Northrop Grumman
Two-Stage Supersonic Sounding Rocket

Presenters: Austin Paothatat, Avery Charley, Koi Quiver, Lindsey Dineyazhe

NAU NORTHERN ARIZONA UNIVERSITY

College of Engineering, Informatics, and Applied Sciences

Project Description

- Our team is working on a two-stage supersonic rocket made from composite materials. We aim to reach an altitude of 40,000 feet while maintaining a speed of Mach 2, all while carrying a payload of 10 pounds. If our project is successful, other capstone projects will have the chance to implement improvements.

- Stakeholders

  Northrop Grumman – $7,000

Customer Requirements (CRs)

- **CR1- Develop a two-stage launch vehicle.**
  - The vehicle will be a two-stage rocket, requiring an initial booster that detaches after use to optimize flight time and speed. Once the first stage is ejected, the second stage will continue the flight.
- **CR2- Use of a specific stage separation device.**
  - The client requests that the team use a particular separation method previously discussed. Details on this system are proprietary to Northrop Grumman and cannot be included in the report.
- **CR3- The vehicle will be constructed of composite materials.**
  - The client prefers the vehicle to be made from a composite material due to its strength and lightweight properties. They also want this composite material to be reusable.
- **CR4- Vehicle will reach an altitude of at least 40,000 ft AGL (Above Ground Level).**
  - The client requires the vehicle to reach a fixed altitude of 40,000 feet. The chosen launch site has an altitude ceiling of 48,000 feet above sea level.
- **CR5- Final launch vehicle will be required to carry a maximum 10 Lb payload that will fit within a 6” diameter bay**
  - A key client requirement is that the vehicle includes a payload bay with a 6-inch diameter and the capability to carry at least a 10-pound payload. This is essential, as the vehicle is intended for research purposes.
- **CR6- Vehicle required to reach a maintain over Mach 2 or roughly 1500 mph and maximize time spent at that speed or greater.**
  - A major client requirement is for the vehicle to not only reach Mach 2 (approximately 1,500 mph) but also to maximize the time spent at this speed or higher. Achieving such speeds will introduce compressible flow dynamics and non-linear effects.
- **CR7- Acceleration of the vehicle needs to meet a minimum of 12g’s.**
  - The force acting on the vehicle at launch should result in at least 12g acceleration.
- **CR8- Vehicle trajectory will be simulated in Rocksim.**
  - The vehicle's trajectory should be modeled in RockSim, a rocket simulation application that allows users to set parameters to predict various measurements for the vehicle.
- **CR9- Vehicle required to use commercial rocket motors.**
  - The team must utilize solid fuel commercial rocket motors for easy vehicle replacement and reuse.
- **CR10- Recovery of entire launch vehicle for reuse.**
  - The client requests that the entire vehicle design be reusable after each launch, except for the motors.

Engineering Requirements (ERs)

