow).
    - Angle of Attack: The angle of attack upon the rocket leaving the launch rail is measured at 5.6 degrees in RASAero, as opposed to the angle of attack from OpenRocket, which is at 6.8 degrees. This leads to an increased apogee since the vertical component of velocity is greater for the RASAero model.

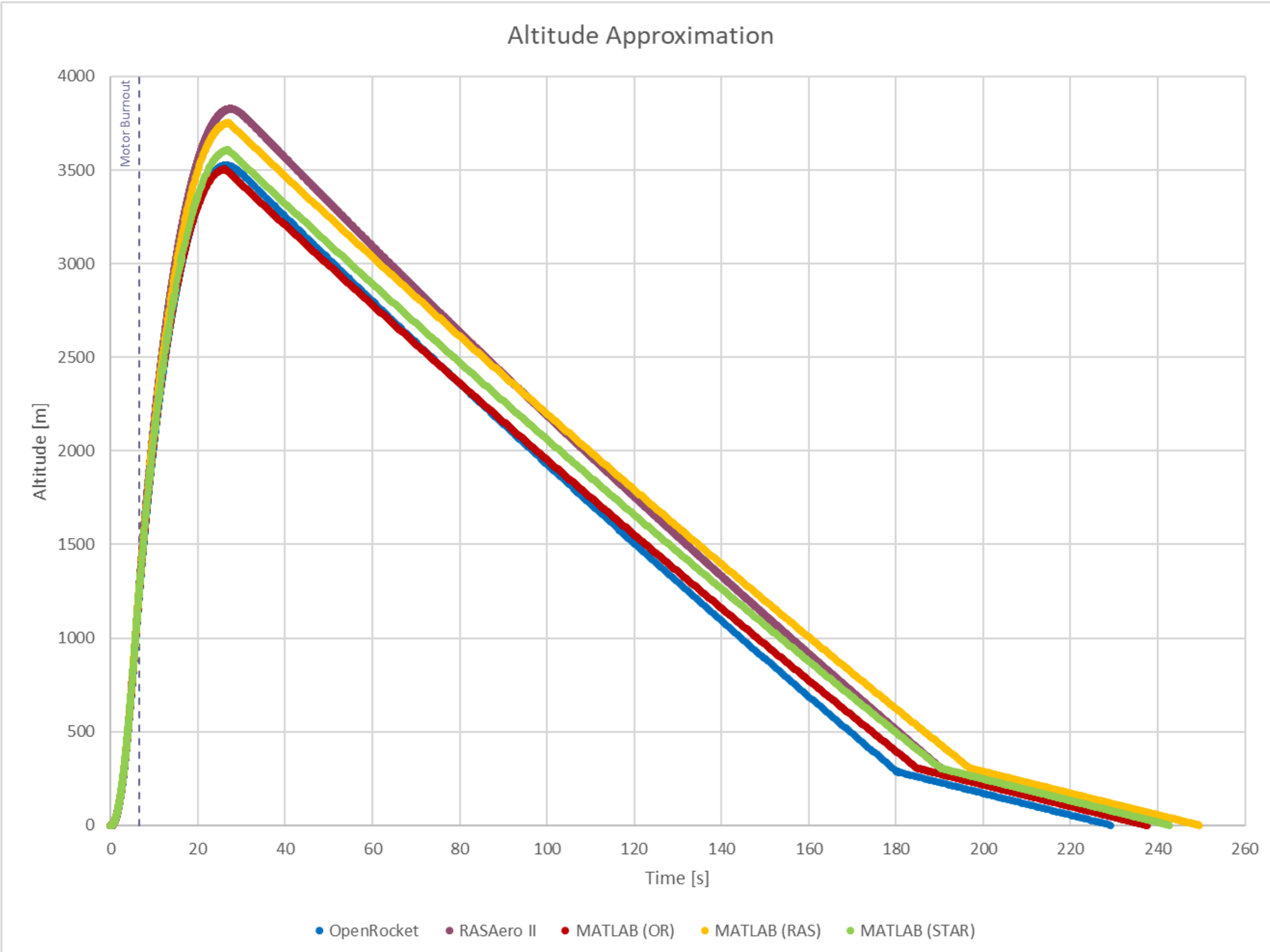


Simulation Results

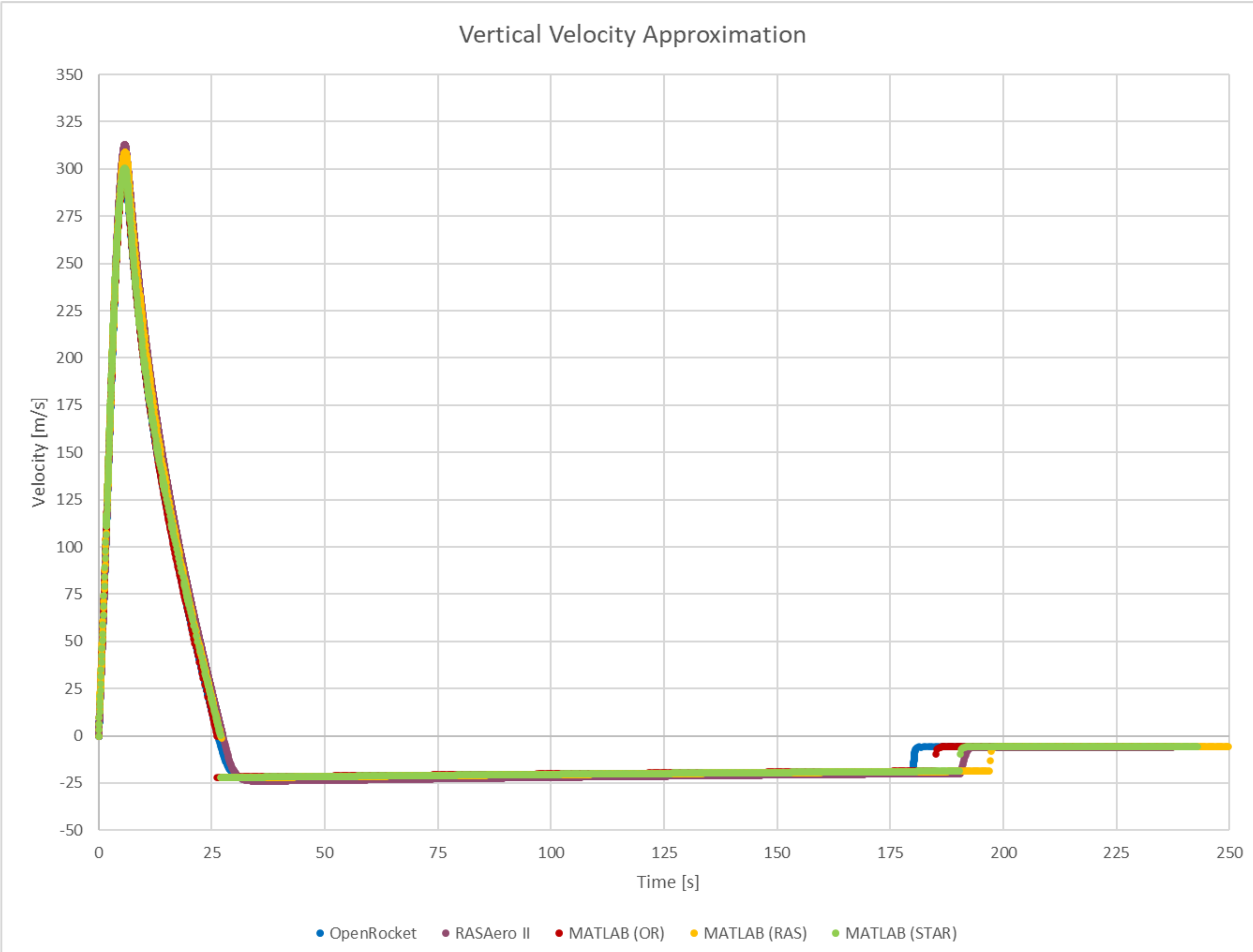
Mach vs. CD: The differences in the CD vs Mach curve explain the different apogees. OpenRocket and Star-CCM+ follow the expected curve, but RAS accurately predicts the initial spike in drag.



