

Active Rocket Controls

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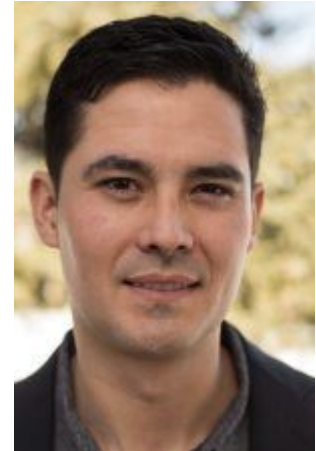
Project Description

The group is tasked research, design, and construct a rocket using one of various methods of active control to dynamically adjust rocket orientation.

We are required to research and compare at least 3 different control systems.

Customer Requirement

- CR 1: Dynamic z-axis control (orientation, stability, trajectory)
- CR 2: Fits 2.5–4" rocket body
- CR 3: Demo launches: Jan '26 (basic), Mar '26 (Tripoli live test)
- CR 4: Real-time feedback, Arduino + RockSim integration
- CR 5: Functions: no-roll & induced roll ± 100 RPM (2 sec, stop)
- CR 6: Comply with Tripoli safety, maintain structural integrity, add fail-safes
- CR 7: Research control strategies; apply ME principles
- CR 8: Include 3D/custom parts; perform trade-off/risk analysis
- CR 9: Deliverables: design report, prototype, post-flight evaluation
- CR 10: \$1000 minimum fundraised



Professor Carson Marty Pete [0]

Engineering Requirements

- ER 1: Have a system mass (rocket,motor, control system) of less than or equal to 10lb.
- ER 2: Fit system into 2.5-4 in. diameter rocket tube
- ER 3: Adjust z-axis orientation and maintain no roll $0 \pm 20^\circ$ and induce a 100 ± 10 RPM
- ER 4: Use IMU sensor and PID algorithm, <50 ms control loop latency, use Arduino, 90% simulation-to-flight correlation.
- ER 5: Withstand level one equivalent motor's loads (70 lbf).
- ER 6: Test flight (Jan 2026), full integrated and working system launch (March 2026)
- ER 7: Maintain a build and design budget of less than or equal to \$2000.
- ER 8: Minimum 50% components 3D-printed/custom, ± 0.1 mm tolerance.
- ER 9: Maintain all safety and technical requirements for tripoli flight checklist (CG,CP,and cord length).

Background/Benchmarking

- AIM-9X Sidewinder (Aerodynamic Control surface) [1]
- SpaceX Falcon 9 (Thrust Vector Control) [2]
- Blue Origin New Shepard (Mass momentum shifting) [3]



[1]



[3]



[2]

System QFD Overview

- Customer Needs and Weights (1-9)
 - Comply with Tripoli safety requirements (9)
 - Dynamic z-axis control (8)
 - Demo launches (7)
- Technical Requirements
 - Weight Constraint
 - Constrained Diameter
 - Z-axis roll control orientation error
- Relationship Matrix (0,3,9 scale)

	Z-axis roll orientation error	Latency
z-axis control	9	9
Safety	3	3

- Roof Correlation (-1,9 scale)
 - Trade-off: Weight vs. Diameter
 - Orientation vs. Latency (9)
- Customer Opinion Survey
 - Aim-9x
 - Falcon 9
 - All Safety

System QFD

Date: September 29, 2025

1	Weight Constraint								
2	Constrained Diameter	-9							
3	Z-axis Roll Orientation Error	9	-3						
4	Decrease control latency	9	-3	9					
5	Dynamic loading	-9	-3	3	9				
6	Reliability	-3	-1	9	-9	9			
7	Cost	9	3	-3	-3	-9	-3		
8	with minimum 50% 3d printed custom parts	9	3	3	3	-3	3	3	
9	Fly Sheet Check	9	3	9	9	3	9	-1	9

