Northrop Grumman Supersonic Rocket

Initial Design Report

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DISCLAIMER

This report was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this report should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such they are not responsible for the accuracy of results or conclusions.

EXECUTIVE SUMMARY

The team's capstone project is to design, fabricate, test, and utilize a separation system in a two-stage supersonic rocket. This separation system will incorporate springs and magnets. The purpose of this separation system is to connect the two stages of the rocket and disconnect them at the separation point. Additionally, to provide an alternative separation mechanism than traditional systems. The main stakeholder is Northrop Grumman Space Systems. They will be funding and overseeing the project throughout its duration. The NRG mentors will be reviewing the work and providing insight into designs and analyses.

The additional goal of the project is to prepare the rocket for flight. Since this capstone is a continuation from last years capstone group, a majority of the rocket is built. Currently there are a few physical modifications needed to the rocket, several analyses, and testing. The physical modifications needed are to the couplers, mandrel, and separation system. The analyses needed are buckling, separation, linear momentum, magnetic, electrical, drag, risk, and RASAero simulation. The necessary tests include avionics, separation system, black powder charges, and potential payload testing. Also, to either find or build a launch tower equipped to handle the rocket.

From last years capstone goals, the rocket is expected to reach 30,000 feet in the air. Achieve a velocity of higher than Mach 2. Finally, be equipped to carry up to a ten-pound payload that NRG has not determined yet.

The current team goal is to finish the rocket and separation system in time for a launch on April 20. Due to the fact a majority of the rocket is already built, the team has the budget for two launches as long as the first launch is successful. The second launch would be around December. From the first launch, the team will analyze the data and figure out ways to make the rocket faster and reach higher altitudes. One current solution is to replace aluminum material with carbon fiber, to decrease weight and increase structural integrity. Another solution is to equip the rocket with higher powered motors.

The current progress includes a manufacturing source and several analyses. Nova Kinetics decided to sponsor some of the project by offering their services to help in manufacturing. This includes the couplers that need to be remanufactured, work to the mandrel, and assisting in carbon fiber designs for future changes. The analyses that have been done are buckling, separation, drag, magnetic power, and RASAero simulation. These analyses either have been or will be reviewed by NRG mentors or NAU faculty where it is appropriate.

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1.0 BACKGROUND

This chapter provides essential context for the Magnetic Separation System project undertaken for Northrop Grumman Space Systems and Northern Arizona University's Rocket Test Platform. It outlines the project's core objectives, stemming from the need for improved staging mechanisms in launch vehicles. Subsequent sections detail the specific deliverables required for the project's successful completion, encompassing design, manufacturing, testing, and documentation. Finally, this chapter defines the key success metrics that will be used to evaluate the project's outcome, referencing testing procedures, analytical calculations, and critical design requirements.

1.1 Project Description

The Magnetic Separation System project addresses critical limitations in existing launch vehicle staging mechanisms. Traditional systems, which rely on mechanical or ordnance-based release, often present complexities in design, challenges in testing, and potential safety hazards. This project, sponsored by Northrop Grumman Space Systems, aims to develop a magnetic separation system that enhances simplicity, testability, and safety for the NG-NAU Rocket Test Platform.

The project's primary objective is to design, manufacture, integrate, and test a magnetic separation system capable of generating sufficient force to separate a two-stage vehicle during flight. This separation force will be determined through rigorous analysis conducted by the student team and reviewed by Northrop Grumman engineers. The system will also incorporate a safe release mechanism to simulate integration and maintenance procedures. Comprehensive ground testing will be performed to ensure the system meets all specified requirements before a final flight test.

The project operates under a Company Controlled Intellectual Property agreement and is subject to Citizenship Restrictions as outlined by Northrop Grumman. The project's budget and fundraising targets will be determined based on material costs, manufacturing requirements, and testing resources. The successful completion of this project holds significant importance as it paves the way for safer, more reliable, and more easily testable staging systems in future launch vehicle designs.

1.2 Deliverables

The successful completion of this project requires the delivery of several key items:

- Functional Prototype: A fully operational magnetic separation system integrated and ready for testing on the NG-NAU Rocket Test Platform.
- Preliminary Design Review (PDR): A formal presentation and documentation package outlining the initial design concepts, system architecture, and preliminary analysis. This deliverable will be presented to Northrop Grumman subject matter experts and leaders for review and feedback.
- Critical Design Review (CDR): A comprehensive presentation and documentation package detailing the finalized design, including detailed engineering drawings, material specifications, manufacturing processes, and complete system analysis. This deliverable will also be presented to Northrop Grumman for review and approval.
- Final Report: A comprehensive document encompassing all aspects of the project, including the design process, analysis results, manufacturing procedures, testing methodologies, and performance evaluation. This report will serve as a complete record of the project and will be delivered to both Northrop Grumman and NAU.
- Testing Data and Analysis: Complete documentation of all ground and flight-testing activities, including raw data, processed results, and detailed analysis demonstrating the system's performance against specified requirements.

These deliverables fulfill both course requirements for NAU Senior Design and the specific needs of Northrop Grumman, ensuring a comprehensive and valuable project outcome.

1.3 Success Metrics

The success of this project will be evaluated based on the following key metrics:

- Separation Force: The magnetic separation system must generate sufficient force to achieve reliable separation of the two-stage rocket vehicle during flight, as determined by engineering analysis and simulations. This will be validated through ground testing using force measurement equipment and high-speed video analysis.
- Safe Release Mechanism: The system must incorporate a safe and reliable release mechanism that allows for controlled separation during integration, maintenance, and testing procedures. The safety and reliability of this mechanism will be assessed through rigorous testing and risk analysis.
- System Weight and Size: The magnetic separation system must adhere to strict weight and size constraints to minimize the impact on the overall performance of the rocket test platform. These parameters will be continuously monitored throughout the design and manufacturing process.

- Durability and Reliability: The system must demonstrate durability and reliability under the harsh conditions of rocket flight, including vibration, acceleration, and temperature extremes. This will be assessed through environmental testing and simulated flight profiles.
- Adherence to Requirements: The final design and prototype must meet all specified performance parameters and functional requirements outlined in the project proposal and subsequent discussions with Northrop Grumman engineers. This will be verified through comprehensive testing and analysis, as documented in the final report.

Successful achievement of these metrics will demonstrate the effectiveness and viability of the magnetic separation system as a potential alternative to traditional staging mechanisms. The testing methodologies and calculations used to assess these metrics will be detailed in subsequent sections of this report.

2.0 REQUIREMENTS

The requirements section of this report outlines both the customer requirements specified in the project proposal and the engineering requirements based on these customer needs. Each requirement is accompanied by a clear definition explaining its relevance to the project and the design elements it pertains to. During the initial phase, the team identified several questions that needed clarification, including which specific requirements the client prioritized. As the project progressed, the engineering requirements were updated and refined through ongoing reviews and meetings with the client. This evolution was influenced by the client's decision to shift the focus of the project from the entire rocket to only the separation system. Thus, the engineering requirements were adjusted to align with this new direction. The team's understanding of the client's needs and expectations evolved throughout the course of the project. The following list presents the current set of customer and engineering requirements, along with the updated Quality Function Deployment (QFD) at this stage of the project.

2.1 Customer Requirements (CRs)

The customer requirements were initially derived from the previous team's specifications. However, as the project's focus evolved, the requirements were updated. The current customer requirements now reflect the revised priorities, specifically emphasizing the separation system and aligning with the objectives set by this year's team.

Reusability

Ensure that the separation system is designed for reusability in future launches.

Functionality

Verify that the separation system functions as intended and performs its role effectively.

Magnets

Incorporate the necessary magnets into the separation system to ensure proper operation.

Two-stage Separation

Develop the separation system to support the two-stage rocket, ensuring all required functions are accurately integrated.

Stability

Ensure the stability of the entire system, confirming that all components function correctly without failure.

Faster than Mach 1
Confirm that the rocket reaches speeds exceeding Mach 1.

30,000 ft Altitude
While not the primary objective, ensure the rocket reaches a minimum altitude of 30,000 feet, with an upper limit of 50,000 feet.

Test Launch
Ensure the rocket is fully prepared for the test launch scheduled for April.

Actual Launch
Achieve the ultimate goal of a successful launch with a fully functioning separation system.

2.2 Engineering Requirements (ERs)

The engineering requirements were established based on the goals that needed to be achieved. Each requirement is quantitative, allowing for measurable values to be assigned. These requirements were identified as the most critical by both the team and the client, given the project's objectives and needs.

Total Weight
Verify the total weight of the two-stage rocket for launch readiness.

Total Drag Force
Calculate the total drag force to assess the separation system's performance.

Thrust Force
Confirm that the thrust force is sufficient to launch both stages of the rocket.

Magnetic Force
Ensure the magnetic force is strong enough to hold the two stages together until disengagement.

Spring Force
Verify that the spring force, in combination with the magnetic separation system, is adequate to ensure a safe and successful launch.

Magnetic Fields
Check that the magnetic fields do not interfere with the rocket's onboard computer system or

any other critical components.

Testing

Ensure that all testing conducted in Rasaero aligns with the calculations for the actual launch.

Altitude

Confirm that the rocket reaches a minimum altitude of 30,000 feet.

Velocity

Ensure the rocket achieves a minimum speed of Mach 1.

2.3 House of Quality (HoQ)

		Engineering Requirements												
Customer Needs	Customer Weights	Total Weight	Total Drag Force	Thrust Force	Magnetic Force	Spring Force	Magnetic Fields	Testing	Altitude	Velocity	1 - Weak	3 - Moderate	9 - Strong	Benchmark Competitors
Reusability	3	6		3	9						A	B	C	
Workability	5			6	9		9		3	3		B	AC	
Magnets	5	6	6	6	9	6	9	9						
Two-Stage Separation	5	6	9	9	9	6	9	9	6				ABC	
Stability	3	9	9	9				3		9		AB	C	
Faster than Mach 1	4	9	6	9				3	6	9			ABC	
30,000 ft altitude	5	6	6	9				3	9	9			ABC	
Test Launch	4						9	9	9	9				
Actual Launch	5	9					9	9	9	9				
Technical Requirement Units		N	N	N	N	N	N/A	N/A	kft	m/s				
Technical Requirement Targets		445	<1000	4200	>Spring Force		N/A	N/A	N/A	N/A				
Absolute Technical Importance		216	156	222	162	60	216	207	195	204				
Relative Technical Importance		2	8	1	7	9	2	4	6	5				
		ATI & RTI												

Separation Types	
A	Mechanical Separation
B	Pyrotechnic Separation
C	Aerodynamic Separation

9 = Strong	
3 = Moderate	
1 = Weak	
Blank = No Relationship	

3.0 Research Within Your Design Space

3.1 Benchmarking

"Most of the information on separation mechanisms is contained in internal company documents which receive little if any general distribution; there is not much material on the subject in the available literature." [1]

Motorized LightBand (MLB) [2] by RocketLab is a mechanical separation system that does not incorporate pyrotechnics. The MLB was introduced in 2006 and has a 100% success rate for 100+ separations on-orbit. According to RocketLab's website, the system is very easy to integrate into rockets, with an average integration time of around one day. The system incorporates a combination of springs, switches, and electronics to have the capacity to be programmed to any specific rocket. Low weight, low height, low shock, low tip off (rotation rate), low reset times, and no consumable initiators are just a few of the reasons why MLB is such a great system. This product is similar to our design due to the fact that it incorporates compressed springs that are used to repel both stages away from each other during separation.

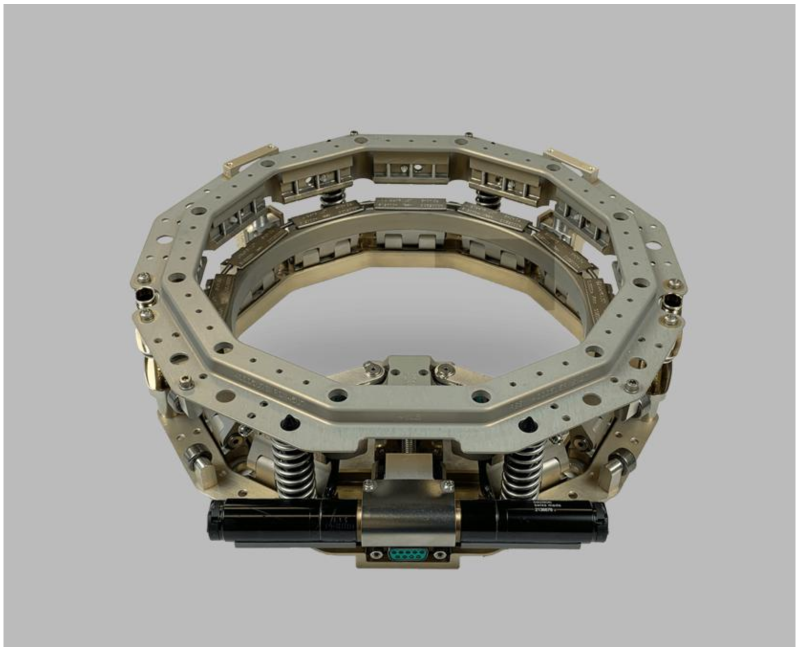


Figure 1: Motorized LightBand

Pyrotechnic separation is also a common method of 2 stage rocket separation that is modernly used. Pyrotechnic separation can consist of either explosive bolts or frangible joints.

