NRG Rocket

Bob Nimcheski
Emanuel Salinas
Lee Freytes Colón
Thomas Sasser
Adriana Fisk
Stonn Billy

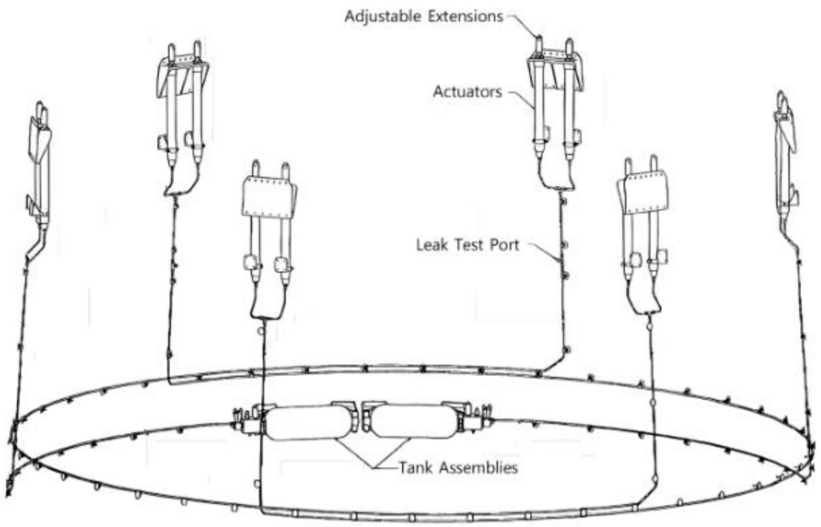
NAU NORTHERN ARIZONA UNIVERSITY

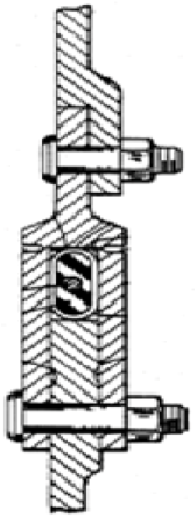
Background, Need, Why Northrop Grumman, and Stakeholder Impact

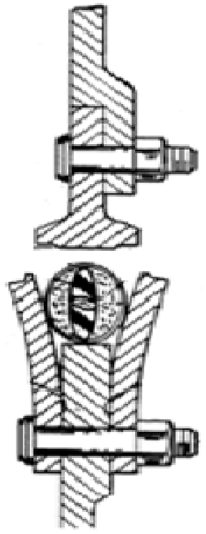
- Background & Traditional Method
  - Rockets traditionally use frangible joints for stage separation due to their simplicity and reliability.
  - Example: Space Shuttle used frangible joints for stability on the launch pad, with controlled explosives as a backup for separation.
- Challenges with Frangible Joints
  - Risk of failure – If the explosive fails, stages remain attached, jeopardizing the mission.
  - High shock loads – Potential to damage sensitive spacecraft equipment.
  - Single-use system – Requires purchasing new explosive material for each launch.
- Magnetic Separation System: A Better Alternative
  - No explosives required – Increases safety and reliability.
  - Reduced shock loads – Protects delicate onboard instruments.
  - Reusable – Lowers operational costs and supports reusable rocket designs.
- Why Northrop Grumman?
  - Pioneered magnetic separation for rockets to enhance cost-effectiveness and reusability.
  - Eliminates need for explosive charges, reducing material costs.
  - Aligns with modern spaceflight goals – safer, more sustainable, and cost-efficient solutions.

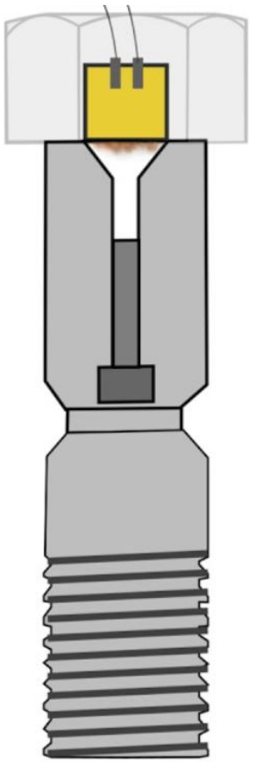
Other Types of Separation Devices

- Frangible Joints
- Pneumatic Stage Separation System
- Explosive Bolts









Salinas, 3

Project Description

- This project revolves around creating a magnetic separation device for a supersonic rocket that will reach a maximum altitude of 50,000 [ft]
- Northrop Grumman is sponsoring this project, and it is important because magnetic separation in rockets can be a much cheaper, safer, and more effective alternative to present devices
- 80% of time will be allocated to separation device research
- 20% of time will be allocated to other parts of the rocket

Quality Function Deployment (QFD)

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
		Engineering Requirements												
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