Legend	
A	AIM-9X Sidewinder
B	SpaceX Falcon 9
C	Blue Origin New Shepard

		Technical Requirements									Customer Opinion Survey				
Customer Needs		Customer Weights													
		Weight Constraint	Constrained Diameter	Z-axis Roll Orientation Error	Decrease control latency	Dynamic loading	Reliability	Cost	Construct with minimum 50% 3d printed custom parts	Fly Sheet Check					
											1 Poor	2	3 Acceptable	4	5 Excellent
1	Dynamic z-axis control	8	3		9	9	3	3	1	3	9		A		BC
2	Fits 2.5-4" rocket body	4		9					3	9		ABC			
3	Demo launches	7			3		3	9	1	3	9		ABC		
4	Real-Time Feedback	1	1		9	9		3	1	3	9				ABC
5	Functions: No roll & Induced roll	6			3	3		3		1			C	B	A
6	Comply with Tripoli safety requirement	9		3	3	3	9	9	1	3			A	B	C
7	Cost effective solution	3	1		1	1	1	3	9	9	1	ABC			
8	Include 3D printed/custom parts	5		9	1	1		3	9	9	1	ABC			
9	Deliverables	2			3		3	9	9	9	9		ABC		
Technical Requirement Units		lb	in	degree RPM	ms	lbf	%	\$	n/a	n/a					
Technical Requirement Targets		≤10lb	2.5-4"	2°, 100 RPM	≤50 ms	70	99%	\$2,000	n/a	n/a					

Literature Review

[4] “TRIPOLI Rocket Association Safety Code” (Handbook). ~*Engineering Standard*

This source discusses the safety regulations that must be followed within the TRIPOLI Rocket Association. This includes the standards for the size and motor type of the level 1 rocket.

[5] “*Thermodynamics and Propulsion*” (Textbook).

Dr. Spakovszky authored this textbook, which discusses thermodynamics, propulsion, and heat transfer operations for rockets.

[6] “*Arduino Tutorials*” (Online).

This resource covers the use of Arduinos in model rocketry. Topics include materials and supplies, data logging, an introduction to GPS on Arduinos, a three-axis accelerometer, and other beginner tutorials.

[7] “*Arduino Rocket Flight Computer*” (Research Paper).

This paper, written by Moschidis and Bithas, describes the process of creating an Arduino-based system to collect and record data for a model rocket.

[8] “*Arduino and MPU6050 Accelerometer and Gyroscope Tutorial*” (Tutorial).

This tutorial explains the operation of the MPU6050 Inertial Measurement Unit (IMU), which integrates a 3-axis accelerometer and a 3-axis gyroscope.

[9] “*When the Data Goes Sideways: Why Your Rocket’s Descent Position Might Be Wrong*” (Newsletter).

Published by Apogee Components, this newsletter discusses methods for recording the orientation of a rocket during flight and how to troubleshoot related problems.

[10] “*Rocksim Information*” (Online).

This article explains how to use Rocksim, which will be applied in the project to simulate the rocket’s design.

Literature Review

[11] J. Barrowman, “TIR-33: Calculating the Center of Pressure of a Model Rocket,” *Nakka-Rocketry*.
This source details the calculation of a rocket’s center of pressure using Barrowman’s classic method.

[12] “*An Actively Stabilised Model Rocket*” (Research Paper).

This research paper provides an overview of basic control systems that can and have been used in rockets, including gyroscopes and gimbaled motors for thrust vectoring.

[13] “*Design and Analysis of a Low-Cost Anti-Missile Missile in Combination with a High Powered Rocket*” (Research Paper).

This source examines different types of sensor integration for rocket control systems.

[14] “*Fundamentals of Aerodynamics*” (Textbook).

This source reviews the fundamentals of aerodynamics, including different flow regimes and significant equations relevant to fin and rocket design.

[15] “*Design of a Servo Mechanism for Controlling Missile Fins in Pitch and Yaw Planes*” (Research Paper).

This source discusses servo motor integration and design, including design equations and supporting references.

[16] “*Feedback Control of Dynamic Systems*” (Textbook).

This source provides an overview of control system theory, including closed-loop control, PID control, and servo control.

[17] “*Model Rocket Guidance by Canards*” (Research Paper).

This source explains how actuated canards can be integrated into a rocket to induce roll via a control system.

Literature Review

[18] “Rocket Center of Gravity,” *Beginner’s Guide to Aeronautics*, NASA Glenn Research Center.

This source explains how to calculate the center of gravity of a rocket from its component masses and positions.

[19] T. Van Milligan, *Numeric Methods in Model Rocket Design*, Apogee Rockets, Technical Publication #17.

This source presents numerical and Barrowman-based methods for calculating center of pressure and analyzing stability.

[20] T. Van Milligan, “How to Find the Center of Pressure on a Rocket,” *Advanced Construction Videos*, Apogee Rockets, video, 12:50.

This source provides a visual demonstration of locating the center of pressure and its role in rocket stability margin.

[21] *International Rocket Engineering Competition Rules & Requirements*, ver. 1.6, ESRA, 2025. ~*Engineering Standard*

This source mandates the reporting of both center of gravity and center of pressure in technical submissions, setting stability margin as a required metric for flight readiness.