Explosive bolts [3] are designed to have a shaft within the bolt that is specifically made to break at a certain location along the bolt's length, where typically the breaking point has a smaller diameter. Within the shaft, a low-density explosive rests on top of a low sensitivity/high density explosive with a wire initiator placed on top of the explosive. The wires are fed to an electronic of your choosing to be programmed to separate at the desired time. At the time of separation, an electric charge is sent through the filament which heats and detonates all the explosives. Once the explosives detonate, the bolt's weakest point (point with smallest diameter) fails and ultimately allows the 2 rocket stages to separate.

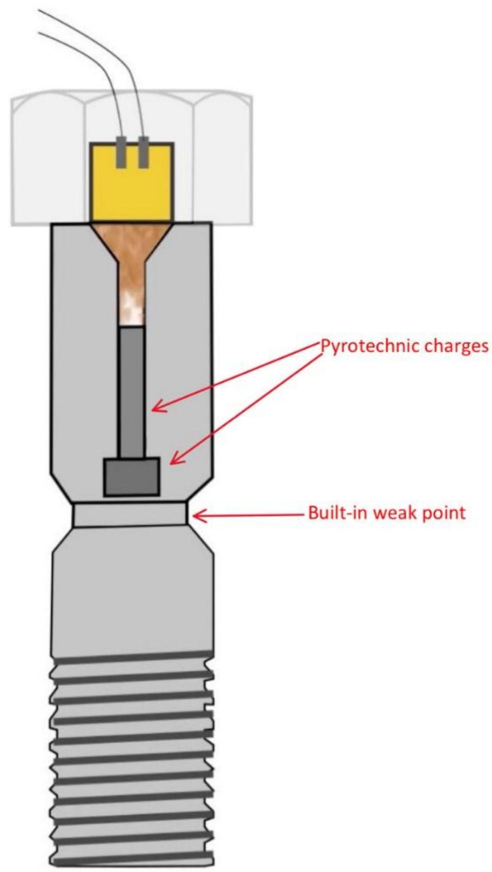


Figure 2: Explosive Bolt

Frangible joints are the second type of pyrotechnic separation that will be discussed. Frangible joints are specifically engineered with built-in weak points. They activate using pyrotechnic charges, similar to explosive bolts, pressure loads, or other mechanisms, and are a popular system because they are lightweight, reliable, react instantaneously, and break clean. As mentioned earlier, frangible joints are similar to explosive bolts because you can wire the pyrotechnic charge to an electronic of your choosing and program the electronic to send an electric charge to the pyrotechnic charge, which when detonated, causes a failure in the joint. The joint is almost always a crucial component that keeps the two stages of a rocket together before separation, therefore, when the frangible joint is broken, separation of the rocket is guaranteed. The built-in weak point of the frangible joint is also designed to break in a manner that will cause interference between the two rocket stages after separation occurs.

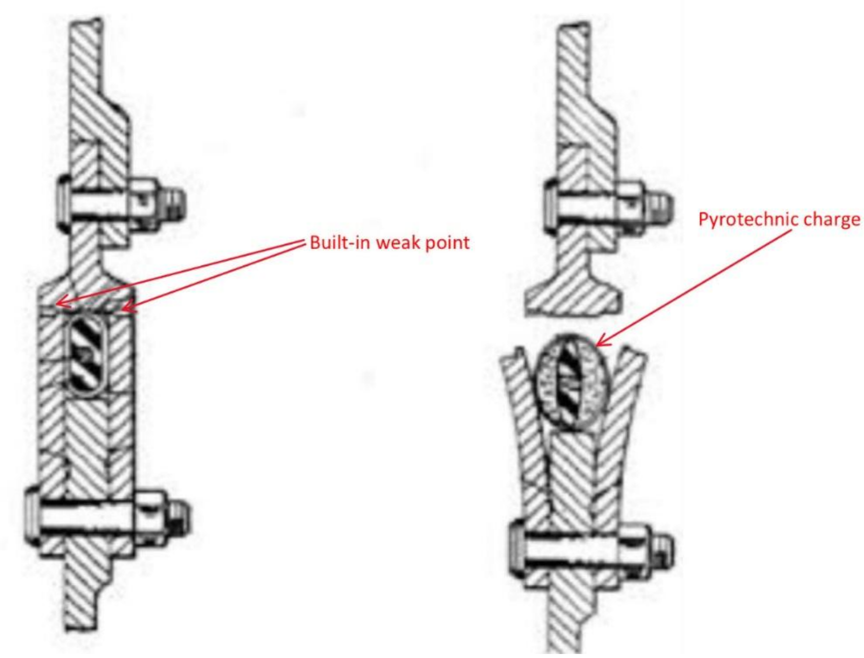


Figure 3: Frangible Joints

3.2 Literature Review

3.2.1 Bobs Sources:

[1] "Flight Separation Mechanisms"

This resource was used only for one sentence, as most of the other information within the document was not as helpful as expected. The sentence that was used was "Most of the information on separation mechanisms is contained in internal company documents which receive little if any general distribution; there is not much material on the subject in the available literature". This sentence was chosen to be the introduction to the benchmarking section of this report due to the fact that it was quite difficult (although not impossible) to find detailed information regarding how different types of separation mechanisms operated.

[2] “Motorized Lightband”

This resource was used to gain more information on specific types of separation systems that are already in production. The benchmarking section of this report details the reasons why this system is used and how it operates. This source also included a user's manual for the device which helped identify the pros and cons of the overall mechanism.

[3] “Explosive Bolt”

This resource was very helpful with understanding how both explosive bolts and frangible joints work. This resource was a video that gave a very simple, yet very helpful overall explanation on how the explosive bolts are designed and how they are detonated. This video helped with the understanding of frangible joints as well because frangible joints are also detonated through a small explosive and are also the main “source” for separation of a multiple stage rocket, making these systems very similar overall. The red labels such as “pyrotechnic charges” and “built-in weak point” were manually inputted and were not included on the stock image.

[4] “FLAT H FRANGIBLE JOINT EVOLUTION”

This resource was simply used for an image. The reason why the image from this source was chosen was because it shows a very great before and after picture of a frangible joint before and after separation. The red labels such as “pyrotechnic charge” and “built-in weak point” were manually inputted and were not included on the stock image.

[5] “Shigley’s Mechanical Engineering Design”

This was a great resource that helped me determine how to calculate the critical buckling load for the separation system. I consulted a professor at Northern Arizona University (NAU) whom I had taken courses with in the past and he recommended I take a look at chapter 4 within this book. This textbook is a required textbook for all students who take Machine Design I (ME365) at NAU. Chapter 4 was the most helpful chapter because it explained how to determine what type of column you have (Johnson or Euler) and how to calculate their critical loads.

[6] “Mechanics of Materials”

This source is also a required textbook that NAU students who take Mechanics of Materials (CENE253) are familiar with. Although nothing in this report was directly pulled from the textbook, it did help get a better general idea for analyzing. In the future I am planning to use this book to find another analysis method to have another validation method for the buckling of the separation device.

3.2.2 Stonns Sources:

[7] "Carbon fiber reinforced plastics with aluminum honeycomb core design methodology for space and surface mining applications" https://www.sciencedirect.com/science/article/abs/pii/S009457652100535X

This source provides a detailed design methodology for creating composite structures using carbon fiber and aluminum honeycomb cores, tailored for space applications. It includes tools like selection charts and classical lamination plate theory.

[8] "Effect of Ply Orientation on the Mechanical Performance of Carbon Fiber Honeycomb Cores" https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10255388/

This study explores how ply orientation in carbon fiber honeycomb cores influences mechanical properties like elasticity and shear moduli, allowing for customization based on specific requirements.

[9] "Composites in the race to space" https://www.compositesworld.com/articles/composites-in-space(2

This article highlights the use of carbon fiber/phenolic composites in the Orion spacecraft's separation system, specifically in compression pads that endure pyro-shock from explosive bolts.

[10] "The energy-absorbing characteristics of carbon fiber-reinforced epoxy honeycomb structures" https://journals.sagepub.com/doi/abs/10.1177/0021998318796161

This research investigates the energy absorption properties of carbon fiber-reinforced epoxy honeycomb under compression, focusing on behavior during impact and failure modes.

[11] "Application of Honeycomb Structures in Key Components of Space Deployable Structures" https://onlinelibrary.wiley.com/doi/10.1155/2022/4756272

This paper examines the use of honeycomb structures in space deployable mechanisms, emphasizing lightweight design and bending behavior as alternatives to traditional materials.

[12] "The MASCOT separation mechanism" https://link.springer.com/article/10.1007/s12567-020-00302-y

This source details the design and testing of a separation mechanism for spacecraft landers, focusing on load management, reliability, and redundancy, though not specifically about composites.

[13] "Beyond Gravity's use of carbon fiber in payload adapters" https://www.beyondgravity.com/en/launchers/separation-systems

This resource showcases Beyond Gravity's use of carbon fiber composites in payload adapters for satellite-launch vehicle separation, emphasizing lightweight construction and efficiency.

3.2.3 Emanuels Sources:

[14] "Welcome to Rasaero.com," Welcome to RASAero.com, https://www.rasaero.com/ (accessed Mar. 9, 2025).

These resources were helpful for installing the RASAero II simulation software on a portable laptop. They also provided valuable guidance on understanding the software and included examples of two-stage rocket simulations. These examples serve as real-world references for comparing the current design of the NRG two-stage rocket. By using these proven designs as benchmarks, we can assess whether our test simulations align with realistic rocket performance.

[15] Rasaero II users manual, http://www.rasaero.com/dloads/RASAero II Users Manual.pdf (accessed Mar. 9, 2025).

The training manual was used to understand the functionality of the rocket simulation for supersonic and hypersonic flights. It provided a comprehensive understanding of the software, enabling accurate simulation data on the performance of a modified two-stage rocket that represents our current design. With the training manual on hand, the user could properly operate the simulation while understanding how the rocket's characteristics affect its capabilities within the system.

[16] "Aerotech N3300R-PS RMS-98/15360 reload kit (1 pack) - 14330P," AeroTech/Quest Division, RCS Rocket Motor Components, Inc, https://aerotech-rocketry.com/products/product_4a713877-dd26-42a3-82a2-adf6b4b498f1 (accessed Mar. 9, 2025).

Understanding the performance of our booster, the N3300R AT, is critical for this capstone project. Having a detailed list of its characteristics and data equips us with the knowledge and skills needed to run an accurate simulation. Key factors such as the booster's burn time, fully loaded weight, and peak thrust provide the necessary data for precise modeling.

Without this understanding, creating a reliable simulation would not have been possible.

[17] Team AEROPAC's 2012 100K' rocket program, https://cdn.hackaday.io/files/22132946895488/AeroPac%202012%20100k'%20Program%20Report.compressed.pdf (accessed Mar. 9, 2025).
When creating a simulation, it is essential to understand not only how the current rocket performs but also how a successful rocket test has performed. By analyzing and comparing the current rocket design to a previously tested rocket, the team can more accurately evaluate simulation results. Since the simulated rocket from AeroPac's 2012 100K' rocket program is available in RASAero II, the team can modify its design to match the current NRG rocket and obtain reliable initial results on its expected performance.

[18] "Magnetism," NASA, https://pwg.gsfc.nasa.gov/Education/Imagnet.html (accessed Mar. 9, 2025).
At the start of the semester, the team had limited knowledge of how an electromagnetic locking system functions. This website provided essential insights not only into how the system works but also what to expect from the magnet's performance, which was crucial for beginning the project. With resources from NASA, the team gained a better understanding of how to modify the existing electromagnetic separation system. Additionally, learning to calculate electromagnetic strength early in the project established a strong foundation for future testing and development of the magnetic separation system.

[19] "EML20MM-12 - round permanent electromagnet 20 mm DIA. 12 volts DC - holding 10.12 lbs.," APW Company, https://apwcompany.com/eml20mm-12/ (accessed Mar. 9, 2025).
Since this capstone primarily involves completing the previous capstone's project, it was crucial to understand the choice and reasoning behind selecting this specific magnet. This website provided the necessary technical data for reanalyzing the remaining challenges of the project. The gathered data included the magnet's pulling power and overall diameter, which informed slight modifications to the CAD design that impacted the bending moment. Additionally, the pulling power is being evaluated for potential replacement with a stronger magnet, and the power requirements for maintaining its strength are being assessed to identify a reliable power source.

[20] Clayton R. Paul, *Introduction to Electromagnetic Compatibility, Second Edition (Online Version)*. John Wiley & Sons Incorporated, 2006.