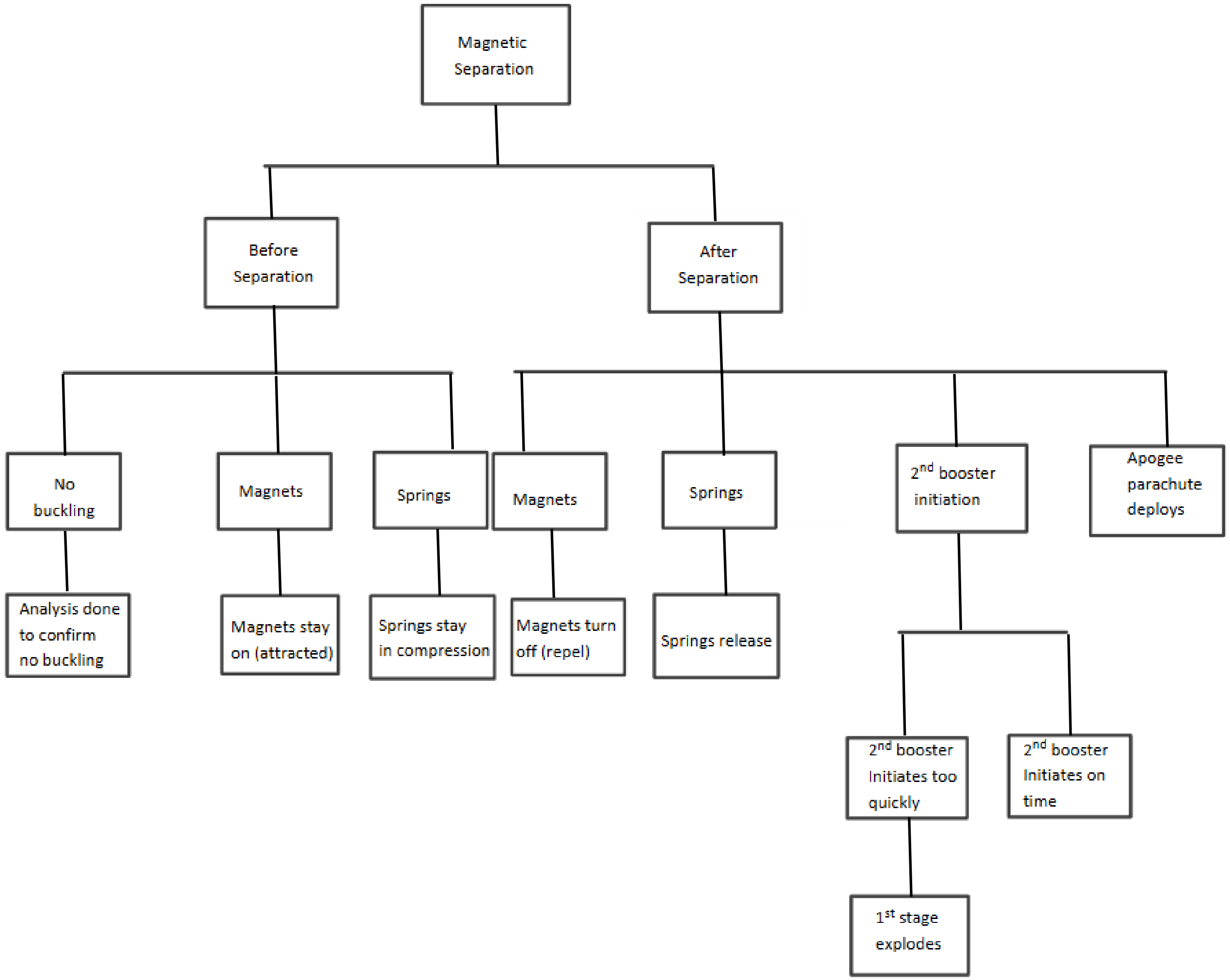
Separation Types	
A	Mechanical Separation
B	Pyrotechnic Separation
C	Aerodynamic Separation

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

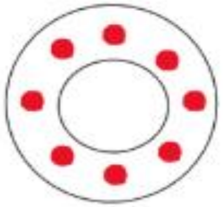
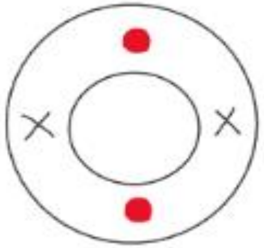
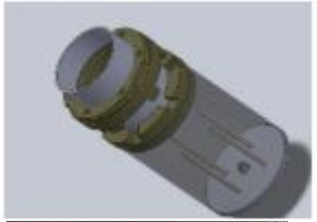
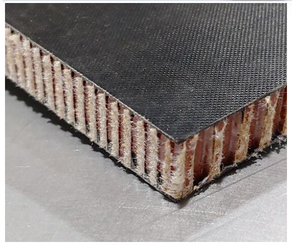
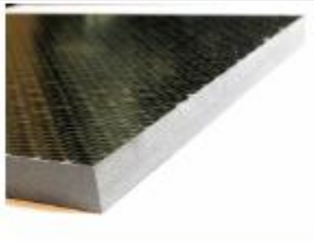
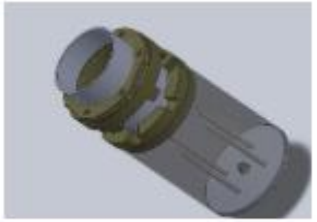
Fisk, 5