[22] G. Solomon and Y. Abreham, “Analytical Calculation on Rocket Stability,” *International Journal of Research and Analytical Reviews*, vol. 7, no. 3, 2020.

This source analyzes center of gravity and center of pressure with fin geometry variations to predict static stability.

[23] R. Cadamuro, M. P. Cardillo, and L. F. Macaluso, “A Static Stability Analysis Method for Passively Stabilized Sounding Rockets,” *Aerospace*, vol. 11, no. 3, p. 242, 2024.

This source introduces an updated stability analysis method for sounding rockets, linking CP/CG placement to flight behavior.

[24] J. Barrowman, “TIR-33: Calculating the Center of Pressure of a Model Rocket,” *Nakka-Rocketry*.

This source details the calculation of a rocket’s center of pressure using Barrowman’s classic method.

Literature Review

[25] *"A Guide to Optimal Altitude: Part 2"* (Newsletter).

This source describes rocketry fundamentals and explains how burn time correlates with altitude.

[26] *"Rocket Propulsion Elements, 9th ed."* (Textbook).

This textbook provides a detailed discussion of various rocket propellants, their associated propulsion systems, and fundamental principles.

[27] *"Combined CAR/NAR/TRA Certified Rocket Motors List."* ~Engineering Standard

This source provides a list of NAR-approved motors along with their characteristics, such as dimensions and mass.

[28] *"AeroTech Master Motor Matrix."*

This source lists motors and their related characteristics, including length, impulse, and weight.

[29] *"Specific Impulse" & "Rocket Thrust Summary,"* NASA (Online).

This source presents simplified equations relating to impulse and thrust.

[30] *"Determination of the Total Impulse of the Solid Rocket Motor by Using Two Mathematical Methods"* (Conference Paper).

This paper describes methods for calculating the total impulse of solid rocket motors.

[31] *"Thrust Vector Control of Solid Propellant Model Rocket"* (Conference Paper).

This source reports on the control of thrust direction in a solid propellant rocket, including experimental results.

Literature Review

[32] *“Compression Tests of Tubing Used in Rocketry”* (Newsletter).

This source examines various materials and methods used to test rocket body compression to failure through stress analysis.

[33] *“Unified Analysis of Aerospace Structures through Implementation of Rapid Tools into a Stress Framework”* (Technical Report). ~*Engineering Standard*

This paper presents how integrating rapid analysis tools into the HyperSizer stress framework streamlines aerospace structural design and supports FAA certification by improving accuracy, traceability, and cycle efficiency.

[34] *“3D Printing Temperature: Effects, Materials and Considerations”* (Technical Guide).

This source reviews different 3D printer filaments, their properties, and the conditions required for proper use.

[35] *“Structural Design and Analysis of High-Powered Model Rockets Using OpenRocket”* (Journal).

This article presents the structural design and analysis of a high-powered model rocket using OpenRocket software, including material selection, stability analysis, and flight simulation results.

[36] *“Nosecone Design – Richard Nakka Rocketry”* (Technical Tutorial).

This article outlines how nosecone shape and size affect drag and stability in different flight regimes and provides practical guidelines for nosecone design in amateur rocketry.

[37] *“Reaction Wheel Based Rocket Active Spin Stabilization”* (Research Paper).

This paper discusses the research and testing of an auto-stabilization method using reaction wheel-based control systems.

[38] *“Introduction to Rocket Design 9. Recovery System”* (Technical Tutorial).

This article explains the control, deployment, and descent phases of rocket recovery systems.

The Rocket Equation

Change in Momentum = Momentum_{Final} - Momentum_{Initial}

$$= m_v \frac{du}{dt} - u_e \frac{dm}{dt}$$

$$\Sigma F = (p_e - p_0)A_e - F_{drag} - mg \cos \theta$$

$$m_v \frac{du}{dt} - \frac{dm}{dt} u_e = (p_e - p_0)A_e - F_{drag} - mg \cos \theta$$

$$\frac{dm}{dt} = \dot{m} \text{ (mass flow rate } \frac{kg}{s})$$

$$\frac{du}{dt} = \frac{1}{m_v} [(p_e - p_0)A_e - F_{drag} - mg \cos \theta + \dot{m} u_e]$$

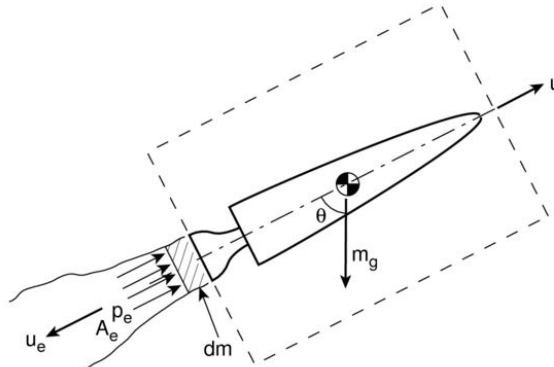


Figure 14.2: Schematic for application of the momentum theorem.