Since NRG pioneered the concept of an electromagnetic separation system, understanding how to develop this idea was essential for the capstone project. The team had little experience working with electromagnets or solving related problems in the classroom. This textbook provided an introduction to electromagnetics, offering the foundational knowledge required for the project. Additionally, NRG specifically required the team to conduct introductory research on electromagnetics to establish a solid foundation for building the electromagnetic separation system.

3.2.4 Thomas' Sources:

[21] R. Hibbeler, *Engineering Mechanics: Dynamics, SI Units*. Pearson, 2023.

The engineering dynamics textbook covers the fundamental dynamics principles and equations. These have been used to conduct the separation analysis. Additionally, the textbook will be used in the linear momentum analysis. After this, it will be helpful towards MATLAB code of a rocket's dynamics.

[22] J. W. Mitchell, R. W. Fox, and A. T. McDonald, *Fox and McDonald's introduction to fluid mechanics.* Hoboken, Nj: Wiley, 2020.

The fluid mechanic textbook has extensive material on drag analysis. This has helped accurately determine the nose drag, fin drag, and skin drag. Additionally, if the team were to do a computation fluid dynamic analysis, the textbook could help in that.

[23] George, *Rocket propulsion elements*. Hoboken, New Jersey: John Wiley & Sons Inc, 2016.

Rocket propulsion elements textbook covers extensively on rocket dynamics. This textbook has information on fundamental rocket dynamics, various propulsion systems, control mechanisms, and testing. This will be helpful in understanding the solid propellant the team is using.

[24] X. Yu, "Separation between Stages of Multistage Carrier Rocket,". Separation between Stages of Multistage Carrier Rocket,

This report covers different types of separation mechanisms and factors to considered. It separates the separation mechanisms into two types, either hot or cold. Where hot separation will have the upper motor ignite while the rocket is still connected. Then cold separation is when the upper motor ignites after the two stages have separated. This offered insight into how the team cannot have the motor ignite if separation system fails, or this could lead to the destruction of the rocket.

[25] "NASA Space Vehicle Design Criteria Flight Separation Mechanisms" 19710019510.pdf

This report by NASA covers various types of separation systems. In this report, they review and test various types of separation systems including hot separation, lateral booster separation, thrust

reversal separation spring separation, and some additional types. In the report, they talk about the applicability of spring force mechanisms.

[26] R. G. Budynas, J Keith Nisbett, and Joseph Edward Shigley, *Shigley's mechanical engineering design*, 11th ed. New York, Ny: Mcgraw-Hill Education, 2020.

The machine design textbook initially helped in the interference fit analysis. From the textbook, it was determined the separation tube did not have an interference fit. However, this could still be used for the couplers to determine the necessary amount of black powder needed to separate other stages of the rocket.

[27] "SOLIDWORKS: Introduction To Finite Element Analysis (FEA)," Udemy. Accessed: Feb. 28, 2025. [Online]. Available: https://nau.udemy.com/course/solidworks-elementary-fea-finite-element-analysis/

This tutorial was through Udemy and was a part of my self-learning assignment. It covered the basics of Finite Element Analysis (FEA). I only got halfway through the basics and FEA on one assembly. I will be using this tutorial more to advance my FEA skills that way I can successfully apply it to the rocket.

[28] Rasaero II users manual, http://www.rasaero.com/dloads/RASAero II Users Manual.pdf (accessed Mar. 9, 2025).

I am planning to help out in the RASAero simulation. From what I have learned, the extensive manual covers every single factor of the actual rocket simulation. This will be very beneficial towards the simulation.

3.2.5 Lee's Sources:

[29] Fu, Yanqin, Zhang, Yulei, Chen, Hui, Han, Liyuan, Yin, Xuemin, Fu, Qiangang, & Sun, Jia. "Ultra-high temperature performance of carbon fiber composite reinforced by HfC nanowires: A promising lightweight composite for aerospace engineering." *Composites Part B: Engineering*, vol. 250, 1 Feb. 2023, 110453.

This study highlights the performance of carbon fiber composites reinforced by HfC nanowires, which improves the material's mechanical properties at ultra-high temperatures. This is particularly valuable when considering carbon fiber materials for the rocket's separation system, as it provides insight into their thermal resistance and structural integrity under extreme conditions.

[30] Finckenor, Miria M. "Materials for Spacecraft." NASA, Marshall Space Flight Center, Alabama.

This document discusses the essential materials used in spacecraft design, highlighting considerations such as material performance in the space environment, structural requirements, and challenges faced in spacecraft hardware fabrication. It offers valuable insights into the selection of materials for spacecraft applications, which can inform decisions about materials for the magnetic release system in the rocket separation mechanism. Additionally, it covers topics like the effects of radiation and thermal control that could be crucial when assessing materials for use in extreme conditions.

[31] Kawamura, M., Katsurayama, H., Otsu, H., Yamada, K., and Abe, T. "Aerodynamic Heating of a Magnetized Body." *AIAA Journal of Aircraft*, 9 Sep 2013.
DOI: 10.2514/1.A32116

This article discusses the effects of aerodynamic heating on magnetized bodies, which is directly relevant for understanding how temperature impacts the performance of the magnetic release mechanism during rocket flight.

[32] van Heerden, A. S. J., Judt, D. M., Jafari, S., Lawson, C. P., Nikolaidis, T., and Bosak, D. "Aircraft thermal management: Practices, technology, system architectures, future challenges, and opportunities." *Progress in Aerospace Sciences*, 2020.

This paper examines thermal management strategies in aerospace applications, which can provide valuable insights for developing a reliable thermal control system for the rocket's separation system, ensuring the materials used can withstand temperature fluctuations during flight.

[33] MATLAB Aerospace Applications - Simulink® and Aerospace Blockset™ User Manual.

This manual offers tools for modeling aerospace systems in Simulink® and can be used for simulating thermal effects on materials in the rocket's separation system, particularly for temperature-dependent magnetic force simulations.

3.2.6 Adrianas Sources:

[34] T. F. Mütsch and M. B. Kowalski, Space Technology: A Compendium for Space Engineering. Berlin: De Gruyter Oldenbourg, 2016.

This textbook contains more educational resources about the fundamentals of aerospace technology such as rocket motors, power supply systems and various constraints of space flight. I used this source more as an educational purpose rather than anything specific.

[35] A. Milne et al., “Conceptual Design Analysis for a two-stage-to-orbit semi-reusable launch system for small satellites,” Acta Astronautica, https://www.sciencedirect.com/science/article/abs/pii/S0094576518304454 (accessed Mar. 9,

2025).

Within this article it gives details of a partially reusable launch vehicle that carries small payloads. The first stage of the rocket is the reusable portion in which the payload is 500kg.

[36] “Damage analysis of explosion blast wave to rocket structure and payload,” Radware bot manager Captcha, https://iopscience.iop.org/article/10.1088/1755-1315/237/3/032060 (accessed March 9, 2025).

This article uses software to analyze rocket stages if there were any damage to the structure and/or payload. It was concluded that overpressure that significantly exceeds safety limits increases the threat to the payload and overall structure.

[37] Nirmith Kumar Mishra et al., “Computational study on rocket payload fairing,” Materials Today: Proceedings, http://www.sciencedirect.com/science/article/pii/S2214785323036428?via%3Dihub (accessed Mar. 9, 2025).

This article is about how to ensure payload safety and integrity through minimizing drag and stress. I used this article along with others to see how best it is to secure a payload to the rocket.

[38] “Payload systems,” NASA, https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/payload-systems/ (accessed March 9, 2025).

This source is from a NASA website detailing payload systems used in rockets and the evolution from firework payloads to satellites and human space missions. I used this information to investigate payloads and the best method to attaching a payload to our already built rocket.

3.3 Mathematical Modeling

3.3.1 Bobs Buckling Analysis:

A two-stage rocket that reaches supersonic speeds will experience very large drag and thrust forces. Drag force and thrust force can be thought of as a compressive force couple as they are both acting in opposite directions during the rockets flight. A concern that the team had was that a hollow cylindrical component of the separation would buckle during flight. The red circles in the figures below show the component in question.

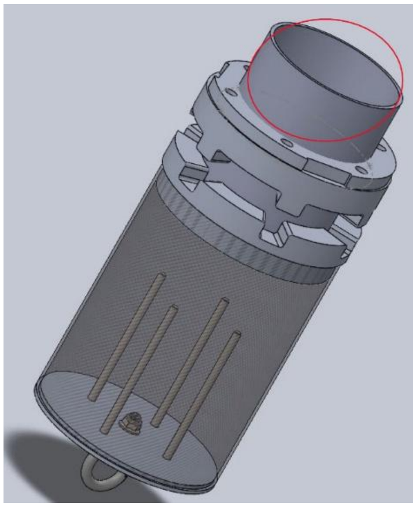


Figure 4: Location of Analysis

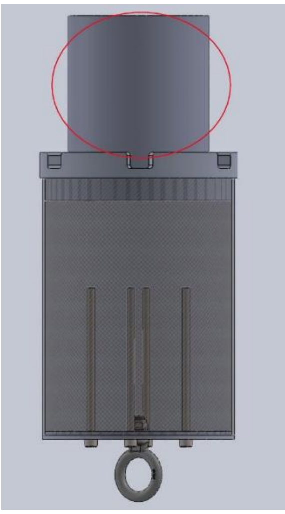


Figure 5: Location on analysis (2)

After conducting self-research and consulting with multiple professors at Northern Arizona University, it was concluded that the hollow cylinder could be treated as either a Johnson column or an Euler column. According to chapter 4 of Shigley's Mechanical Engineering Design [5], if the theoretical slenderness ratio $(l/k)_1$ is less than the actual slenderness ratio (l/k), only then can we use the Euler Column Formula. Although it is mentioned elsewhere in this report, the material being analyzed on this component is aluminum.

$$\left(\frac{1}{k}\right)_1 = \left(\frac{2\Pi^2 CE}{S_y}\right)^{\frac{1}{2}} \quad (1)$$

After confirming that our column could be analyzed as an Euler column, I began the calculations for solving for critical buckling load assuming aluminum properties for the device. The equation for critical buckling load for an Euler column can also be found within reference [5] on page 208. I assumed fixed-fixed end conditions for the most conservative approach therefore our end condition constant (C) is equal to one. It is also worth noting that reference [6] was also used to gain a better general understanding for analysis.

$$\frac{P_{cr}}{A} = \frac{c\Pi^2 E}{\left(\frac{l}{k}\right)^2} \quad (2)$$

P_{CR}= Critical Thrust Force [N]
A= $(\pi r_2^2 - \pi r_1^2)$= Cross-sectional Area [m^2]
r= d/2= Radius [m]
t= $(r_2 - r_1)$= thickness [m]
C= End-condition Constant [unitless]
E= Modulus of Elasticity [Pa]
l= Length of Column [m]
k= d/4= Radius of Gyration [m]
d= Diameter [m]

The equation was solved, and I got a final answer of around 18,000 pounds. To validate the results of this calculation, I created a MATLAB function that would calculate the critical buckling load of our component with any desired thickness. (Note: you can only input an inner diameter value into the function due to the fact that the outer diameter is fixed. The outer diameter is fixed because we would need to redesign the rest of the rocket if we changed the outer diameter of the separation device). Next, I created a MATLAB code that plotted the relationship between critical buckling load and thickness of the cylinder's wall. The wall thickness for this calculation ranges from a fully solid cylinder up until a thickness of zero. Figure [5] shows us that with a theoretical maximum load of around 1000 pounds, our cylinder wall thickness would only need to be around 0.6 millimeters thick, whereas Figure [6] shows us that with our actual wall thickness of 6.25 millimeters, the cylinder should be able to withstand 18,153 pounds. Figure [7] shows us the buckling MATLAB function with data from our rocket inputted. The figures are shown below but the codes can be found in Appendix A.