- **ER1- Max Velocity – Mach 2 or 1500 mph**
  - The vehicle's velocity refers to its speed in flight. The main engineering goal is to reach Mach 2 (1,500 mph) and maintain it for at least 30 seconds.
  - The requirement is a two-sided constraint influenced by body size, with other factors also affecting vehicle velocity. Every rocket part impacts velocity, as added or removed weight will change it.
- **ER2- Separation Event – Successful or unsuccessful separation**
  - The project requires a simple yes or no on whether the separation works with the chosen device. It's not focused on designing a separation system, but the vehicle needs two stages.
  - This requirement presents a one-sided constraint, as the only factor affecting the separation event is the separation device and method. Nothing else influences the separation event.
- **ER3- Altitude – 40,000 ft AGL (Above Ground Level)**
  - Altitude is a critical engineering requirement, as the team is responsible for ensuring the vehicle achieves the client's target of 50,000 feet, which is the maximum elevation allowed at the selected launch site.
  - This requirement is a two-sided constraint; weight and speed impact the vehicle's altitude. Changing weight or fins will affect the altitude it can reach.
- **ER4- Payload Weight – 10lbs**
  - The client requires the research vehicle to sustain supersonic flight with a 10 lbs. payload and safely return to the ground. The exact payload is unknown, but the vehicle must maximize the weight it can carry while maintaining supersonic flight.
  - This requirement is a one-sided constraint that cannot change due to the client's needs. This goal is fixed and will only influence other requirements, rather than being adjustable.
- **ER5- Cost of production - $7000 USD**
  - The client wants a cost-effective vehicle that can be reused and built more without high expenses. The project budget is approximately $7000; staying within this limit will fulfill this engineering requirement. Building the vehicle for less will result in an even better outcome.
  - This requirement is a one-sided constraint since we can't design specifically for low production costs. We can focus on using affordable materials and parts, but production costs don't significantly impact this project.
- **ER6- Reusable – more than 1 use**
  - The requirement will be evaluated based on how many uses the vehicle can withstand before major maintenance or replacement is needed. The team can only launch the final product once or twice. If the vehicle shows minimal damage post-launch, they will estimate its total usable lifespan.
- **ER7- Payload Volume – 282.7 in^3**
  - The client prioritized payload weight over volume and did not specify a volume requirement. The team assumes a 10 lbs. payload is under 10 inches tall. Success is defined as reaching 282.7 in^3 in volume.
  - This is a two-sided constraint because the team's engineering capabilities influence the lightweight constraint. It can be affected by other requirements, making it more complex than a one-sided constraint.

QFD

QFD below shows some older requirements set, but the team found they were able to reduce the body diameter and increase the size of the motors

- positively affected all the ERs and CRs making the goals set more attainable

Body Ranking System

- 9 – Strong
- 3 – Moderate
- 1 – Weak
- 0 -- None

System QFD

Project:	**Two Stage Supersonic Rocket**
Date:	3/18/2024

#		1	2	3	4	5	6	7	8	9
1	Altitude	(++)								
2	Body Diameter		(++)							
3	Vehicle Speed	(++)		(++)						
4	Vehicle Acceleration	(++)		(++)	(++)					
5	Payload Weight	(+)	(+)	(+)	(+)	(++)				
6	Seperation Event		(+)	(+)			(++)			
7	Reusable		(+)	(+)	(+)	(+)	(+)	(++)		
8	Payload Volume		(++)			(+)			(++)	
9	Body Material		(+)	(+)		(+)	(+)	(++)		(++)

#	**Customer Needs**	**Customer Weights**	Technical Requirements: Altitude	Body Diameter	Vehicle Speed	Vehicle Acceleration	Payload Weight	Seperation Event	Reusable	Payload Volume	Body Material	Customer Opinion Survey: *1 Poor*	*2*	*3 Acceptable*	*4*	*5 Excellent*
1	Lightweight	4	9	3	9	9	9	1	3	1	9					
2	Altitude	7	9	1	9	9	9	9		1	3					
3	Max Velocity	8		1	9	9	9	9		1	3					
4	Payload Weight	5	3	9	9	9	9				1					
5	Cost of Production	3		3				1	9	1	9					
6	Separation Event	6	1	1	3	1		9	1		1					
7	Payload Volume	1		9	1		3			9						
8	Reusable	2		1	1	3		1	9	1	9					
	Technical Requirement Units		ft	in	mach	g's	Lbs	N/A	# of uses	in^3	lbs					
	Technical Requirement Targets		40000	6.25	2	12	10	Successful or not	5	282.7	45					
	Absolute Technical Importance		120	98	237	228	219	198	63	33	137					
	Relative Technical Importance		12.0	9.81	23.7	22.8	21.9	19.8	6.3	3.3	13.7					
			6	7	1	2	3	4	8	9	5					

Background and Benchmarking

Wildman Jr Kit:

- Pros:
  - Small diameter
  - **Low cost**
  - **Simple design**
- Cons:
  - No payload capability
  - **Doesn't meet our requirements**

Figure 1: Wildman two stage rocket kit [1]

Hyimpulse: Commercial launch provider

- Pros:
  - **Exceeds requirements**
  - Recoverable rocket and payload
- Cons:
  - **Expensive**
  - Requires large team and ground support equipment