$\frac{du}{dt}$ = Acceleration of the vehicle (m/s^2) Ex: $52 m/s^2$

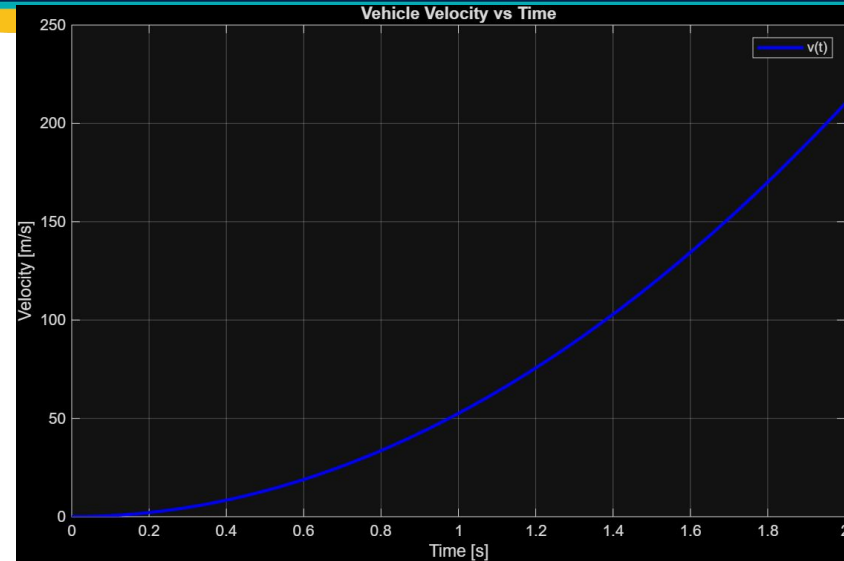
m_v = mass of vehicle Ex: $4kg$

u_e = Exit velocity (m/s) Ex: $2800 m/s$

F_{drag} = Drag force (N) Ex: 0

$(p_e - p_0)A_e$ = Net pressure thrust force ($Pa \cdot m^2 = N$) Ex: 0

$mg \cos \theta$ = Weight (N) = $40N$



To test the equation, it was entered into matlab, and appropriate approximated values were entered to verify that the equation works. It is shown that at 1 second, the velocity is approximately 52 m/s which is a reasonable answer and meets the launch requirements given by Tripoli. However, the equation accounts for continuous acceleration which is not applicable. The burn time for a level 1 rocket is apprizmatly 1-1.5 seconds. It was assumed that there is not drag force, and that the difference in pressure is zero.

Fin Design

How does fin design parameter affect force and damping moments for a high powered rocket?