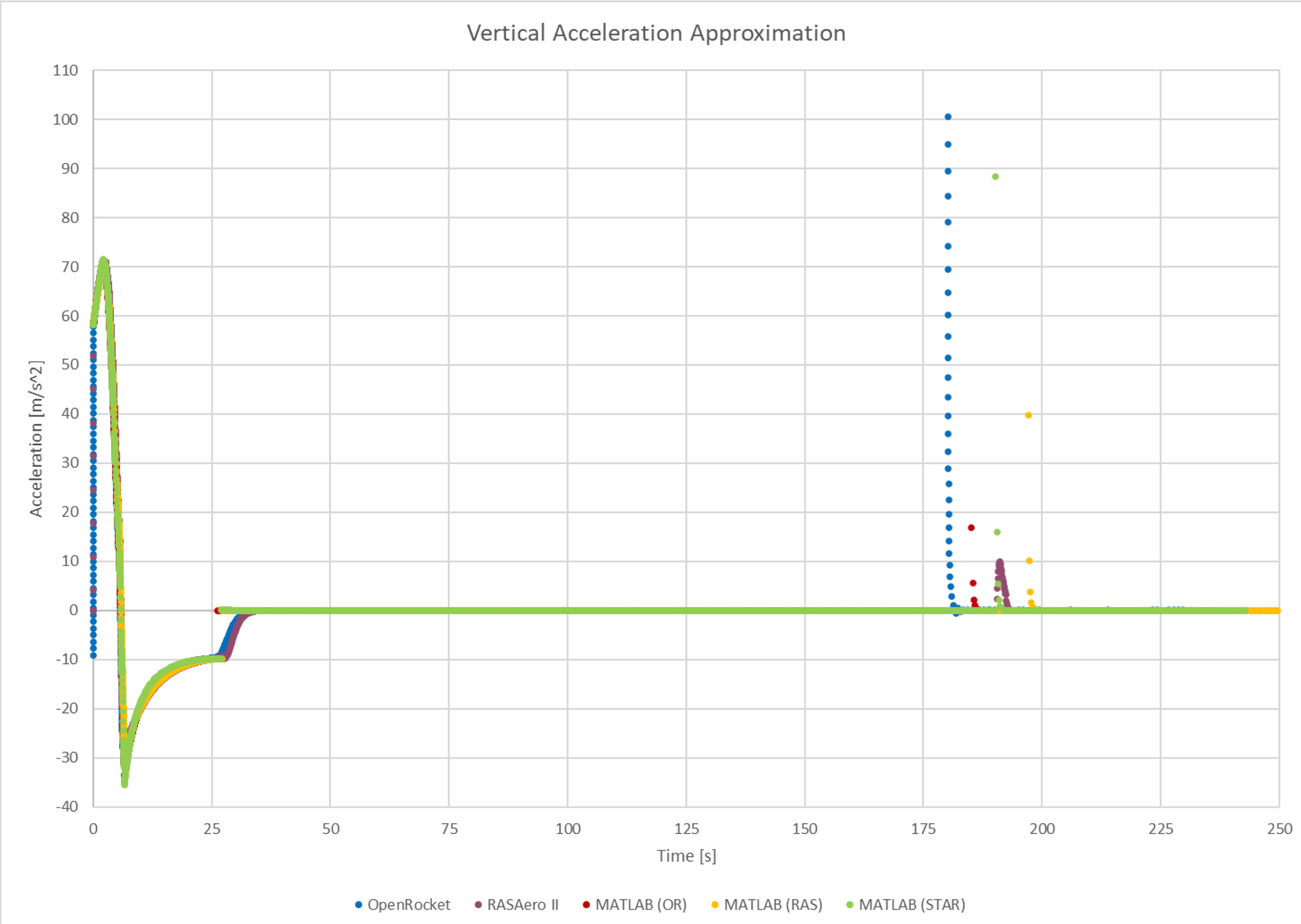
Altitude: With the current rocket assembly, none of the simulations reach our target apogee range. We intentionally designed the rocket to reach an apogee higher than our range to allow for unforeseen circumstances. By doing so, we have given ourselves a buffer. It would be difficult to increase our estimated apogee, but we can easily drop it by adding mass. Methods of doing so are listed below.



Velocity: Our rocket's maximum velocity approaches the maximum velocity and in some simulations, surpasses it. For the recovery phase, the estimated velocity is relatively consistent across all of the simulations.



Acceleration:



Mass Estimation

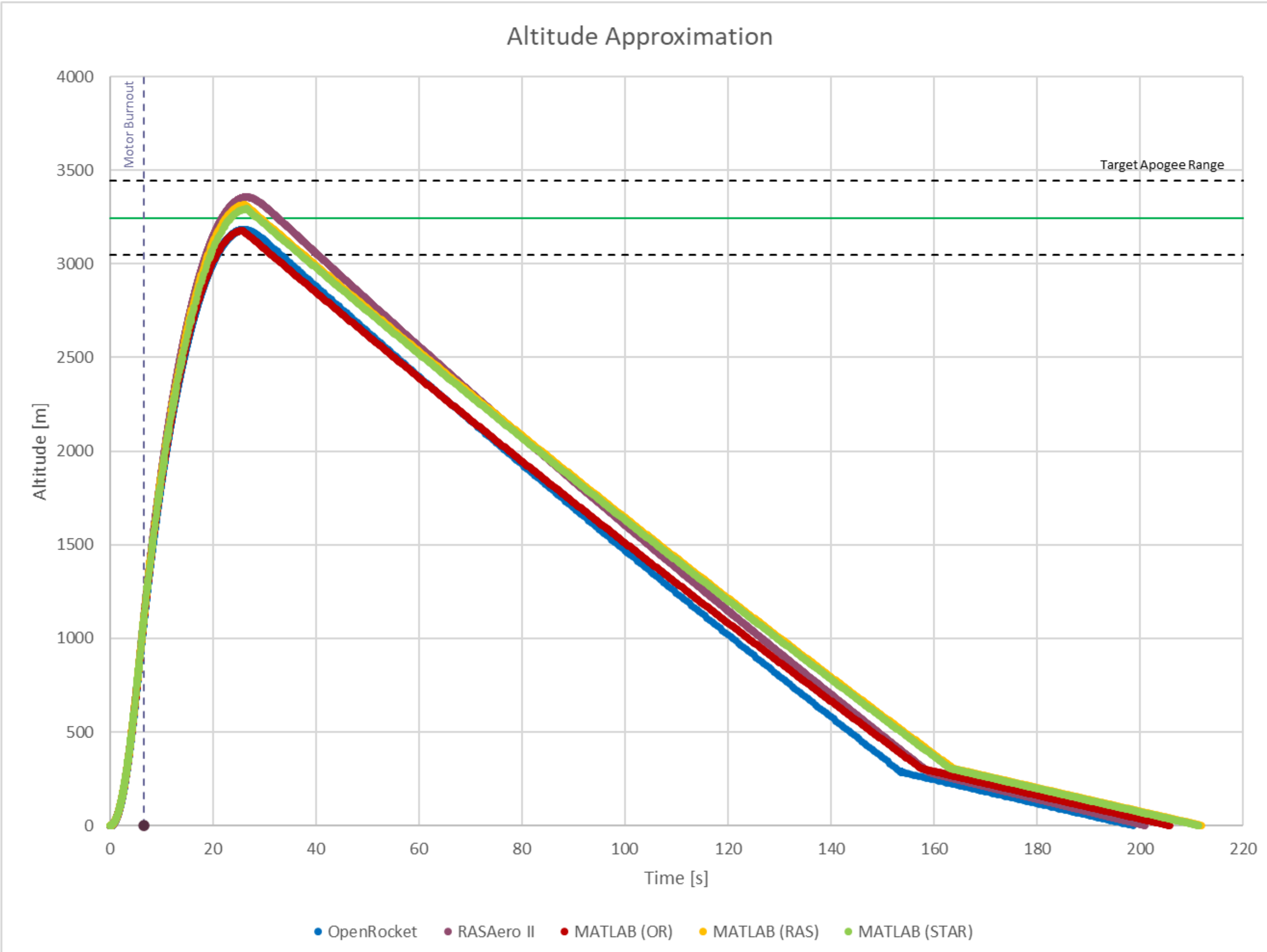
Overview:

- Mass will be added to the rocket in order to bring the apogee down into the desired apogee range and reduce the maximum velocity of the rocket below our allotted value.
- The simulations below consider 4 kilograms in added mass to the rocket.

Manufacturing Process:

- The mass will be added to after the manufacturing process is complete and the rocket is weighed. The actual weight will be compared to the weight of the rocket in OpenRocket without the added mass. The difference between the actual and projected weights will be then used to determine how much weight will be added to the rocket.
- From there, mass will be added to the bottom coupler of the rocket, since it is near the center of gravity of the rocket, therefore adding mass at the location would not affect the stability of the rocket.
- The mass will be added by using sand, and a maximum of 6 kg can be added.

Results:



Wind Analysis

Overview: To analyze the potential effects that wind may have during launch, we conducted four tests using different wind speeds on our unweighted rocket. We used 2.353 m/s for the no wind simulation because variance is negligible in this case. Additionally, we researched the wind speeds in June of the past few years to see the maximum velocity that we can expect on launch day. We also tested speeds in between these values.

No Wind (2.235 m/s, 7.33 ft/s)

- Average Apogee: 3554.70 ± 3.13 m (11660 ft)
- Average Maximum Velocity: 305 m/s
- Average Maximum Acceleration: 72.33 m/s^2
- Average Time to Apogee: 26.5 s
- Average Flight Time: 233.2 s

Low Wind (4.470 m/s, 14.67 ft/s)