Black Box Model

Detailed Decomposition Model



Concept Generation Morphological Matrix

Subsystem:	1	2	3
Dispersion:			
Material composition:		 	 

<u>KEY:</u>

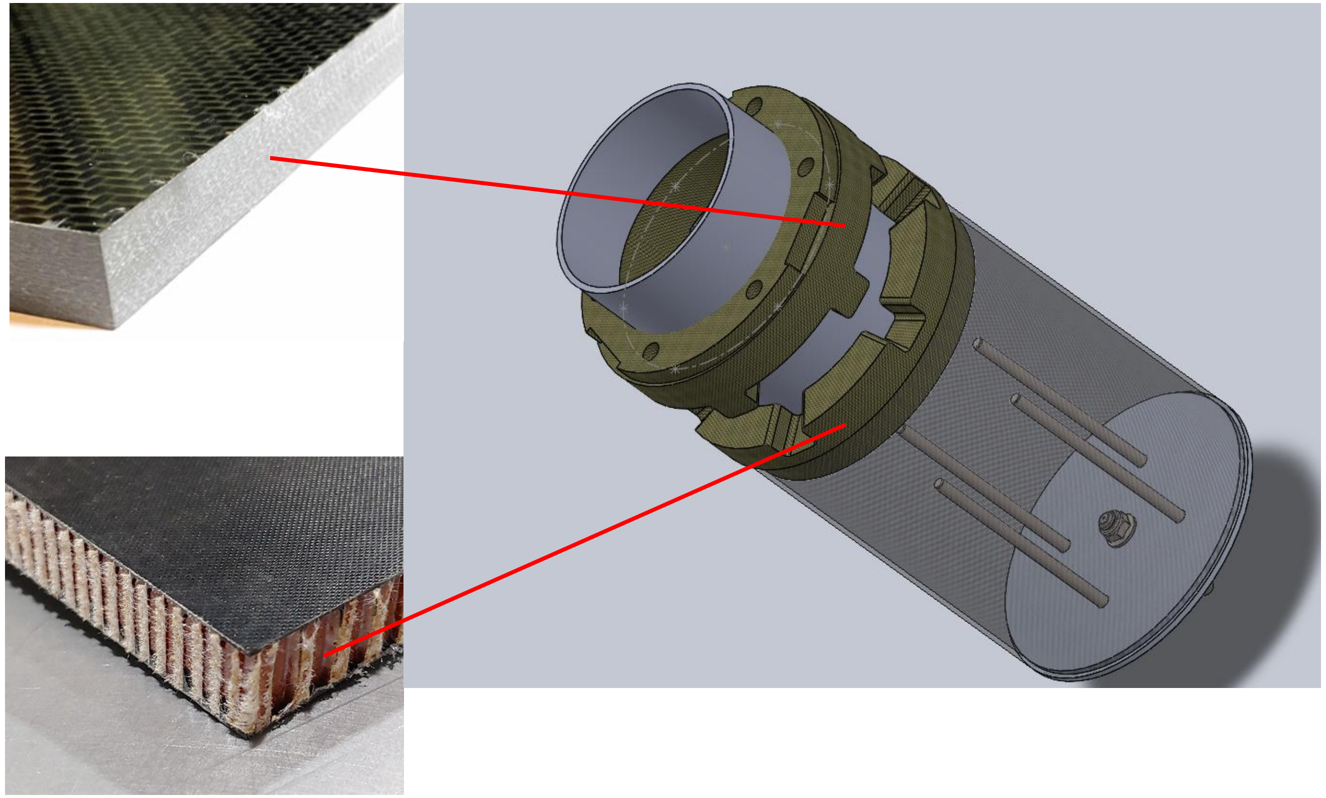
= magnet

= spring

X = black powder charge

Concept Generation: Fully Carbon Fiber & Honeycomb Core

- These concepts were generated on improving from the current aluminum design.
  - Fully Carbon Fiber Base
  - Honeycomb core wrapped in Carbon Fiber
- Advantage Fully Carbon
  - High strength in Compression and Tension
- Disadvantage of Fully Carbon
  - Weight
  - Cost of Materials
- Advantage of Honeycomb Core
  - Light and reduce of carbon fiber
  - High Compression Load
- Disadvantage
  - Manufacturing Challenges
  - Honeycomb core lacks in tension