D: Rocket tube diameter

L_r : Rocket Length

r_t : Rocket radius

A_r : Rocket surface area

I_{xx} : Moment of inertia

N: Number of fins

δ : Fins Deflection

$$D = 4 \text{ in} = 0.1016$$

$$L_r = 1.26365 \text{ m}$$

$$r_t = 0.0508 \text{ m}$$

$$A_r = \pi r_t^2 = 0.008107 \text{ m}^2$$

$$v_o = 150 - 200 \text{ m/s}$$

$$I_{xx} = \frac{mr_t^2}{2} = 0.00163 \text{ kg} - \text{m}^2$$

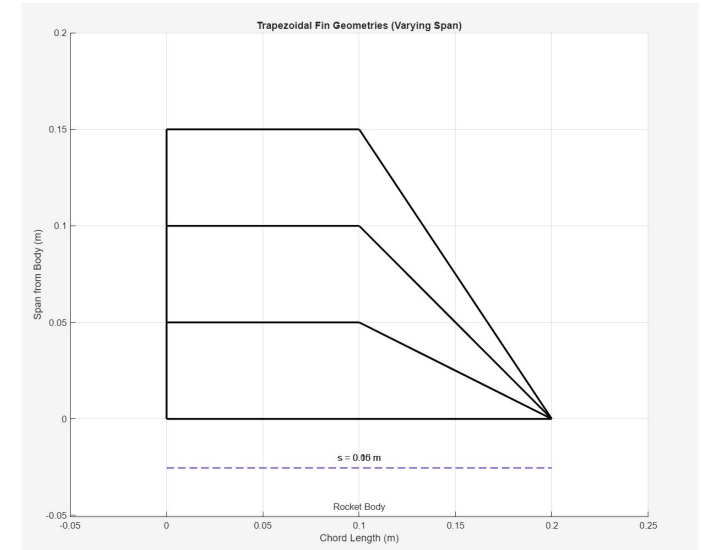
$$N = 4 \text{ fins}$$

$$\text{Burn Rate} = 0.759\text{-}0.821$$

$$SM = \frac{x_{cp} - x_{cg}}{L_r}$$

$$Y_{ma} = \frac{s(C_r + 2C_t)}{3(C_r + 2)} = 0.0444 \text{ m}$$

$$\text{lever arm} = Y_{ma} + r_t = 0.0952 \text{ m}$$



[11]

Roll Moment

How will we induce a 100 RPM roll about the z-axis? How much torque is required by a motor?

M_{Roll} : Roll moment

M_f : Roll Force Moment

M_d : Roll Damping Moment

ρ : Density

v_o : Rocket Speed in relation
to the wind

A_r : Reference Area

L_r : Reference Length and or
Rocket Diameter

$C_{lf\delta}$: Roll moment lift coefficient

Steady State roll rate: Fin cant angle

ω : Angular Velocity

$$M_f = \frac{1}{2} \rho v_o^2 A_r L_r C_{lf\delta} \delta$$

$$M_d = \frac{1}{2} \rho v_o^2 A_{ref} L_{ref} C_{lf\omega} \frac{\omega L_{ref}}{2v_o}$$

$$\delta = \frac{C_{lf\omega} \omega L_r^2}{4v_o C_{lf\omega}}$$

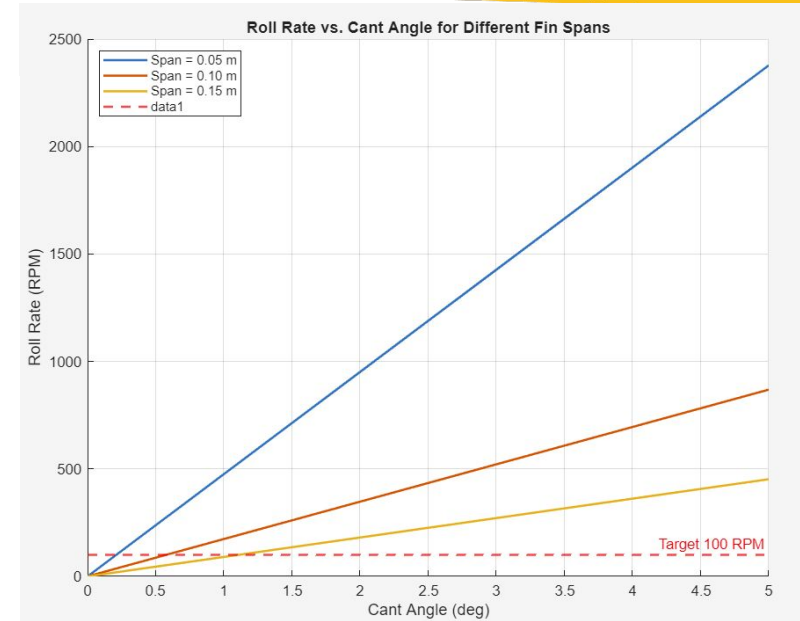
$$\delta = 0.0156 \text{ rad } (0.9) \text{ for } 100 \text{ RPM}$$

$$M_f = M_d = 4.66 \text{ N-m}$$

H: Hinge Moment

$$\bar{H} = \bar{q} S_f \bar{c} C_h = -1.1 \text{ Nm per fin}$$

$$\text{Required Torque} | \tau_s = 6.6 \text{ Nm}$$



Centers & Stability

Significant masses:

Nose cone, electronics, body, tube, fins, motor

$$X_{cg} = \frac{\sum m_i x_i}{\sum m_i}$$

Center of Gravity [in]

Parts	Mass (oz)	x from tip (in)	m*x
Nose cone	5	4.6	23
Arduino	0.88	15	13.2
Body tube	13	29.88	388.44
Fins	2	43.25	86.5
Motor	9.81	44.75	438.9975
TOTAL	30.69		950.1375
CG from nose (in)	30.95918866		