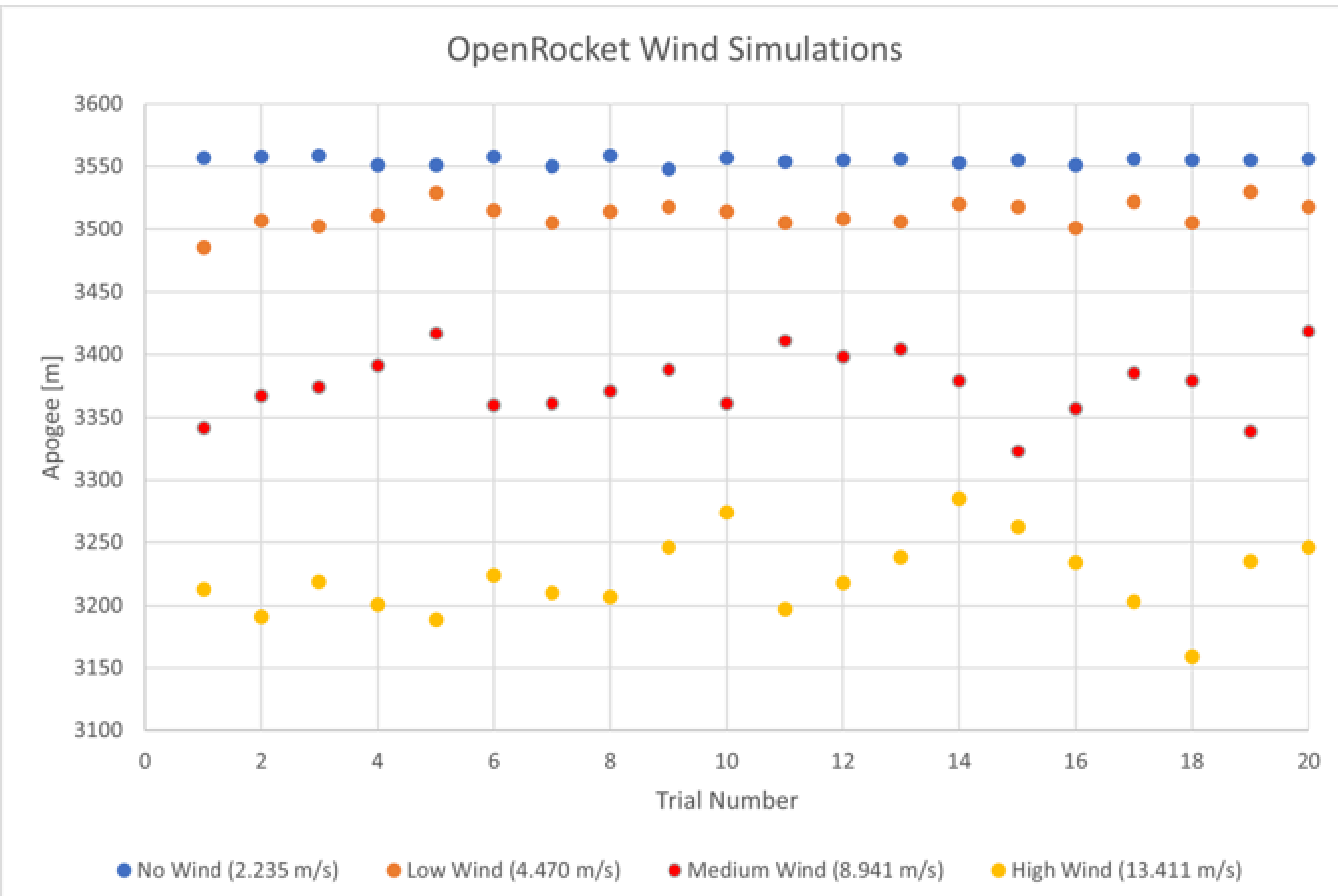
- Average Apogee: 3511.65 ± 10.45 m (11522.31 ft)
- Average Maximum Velocity: 304.95 m/s
- Average Maximum Acceleration: 72.55 m/s^2
- Average Time to Apogee: 26.25 s
- Average Flight Time: 231 s

Medium Wind (8.941 m/s, 29.34 ft/s)

- Average Apogee: 3376.30 ± 10.45 m (11076 ft)
- Average Maximum Velocity: 303.5 m/s
- Average Maximum Acceleration: 72.85 m/s^2
- Average Time to Apogee: 25.7 s
- Average Flight Time: 225 s

High Wind (13.411 m/s, 44.0 ft/s)

- Average Apogee: 3222.55 ± 30.70 m (10574.15 ft)
- Average Maximum Velocity: 301.5 m/s
- Average Maximum Acceleration: 73.85 m/s^2
- Average Time to Apogee: 25.15 s
- Average Flight Time: 220 s



Next Steps

- Further CFD Analysis: Further evaluate pressure values induced upon vehicle during flight and evaluate if materials and manufacturing plan are sufficient. Run 3-D model for further analysis on flow, with rail buttons and updated launch trajectory/fin dimensions.
- Wind Tunnel Testing: Simulate flow across a model of rocket in a wind tunnel to get drag data on a real life model.
- Mass Certainty/Updating: Correctly model mass of each part when manufactured to get accurate models of launch vehicle and simulations of flight trajectory.
- Surface Finish Testing: Evaluate surface finish on components after manufacturing, update simulation models.

PROFILE MANUFACTURING

Introduction: This serves as an outline of the *preliminary* composite manufacturing processes and materials we intend to use for the aerodynamic profiles. Manufacturing information on molds for such parts will not be covered in the following guidelines, however, notes will be provided on necessary mold treatments to ensure successful part removal and mold protection. Finally, there will be details of this plan that will be marked with an asterisk* to indicate that this element of the procedure is subject to change. If there are any questions related to these items, please feel encouraged to raise them at the end of the "Aerodynamics" portion of CDR.

Material Criteria

STAR CCM+, MATLAB, and OpenRocket analyses helped to shape our criteria for selected materials. Using CFD analysis to model the dynamic pressure of the rocket, we determined the maximum compressive load experienced by the rocket to be 132600Pa (~19 psi). It should be noted that this estimate assumes all dynamic pressure to be exerting compressive stress on the rocket. This assumption was made because carbon fiber and fiberglass are both weaker in compression than tension. Therefore, by observing the maximum pressure and assuming the loading to produce solely compressive stress, we could ensure our material was strong enough to endure such loading, even if some of that loading did exert tensile stress on the rocket. Given the maximum compressive loading, we determined that the material's compressive strength needed to be at least 10% higher than that value, providing our first mechanical constraint.

