

NRG Hypersonic Rocket Capstone Project

Robert Nimcheski

Stonn Billy

Adriana Fisk

Lee Freytes Colón

Emanuel Salinas

Thomas Sasser

Project Description

- Design and produce a 24hp 2 stage hypersonic rocket with a magnetic separation system
- Northrop Grumman is the client and sponsor
- Important because magnetic separation has never been used in rockets previously
- Magnetic separation has the potential to improve simplicity, testability, and safety for 2 stage rocket separations

Background and Benchmarking

- Mechanical separation
 - Frangible joints are commonly used in mechanical separation
 - Mechanical separation is triggered by a pyrotechnic charge, springs, etc.
- Pyrotechnic separation
 - Uses an explosive to separate stages of a rocket
 - Frangible joints can also be paired with pyrotechnic separation
- Aerodynamic separation
 - Incorporates aerodynamic forces to separate stages of a rocket
 - Not as common to pair with a frangible joint

Customer Requirements

- Magnetic separation system
 - Overall system shall provide adequate force to separate the two stages
 - Able to safely release mechanism for integration or maintenance
 - Ground testing of the system to demonstrate requirements are met
- Budget
 - \$7,000
- Analysis
 - Force analysis (thrust, drag, lift, etc.)
 - Simulation analysis through RASAero and MATLAB

Customer Requirements (cont.)

- Rocket requirements
 - 8-12 feet in length
 - 2 stages
 - Made from advanced composite materials
 - Scientific payload (to be determined)
 - Reach a minimum of 50,000 feet in altitude
 - Utilize commercial off-the-shelf solid rocket motors
 - Test launch at Phoenix Tripoli Rocket Range

NOTE: These requirements were requirements for the previous capstone team

Engineering Requirements

Customer Needs	Customer Weights	Technical Requirements							
		Material Analysis	Mass Properties Analysis	Separation with Magnet Analysis/ Simulation	Dynamic Simulation and Analysis	Magnet and Electronic Analysis	Weight and Payload Simulation	Rocket Simulation (RASaero)	Two-Stage Analysis and Simulation
Magnetic Separation	5								
8-12ft in Length	4								
Two Stages	5								
Advanced Composite Materials	4								
Payload Capabilities	3								
Reach 50,000ft in Altitude	3								
Scale-up Feasibility	2								
Test Launch in April	5								
Technical Requirement Units		#VALUE!	#VALUE!	precision	accuracy	precision	accuracy	accuracy	precision
Absolute Technical Importance		#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
Relative Technical Importance									

Technical requirements

- Material Analysis
- Mass Properties Analysis
- Separation with Magnet Analysis/ Simulation
- Dynamic Simulation and Analysis
- Magnet and Electronic Analysis
- Weight and Payload Simulation
- Rocket Simulation (RASaero)
- Two-Stage Analysis and Simulation

Bob's Research (Sources)

- Papers:

- F. Stuart, J. Goto, and E. Sechler, “LOAN COPY: RETURN T@ AFWL (WLIL-2) THE BUCKLING OF THIN-WALLED CIRCULAR CYLINDERS UNDER AXIAL COMPRESSION A N D B E N D I N G.” Available: <https://ntrs.nasa.gov/api/citations/19680023754/downloads/19680023754.pdf> (accessed Feb. 10, 2025)
- J. Peterson, “Technical Note,” www.nasa.gov, Oct. 1960. <https://ntrs.nasa.gov/api/citations/20040016415/downloads/20040016415.pdf%E2%80%8B> (accessed Feb. 10, 2025).
- R. Newlands, M. Heywood, and A. Lee, “Rocket vehicle loads and airframe design Aspirespace technical papers Authors.” Accessed: Jan. 03, 2025. [Online]. Available: <http://www.aspirespace.org.uk/downloads/Rocket%20vehicle%20loads%20and%20airframe%20design.pdf>

- Websites:

- R. Nakka, “Richard Nakka’s Experimental Rocketry Site,” www.nakka-rocketry.net, Jul. 20, 2022. https://www.nakka-rocketry.net/RD_body.html (accessed Feb. 10, 2025)
- D. Holmes, “Mechanics of Materials: Bending – Normal Stress» Mechanics of Slender Structures | Boston University,” Bu.edu, 2019. <https://www.bu.edu/moss/mechanics-of-materials-bending-normal-stress/> (accessed Feb. 10, 2025)
- “Beam Stress & Deflection | MechaniCalc,” Mechanicalc.com, 2011. <https://mechanicalc.com/reference/beam-analysis> (accessed Feb. 10, 2025)

- Books:

- R. C. Hibbeler, *Engineering Mechanics: Dynamics, SI Units*. Pearson, 2023. (Chapter 13) (accessed Feb. 10, 2025)
- R. C. Hibbeler, *Mechanics of materials*. Boston: Prentice Hall, 2014. (accessed Feb. 10, 2025)
- R. Budynas and K. Nisbett, *Shigley’s Mechanical Engineering Design*. McGraw-Hill, 2014. (Chapter 4) (accessed Feb. 10, 2025)

Bob's Research (Bending Moment in Separation Device)

- Buckling concerns within the separation device
- Will treat the section as a "Euler Column" for analysis
- Material: Aluminum
- Assuming pin supports for conservative approach
- Weight will include entire rocket body above separation device

Bob's Research (Bending Moment in Separation Device)

$$\Sigma F_y = ma$$

F_D = Drag Force [N]

F_G = Gravitational Force [N]

F_L = Lift Force [N]

F_W = Weight [N]

F_T = Thrust Force [N]

m = Mass [kg]

a = Acceleration [m/s^2]

Solve for F_T

$$(C\pi^2 E)/(l/k)^2 = P_{CR}/A$$

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]

Solve for P_{CR}

$$F_T < P_{CR} ??$$

Bob's Research (Bending Moment in Separation Device)

- If $F_T > P_{CR}$, to increase P_{CR} we can.....
 - Use a stronger material (Increase E)
 - Design the area of separation to be shorter in height (Decrease l)
 - Use a larger diameter (Increase d which directly increases k)
 - Increase the cross-sectional area (Increase A)
 - Increasing wall thickness directly increases cross-sectional area (Increase t)

Stonn's Research (Sources)

Textbooks

- A. A. Baker and M. J. Boswell, *Composite Materials for Aircraft Structures*, 2nd ed. Reston, VA: American Institute of Aeronautics and Astronautics, 2014.
- W. D. Callister and D. G. Rethwisch, “Composites,” in *Materials Science and Engineering: An Introduction*, 10th ed. Hoboken, NJ: Wiley, 2018, Ch. 16, pp. 595.

Articles

- Raja, T., Devarajan, Y. and kailiappan, N. (2024) *Study on enhancing mechanical and thermal properties of carbon fiber reinforced epoxy composite through zinc oxide nanofiller - discover Applied Sciences*, SpringerLink. Available at: <https://link.springer.com/article/10.1007/s42452-024-06270-w>
- Georgantzinou, S.K. et al. (2023) *Composites in aerospace and Mechanical Engineering, Materials (Basel, Switzerland)*. Available at: <https://pmc.ncbi.nlm.nih.gov/articles/PMC10673402/>
- “Material Science Research India – An International Peer Reviewed Research Journal,” *Materialsciencejournal.org*, 2023. <https://www.materialsciencejournal.org/>

Websites

- Yancey, Dr. Robert. “Meeting the High-Temperature Material Challenges of Hypersonic Flight Systems | Hexcel.” *Hexcel.com*, 2025, hexcel.com/Resources/hypersonics.

Stonn's Research (Carbon-Fiber Material Analysis)

$$\text{Weight Reduction} = \left(1 - \frac{\rho_{cf}}{\rho_{al}}\right) \times 100$$

ρ_{cf} = density of carbon

ρ_{al} = density of aluminum

- Reduce the weight of the aluminum release mechanism to carbon fiber.
- Speak to Jim about how much material would be donated.

Adriana's Research (Sources)

Websites

- “Payload Systems.” NASA, NASA, 20 Nov. 2023, www1.grc.nasa.gov/beginners-guide-to-aeronautics/payload-systems/.