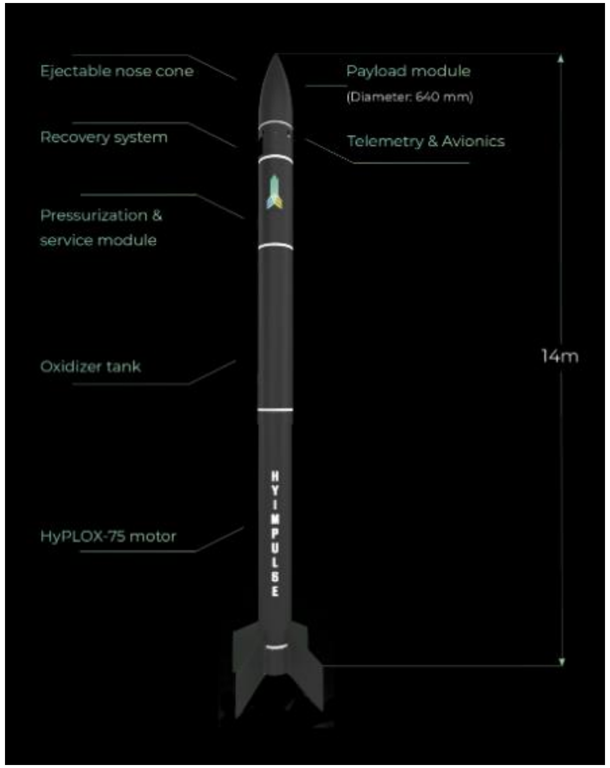
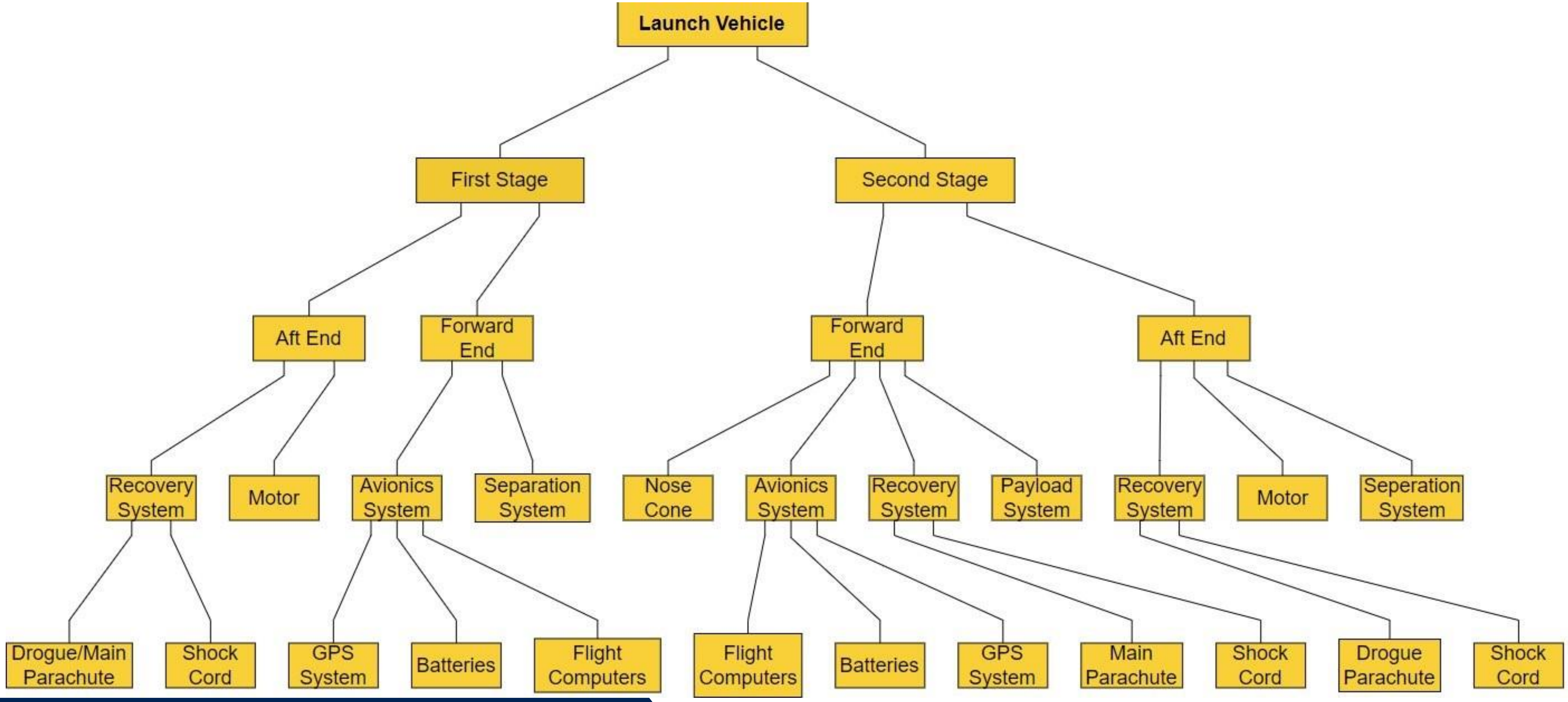
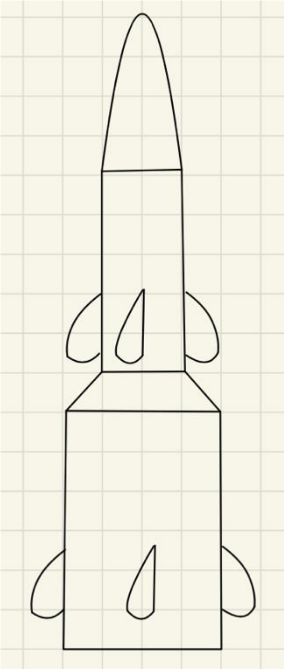
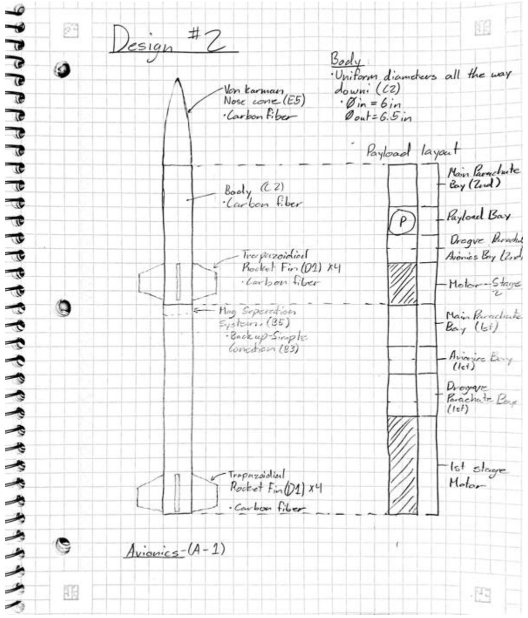