Factor of Safety Table

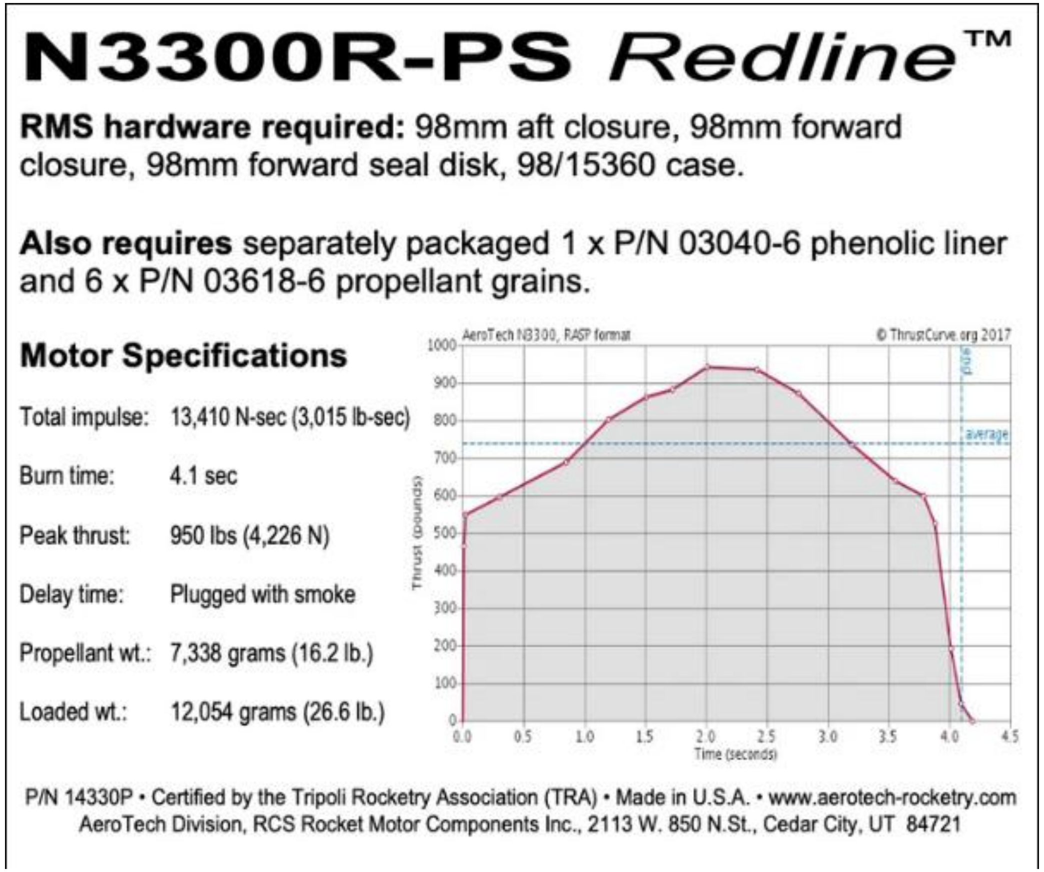
★ASSUME MAXIMUM DRAG OF 1000 LBS ★

[2]

Material/Component:	Type of Loading:	Factor of Safety (FoS):
Aluminum/Separation device	Static	N/A
Aluminum/Separation device	Dynamic/Compressive	18.15
Carbon Fiber/Separation device	Static	N/A
Carbon Fiber/Separation device	Dynamic/Compressive	39.46
Carbon Fiber & Honeycomb Core/Separation device	Static	N/A
Carbon Fiber & Honeycomb Core/Separation device	Dynamic/Compressive	TBD

Theoretical Velocity and Height; Given

- Assumption
  - No Air Resistance
- First Stage
  - Avg. Thrust: 3336.165 N
  - Mass of Rocket: 46.81 kg
  - Initial Velocity: 0
  - Time: 4.1 s
- Second Stage
  - Mass of Rocket: 23.405 kg
  - Time: 4.1 s



N3300R-PS *Redline*™

RMS hardware required: 98mm aft closure, 98mm forward closure, 98mm forward seal disk, 98/15360 case.

Also requires separately packaged 1 x P/N 03040-6 phenolic liner and 6 x P/N 03618-6 propellant grains.

Motor Specifications

Total impulse:	13,410 N-sec (3,015 lb-sec)
Burn time:	4.1 sec
Peak thrust:	950 lbs (4,226 N)
Delay time:	Plugged with smoke
Propellant wt.:	7,338 grams (16.2 lb.)
Loaded wt.:	12,054 grams (26.6 lb.)

P/N 14330P • Certified by the Tripoli Rocketry Association (TRA) • Made in U.S.A. • www.aerotech-rocketry.com
AeroTech Division, RCS Rocket Motor Components Inc., 2113 W. 850 N.St., Cedar City, UT 84721

Theoretical Velocity and Height

- First Stage
  - Avg. Thrust – mg = ma
  - a = 61.46 m/s^2
  - Vf1 = Vo + (at)
    - Vf1 = 251.986 m/s
  - Y1 = Yo + Vot +0.5at^2
    - Y1 = 1694.78 ft
  - M1 = 0.734
    - Subsonic
      - M<1
- Second Stage
  - Avg. Thrust – mg = ma
  - a = 132.73 m/s^2
  - Vf1 = Vo + (at)
    - Vf2 = 796.179 m/s
  - Y2 = Y1 + Vf1t + 0.5at^2
    - Y2 = 8744.42 ft
  - M2 = 2.32
    - Supersonic
      - M>1
- Max Height
  - Vf = 0 at max height
  - Vf = Vo +(-g)t
  - Y3 = Y2 + Vf2t + 0.5(-g)t^2
    - Y3 = 114,744 ft