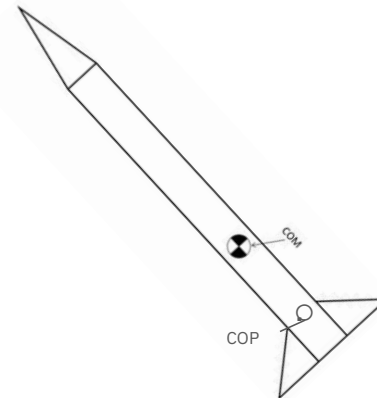
$$SM = \frac{X_{cp} - X_{cg}}{D}$$

Stability Margin [calibers]

$$X_{cp} = \frac{\sum (C_{N\alpha,i} \cdot l_i)}{\sum C_{N\alpha,i}}$$

Center of Pressure [in]

With COG calculated as 30.96 in, in the future, the CP and SM can be calculated for gauging z-axis stability



Hi-Tech Specs

Height: 49.75"

Weight: 20 oz.*

Diameter: 2.630"

*Be sure to weigh your rocket!

Your build may be above or below the specified weight. The actual weight must be entered into the sim software to get correct flight statistics.

Total & Specific Impulse

$$I = F\Delta t = \int F dt = \int \dot{m}V dt = mV$$

$$I_{sp} = \frac{I}{mg_0} = \frac{V}{g_0} = \frac{F}{\dot{m}g_0}$$

Max Velocity: 52 m/s

Weight: 4 kg

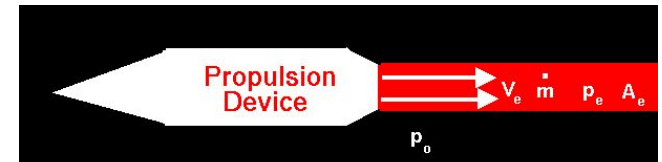
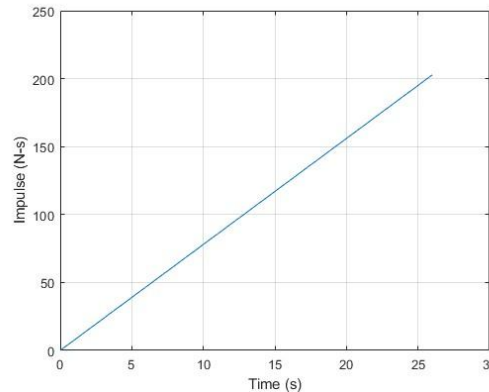
$\dot{m} = 0.15 \text{ kg/s}$

$g_0 = 9.81 \text{ m/s}^2$

$T_f = W/\dot{m} = 26.6667 \text{ s}$

$F = \dot{m} * V = 7.8 \text{ N}$

$I_{sp} = F/\dot{m}g_0 = 5.3 \text{ s}$



[29]

I = Total Impulse [N/s]

I_{sp} = Specific Impulse [s]

F = Force (Thrust) [N]

t = Time [s]

V = Velocity [m/s]

$\dot{m}$ = Mass Flow Rate [kg/s]

g_0 = Acceleration due to Gravity [m/s²]

Body Stress & Nose Geometry

Cross sectional area

$$A_c = \pi(r_{out}^2 - r_{in}^2) = \pi((0.0375 \text{ m})^2 - (0.0365 \text{ m})^2)$$

$$A_c \approx 2.32 \times 10^{-4} \text{ m}^2$$

Max. Compressive Stress

$$\sigma = \frac{F}{A_c} \quad \sigma = \frac{F}{A_c} = \frac{113.3 \text{ N}}{2.32 \times 10^{-4} \text{ m}^2}$$

$$\sigma \approx 488,362 \text{ Pa} \approx 0.49 \text{ MPa}$$

Calculated stress of 0.49 MPa << 60 MPa

Compressive Strain:

$$\epsilon = \frac{\sigma}{E} \quad \epsilon = \frac{\sigma}{E} = \frac{4.88 \times 10^5 \text{ Pa}}{3.5 \times 10^9 \text{ Pa}}$$

$$\epsilon \approx 1.4 \times 10^{-4}$$

E=3.5 GPa
(σ)=60 MPa
Polylactic Acid
Outer Diameter=75mm/2=r_o
Inner Diameter=73mm/2=r_i
L0=1.2m
AeroTech H55 motor~ F=113.3N