OpenRocket analysis revealed a need for a surface finish of 125 ± 25 μm in order to reach our target apogee. This was determined by altering the surface finish of the entire rocket and comparing the resulting apogee for each value. Additionally, analyses were conducted on each individual part, to determine where an excellent surface finish would be most influential. This research concluded that the parts whose surface finish was most crucial to the apogee of the rocket were the body tube and fins. While surface finish data is not provided on a material data sheet, there are certain materials, as aforementioned, specifically manufactured to yield a high-quality surface finish. Additionally, a proper curing procedure can also help to ensure an optimal surface finish. We will conduct testing to ensure these surface finish criteria are met once we receive our material, after CDR. This testing will involve small-scale layups following the same procedure we intend to use to each part, and measuring variance in surface finish using a surface roughness meter.

MATLAB analyses also helped shape our material criteria. Fin fluttering was a large concern when we began to consider different materials. The safety Mach value for our fin fluttering analysis was directly impacted by the shear modulus of the fin material. After comparing different shear values, it was determined that our minimum value for shear modulus was 3.5 GPa (0.5 Msi). A value higher than this would not necessarily introduce any issues. However, it should be noted that as a material's shear modulus increases (corresponding with an increase in stiffness), it becomes more brittle. Therefore, we did not want to choose a material with a shear modulus exceptionally higher than our minimum value.

To conclude, our limiting mechanical criteria were a compressive strength (CS) value of 19 psi or higher, a shear modulus (SM) of 3.5 GPa or higher for the fin material, and a final surface finish of 125 ± 25 μm. Our final material choices had the following data:

- *AX-5201 & AX-5201 TECH:* CS - 552 MPa (80 ksi), SM - 4.1 GPa (0.60 Msi)
- *AX-3201:* CS - 482 MPa (70 ksi), SM - not relevant, not used on fins

NOTE: An additional consideration in our material selection process was that our material is being kindly donated by CompositesOne/Axiom, and therefore we were limited in the materials they offered for donation.

Materials

Carbon Fiber Prepregs:

- AX-5201XL-284-50” RC42 CLEAR → “AX-5201”
    - TDS:

AX-5201XL Carbon Fabric Prepreg

Vacuum Bag Processing / Excellent Surface Quality / Flexible Cure Cycle / Large Part Construction

Table 7. Typical Physical Properties

Property	Style 282	Style 284	Style 670
Standard Resin Content	42%		38%
Lamina Density[1]	0.054 lb/in³ (1.5 g/cm³)		
Fabric Weave	Plain	2x2 Twill (3K)	2x2 Twill (12K)
Fabric Areal Weight	5.8 oz/yd² (197 g/m²)		19.8 oz/yd² (671 g/m²)
Cured ply thickness[1]	.0085” (.22 mm)		. 027” (.7 mm)

» [1]AX-5201XL cured under vacuum for 4 hrs at 250°F

Table 8. Typical Mechanical Properties

Property	Test Method	Test Condition	Strength	Modulus
Tensile properties[1]	ASTM D3039	75°F (24°C)	110 ksi (758 MPa)	8.9 Msi (61XXX GPa)
Compressive properties[1]	SACMA SRM 1	75°F (24°C)	80 ksi (552 MPa)	7.9 Msi (54 GPa)
In-plane Shear[1]	ASTM D3518	75°F (24°C)	13.8 ksi (95 MPa)	0.60 Msi (4.1 GPa)
Interlaminar shear strength[1]	ASTM D2344	75°F (24°C)	10.5 ksi (72 MPa)	N/A

» [1]10 ply laminate AX-5201XL-284 cured under vacuum for 4 hrs at 250°F

PRODUCT DATA SHEET

- AX-5201XL-284TECH-50” RC42 CLEAR → “AX-5201 TECH”
    - TDS:

AX-5201XL-284TECH

Vacuum Bag Processing / Excellent Surface Quality & Low Void Content / Flexible Cure Cycle / Large Part Construction

PRODUCT DATA SHEET

Recommended Cure Cycle

» Bagging recommendations:
- Use edge, surface, and/or inter-ply breathers for best performance.
- 26 inHg vacuum minimum
- Leak-check to 1 inHg drop in 5 mins

» Curing Instructions for “Show-Room” finish:
- Layup first ply of AX-5201XL-284TECH with “drier” side facing the mold surface.
    - If using AX-5201XL-284TECH/1080, apply the scrim side to the mold surface.
- Bag first ply using perforated release film, bleeder/breather, and bagging film. It is not recommended to use peel-ply or it may disturb the first ply when removing.
- Cure under vacuum for 1 hour at 160°F (1-5°F/min ramp recommended, in-hot is optional for faster processing).
- Remove bagging consumables and continue lay-up with remaining plies.
- Bag and cure in accordance with cure recommendations listed on page 2 above, with the following improvements:
    - » No room temp debulks needed for ideal surface finish
    - » Tolerant to poor vacuum as low as 26 inHg
    - » Tolerant to leaks as high as 2 inHg drop in 5 minutes
    - » No intermediate dwell required
    - » Tolerant to fast ramp rates (In-Hot/Out-hot processing is optional) for shorter cycle time and higher through put.