Theoretical Velocity and Height

- Very conservative calculation
  - What's not included
    - Drag force
    - Area
- What's Next?
  - New set of analysis taking in account of drag force
  - RASAero II Simulations

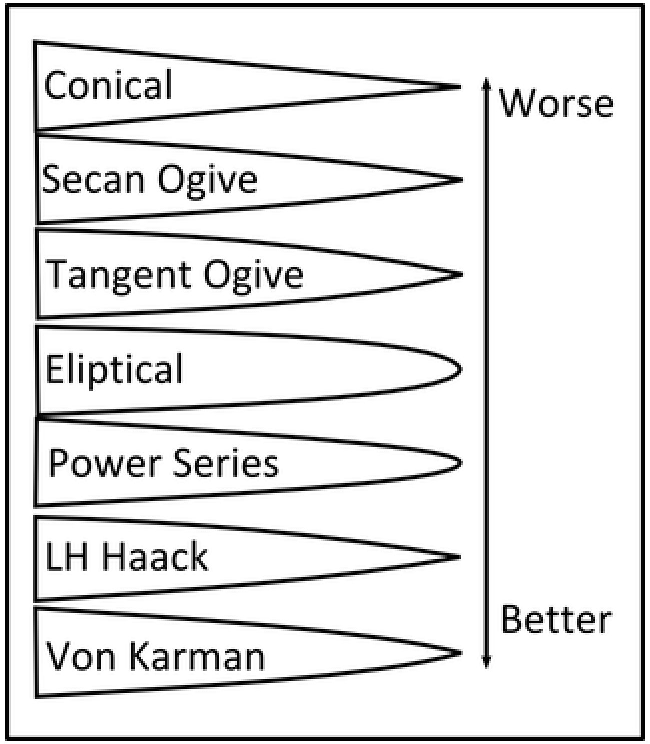
$$ma = F_T - mg - \tfrac{1}{2}\rho a^2 t^2 \left[C_{\delta fin} \cdot A_{fin} + C_{\delta skin} A_{skin} + C_{\delta Nose} A_{Nose} \right]$$

Assuming

1. Constant Mass
2. Constant Air Density
3. Constant Gravity
4. Avg. Thrust Force is Constant

Adriana’s Analysis – Nose Cone Drag Force

- L-D Von Karman Haack Series Nose Cone shape
  - The shape of the cone is found by calculating C
  - Goal is to have minimum drag – range: 0-0.66
- Haack Series shape equation
  - $\theta = \cos^{-1}(1 - \frac{2x}{L})$
  - $y = \frac{R}{\sqrt{\pi}} \sqrt{\theta - \frac{\sin(2\theta)}{2} + C sin^3(\theta)}$
    - C = 0; minimum for given length and diameter
  - $D = Cd\,\frac{\rho V^2}{2} A\;; A = \pi r^2$, *r=3.085in*
    - ***D : Drag Force = 5.4 pounds***
    - *Cd : Drag Coefficient = 0.05*
    - *ρ : Density = 0.0408 pound per foot^3*
    - *V : Velocity = 2611 ft/s*
    - *A : Reference Area = 2.4108 ft/s^2*
- Assumptions based on design
  - Nose cone drag will be minimal
  - Optimal for performance– speed and weight



Lee’s Analysis (Fin Drag)

```
% 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)
```

- 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.

Stonn's Analysis: Skin Friction Drag Analysis

- Skin Drag at Mach 2 (30,000 ft)
- Drag Forces
  - D_{Total} = 44.1 lbf
  - $D_{Stage\ 1} = 17.8\ lbf$
  - $D_{Stage\ 2} = 26.3\ lbf$
  - Re = 7.31×10^7 (turbulent)
  - Low drag at peak speed

- Rocket Specs
  - Length = 158.85 "
  - Diameter = 6.17'
  - Wetted Area: 21.38 ft^2

- Thrust Context:
  - 44.1 lbf drag = 4.6% of the 950 lbf thrust.
  - 26.3 lbf drag = 2.6% of the 950 lbf thrust