Articles

- Author links open overlay panelNirmith Kumar Mishra a, et al. “Computational Study on Rocket Payload Fairing.” *Materials Today: Proceedings*, Elsevier, 5 July 2023, www.sciencedirect.com/science/article/pii/S2214785323036428?via%3Dihub.
- “Damage Analysis of Explosion Blast Wave to Rocket Structure and Payload.” *Radware Bot Manager Captcha*, iopscience.iop.org/article/10.1088/1755-1315/237/3/032060. Accessed 10 Feb. 2025.
- Author links open overlay panelChristie Alisa Maddock a, et al. “Conceptual Design Analysis for a Two-Stage-to-Orbit Semi-Reusable Launch System for Small Satellites.” *Acta Astronautica*, Pergamon, 21 Aug. 2018, www.sciencedirect.com/science/article/pii/S0094576518304454.

Books

- Thomas F. Mütsch, and Matthias B. Kowalski. *Space Technology : A Compendium for Space Engineering*. De Gruyter Oldenbourg, 2016. *EBSCOhost*, research.ebsco.com/linkprocessor/plink?id=e38bd839-37b2-35f9-af78-a7bac0716624.

Adriana's Research (Payload System)

- Payload Types
 - Weather, navigation, fireworks, or sensors
- Two-Stage Rockets with added payloads
 - Previous rockets that used payloads; Successes and Failures
- Stress and Pressure
 - Pressure, Stress and Strain analysis on payload system
- Purpose payload serves
 - What we want the payload to do (if given the option)

Adriana's Research (Mathematical Modeling)

Time of Flight, t

$$t = 2v \sin \beta \frac{R^2}{\mu}$$

v – start velocity

β – dropping inclination angle

R – radius of the surface of the planet

μ – standard gravitational parameter

At 50kft considered "space equivalent zone" (high altitudes)

- Atmospheric Pressure at 50kft is 1.68psi

$$P_h = P_0 e^{\frac{-mgh}{kT}}$$

P_h – pressure at height h

P_0 – sea level pressure

m – mass of one air molecule

g – acceleration due to gravity

k – Boltzmann's constant

T – absolute temperature

Emanuel's Research (Electromagnetic Interference)

- Textbooks
 - “Introduction to Electromagnetic Capability” by Clayton R. Paul
 - “Electromagnetic Interference and Compatibility” by Paolo Stefano Croveti
- Papers
 - “Electro-magnetic interference reduction in electronic systems” by Jeffrey P. Mills
 - “Applications of Maxwell's Equations” by Cochran, J. F. (John Francis), Heinrich, B. (Bretislav)
 - “Maxwell’s Equations for Magnets” by Andy Wolski
- Online Resources
 - <https://pwg.gsfc.nasa.gov/Education/Imagnet.html>
 - <https://www.nasa.gov/missions/mms/nasa-spacecraft-discovers-new-magnetic-process-in-turbulent-space/>

Emanuel's Research (Mathematical Modeling)

Maxwell Equations

- Faraday's Law of Electromagnetic Induction
 - $EMF = -N \frac{\Delta\Phi}{\Delta t}$
 - EMF: Electromotive force in volts.
 - N: Number of turns in the coil.
 - Φ : Magnetic flux.
 - t: Time interval over which the flux changes.
- Ampere's Law
 - $\Delta B = \mu_0 \left(J + \varepsilon_0 \left(\frac{\partial E}{\partial t} \right) \right)$
 - ΔB : Curl of the magnetic field
 - μ_0 : Free Space, a constant value of $4\pi \times 10^{-7} \text{ N/A}^2$.
 - J: The current density vector (in amperes per square meter, A/m^2)
 - ε_0 : The permittivity of free space, a constant value of 8.85×10^{-12}

Northrop Grumman Concerns

- Two-stage middle component has wiring near the magnets of the system.
- The magnets might interfere with the sensors and avionics of the rocket while in flight.
- Analysis and calculations will need to take place to determine if the magnetic field is strong enough to mess with the electronics.
- CAD design would need to be revised if needed.

Thomas' SOTA Literature Review

Textbooks:

- “Rocket Propulsion Elements” By George P. Sutton
- “Fox and McDonald’s Introduction to Fluid Mechanics”
- “The Flight of Uncontrolled Rockets”

Online Sources:

- J. Davies *et al.*, “Preliminary design and test of high altitude two-stage rockets in New Zealand,” *Aerospace Science and Technology*, vol. 128, p. 107741, Sep. 2022, doi: [10.1016/j.ast.2022.107741](https://doi.org/10.1016/j.ast.2022.107741).