Table 9. Typical Physical Properties

Property	Style 284TECH	Style 284TECH/1080
Standard Resin Content	42%	
Lamina Density[1]	0.054 lb/in³ (1.5 g/cm³)	0.056 lb/in³ (1.5 g/cm³)
Fabric Weave	2x2 Twill (3K)	284TECH: 2x2 Twill (3K) 1080: Plain Weave
Fabric Areal Weight	5.8 oz/yd² (197 g/m²)	7.2 oz/yd² (245 g/m²)
Cured ply thickness[1]	.0085” (.22 mm)	.010” (.26 mm)

» [1]AX-5201XL cured under vacuum for 4 hrs at 250°F

- NOTE: AX = Axiom (Manufacturer), 5 = Carbon Fiber, 201XL = Resin System, 284 = Fabric Style, 50” = Roll Length, RC42 = Resin Content, “CLEAR” = Color

Fiberglass Prepregs:

- AX-3201XL-1210-50” RC38 CLEAR → “AX-3201”
    - TDS:

AXIOM MATERIALS

AX-3201XL Fiberglass Fabric Prepreg

Vacuum Bag Processing / Excellent Surface Quality / Flexible Cure Cycle / Large Part Construction

PRODUCT DATA SHEET

Table 4. Typical Lamina Physical Properties

Property	Style 1080	Style 120	Style 7781	Style 3783	Style 1210
Standard Resin Content	50%		38%		
Lamina Density[1]	0.061 lb/in³ (1.7 g/cm³)		0.066 lb/in³ (1.8 g/cm³)		
Fabric Weave	Plain	4H Satin	8H Satin	8H Satin	2x2 Twill
Fabric Areal Weight	1.42 oz/yd² (48 g/m²)	3.07 oz/yd² (104 g/m²)	8.95 oz/yd² (304 g/m²)	16.1 oz/yd² (546 g/m²)	26.0 oz/yd² (880 g/m²)
Cured ply thickness[1]	.0020" (.05 mm)	.0044" (.11 mm)	. 010" (.25 mm)	. 018" (.46 mm)	.029" (.74 mm)

[1]AX-3201XL cured under vacuum for 4 hrs at 250°F

Table 5. Typical Mechanical Properties

Property	Test Method	Test Condition	Strength	Modulus
Tensile properties[1]	ASTM D638	75°F (24°C)	75 ksi (517 MPa)	3.9 Msi (27 GPa)
Compressive properties[1]	ASTM D695	75°F (24°C)	70 ksi (483 MPa)	3.7 Msi (26 GPa)
Flexural properties[1]	ASTM D790	75°F (24°C)	100 ksi (689 MPa)	4.1 Msi (28 GPa)

[1]10 ply laminate, AX-3201XL cured under vacuum for 4 hrs at 250°F.

Aramid Honeycomb Core:

- ACP Composites: Aerospace Grade Standard Cell Honeycomb Core, 48" x 96", 0.06" Thickness, ⅛" Cell, 1.8 PCF → "Honeycomb"
    - Link

Material Justification

We opted for prepreg materials for this project to simplify the layup process. We did not require a composite with an abnormal resin content, nor do we have any part geometries complex enough to warrant the extra labor of the wet layup process. The wet layup process involves layering sheets of fabric, either aramid, carbon fiber, or fiberglass, "painting" layers of resin in between plies. The club has used this process in previous years but often struggled to manufacture parts with consistent resin content, and consequently, consistent strength properties. Therefore, for Crescendo, we have opted for prepreg composites. The term "prepreg" refers to a fabric pre-impregnated with resin, meaning we do not have to do the extra research of resin-fabric compatibility, nor the extra labor of adding resin to the fabric ourselves. Although prepregs are usually stiffer and more difficult to shape than dry fabric, the rocket does not have part geometries where the extra flexibility would be especially advantageous. Prepregs can also be manufactured to have specific properties, such as flame retardance, UV resistance, and smooth surface finish. With this in mind, we sought to find a prepreg that yielded a smooth surface finish while also meeting our mechanical constraints. As for the different fabric choices for our prepreg, we opted for primarily carbon fiber. Compared to fiberglass, carbon fiber can endure higher loads, both compressive and tensile, making it a more optimal choice for our rocket. The one exception on the rocket is the Avionics body tube. While carbon fiber is all-around stronger than fiberglass, it does not allow sufficient transmission of RF signals. The Avionics Team relies on such signals to transmit data from the rocket to the ground. Fiberglass, however, allows for the transmission of these signals and was therefore chosen as the material for the body tube housing the avionics stack.