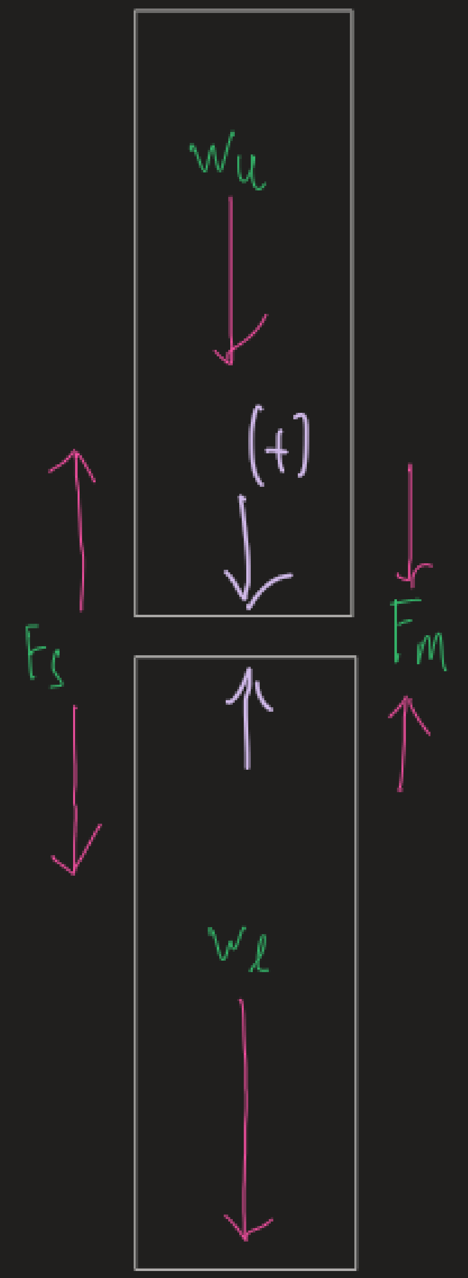
- Equations
  - $D = \left(\frac{1}{2}\right)\rho v^2 C_f A$
    - v = 2008 $\frac{ft}{s}$
    - $\rho = 0.02747\ \frac{lb}{ft^3}$
    - $C_f = 0.00119$ (smooth finish)
    - A = 21.38 ft^2
  - $\text{Re} = \frac{\rho v L}{\mu}$
    - L = 13.27 ft, 5.5 ft, 7.7 ft
    - μ = 3.12 x $10^{-7}\ \frac{lb}{ft}$

Dynamic Analysis

- Four points will be considered:
  - Before launch at rest, with no normal force.
  - During launch with thrust force greater than zero.
  - During launch with no thrust force, & before separation.
  - During launch, at point of separation.

Dynamic Separation Analysis

- Before launch at rest, with no normal force:
  - Drag force, thrust force are zero.
  - Only existing forces are weight, magnetic, and spring.
- $F_m + W_u >= F_s + W_l$
  - This results in maintaining connection.



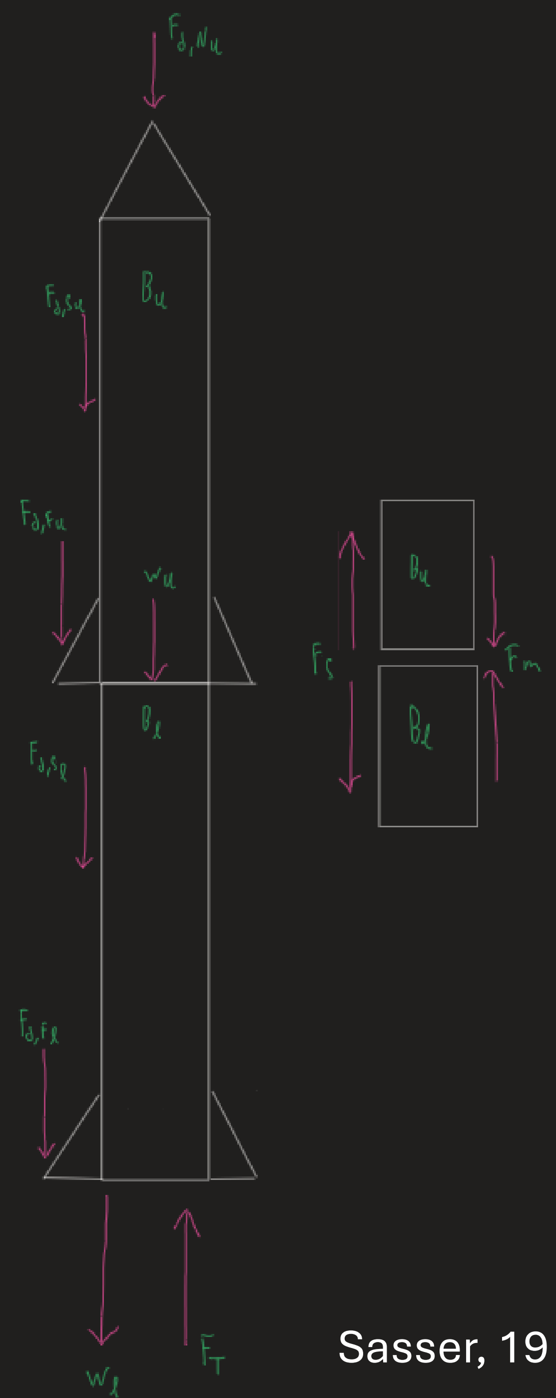
Dynamic Separation Analysis

- During launch with thrust force greater than zero.