$$\Delta L = \epsilon \times L_0 = (1.4 \times 10^{-4})(1.2 \text{ m})$$

$$\Delta L \approx 1.68 \times 10^{-4} \text{ m} \approx 0.17 \text{ mm}$$

Nose Drag Force

$$F_{dn} = \frac{1}{2} \rho V^2 C_{Dn} A$$

$$V^2 = 52^2 = 2704$$

$$q = \frac{1}{2} \rho V^2 = 0.5(1.18)(2704) = 1595.36 \text{ Pa}$$

$$F_{dn} = q C_{Dn} A = 1595.36(0.15)(4.42 \times 10^{-3})$$

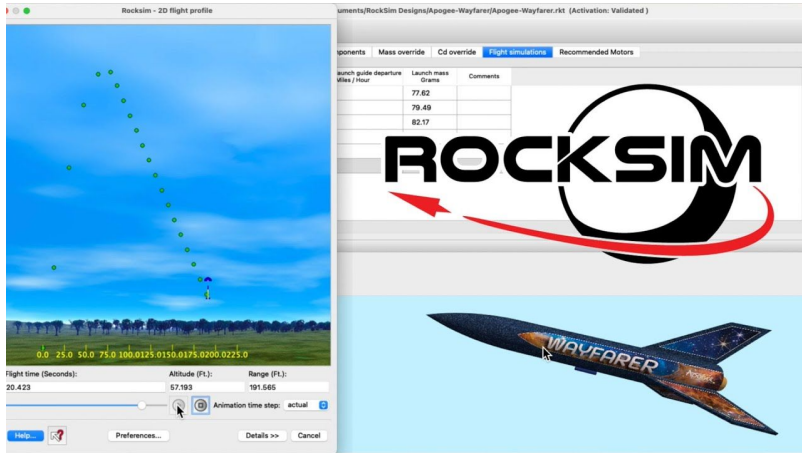
$$F_{dn} \approx 1.06 \text{ N}$$

Shape: Haack series
Drag Coeff.: CD=0.15
A=πr^2=4.42x10^-3 m^2
ρ=1.18 kg/m^3 (Phoenix AZ- Winter)

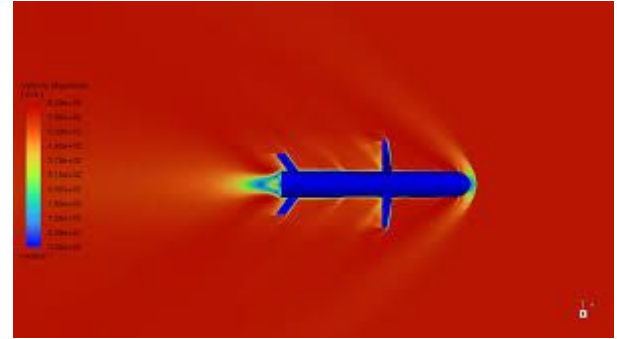
Mathematical Summary

Engineering Requirement	Calculation	Design	Validation
ER1 and ER2	Rocket Equation	Helps inform the velocity of the rocket at different heights. This can help with future calculations regarding the spin of the rocket due to forces that are acting on it as well as atmospheric pressure	Graphed in MATLAB with approximation values.
ER3	Fin Design and Roll Moment Calculation	Help determine the required moment forces needed to induce and maintain z-axis roll. Establish a correlation of fin design and roll rate.	Graphed in matlab using Barrowman equations.
ER5	Impulse/Specific Impulse	Helps determine motor efficiency and performance. Helps compare amount of thrust produced to much propellant is used.	Calculated and Graphed through MATLAB
ER6 and ER7	Stress / Nose Analysis	Verifies structural integrity of materials used during launch. With the values calculated, this may support much higher forces induced on our rocket in various situations during later testing.	Calculated using approximate dimensions and materials planned for use.
ER9	Center of Gravity	Ensures the rocket maintains a proper stability margin by comparing CG to CP. Guides placement of electronics, payload to achieve stable flight.	Calculated using approximate dimensions based on parts, rocket model dimensions