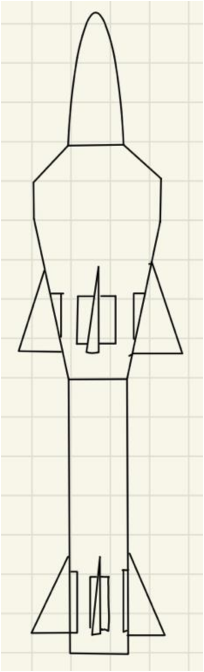
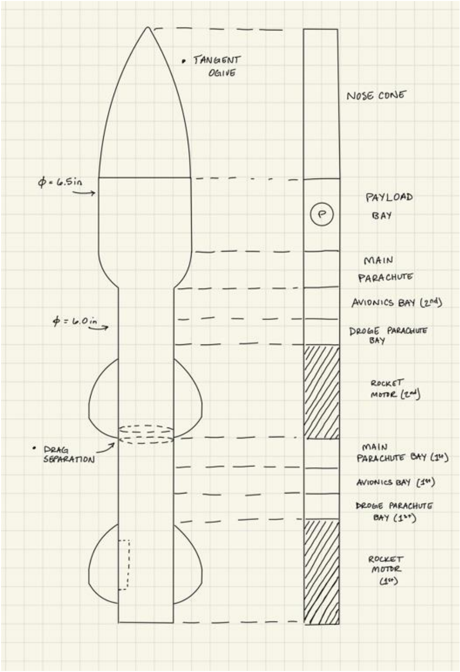
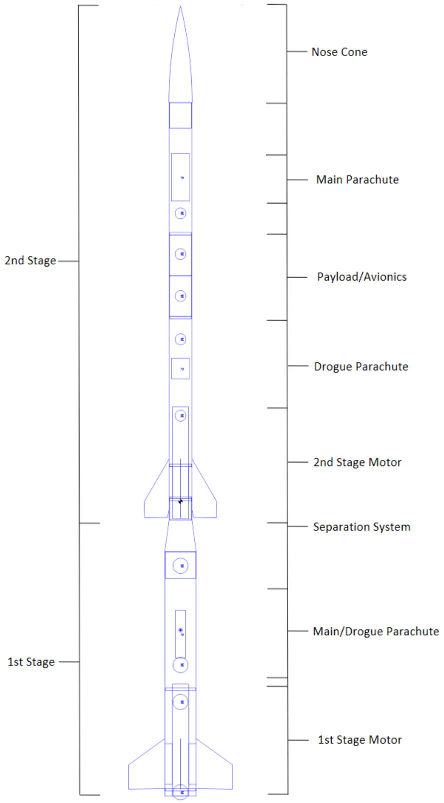
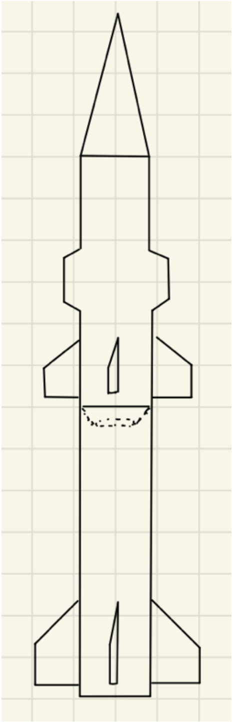