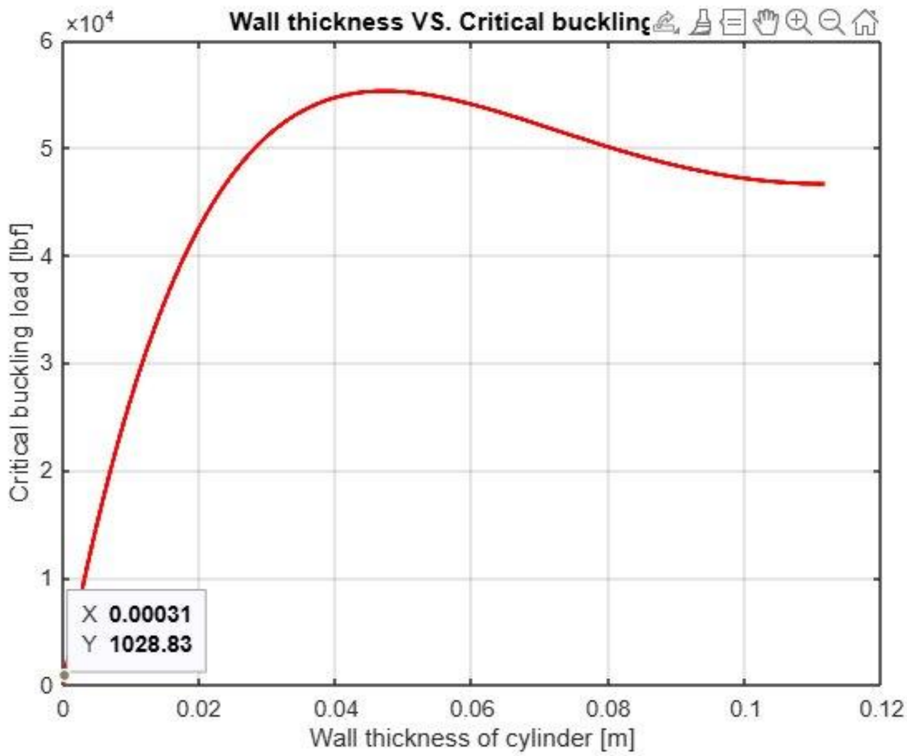


Figure 6: Theoretical Wall Thickness for 1000 Pound Load

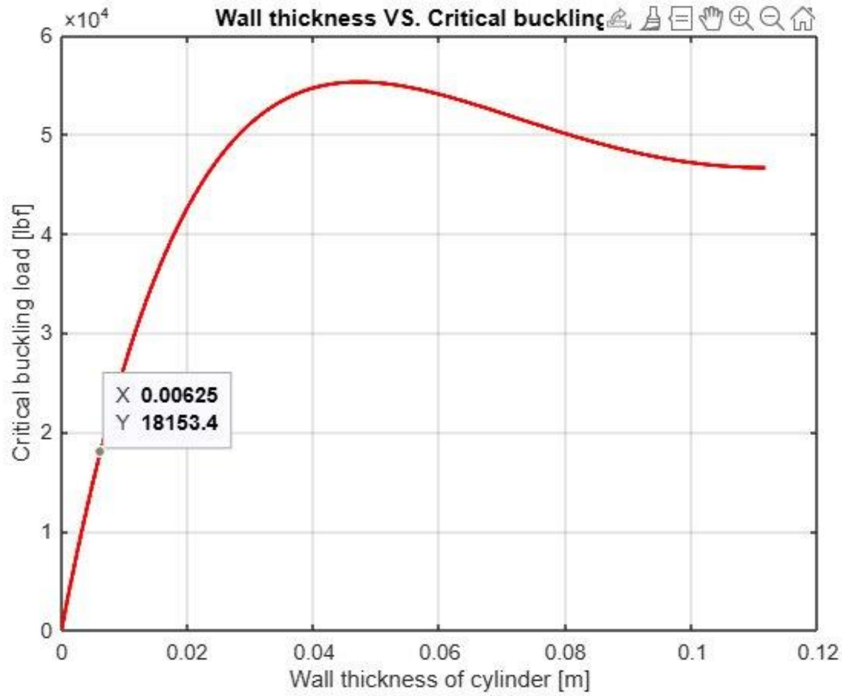


Figure 7: Actual Wall Thickness vs. Critical Buckling Load

```
function[Pcr]= Changing_inner_diameter(di)
%Computes critical buckling load of separation device
% Inputs: inner and outer diameters (respectfully)
Do= 0.11166; % [m] (outer diameter acquired from CAD
C= 1; % [unitless] (end condition constant)
E= 69e9; % [Pa] (young's modulus)
L= 0.1397; % [m] (length aquired from CAD files)
A= pi*(((Do/2)^2)-((di/2)^2)); % [m^2]
I= (pi/64)*((Do^4)-(di^4)); % [m^4]
k= I/A; % [m]
Pcr=(((A*(C*(pi^2)*E)))/(((L/k)^2)))*(0.224809); % [l
end
```

Command Window

New to MATLAB? See resources for Getting Started.

```
>> Changing_inner_diameter(0.10541)

ans =

    18.1534202949223e+003
```

Figure 8: Buckling MATLAB Function (in pounds)

In conclusion, this analysis has shown that the separation mechanism for this rocket should not buckle. With a final calculation of a critical buckling load of 18,153 pounds with our current wall thickness, this gives us a factor of safety of around 18.15, which exceeds standards and expectations.

3.3.2 Stonns Magnetic Power Analysis:

The magnetic release mechanism for our two-stage hypersonic rocket employs six EML20mm-12 electromagnets from APW Company to secure the stages together during the 4.1-second burn of the first-stage solid propellant motor, with stage separation occurring immediately after burnout when power to the magnets is cut off. Unlike permanent electromagnets that hold without power, these units require constant 12 V DC to maintain their magnetic field, keeping the separation mechanism engaged until the propellant is exhausted. At 4.1 seconds, de-energizing the magnets releases the stages. This analysis sizes a battery to supply continuous power to the electromagnets for the 4.1-second duration, incorporating a safety margin to ensure reliable operation under hypersonic conditions. The selected battery must meet these energy and power demands while adhering to the rocket's strict weight and volume constraints, providing a critical power solution for this mission phase.

$$\text{Power} = \text{Voltage} \times \text{Current} \quad (3)$$

$$\text{Total Power} = \text{Power} \times 6 \quad (4)$$

$$\text{Energy} = \text{Power} \times \text{Time} \quad (5)$$

$$\text{Current} = \text{Power} / \text{Voltage} \quad (6)$$

$$\text{Ah} = \text{Wh} / \text{Voltage} \quad (7)$$

Above shows the equations needed to select a battery that will be able to meet these conditions for the 6 electromagnetics. Below are the table values from these calculations. From the calculations the 3S lithium-ion pack with at least 250 mAh capacity and a discharge rate of at least 10C, ensuring 1.5 A for 4.1 seconds without significant voltage drop.

Table 1: Battery Calculation from given parameters of the electromagnets. From these calculations a battery can, be selected to meet these requirements to hold a constant steady of power supply during launch.

	Values
Energy	2160 J
Max Current	1.5 A
Capacity	2.58 mAh
Power	18 W

3.3.3 Emanuels RASAero II Simulations:

The following simulation represents the expected performance of a two-stage rocket using N3300 Aerotech boosters. This simulation is based on a modified AeroPac 104K Carmack Prize Rocket, which was the first rocket to use Global Positioning System (GPS) data to measure an apogee altitude exceeding 100,000 feet, earning it the Carmack Prize.
The modifications to the original rocket include a change in motors, a nose cone replacement to match our current design, an updated booster type, and an increase in the rocket's length.
The purpose of this simulation is to provide an estimate of the rocket's performance and to compare it with real-world test data from previous launches.

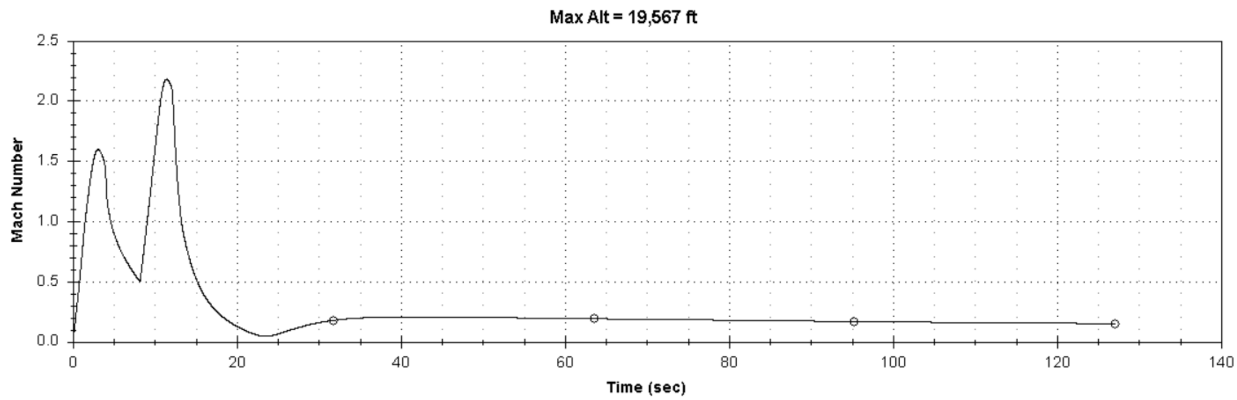
Figure 9: RASAero II Main Screen with scale rocket drawing for the two-stage NRG Rocket w/ N3300R AT Boosters

Here's a refined version with improved grammar and flow:

- LV Haack nose cone installation
- Replacement of boosters with N3300R AT Boosters
- Increase in second-stage length to 92 inches
- Additional increase in second-stage length by 66.02 inches
- Modification of fin tails to align with last semester's schematics

These refined modifications establish a baseline for understanding the performance of the current NRG two-stage magnetic separator rocket. With these changes, we can estimate the rocket's vertical velocity and assess whether further modifications are needed to enhance its speed.

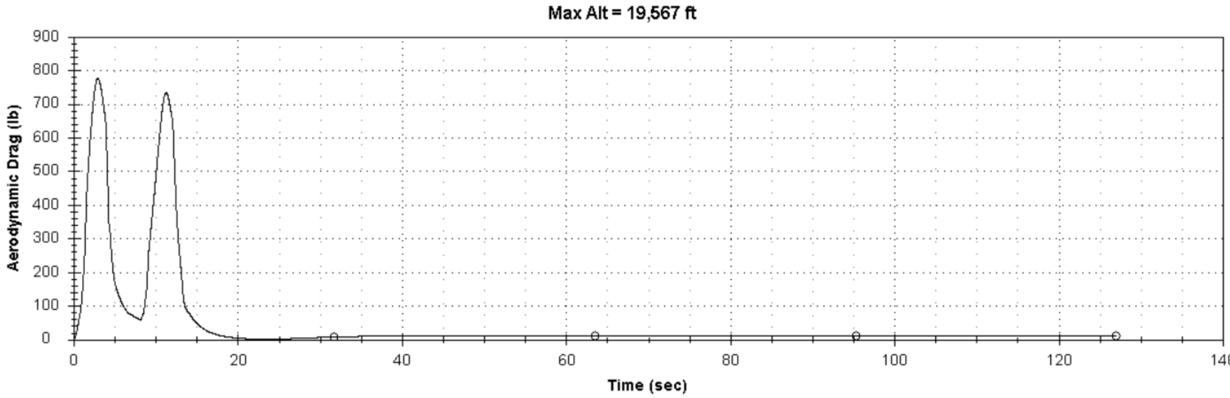
Below is the simulation graph depicting the rocket's vertical velocity. As shown, the modified rocket achieved a maximum Mach number of 2.16, successfully reaching the supersonic speeds required by NRG's clients.



Time (sec)	Stage	Stage Time (sec)	Mach Number	Angle of Attack (deg)	CD	CL	Thrust (lb)	Weight (lb)	Drag (lb)	Lift (lb)	Accel (ft/sec^2)	Accel-V (ft/sec^2)	Accel-H (ft/sec^2)
11.17	S	6.99	2.16	0.00	1.013	0.000	812.08	13.67	730.66710	0.00000	159.2	154.3	38.9
11.18	S	7.00	2.16	0.00	1.013	0.000	808.99	13.62	731.06640	0.00000	151.6	146.9	37.4
11.19	S	7.01	2.16	0.00	1.013	0.000	805.90	13.58	731.41920	0.00000	144.1	139.6	35.8

Figure 10: RASAero II Flight Simulation output for the two stage NRG Supersonic Rocket, Mach number versus time for powered flight and coast to apogee, ballistic descent to impact.

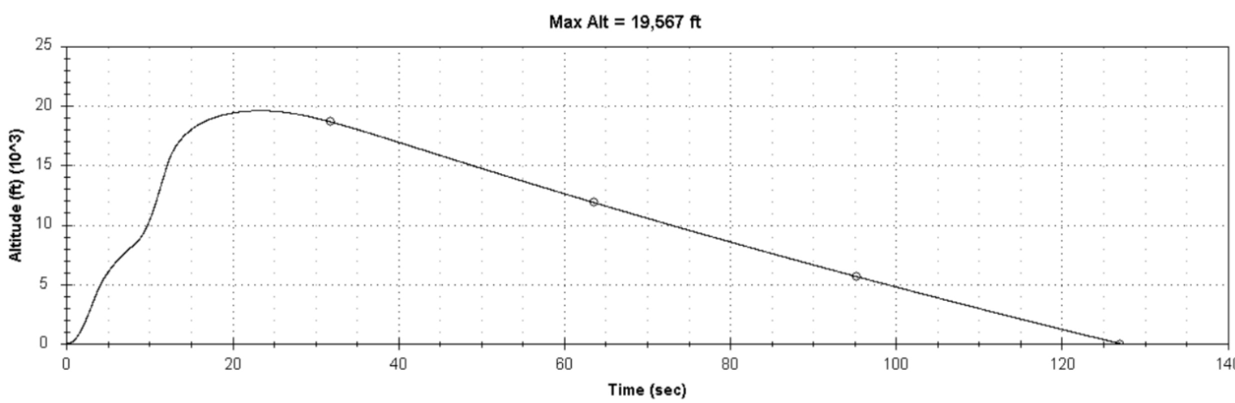
With the hand calculations completed, RASAero II can generate a simulated drag comparison. It is important to remember that this rocket is a modified version of RASAero's two-stage rocket, designed to simulate the performance of the current NRG design. The NRG rocket is expected to outperform this simulation due to the addition of the magnetic separation system and the use of modified materials, such as carbon fiber. This simulation allows us to combine and analyze the drag forces acting on the nose, body, and fins across both subsonic and supersonic speeds. As we can see with the simulation, the drag coefficient drops sub-10-sec indicating the time the separation from 1st stage to second stage occurred.