- Upper and Lower Drag Forces:
  - $F_{d,U} = F_{d,N} + F_{d,S1} + F_{d,F1}$
  - $F_{d,L} = F_{d,S2} + F_{d,F2}$

- Analyzing for connection between stages:
  - ma = 0 at separation point relative to the rocket.
  - Positive is compression.
  - $F_T + F_{d,U} + W_u + F_m >= F_s + F_{d,L} + W_l$

- When Thrust force is over:
  - $F_{d,U} + W_u + F_m >= F_s + F_{d,L} + W_l$
  - To maintain connection



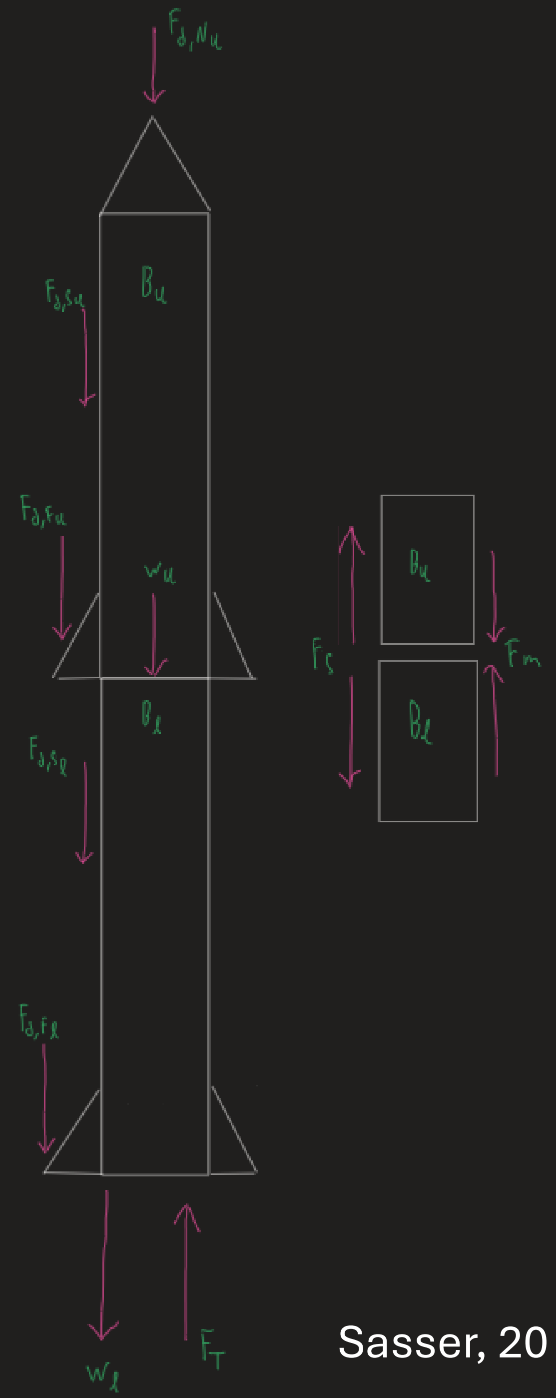
Sasser, 19

Dynamic Separation Analysis

- During launch at separation point:
  - When Fm is switched to act in tension.
  - Positive is in tension.
  - $F_m + F_s + F_{d,L} + W_l > F_{d,U} + W_u$

- This equation results in separation.

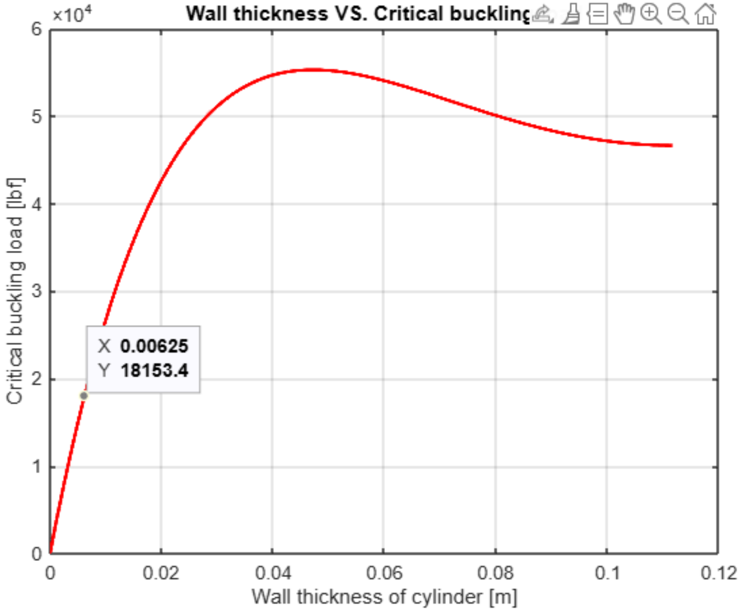
- These equations will be accurately calculated when separation altitude window is identified.