Figure 2: Hyimpulse sounding rocket [2]

Functional Decomposition



Designs Generated

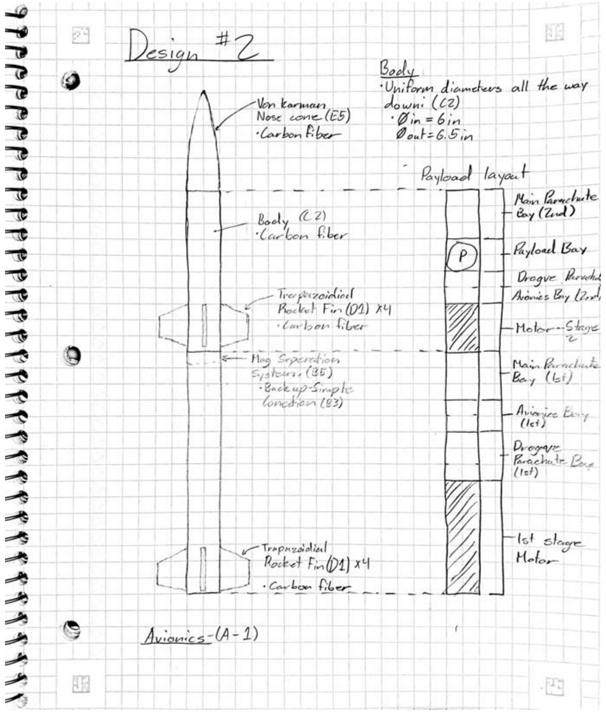
Design 1	Design 2	Design 3	Design 4	Design 5	Datum
					