Time (sec)	Stage	Stage Time (sec)	Mach Number	Angle of Attack (deg)	CD	CL	Thrust (lb)	Weight (lb)	Drag (lb)	Lift (lb)	Accel (ft/sec^2)	Accel-V (ft/sec^2)	Accel-H (ft/sec^2)
11.17	S	6.99	2.16	0.00	1.013	0.000	812.08	13.67	730.66710	0.00000	159.2	154.3	38.9
11.18	S	7.00	2.16	0.00	1.013	0.000	808.99	13.62	731.06640	0.00000	151.6	146.9	37.4
11.19	S	7.01	2.16	0.00	1.013	0.000	805.90	13.58	731.41920	0.00000	144.1	139.6	35.8

Figure 11: RASAero II Flight Simulation output of the drag coefficient of the rocket with respect to time.

One major design decision in the simulation was determining the timing of the separation system between Stage 1 and Stage 2. A conservative approach was taken by setting the separation delay to 4 seconds, allowing for further linear analysis of the separation system before refining the timing. The separation is expected to occur in under 4 seconds, which would reduce momentum loss and increase the rocket's maximum altitude. Below are the simulated results for the rocket's maximum altitude and the effects of a 4-second delayed separation for Stage 2. The results indicated that the rocket would reach a maximum altitude of 19,567 ft.



Time (sec)	Stage	Stage Time (sec)	Mach Number	Angle of Attack (deg)	CD	CL	Thrust (lb)	Weight (lb)	Drag (lb)	Lift (lb)	Accel (ft/sec^2)	Accel-V (ft/sec^2)	Accel-H (ft/sec^2)	Veloc (ft/se
11.07	S	6.89	2.14	0.00	1.014	0.000	842.97	14.12	724.06140	0.00000	238.0	231.6	54.9	2,33
11.08	S	6.90	2.14	0.00	1.014	0.000	839.88	14.07	724.93990	0.00000	229.8	223.6	53.3	2,33
11.09	S	6.91	2.14	0.00	1.014	0.000	836.79	14.02	725.76900	0.00000	221.8	215.7	51.6	2,33

Figure 12: RASAero II Flight Simulation output for the two stage NRG Electromagnetic Separation, altitude versus time for powered flight and coast to apogee, and ballistic descent to impact.

3.3.4 Lees Thermal Expansion Analysis:

This analysis focuses on the dynamic forces that affect the rocket's separation system, particularly the role of thermal effects on the magnets used for stage separation. Three material concepts are being evaluated for the magnetic release mechanism: Aluminum, Fully Carbon Fiber, and Honeycomb Core with Carbon Fiber. These materials influence the thermal behavior of the magnetic release system and its ability to handle the dynamic loads during launch, flight, and separation.

1. Overview of the Magnetic Release System

The magnetic release system is designed to hold the upper and lower rocket stages together before separation and release them when required. The primary forces involved in the system are magnetic force (Fm), spring force (Fs), drag force (Fd), and the weight (W) of the stages. The magnetic force plays a vital role in either maintaining or releasing the connection between the stages, depending on the temperature and material properties involved.

2. Material Concepts for the Magnetic Release Mechanism

Three materials have been identified for the magnetic release system, each with different thermal properties that affect the performance of the magnets.

Aluminum

- Properties:
  Aluminum is widely used in aerospace applications due to its light weight, good thermal conductivity, and corrosion resistance. However, it has lower strength compared to some other materials and its thermal expansion coefficient is relatively high. This means that aluminum components expand more with temperature fluctuations, which could impact the precision of the magnetic release mechanism.

- Thermal Effects:
  Aluminum's high thermal conductivity helps dissipate heat, making it less susceptible to

temperature buildup during flight. However, its expansion in response to thermal changes could affect the alignment of the magnetic system, causing misalignment between magnets and reducing the effectiveness of the magnetic force. The thermal expansion of aluminum can also lead to a reduction in the overall force exerted by the magnets.

Fully Carbon Fiber

- Properties:
  Carbon fiber is a high-strength, lightweight material with exceptional thermal resistance. Carbon fiber has a much lower coefficient of thermal expansion compared to metals like aluminum, which makes it more stable under temperature fluctuations. Carbon fiber materials can withstand high temperatures without significant degradation of their structural or magnetic properties.

- Thermal Effects:
  Carbon fiber's minimal thermal expansion is beneficial for maintaining the alignment of the magnets in the release system. Since carbon fiber is thermally stable, it is less likely to experience any dimensional changes that could affect the effectiveness of the magnetic force. However, carbon fiber is also an insulator, meaning it doesn't dissipate heat as effectively as aluminum. This can result in localized hot spots during flight, potentially affecting the magnets' performance.

Honeycomb Core with Carbon Fiber

- Properties:
  The honeycomb core structure, when combined with carbon fiber, offers an excellent balance of strength, lightweight design, and thermal efficiency. This composite material is highly effective in aerospace applications where reducing weight is crucial without sacrificing structural integrity. The honeycomb core provides better insulation properties compared to solid carbon fiber, helping mitigate thermal expansion effects.

- Thermal Effects:
  The honeycomb core with carbon fiber is designed to maintain structural integrity under extreme thermal conditions while minimizing weight. This material is particularly effective at preventing heat buildup, which would help in keeping the magnets at a stable

operating temperature. The core structure also ensures that any thermal expansion of the outer layers of carbon fiber does not significantly affect the performance of the magnetic release system.

3. Thermal Effects on Magnetic Force and Separation System Performance

As described previously, the performance of the magnetic release mechanism is dependent on the temperature and the material properties. When considering the thermal effects on magnetic force, the temperature-dependent magnetic force can be modeled for each of the materials. The magnetic release system must be designed to handle thermal effects at varying altitudes and speeds. By considering the impact of temperature on the magnetic force, we can ensure that the separation system performs correctly under different conditions.

Mathematical Modeling:
Equations used:

Thermal Expansion:

$$\Delta L = \alpha \cdot L_0 \cdot \Delta T \tag{8}$$

Magnetic Force Equation (temperature dependent):

$$F_m(T) = F_{m0} \times (1 - \alpha_{\text{magnet}} \times (T - T_0)) \tag{9}$$

The reason behind using MATLAB to simulate the thermal effects on magnets in the rocket separation system is to better understand the behavior of three materials—Aluminum, Fully Carbon Fiber, and Honeycomb Core with Carbon Fiber—under different temperature conditions. This simulation helps us model the dynamic forces acting on the magnetic release mechanism as it undergoes thermal expansion and experiences temperature-dependent changes in magnetic force.

Mathematical modeling provides an essential way to predict the impact of temperature changes on material properties such as thermal expansion and magnetic force. This is crucial in aerospace engineering where precise performance is required under varying environmental conditions. The use of MATLAB for this simulation is beneficial for the following reasons:

1. Simulating Temperature Effects: By modeling the behavior of each material's thermal expansion and the corresponding change in magnetic force, we can visualize how the

materials perform across a range of temperatures. This insight is critical for optimizing the material choice for the magnetic release mechanism in a rocket separation system, ensuring that it operates efficiently in extreme conditions, such as high altitudes and varying flight speeds.

2. Temperature-Dependent Magnetic Force: The thermal expansion of the materials affects the alignment of the magnetic system, which can lead to either an increase or decrease in the magnetic force required for separation. Using MATLAB, we simulate this interaction by incorporating the material properties and temperature fluctuations. By calculating the temperature-dependent magnetic force, we can identify the optimal range of operating temperatures for the separation system.

3. Material Comparison: The simulation allows us to compare the three materials (Aluminum, Fully Carbon Fiber, and Honeycomb Core with Carbon Fiber) in terms of their thermal expansion, heat dissipation, and magnetic force stability. Through this comparison, we can understand the trade-offs between materials in terms of structural integrity, thermal stability, and overall system performance.

The simulation produces graphs that visually demonstrate the following:

1. Thermal Expansion: The change in length of each material as a function of temperature. Aluminum exhibits a larger change in length compared to carbon fiber and the honeycomb core due to its higher coefficient of thermal expansion.

2. Magnetic Force: The magnetic force required for separation as the temperature increases. Materials with higher thermal expansion (like aluminum) experience a greater reduction in magnetic force as their size changes. In contrast, materials like carbon fiber, with minimal thermal expansion, maintain more stable magnetic forces over the temperature range.

By simulating these interactions, the MATLAB model helps us understand the behavior of the materials in a rocket separation system, ensuring that the system will perform reliably across varying environmental conditions.

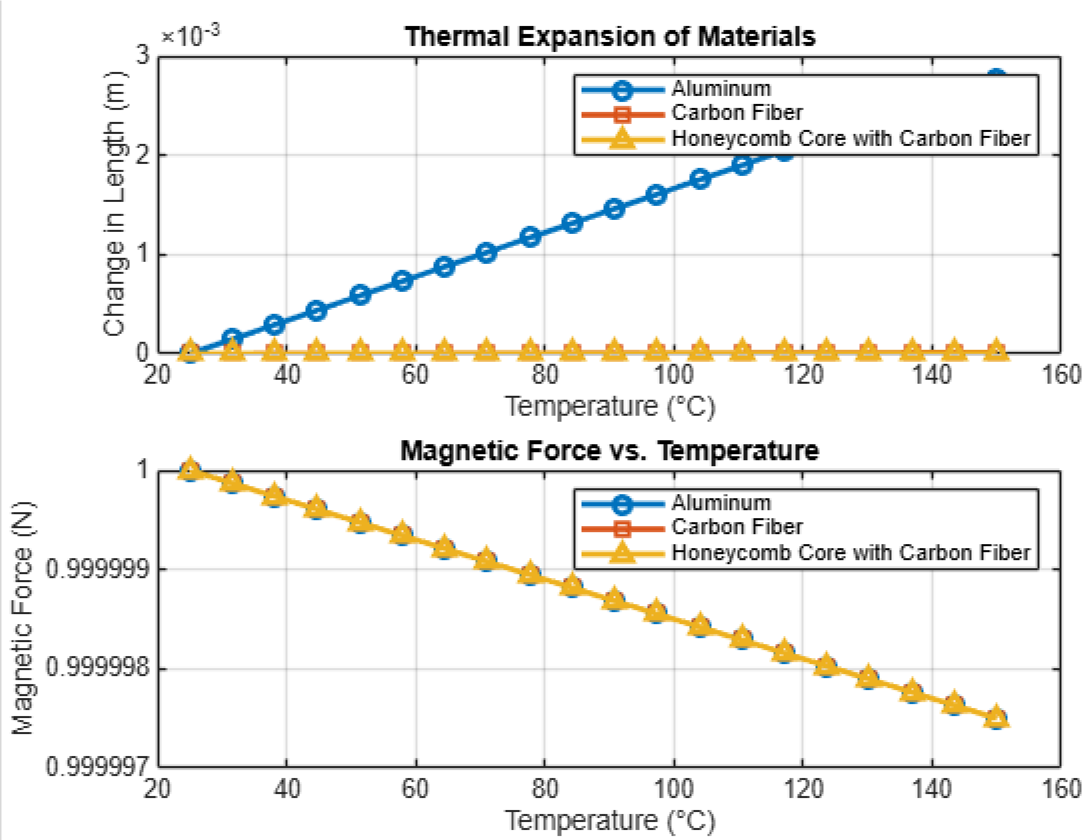


Figure 13: The plots generated from the Matlab code for Thermal Expansion of Materials and Magnetic Forces vs Temperature.

```
For Aluminum: As temperature increases, the change in length increases, which may affect the alignment of the magnets.
For Carbon Fiber: Minimal thermal expansion, but heat buildup may occur due to insulation properties.
For Honeycomb Core with Carbon Fiber: A balance between minimal expansion and effective thermal insulation.
```

Figure 14: The conclusion and results from the Matlab code.

3.3.5 Adriana's Analysis:

The analysis of drag force on the cone, fins, and skin friction aims to determine the total drag on the rocket, helping to assess the impact of drag on the performance of the separation system.

I. Drag Force on Cone
   a. $D = Cd\,(\frac{\rho V^2}{2})$
      i. $D: Drag\ Force$
      ii. Cd: Drag Coefficient
      iii. $\rho: Air\ Density$

iv. V: $Velocity$

The drag force on the cone was found to be small enough that it is negligible.