Manufacturing Procedure

Body Tube, Nose Cone and Boat Tail:

- Aluminum Mold* with mold sealer and mold release (likely Chemtrend) to prevent Galvanic corrosion between carbon fiber and aluminum, as well as seal any imperfections in the mold to create a better surface finish for layups.
- First layer will be the 5201XL TECH with the drier side applied against the mold surface. After first layer is applied, we will debulk under vacuum for 1 hour at 160 °F (thought debulking in hot is optional), being sure to properly apply surface and edge breathers, as well as perforated release film as recommended by the TDS. Also, make sure to check the vacuum seal by doing a pressure drop test. If pressure drops, more than 1inHg in 5 minutes, do not use. It should also be noted that peel ply is not recommended with the use of the 5201XL TECH.
- Once debulking is complete, remove from vacuum bag and layer three plies of the 5201XL over the base layer. You should now have four plies of material. Debulk under vacuum, out of oven, for 1 hour, again making sure to conduct a pressure drop test.
- Repeat this process with another three plies. At this point you should have a total of 7 plies. Now layer yet another 2 more plies of the 5201XL to increase the total to 9. For the final layer, we will use the 5201XL TECH, laying the drier said against the laminate with the wetter side face up. Conduct a final debulk, placing the laminate under vacuum then curing it in the oven at one of the cure cycles recomended on the TDS. This has not yet been finalized and is open for input.

Table 1. Recommended Cure Cycle[1]

Optimum properties are achieved when cured under vacuum according to one of the following:

Service Temp	AX-201XL	AX-201XL/FR
Up to 180°F (82°C)	• 8 hrs @ 160°F (71°C) • 3 hrs @ 180°F (82°C) • 15 mins @ 250°F (121°C) • 10 mins @ 280°F (138°C)	• 8 hrs @ 190°F (88°C)
Up to 250°F (121°C)	• Initial cure as above followed by 4 hour/250°F (121°C) post cure • 2.5 hrs @ 250°F (121°C) • 1.5 hrs @ 280°F (138°C)	• Initial cure as above followed by 5 hours/250°F (121°C) post cure, or • 3 hrs @ 250°F (121°C), or • 2 hrs @ 280°F (138°C)

[1]Time and temperatures are the minimum measured on part.

PRODUCT DATA

Cure Considerations

» Suggested ramp rate:
- Heat-up: 1-4°F/minute (0.6-2°C/min)
- Cool-down: 10°F/minunte (6°C/min)

» Temperature heat up and cool down under pressure is recommended.

» Parts can be free-standing post cured with slower ramp rates (0.5°F/min) but large or heavy parts should be simply supported.

» For optimum surface finish, dwell at 160°F (54°C) for 1 hour before continuing to higher temperatures.

Bagging Considerations

» Apply pressure:
- Minimum: 22 inHg vacuum
- Vac-bag, autoclave, and press-cure compatible

» For best surface finish and void content:
- For easier, faster, and more tolerant processing, use AX-5201XL-284TECH as a surface ply (see additional curing details in the "AX-5201XL-284TECH" section below)
- Use edge, surface, and inter-ply breathing techniques such as dry-tow breathers.
- Debulk at 28 inHg vacuum or greater for 60 minutes at room temperature.
- Leak-check the vac-bag by removing the vacuum source and measuring internal pressure. There should be no vacuum

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Avionics Body Tube

- The avionics body tube will be manufactured out of fiberglass. Because the fiberglass has a higher laminate thickness than the carbon fiber, we will only need three layers, meaning only one debulk before curing. This debulk will follow the same procedure as above. Once complete, the laminate will be cured according to one of the recommended cure cycles.

Fins

- The fins will be comprised of 1 layer of the ACP Honeycomb Core, with 7 layers of the 5201XL on either side, completed by one layer of the 5201XL TECH on the outside to maximize surface finish. These layers will follow the same procedure as the body tube, nose cone and boat tail above, debulking every 3 layers.

Next Steps

The next steps for profile manufacturing will be compiling a more detailed manufacturing plan and schedule, to ensure everything is completed before our flight readiness review in early May. With this manufacturing plan will also be a testing plan for surface finishish, involving small scale layups that follow our planned manufacturing procedure. These will serve as samples to help us gauge how much we need to adjust our layup process/how much post manufacturing work we will have to do to achieve our desired surface finish. We will measure surface finish with surface roughness gauges and develop a more in-depth procedure after

CDR. The goal of the overall manufacturing plan is to create a document that future CPSS members can reference for composite manufacturing and surface finish testing.