Pugh Chart

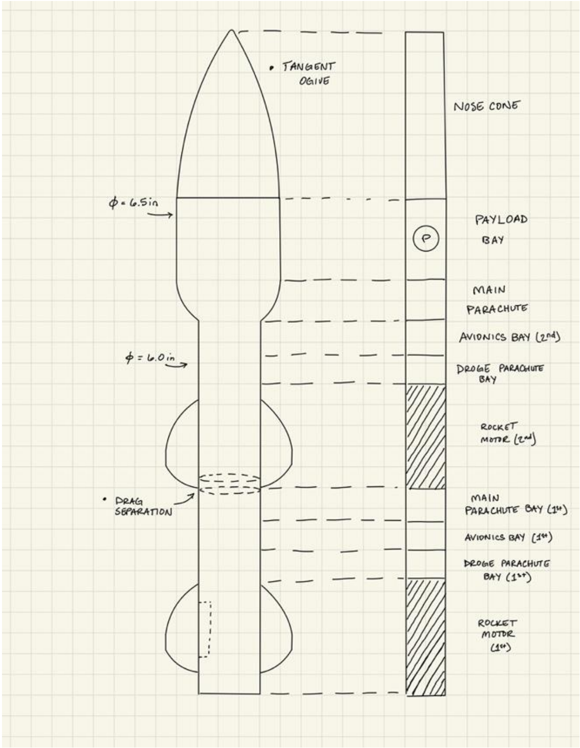
Concept Criteria	Design 1	Design 2	Design 3	Design 4	Design 5	Design 6
Max Velocity	- (wide body, more drag)	+ (aerodynamic)	- (high drag force)	S	S	datum
Separation Event	S	+	S	+	+	datum
Payload Capacity	-(unstable)	+(stable)	S	S	-	datum
Altitude	-	+(max velocity	-	S	S	datum
Lightweight	-(wide body)	+(less material)	-	S	-	datum
Cost of Production	-(more material)	+(less material)	-	S	-	datum
Reusable	S	S	S	S	S	datum
Payload Volume	-	-	+	S	-	datum
∑+	0	6	1	1	1	N/A
∑-	6	1	4	0	4	N/A
∑s	2	2	3	7	3	N/A

Pugh Chart Results

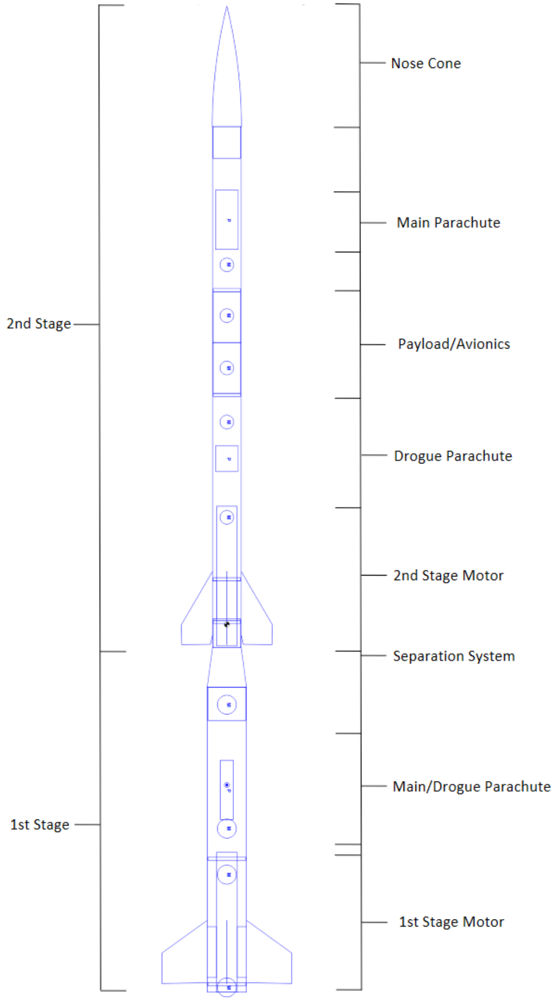
Design 2



Design 4



Design 5



Decision Matrix

Criterion	Weight	Design 2		Design 4		Design 5	
		Un-weighted score	Weighted score	Un-weighted score	Weighted score	Un-weighted score	Weighted score
Max Velocity	30%	100	30	90	27	95	28.5
Separation Event	0%						
Altitude	25%	100	25	90	22.5	95	23.75
Payload Weight							
Lightweight	15%	85	12.75	70	10.5	80	12
Cost of Production	15%	95	14.25	75	11.25	90	13.5
Reusable	10%	95	9.5	95	9.5	95	9.5
Payload Volume	5%						
Total	100%	Sum:	91.5	Sum:	80.75	Sum:	87.25