II. Drag Force on Fin

a. Fin drag is proportional to surface area, velocity squared, and air density. Reducing drag is essential for improving rocket efficiency and stability at supersonic speeds. Future improvements could focus on refining fin shapes, using lower-drag materials, or adjusting fin positioning to minimize resistance. Future improvements could focus on refining fin shapes, using lower-drag materials, or adjusting fin positioning to minimize resistance.

```
% Rocket Fin Drag Calculation
% Author: Lee Freytes Colón
% Date: March 2, 2025

clc; clear; close all;

%% Given Data
rho = 0.0880349; % Air density at 20,000 ft (kg/m^3)
v = 686; % Velocity in m/s (Mach 2)
Cd = 0.005; % Drag coefficient
A_single = 0.01677; % Area of one fin in m^2
num_fins = 6; % Number of fins

%% Total Area Calculation
A_total = num_fins * A_single;

%% Drag Force Calculation for One Fin
D_single = 0.5 * rho * v^2 * Cd * A_single;

%% Total Drag Force Calculation
D_total = 0.5 * rho * v^2 * Cd * A_total;

%% Display Results
fprintf('Total fin area: %.5f m^2\n', A_total);
fprintf('Drag force for one fin: %.2f N (%.3f lbf)\n', D_single, D_single * 0.224809);
fprintf('Total drag force for six fins: %.2f N (%.3f lbf)\n', D_total, D_total * 0.224809);
```

```
Total fin area: 0.10062 m^2
Drag force for one fin: 1.74 N (0.390 lbf)
Total drag force for six fins: 10.42 N (2.343 lbf)
```

III. Drag Force on Skin

a. Drag Forces

i. $D_{total} = 44.1\ lbf$

ii. $D_{stage1} = 17.8\ lbf$

iii. $D_{stage2} = 226.3\ lbf$

iv. $Re = 7.31 * 10^7 (turbulent)$

v. Low drag at peak speed

b. Rocket Specs

i. Length = 158.95”

ii. Diameter = 6.17’

iii. Wetted Area = 21.38 ft sq

c. Thrust Context

i. 44.1 lbf drag = 4.6% of 950 lbf thrust

ii. 26.3 lbf drag = 2.6% of 950 lbf thrust

d. Equations Used

i. $D = (\frac{1}{2})\rho v^2 C_f A$

1. v = 2008 ft/s

2. $\rho = 0.02747 \frac{lb}{ftsq}$

3. $C_f = 0.0119\ (smooth\ finish)$
4. $A = 21.38\ ft\ sq$

ii. $Re = \frac{\rho v L}{\mu}$

1. $L = 13.27\ ft, 5.5\ ft, 7.7 ft$
2. $\mu = 3.12 * \ 10^{-7} \frac{lb}{ft}$

3.3.6 Thomas' Separation Dynamic Analysis:

This analysis is concerning the dynamic forces on the rocket affecting the separation system. These forces include weight, total drag, thrust, spring, and magnetic. During this analysis, these forces will be analyzed at the upper and lower stages of the rocket. It is done this way since the separation system will either be acting in compression or tension. When separation is not wanted, the system will be acting in compression. During this, the upper forces, with the magnetic force will assist in maintaining connection. While the lower forces, with the spring force will oppose maintaining connection. When separation is wanted, the system acts in tension. During the separation stage, the upper forces will resist separation. While the lower forces, with the spring and magnetic forces will assist in separation. Four stages of the launch will be analyzed. Before takeoff, during flight with thrust force active, during flight with no thrust force, and during flight when separation is wanted. This analysis is critical in determining the necessary magnetic and spring forces to cause separation.

The main concerning force is the total drag on each stage. There is nose drag, skin drag, and fin drag. From Equation (10), drag is dependent on the coefficient of drag, air density, velocity, and surface area. The two variables that are not constant are air density and velocity. Air density is dependent on the altitude of the rocket. While velocity is dependent on the acceleration of the rocket. When the RASAero simulation is refined enough to closely simulate the rocket flight, the team will be able to identify the altitude and velocity at separation. Currently, these will be estimated through a MATLAB program. The MATLAB program will be iterating over a range of velocities, and altitudes. The goal is to determine the highest differential drag force between the upper and lower stages, that way the separation mechanism will be designed to work successfully in this scenario.

$$F_D = \frac{1}{2} C_d P V^2 A \qquad (10)$$

Considering the first point of interest, before launch. Equation (11) defines the necessary forces to maintain connection between the upper and lower stages. Figure (15) shows the free body diagram of these forces. There you can see that the magnetic force with the upper weight must be greater than or equal to the spring force with the lower weight. With the upper stage of the rocket being taller than the lower stage, this results in the upper stage having a greater weight than the lower stage. This is validated by each stage containing the same systems (igniters, motors, avionics bay) additionally, the upper stage is capable of storing a ten-pound payload. This results in the magnetic force must be greater than or equal to the spring force, in order to maintain connection.

$$F_m + W_U \geq F_S + W_L \tag{11}$$

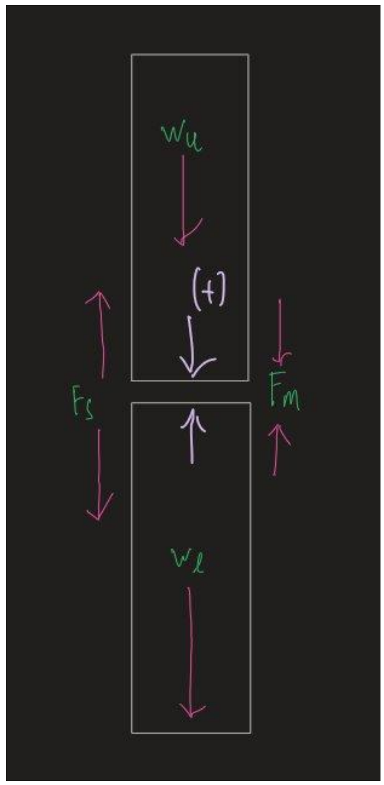


Figure 15: Separation System FBD

The second point of interest is during the flight while the thrust force from the lower motor is active. Here the rocket needs to maintain connection, Equation (12) shows the necessary forces to cause this. Figure (16) shows the forces acting on the rocket during flight. Another factor to consider is that the upper stage will be experiencing higher total drag than the lower stage will. This is due to the fact that the upper stage is taller which results in higher skin drag than the lower stage, and the upper stage has nose drag while the lower stage does not. Equation (13 & 14) shows the total drag for both the upper and lower stages. Also, with the assumption that the acceleration is positive (upwards), this results in the thrust force being greater than the forces resisting acceleration, shown in Equation (15). With this and knowing that the upper stage drag will be greater than the lower stage drag, this validates that the separation system will maintain connection while thrust force is active.

$$F_T + F_{D,U} + W_U + F_m \geq F_S + F_{D,L} + W_L \quad (12)$$

$$F_{D,U} = F_{D,S1} + F_{D,F1} + F_{D,N} \quad (13)$$

$$F_{D,L} = F_{D,S2} + F_{D,F2} \quad (14)$$

$$F_T > F_{D,U} + W_U + F_{D,L} + W_L \quad (15)$$

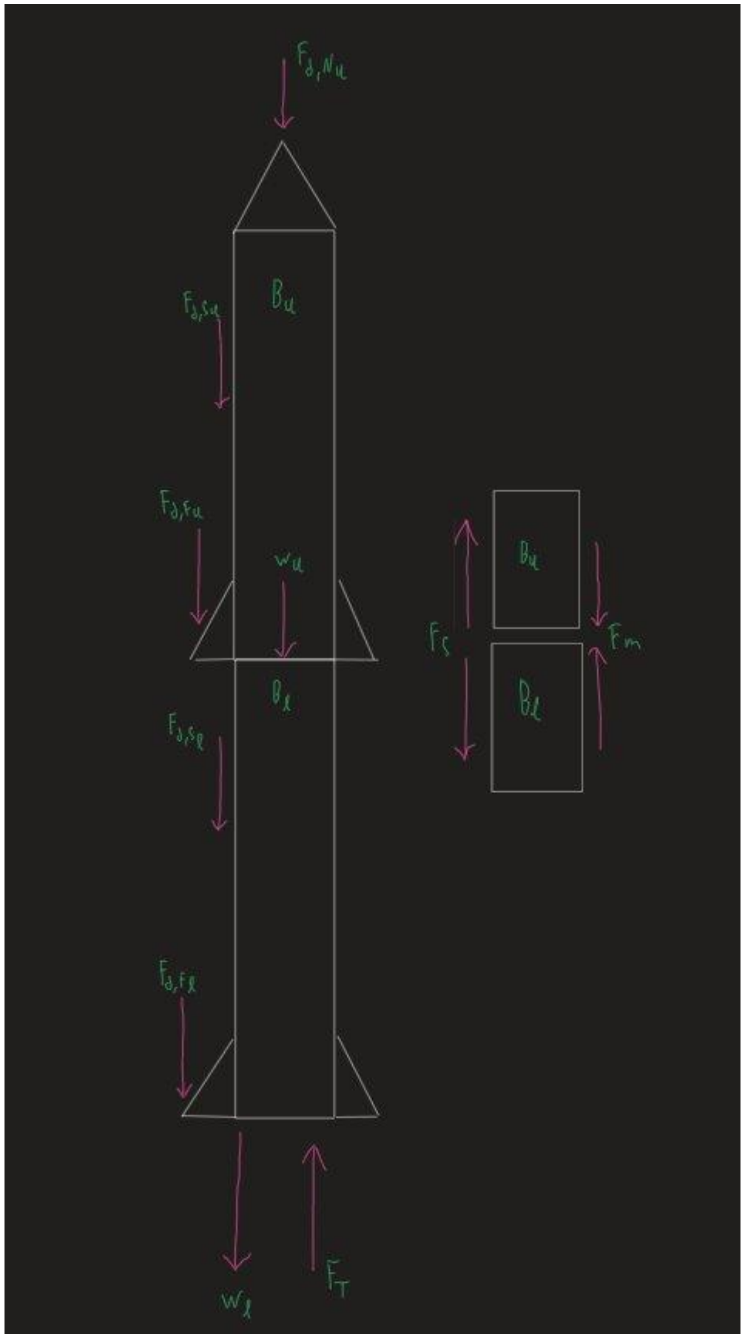


Figure 16: Rocket FBD

The next point considered is during the flight with no thrust force, and before separation is wanted. A point worth noting is that when the lower stage motor is over, this is when separation needs to occur. In order to preserve as much velocity as possible. That way the rocket can reach a higher altitude and higher top velocity. However, to confirm that the separation system will not cause premature separation, this is the ideal point to consider since the differential drag force will be the highest then. Equation (16) shows the relation in order to maintain connection. From the previous two points considered, magnetic force must be greater than or equal to spring force, upper weight is greater than lower weight, and the upper drag force is greater than the lower drag force. This confirms at this point of interest, the separation system will maintain connection.

$$F_{D,U} + W_U + F_m \geq F_S + F_{D,L} + W_L \tag{16}$$

The final point to consider is the separation point. Equation (n) shows that the magnetic force, spring force, lower weight, and the lower drag force must be greater than the upper drag force and upper weight. This will result in the lower body having a greater deacceleration than the upper body, causing separation. This is where the MATLAB program is utilized to determine the magnetic and spring forces. Figure (17) shows a table including the total drag of each stage at various altitudes and velocities. Currently, the team is assuming separation will happen anywhere between 10,000 and 20,000 feet. Another assumption currently is that the rocket will be in incompressible flow. For a conservative estimate, Figure (18) shows the altitude and velocities considered for Equation (17). When the RASAero is accurately done, the team will be able to determine the altitude, velocity, and differential drag force at the point of separation. Then with that data, this analysis will be redone to confirm that the separation system will work successfully.