Bob’s Analysis

[1]

- Separation device buckling analysis method 1: Used analysis to determine the use of Euler column analysis. Performed Euler column analysis by hand to determine critical buckling load
- Separation device buckling analysis method 2: used Euler column analysis with Pcr=1000 [lbf] and solved for inner diameter




```
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
```

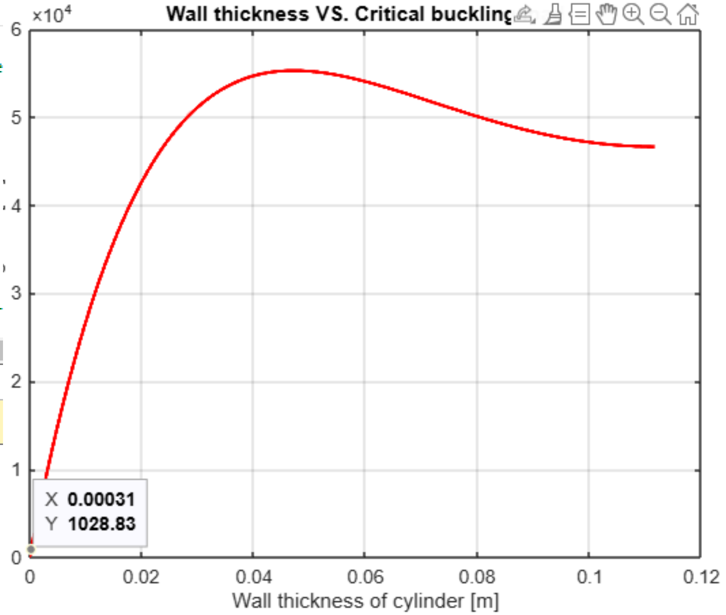
Command Window

New to MATLAB? See resources for Getting Started.

```
>> Changing_inner_diameter(0.10541)

ans =

   18.1534202949223e+003
```



Gantt Chart

NRG Hypersonic Rocket

Start Date: 01/20/2025

Week 7 (03/03 - 03/09) | Week 8 (03/10 - 03/16) | Week 9 (03/17 - 03/23) | Week 10 (03/24 - 03/30)

Stage 3: Separation Completion		**Completion (%)**	**14d**
Order Final Materials	Bob	0	1d
Validate Cumulative Drag	Lee	0	3d
Validate Dynamic Analysis	Thomas	0	1d
Characterize Spring Force	Thomas	0	2d
Characterize Magnet Force	Thomas	0	2d
Client Meeting 3	Team	0	1d
Initial Design Report	Team	0	3d
Website Finalization	Adriana	0	2d
Slots for Release Mechanism Machined out	Team	0	2d
Complete Separation System	Team	0	2d
Stage 4: Finalize Rocket		**Completion (%)**	**#d**
Order Fabricated Parts	Bob, Stonn	0	1d
Rework mandrel / apply chem-lease	TBD	0	2d
Refabricate Couplers x2	TBD	0	2d
Sand couplers for dry fit	TBD	0	1d
Assemble Rocket	Team	0	2d
Finalize Data Measurements	Thomas, Stonn, Bob	0	2d
Finalize RASAero Simulation	Emanuel	0	2d
Finalize Launch Procedure	Team	0	2d
Stage 5: Data Analysis			**#d**

Budget

- The budget for our project is $5000, $0 have been spent but we are planning to buy the drogue and main parachutes soon (estimates shown below).
- We have raised $700 on GoFundMe so far

	Description:	Amount [$]:
Available funding -	Northrop Grumman funding	+$5,000
Donations -	GoFundMe	+$700
Current Expenses -	N/A	-$0
In-progress expenses -	N/A	-$0
Upcoming expenses -	36" DROGUE CHUTE [2] 144" MAIN CHUTE [2]	-$236.34 -$770
Net Balance:		$4,693.66 (after upcoming expenses)

Bill of Materials (BoM)

Line Number	Item	Description	Quantity	Unit Cost	Total Cost	Need Date	Order By Date	Date Ordered	Date Received	**Grand Total**	**$3,544.32**
1	Magnets	40 lbf	2	$10.00	$20.00	3/1/2025	2/15/2025	2/10/2025	2/24/2025		
2	Booster	N3300R	2	$1,153.99	$2,307.98	Nov-25	Aug-25	N/A	M/A		
3	Carbon Fiber	Material	TBD	Donated	Nothing	Aug-25	N/A	N/A	N/A		
4	Honey comb Core	Standard Cell Aramid Honeycomb is a lightweight, high strength, nonmetallic honeycomb core material used to add stiffness in weight critical applications 24"x48"	2	$155	$310	25-Aug	N/A	N/A	N/A		
5	Parachutes	36-in Drogue Parachutes	2	$118.17	$136.34	4/20/2025	4/1/2025	N/A	N/A		
6	Parachutes	144-in Main Chute	2	$385	$770	4/20/2025	4/1/2025				
7											
8											
9											
10											

Conclusion

- Next Steps:
  - Machine out slots in separation system.
  - Characterize spring and magnet force.
  - Solve for Acceleration to determine accurate kinematics.
  - Finalize RASAero simulation.

References

[1] R. Budynas and K. Nisbett, *Shigley's Mechanical Engineering Design*. McGraw-Hill, 2014.

[2] The Engineering ToolBox, "Young's Modulus - Tensile and Yield Strength for common Materials," *Engineeringtoolbox.com*, 2003.https://www.engineeringtoolbox.com/young-modulus-d_417.html

[3] ACP Composites, "Aramid Honeycomb Core - Standard Cell", 2025 https://acpcomposites.com/shop/core-materials/honeycomb-core/aramid-honeycomb-core-standard-cell

[4] "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. 3, 2025).