Final Design

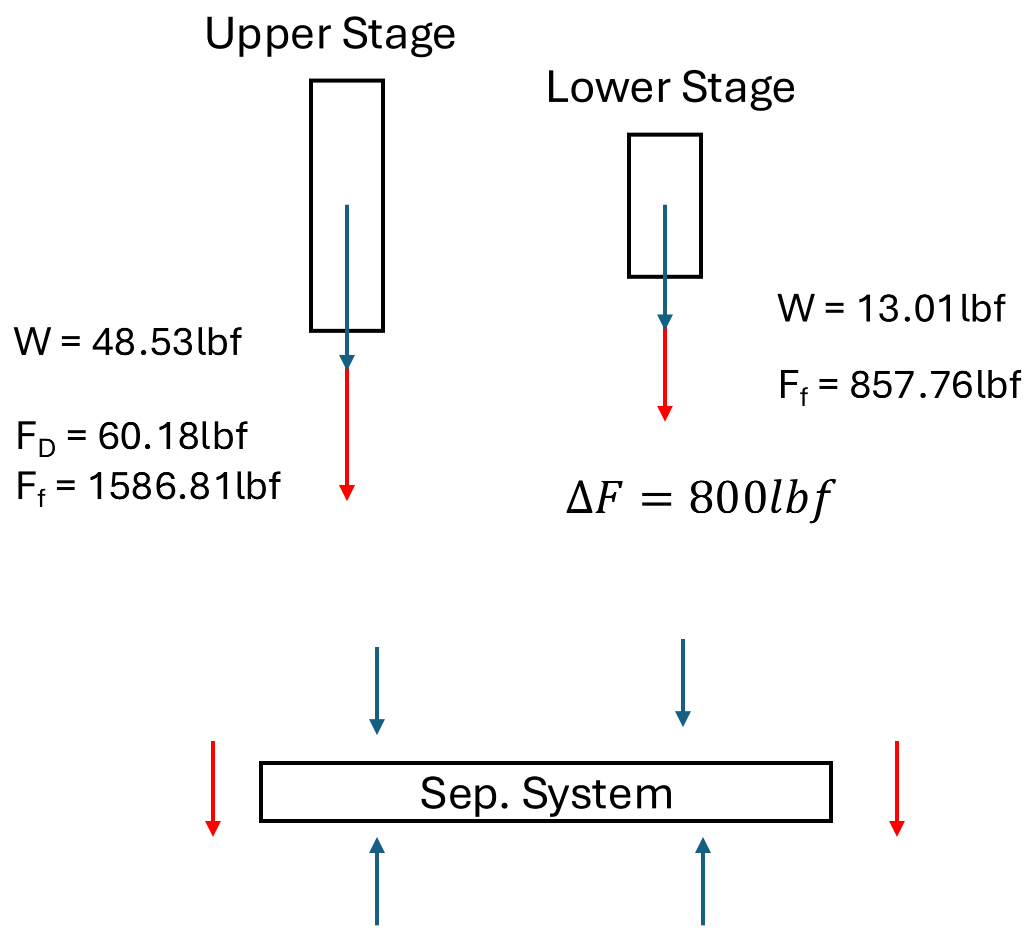
- Pros
  - Balanced weight distribution
  - Simple aerodynamic body
  - Simplified Avionics and Recovery systems
  - Easily manufacturable
  - Best performance

Engineering Calculations: Separation Sys.