Mathematical Simulation



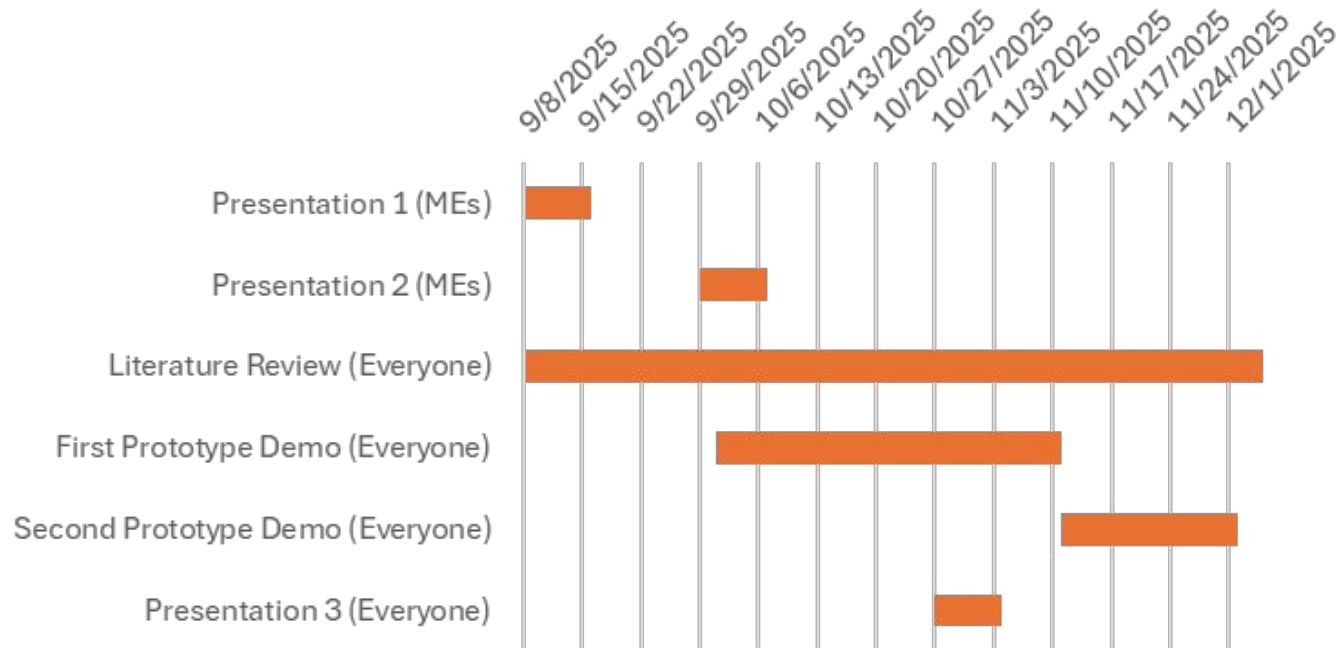
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Tentative Schedule

ME 476C Active Rocket Control Gantt Chart



Tentative Schedule Cont.

- First test launch by Jan 26, 2026.
 - Aim to test Arduino Sensors (EEs)
- Second test launch by Mar. 2026.
 - Will test Arduino Sensors and movement requirements. (Everyone)
- At some point in time the team aims to test the rocket at Embry Riddle University, utilizing their wind tunnels. TBD. (MEs)
- Team Meetings
 - MEs meet at least once a week outside of capstone class.
 - Might increase further along in the semester.
 - Customer meeting once a week.
 - EEs will meet once a week, and bi-weekly with MEs.

Current Budget

	Expended	Funded	Notes
Funds			
Starting Funds		\$ 500.00	NAU
Fundraised		\$ -	Minimum needed \$1000
TOTAL		\$ 500.00	
EXPENSES			
Motors	\$ 300.00		Estimate for around 4 single use motors
Rocket Kit	\$ 110.00		Hi-Tech
Arduino	\$ 60.00		2 @ \$30 each
Sensors	\$ 30.00		2 @ \$15 each
Filament	\$ 110.00		PLA; 2 kg @ \$52 each
Epoxy	\$ 48.00		8 Sticks @ \$6.00
Electrical Miscellaneous	\$ 100.00		
Travel			Remaining Budget can be allocated for travel expenses
TOTAL EXPENSES	\$ 658.00		Projected
Balance		-\$158.00	

Fundraising

- Minimum amount to Fundraise: \$1000
- Methods
 - Donations
 - Personal
 - (Gofundme) - created
 - Food chain fundraisers

Conclusion

Thank You!
Questions?

Work Cited Page

[1] AIM-9L Sidewinder (modified) copy,” *Wikimedia Commons*, [Online]. Available:

https://upload.wikimedia.org/wikipedia/commons/8/88/AIM_9L_Sidewinder_%28modified%29_copy.jpg

[2] Blue Origin moves New Shepard-27 launch again—now it’s Friday, hopefully,” *SatNews*, Oct. 10, 2024. [Online]. Available:

<https://news.satnews.com/2024/10/10/blue-origin-moves-new-shepard-27-launch-again-now-its-friday-hopefully/>

[3] S. Clause, “How does thrust vector control work and what purpose does it serve in rocketry?,” *Medium*, Feb. 15, 2024. [Online]. Available:

<https://medium.com/@SammyClause/how-does-thrust-vector-control-work-and-what-purpose-does-it-serve-in-rocketry-18fecb29cef6>

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