Currently there are six magnets and six springs in the separation system. The previous capstone team had assembled a prototype containing these magnets and springs. The individual magnetic force is 10 pounds and so is the individual spring force. Currently this is too low to cause separation. The team will be considering ordering 25 to 50-pound force springs and magnets for the system. Below you can see the calculations done for each one.

$$F_m + F_S + F_{D,L} + W_L > F_{D,U} + W_U \tag{17}$$

Table Name: Total Drag Table

Altitude (kft)	Density (lb/ft^3)	Velocity (ft/s)	Total Rocket Drag (lb)	Total Top Drag (lb)	Total Lower Drag (lb)
0	0.0765	400	251.23	170.13	81.1
0	0.0765	600	565.26	382.78	182.48
0	0.0765	800	1004.9	680.5	324.42
0	0.0765	1000	1570.2	1063.3	506.91
10	0.0565	400	185.55	125.65	59.9
10	0.0565	600	417.5	282.72	134.78
10	0.0565	800	742.19	502.59	239.6
10	0.0565	1000	1159.7	785.31	374.38
20	0.0408	400	134	90.74	43.26
20	0.0408	600	301.49	204.16	97.33
20	0.0408	800	535.95	362.93	173.02
20	0.0408	1000	837.45	567.09	270.36
30	0.0287	400	94.26	63.83	30.43
30	0.0287	600	212.07	143.61	68.46
30	0.0287	800	377.01	255.3	121.71
30	0.0287	1000	589.08	398.91	190.17

Figure 17: Total Drag

Table Name: Total Drag Table

Altitude (kft)	Density (lb/ft^3)	Velocity (ft/s)	Total Rocket Drag (lb)	Total Top Drag (lb)	Total Lower Drag (lb)
10	0.0565	800	742.19	502.59	239.6

Figure 18: Total Drag Considered

- Separation analysis with 25-pound force magnets and springs:

$$\mathbf{F_m} + \mathbf{F_S} + \mathbf{F_{D,L}} + \mathbf{W_L} = (6*25lb) + (6*25lb) + 239.6lb + 35.4168lb = 575.02\ lb$$

$$\mathbf{F_{D,U}} + \mathbf{W_U} = 502.59\text{lb} + 51.6168\text{lb} = 554.21\text{ lb}$$

$$575.02 > 554.21\text{ lb}$$

- Separation analysis with 50-pound force magnets and springs:

$$\mathbf{F_m} + \mathbf{F_S} + \mathbf{F_{D,L}} + \mathbf{W_L} = (6*50lb) + (6*50lb) + 239.6lb + 35.4168lb = 875.02\ lb$$

$$\mathbf{F_{D,U}} + \mathbf{W_U} = 502.59\text{lb} + 51.6168\text{lb} = 554.21\text{ lb}$$

$$875.02 > 554.21\text{ lb}$$

From this you can see that the 25 and 50-pound force springs and magnets will cause separation. However, if the total drag force on the upper stage was higher, the 25-pound force magnets and springs might fail to cause separation. This is why the 50-pound force magnets and springs should be utilized. The next steps from this analysis are to order new magnets and springs. Create a way to test them to characterize their forces. Analyze the thermal effects on the magnets and how they affect their force output. Then to redo the analysis once the RASAero simulations are complete.

4.0 Design Concepts

4.1 Functional Decomposition

Functional decomposition model shown in Figure 19 serves as a foundational engineering design technique in the development of the magnetic release mechanism for our two-stage hypersonic rocket, systematically breaking down the complex system into a hierarchy of manageable sub-functions to ensure comprehensive coverage of all operational requirements. The top-level function, defined as "Enable Reliable Stage Separation," encapsulates the mechanism's primary objective and is decomposed into critical sub-functions: "Hold Stages Together During Launch and Ascent," "Release Stages at the Right Time," "Integrate with Rocket Systems," and "Ensure Safety and Redundancy." These are further refined into specific tasks, such as generating sufficient magnetic holding force to withstand the extreme vibrations and thermal loads of hypersonic flight, triggering a precise and timely release based on sensor or timing inputs, and incorporating fail-safes to mitigate risks of separation failure. This structured approach is vital for a hypersonic rocket application, where operational reliability at Mach 2 conditions is non-negotiable. By detailing all necessary functions, the decomposition not only prevents oversight of critical design elements but also provides a clear framework for subsequent concept generation, selection, and integration, facilitating effective collaboration among team members and stakeholders throughout the project lifecycle.

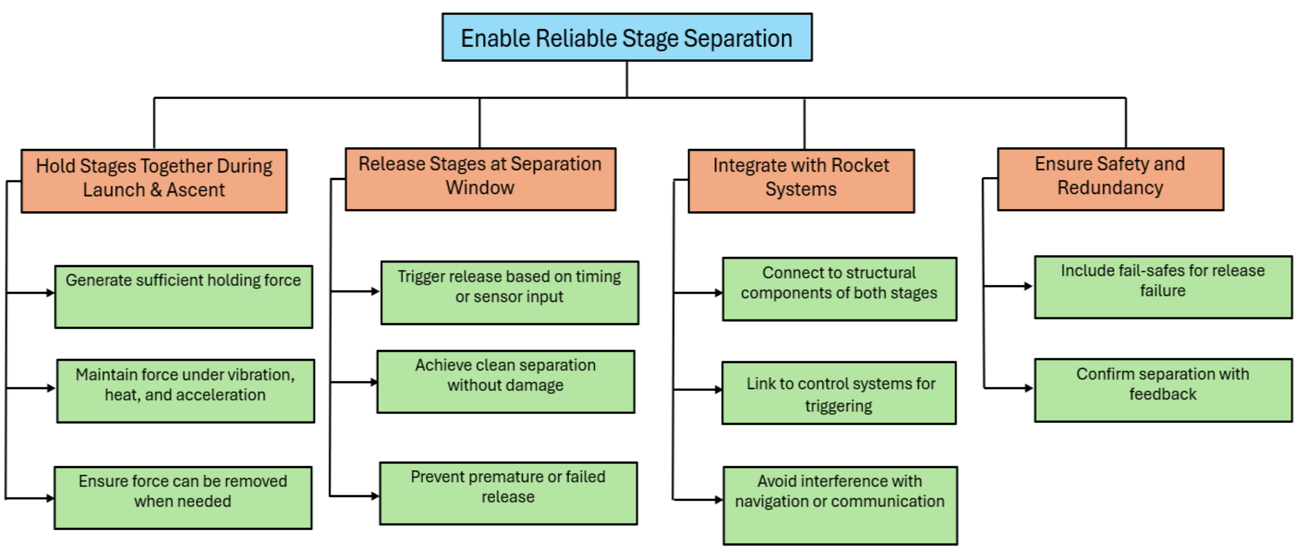


Figure 19: Functional Decompostion model of the magnetic release mechanism. Broken down for each subsystem requirements ensure reliability.

4.2 Concept Generation

Following the April 20th launch with the existing aluminum design, our team has been exploring alternative concepts for the magnetic release mechanism, focusing on material selection and their implications. Two new concepts have emerged: a fully carbon fiber design and a hybrid design featuring a honeycomb core with carbon fiber shown in Figure 20. Each option, including the current aluminum design, presents distinct advantages and disadvantages, influenced by factors such as weight, strength, and manufacturing complexity. These designs have been developed with manufacturing processes in mind, identifying the specific materials needed for the carbon fiber mechanisms. NovaKinetics has contributed by supplying carbon fiber materials and offering their expertise and equipment at their facility to support the fabrication of these advanced designs.

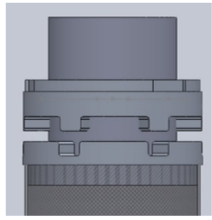
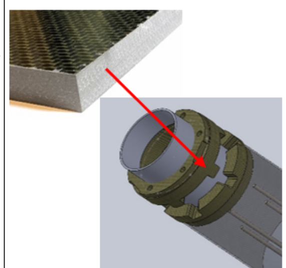
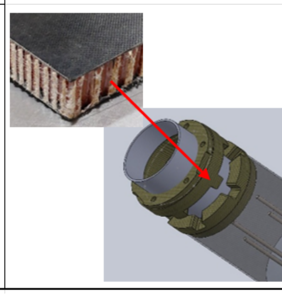
Concept Generation Matrix				
	Description	Image	Pros	Con
Concept 1 - Aluminum	The structure will be primarily made of aluminum, a lightweight, strong, and cost-effective material. This option is often used for outer casings or structural components, where weight reduction is important but higher strength is also necessary.		Lightweight and durable. Relatively low cost compared to advanced composites. Good thermal and electrical conductivity. Easier to work with (e.g., machining).	Lower strength-to-weight ratio than carbon fiber. Less resistant to high-stress conditions compared to carbon fiber. More prone to corrosion (especially in harsh environments).
Concept 2 - Fully Carbon	The structure will be made entirely from carbon fiber, a high-performance material known for its high strength-to-weight ratio. This option is ideal for high-performance aerospace applications where weight reduction and strength are critical.		Excellent strength-to-weight ratio. High stiffness, which is advantageous for structural integrity. Lightweight, which contributes to better performance. Excellent fatigue resistance.	High cost. More difficult to work with (e.g., requires specialized tools for cutting, shaping). Vulnerable to impact damage and is more brittle than metals. Difficult to repair if damaged.
Cocnept 3 - Honeycomb Core	This concept combines carbon fiber with a honeycomb core, often used in aerospace applications for panels and structural components. The honeycomb core provides excellent strength while minimizing weight.		Extremely lightweight while maintaining structural integrity. High strength-to-weight ratio due to the sandwich structure. Superior insulation properties. Excellent stiffness in bending.	More complex and expensive to fabricate than solid carbon fiber or aluminum. Vulnerable to shear and impact forces in certain applications. Requires precise manufacturing to maintain structural performance.

Figure 20: Concept Generation of three designs of the release mechanism. Aluminum (Current), Fully Carbon, and a Honeycomb core with Carbon Fiber.

4.3 Selection Criteria

The selection criteria for choosing among the three material concepts for the magnetic release mechanism current Aluminum, Fully Carbon Fiber, and Honeycomb Core with Carbon Fiber are rooted in the engineering requirements essential for a two-stage hypersonic rocket. These criteria include weight, strength-to-weight ratio, thermal resistance, manufacturing complexity, cost, and vibration resistance, each chosen to ensure the mechanism performs reliably under extreme flight conditions while aligning with project constraints. Weight will be assessed by determining the total mass of the mechanism, critical for optimizing rocket efficiency. Strength-to-weight ratio will evaluate the material's ability to withstand launch and hypersonic loads relative to its density, ensuring structural integrity. Thermal resistance will measure the maximum temperature each material can endure, vital for surviving hypersonic heating. Manufacturing complexity will consider the number of fabrication steps and specialized processes required, reflecting feasibility with NovaKinetics' support. Cost will encompass material and production expenses, balancing performance with budget. Vibration resistance will gauge the material's capacity to endure dynamic loads during launch and ascent. These criteria will be quantified through calculations for designed components, such as mass and stress analyses, and specifications for purchased materials, like carbon fiber properties from NovaKinetics, with results to be summarized once specific design parameters are finalized. This approach ensures a data-driven selection tailored to the rocket's demanding operational environment.

Table 2: Selection Criteria with governing equations to be used to quantify concept generations.

Selection Criteria	**Calculations to be used:**
Weight:	Mass = Density × Volume ($m = \rho \times V$).
Strength-to-Weight Ratio:	Specific Strength = Strength / Density (σ/ρ).
Thermal Resistance:	No direct equation but will compare max operating temperatures from material specs to expected hypersonic heat loads.
Manufacturing Complexity:	Qualitative count of steps (e.g., layup, curing), no equation, but tied to process time/cost estimates.
Cost:	Total Cost = Material Cost + Fabrication Cost. Material cost = price/kg × mass; fabrication cost from process complexity.
Vibration Resistance:	Factor of Safety (FoS) = Material Strength / Applied Stress ($FoS = \sigma_y / \sigma$). Stress ($\sigma = F/A$) uses force from acceleration ($F = m \times a$) and mechanism area.

4.4 Concept Selection

To determine the best material for the magnetic release mechanism, a structured selection process was conducted using a Morphological Matrix, a Pugh Chart, and a Decision Matrix. This approach ensures a data-driven evaluation based on key engineering criteria.

4.4.1 Morphological matrix

The Morphological Matrix identifies the three material options and evaluates them across critical design criteria.

Table 3:Critical Design Criteria Matrix

Selection Criteria	Aluminum (Datum)	Fully Carbon Fiber	Honeycomb Core with Carbon Fiber
Weight	Moderate	Low	Very Low
Strength-to-Weight Ratio	Moderate	High	High
Thermal Resistance	Low	High	Moderate
Manufacturing Complexity	Low	High	High
Cost	Low	High	Moderate
Vibration Resistance	Moderate	High	High

4.4.2 Pugh Chart

A Pugh Chart was used to compare the Fully Carbon Fiber and Honeycomb Core with Carbon Fiber options against Aluminum, which is designated as the datum (baseline).

Table 4: Pugh Chart from the three-concept generation

Criteria	Aluminum (Datum)	Fully Carbon Fiber	Honeycomb Core with Carbon Fiber
Weight	S	+	++
Strength-to-Weight Ratio	S	+	+
Thermal Resistance	S	+	S
Manufacturing Complexity	S	-	-
Cost	S	-	-
Vibration Resistance	S	+	+

4.4.3 Decision Matrix

A Decision Matrix was created to quantitatively score each material against the selection criteria.

Table 5: The Decision Matrix that quantify the rubric score.

Criteria	Weight (%)	Aluminum	Fully Carbon Fiber	Honeycomb Core with Carbon Fiber
Weight	30%	70	90	95
Strength-to-Weight Ratio	25%	60	90	85
Thermal Resistance	15%	50	90	80

Manufacturing Complexity	10%	80	40	50
Cost	10%	90	40	50
Vibration Resistance	10%	70	90	85
Total Weighted Score	100%	71.5	75.5	77.25

4.4.4 Final Concept Selection

Based on the Pugh Chart and Decision Matrix, the Honeycomb Core with Carbon Fiber is the optimal choice for the magnetic release mechanism.

Final Justification:

- Best weight reduction while maintaining high strength.
- High strength-to-weight ratio with superior bending stiffness.
- Excellent vibration resistance to withstand launch stresses.
- Higher cost and fabrication complexity, but NovaKinetics' support makes this feasible.