Thomas' Research (Dynamic Analysis)

- The following analysis is concerning the dynamic forces the rocket exhibits during the flight takeoff.
- With these forces known, they can be accurately simulated.
- The rocket flight will be simulated through RASAero and MATLAB.
- The goal of the analysis is to accurately model all of the forces throughout time and altitude, while providing a conservative estimate.

Thomas' Research (Dynamic Analysis)

Drag on cylinders:

$$\bullet D_1 = C_{D,1} \frac{1}{2} p A_{cyl,1} v^2 \quad D_2 = C_{D,2} \frac{1}{2} p A_{cyl,2} v^2$$

Lift on Cylinders:

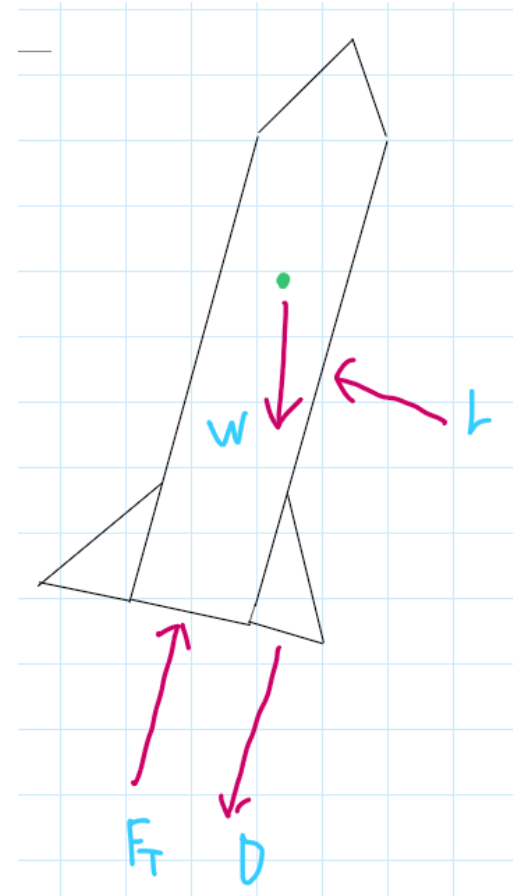
$$\bullet D_4 = C_{D,4} \frac{1}{2} p A_{cyl,3} v^2 \quad D_5 = C_{D,5} \frac{1}{2} p A_{cyl,4} v^2$$

Drag on fins:

$$\bullet D_3 = 8C_{D,3} \frac{1}{2} p A_{Fin} v^2$$

Total Drag:

- $D_{Eq} = D_1 + D_2 + D_3$
 - C_D : Coefficient of Drag
 - p : Air Density
 - A : Area normal to flow
 - v : Velocity



Thomas' Research (Dynamic Analysis)

Impulse:

- $I_{t,1} = F_{T,1}t_1$ $I_{t,2} = F_{T,2}t_2$
- $I_{Total} = I_{t,1} + I_{t,2}$
 - I_t : Impulse (**Ns**)
 - F_T : Thrust Force (**N**)
 - t_1 : Booster 1 thrust duration (**s**)

Thrust Force:

- $F_T = m'v_e + (P_e - P_0)A_e$
 - m' : Mass flow rate of exhaust ($\frac{kg}{s}$)
 - v_e : Exhaust velocity ($\frac{m}{s}$)
 - P_e : Exhaust Pressure (**Pa**)
 - P_0 : Ambient Pressure (**Pa**)
 - A_e : Nozzle exit area (**m²**)

Weight:

- $W = mg$
 - m : Mass (**kg**)
 - g : Gravity ($\frac{m}{s^2}$)
 - W : Weight (**N**)

Gravity:

- $g = g_0 \left(\frac{R_0}{R_0 + h} \right)^2$
 - g_0 : Gravity at sea level ($\frac{m}{s^2}$)
 - R_0 : Earth's radius at sea level (**km**)
 - h : Vertical displacement from R_0 (**km**)

Lee's Research (Sources)

Books:

- "Fundamentals of Rocket Propulsion" by DP Mishra
- "Mechanisms and Mechanical Devices Sourcebook" by Neil Sclater and Nicholas P. Chironis
- Flight Separation Mechanisms by NASA

Papers:

- The electromagnetic separation system for the small spherical satellite Q-SAT
- Design, Analysis, and Testing of an Electromagnetic Booster Separation System
- Separation and Release Devices for Aeronautical and Astronautical Systems: A Review

Websites:

- <https://ntrs.nasa.gov/>
- <https://www.nakka-rocketry.net/techref.html>

Lee's Research (Wall Thickness for Magnetic Separator)

The objective is to determine optimal wall thickness for the magnetic separator to ensure strength, minimal magnetic interference, and stability.

Considerations:

- Material selection:
 - Steel, Aluminum, Carbon fiber
- Mechanical Strength:
 - Formula: $t = \frac{P \cdot r}{2 \cdot \sigma_{\text{yield}}}$
 - Account for external forces such as: thrust, separation forces, and payload weight
 - Applying a safety factor of around 1.5-2.5

Lee's Research (Wall Thickness for Magnetic Separator)

- Magnetic efficiency:
 - Avoid thickness that can ruin the magnetic field or cause errors to the stage separation.
- Thermal Considerations:
 - Coefficient of thermal expansion: ensuring no material failure due to heat.
 - Probably considering in using the thermal expansion formula(see next slide) to calculate possible changes
- Expected outcomes:
 - Optimized wall thickness for strength, magnetic performance, and thermal stability.
 - A validated design through simulations(ANSYS?) and prototype testing.

Lee's Research (Wall Thickness for Magnetic Separator)

- Linear thermal expansion

$$\Delta L = L_0 \cdot \alpha \cdot \Delta T$$

Where:

- ΔL = Change in length (m or in)
- L_0 = Original length (m or in)
- α = Coefficient of linear expansion (per degree Celsius or per degree Fahrenheit)
- ΔT = Change in temperature (°C or °F)

- Volumetric thermal expansion

$$\Delta V = V_0 \cdot \beta \cdot \Delta T$$

Where:

- ΔV = Change in volume (m³ or in³)
- V_0 = Original volume (m³ or in³)
- β = Coefficient of volumetric expansion (which is approximately 3 times the coefficient of linear expansion for isotropic materials)
- ΔT = Change in temperature (°C or °F)

Schedule

NRG Hypersonic Rocket			Week 4 (02/10 - 02/16)							Week 5 (02/17 - 02/23)							Week 6 (02/24 - 03/02)							Week 7 (03/03 - 03/09)						
Start Date: 01/20/2025			M	T	W	TH	F	SA	SU	M	T	W	TH	F	SA	SU	M	T	W	TH	F	SA	SU	M	T	W	TH	F	SA	SU
Stage 2		22d																												
Team Meeting 3	Team	1d																												
HW-03 Self Learning	Team	3d																												
Staff Meeting 2	Team, Professor	1d																												
PM Meeting 1	Emanuel	1d																												
Client Meeting 2	Team	1d																												
Concept Generation	Team	2d																												
Engineering Analysis 1 (TBD) Thomas		3d																												
Engineering Analysis 2 (TBD) Emanuel		3d																												
Engineering Analysis 3 (TBD) Stonn		3d																												
Engineering Analysis 4 (TBD) Bob		3d																												
Engineering Analysis 5 (TBD) Adriana		3d																												
Engineering Analysis 6 (TBD) Lee		3d																												
Concept Evaluation	Team	2d																												
Schedule	Thomas, Emanuel	1d																												
Budget	Bob, Stonn	1d																												
Bill of Materials	Team	2d																												
Presentation 2 Finalization	Team	3d																												
Stage 3		#d																												

Budget

- Fundraising

- 10% of \$7,000 therefore \$700
- GoFundMe
- Material donations
- Possible food drive or plant drive

- Funding

- \$7,000

	Description	Amount [\$]
Available funding	Total funding	\$7,000
Current expenses	N/A	-\$0
Processing expenses	Magnet set to familiarize ourselves with magnetic forces	-\$15
Upcoming expenses	N/A	-\$0
Net Balance:		\$6,985



Thank You!