Thus, Honeycomb Core with Carbon Fiber will be used for the final design, ensuring optimal performance for the hypersonic rocket while maintaining structural integrity and reducing weight.

5.0 CONCLUSIONS

The main project goals are to build a separation system and to prepare the rocket for flight. Additionally, to have the rocket reach 30,000 feet in the air, reach higher than Mach 2 speed, create a successful separation system, and carry a ten-pound payload. The separation system currently requires ordering new springs and magnets, manufacturing the plates to hold the springs and magnets, then testing to see if the device works before launch. The rocket requires manufacturing to a few components, testing the avionics, testing the black powder charges, and a refined RASAero simulation.

From this report, several analyses were completed. The buckling analysis determined that the structural integrity of the rocket has a factor of safety of 18. The drag force analyses assisted in the separation analysis. The separation analysis determined the minimum pound force for the magnets and springs, being 25 pounds. The magnetic power analysis determined the battery specifications needed for the magnets. The RASAero simulation is giving insight into expected flight forces and working towards a refined simulation.

The next steps in the project include ordering the final materials, finish manufacturing, complete final analyses, and testing. For materials, the team needs new magnets and springs, parachutes, and one motor. This is all that will be required for the April 20th launch. If that launch is successful, the team will need two new motors, and any additional replacement parts. For manufacturing, the team needs to work with Nova Kinetics to get the couplers manufactured, plate holes manufactured, and the mandrel reworked. After that, the couplers needed to be sanded down until a tight fit is created within the rocket. The final analyses include thermal effects on magnets, magnetic field, refined RASAero simulation, and linear momentum. Following these analyses, the necessary tests to perform are black powder charges, separation system, avionics, and potential payload testing. For testing, the team will be developing test plan reports and sending them to the NRG mentors to review. They will be providing feedback and from there the team will move forward with testing.

Additional tasks include finding a sponsor for the April 20th launch, finding or building a launch rail, and refining the CAD files. Currently the team is needed an individual with a level 3 certification to sponsor our launch. Essentially, they will be approving our work. In order for them to do this, the RASAero simulation and CAD must be close to perfect. Following this, currently the team does not have access to a launch rail large enough to the rocket. The team will be reaching out to the rocket club mentor to see if he or anyone he knows has a launch rail of this size.

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7.0 APPENDICES

7.1 Appendix A: Robert Nimcheski’s MATLAB Codes

7.1.1 A-1: Column Buckling Function:

```
function[Pcr]= Changing_inner_diameter(di)
%Computes critical buckling load of separation device
% Inputs: inner and outer diameters (respectfully)
Do= 0.11166; % [m] (outer diameter acquired from CAD files)
C= 1; % [unitless] (end condition constant)
E= 69e9; % [Pa] (young's modulus)
L= 0.1397; % [m] (length aquired from CAD files)
A= pi*(((Do/2)^2)-((di/2)^2)); % [m^2]
I= (pi/64)*((Do^4)-(di^4)); % [m^4]
k= I/A; % [m]
Pcr=(((A*(C*(pi^2)*E)))/(((L/k)^2)))*(0.224809); % [lbf] (critical buckling load
equation)
end
```

7.1.2 A-2: Critical Buckling Load Solution & Plot:

```
% Assumptions:
% 1). euler column (performed analysis to confirm this approach is valid)
% 2). pin/pin end conditions (conservative approach)
% 3). hollow cylinder (therefore k=I/A)
% 4). assume maximum drag of 1000 [lbf]
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Parameters:
Do= 0.11166; % [m] (outer diameter acquired from CAD files)
Di= 0.10541; % [m] (inner diameter acquired from CAD files)
C= 1; % [unitless] (end condition constant)
```

```
E= 69e9; % [Pa] (young's modulus)
L= 0.1397; % [m] (length aquired from CAD files)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Equations:
A= pi*(((Do/2).^2)-((Di/2).^2)); % [m^2] (cross sectional area of a hollow cylinder)
I= (pi/64)*((Do.^4)-(Di.^4)); % [m^4] (moment of inertia for a hollow cylinder)
k= I/A; % [m] (effective length factor)
format longeng
Pcr=(((A*(C*(pi^2)*E)))/(((L/k)^2)))*(0.224809); % [lbf] (critical buckling drag on rocket including newton to pound-force conversion)
disp(['The critical buckling load is ',num2str(Pcr),' [lbf] with a wall thickness of 6.25 [mm]'])
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Inner diameter VS. Pcr plot
di1= 0:.0001:0.11166; % [m] (changing thickness from solid cylinder to 0.00001 [m])
a1= pi*(((Do/2).^2)-((di1/2).^2)); % [m^2] (areas with changing diameter)
i1= (pi/64)*((Do.^4)-(di1.^4)); % [m^4] (moment of inertias with changing diameter)
Pcr1=(((a1*(C*(pi^2)*E))) / (((L/(i1/a1))^2))) * (0.224809); % [lbf] (critical buckling drag on rocket including newton to pound-force conversion)
figure(1);
plot(Do-di,Pcr1,'r','linewidth',2);
ylabel('Critical buckling load [lbf]')
xlabel('Wall thickness of cylinder [m]')
grid on
title('Wall thickness VS. Critical buckling load')
```

7.1.3 A-3: MATLAB Code Separation Analysis:

Air Density & Velocity

P_Air = [0.0765, 0.0565, 0.0408, 0.0287]; % lb/ft^3
% Density for [0, 10000, 20000, 30000]
Vel = [400, 600, 800, 1000]; % Ft/s

Fin Parameters:

Cd_Fin = 0.005;
A_Fin = 0.18051078; % ft^2

Skin Parameters:

Hu = 7.7; % ft
Hl = 5.5; % ft
D = 0.51284; % ft
A_Skin_Top = pi * D * Hu;
A_Skin_Low = pi * D * Hl;
A_Skin_Total = A_Skin_Low + A_Skin_Top;

Cd_Skin = 0.00119;

Nose Parameters:
Cd_Nose = 0.05;
A_Nose = pi * ((D / 2)^2);
Cumulative Drag Force:
data_Top = [];
data_Low = [];
data_Total = [];

Altitude = [0, 10, 20, 30];

```
for i = 1 : 1 : 4
   for j = 1 : 1 : 4
      Fd_Fin = round(3 * (0.5 * P_Air(1, i) * Vel(1, j)^2 * Cd_Fin * A_Fin), 2); % 3 fins
      Fd_Fin_Total = round(2 * Fd_Fin, 2);
      Fd_Nose = round(0.5 * P_Air(1, i) * Vel(1, j)^2 * Cd_Nose * A_Nose, 2);
      Fd_Skin_Top = round(0.5 * P_Air(1, i) * Vel(1, j)^2 * Cd_Skin * A_Skin_Top, 2);
      Fd_Skin_Low = round(0.5 * P_Air(1, i) * Vel(1, j)^2 * Cd_Skin * A_Skin_Low, 2);
      Fd_Lower_Total = round(Fd_Fin + Fd_Skin_Low, 2);
      Fd_Top_Total = round(Fd_Fin + Fd_Skin_Top + Fd_Nose, 2);
      Fd_Total = round(Fd_Lower_Total + Fd_Top_Total, 2);

      data_Top = [data_Top; Altitude(1, i), P_Air(1, i), Vel(1, j), Fd_Fin, Fd_Nose,
Fd_Skin_Top];
      data_Low = [data_Low; Altitude(1, i), P_Air(1, i), Vel(1, j), Fd_Fin, Fd_Skin_Low];
      data_Total = [data_Total; Altitude(1, i), P_Air(1, i), Vel(1, j), Fd_Total, Fd_Top_Total,
Fd_Lower_Total];
   end
end

T_Top = array2table(data_Top, 'VariableNames', {'Altitude (kft)', 'Density (lb/ft^3)', 'Velocity
(ft/s)', 'Fin Drag (lb)', 'Nose Drag (lb)', 'Skin Drag (lb)'});
T_Low = array2table(data_Low, 'VariableNames', {'Altitude (kft)', 'Density (lb/ft^3)', 'Velocity
(ft/s)', 'Fin Drag (lb)', 'Skin Drag (lb)'});
T_Total = array2table(data_Total, 'VariableNames', {'Altitude (kft)', 'Density (lb/ft^3)', 'Velocity
(ft/s)', 'Total Rocket Drag (lb)', 'Total Top Drag (lb)', 'Total Lower Drag (lb)'});
```

```
T_Top.Properties.Description = 'Top Section Drag Table';
T_Low.Properties.Description = 'Lower Section Drag Table';
T_Total.Properties.Description = 'Total Drag Table';

disp('Table Name: ' + string(T_Top.Properties.Description))
disp(T_Top)

disp('Table Name: ' + string(T_Low.Properties.Description))
disp(T_Low)

disp('Table Name: ' + string(T_Total.Properties.Description))
disp(T_Total)
```

Weight:

```
m_Low = 23.405; % kg
m_Top = 23.405; % kg

W_Low = (m_Low * 9.81) * 0.22480894387096; % lb
W_Top = (m_Top * 9.81) * 0.22480894387096; % lb

W_Propellant = 16.2; % lb
```

Separation Analysis (Separation Point)

```
Fm = 50;
Fs = 50;
Fd_L = 239.6
Fd_T = 502.59

Left_Side = (6  * Fm) + (6 * Fs) + Fd_L + (W_Low - W_Propellant)
Right_Side = Fd_T + W_Top
h = (W_Low - W_Propellant)
```

7.2 Appendix B: Lee's MATLAB Code

7.2.1: MATLAB Code Thermal Effects:

```
% Thermal Effects on Magnets in Rocket Separation Systems
% By: Lee Freytes Colón
clc;
```

```
clear;
close all;
% 1. Constants and Material Properties
% Initial temperature (reference temperature)
T0 = 25; % degrees Celsius
% Coefficients of thermal expansion for materials (in 1/°C)
alpha_Al = 22.2e-6; % Aluminum
alpha_CF = 0.1e-6; % Carbon Fiber
alpha_Honeycomb_CF = 0.05e-6; % Honeycomb Core with Carbon Fiber (estimated)
% Initial Magnetic Force at reference temperature (in Newtons)
Fm0 = 1.0; % magnetic force at T0 (arbitrary units)
% Thermal coefficient for the magnet materials (in 1/°C)
alpha_magnet = 0.02e-6; % Example value for magnet (could vary based on material)
% Temperature Range for simulation (20 different temperatures)
temperature_range = linspace(25, 150, 20); % from 25°C to 150°C
% 2. Thermal Expansion Calculations
% Length of component (arbitrary units)
L0 = 1; % initial length in meters
% Aluminum thermal expansion (ΔL)
deltaL_Al = alpha_Al * L0 * (temperature_range - T0);
% Carbon Fiber thermal expansion (ΔL)
deltaL_CF = alpha_CF * L0 * (temperature_range - T0);
% Honeycomb Core with Carbon Fiber thermal expansion (ΔL)
deltaL_Honeycomb_CF = alpha_Honeycomb_CF * L0 * (temperature_range - T0);
% 3. Magnetic Force Calculations (Temperature Dependent)
Fm_Al = Fm0 * (1 - alpha_magnet * (temperature_range - T0)); % Aluminum
Fm_CF = Fm0 * (1 - alpha_magnet * (temperature_range - T0)); % Carbon Fiber
Fm_Honeycomb_CF = Fm0 * (1 - alpha_magnet * (temperature_range - T0)); % Honeycomb
Core with Carbon Fiber
% 4. Plotting Results
figure;
subplot(2,1,1);
plot(temperature_range, deltaL_Al, '-o', 'LineWidth', 2, 'DisplayName', 'Aluminum');
hold on;
plot(temperature_range, deltaL_CF, '-s', 'LineWidth', 2, 'DisplayName', 'Carbon
Fiber');
plot(temperature_range, deltaL_Honeycomb_CF, '-^', 'LineWidth', 2, 'DisplayName',
'Honeycomb Core with Carbon Fiber');
title('Thermal Expansion of Materials');
xlabel('Temperature (°C)');
ylabel('Change in Length (m)');
legend('show');
grid on;
subplot(2,1,2);
plot(temperature_range, Fm_Al, '-o', 'LineWidth', 2, 'DisplayName', 'Aluminum');
```

```
hold on;
plot(temperature_range, Fm_CF, '-s', 'LineWidth', 2, 'DisplayName', 'Carbon Fiber');
plot(temperature_range, Fm_Honeycomb_CF, '-^', 'LineWidth', 2, 'DisplayName',
'Honeycomb Core with Carbon Fiber');
title('Magnetic Force vs. Temperature');
xlabel('Temperature (°C)');
ylabel('Magnetic Force (N)');
legend('show');
grid on;
% 5. Conclusion
fprintf('For Aluminum: As temperature increases, the change in length increases,
which may affect the alignment of the magnets.\n');
fprintf('For Carbon Fiber: Minimal thermal expansion, but heat buildup may occur due
to insulation properties.\n');
fprintf('For Honeycomb Core with Carbon Fiber: A balance between minimal expansion
and effective thermal insulation.\n');
```