- Conditions of Separation
  - Altitude = 9500 ft
  - Velocity = 430mph (630.67ft/s)

- Holding Strength:
  - 10.12lbf * 6 = 60.72lbf ≥ W_1 = 13.01lbf

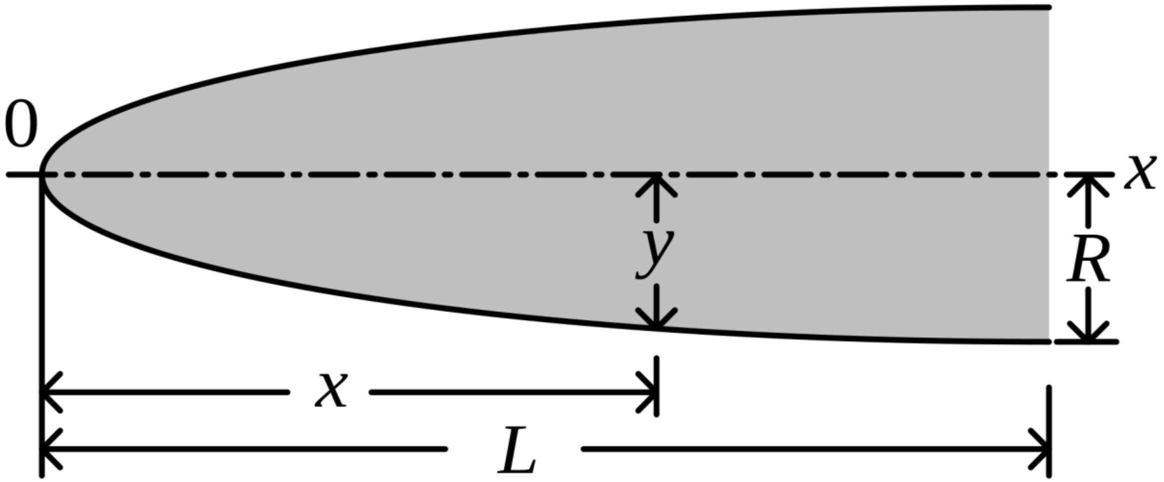
- Assisted Separation Strength:
  - F = -kx = -4.9lbf/in(-2.54in)→ 12.446lbf
  - Number of Springs (3) → 37.34lbf



Engineering Calculations: Nose Cone

Fineness Ratio

$$Fineness\ ratio = \frac{L}{D} = \frac{26}{6.25} = 4.16:1$$



Stagnation Temperature

$$T_{stag} = T_s\left(1 + \frac{\gamma - 1}{2} * Ma^2\right)$$

$T_s = 215K$
$\gamma = 1.4$
$\mathrm{Ma} = 2$

$T_{stag} = 387$ K

Typical cure temperatures for carbon fiber pre-pregs ~ 250 °F or 350 °F, therefore a resin system that is cured at 350 °F would be preferred

Engineering Calculations: Fin Drag

- Used the Drag Force formula:

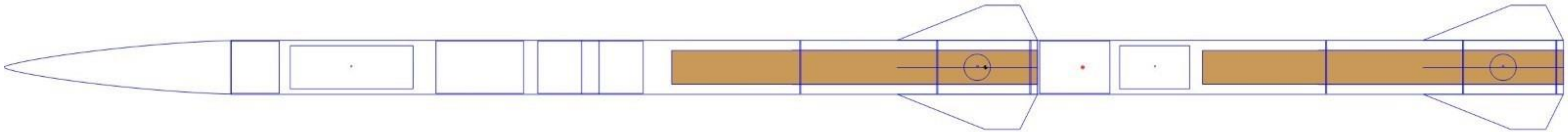
$$D = \frac{1}{2}\rho v^2 C_d A,$$

- Variables:
- C_d = 0.005
- V = Mach 2 = 1535 (mph) = 686 (m/s)
- A = 26 (in^2) = 0.103226 (m^2)
- *P* = 8.80349*10^-2 (kg/m^3) = 0.0880349 (kg/m^3)

- Answer:
- D = 10.7 N = 2.403 (lbf) (Individual fin)
- D_tot = 10.7 N * 8 = 85.53 (N) = 19.23 (lbf) (total of all fins)

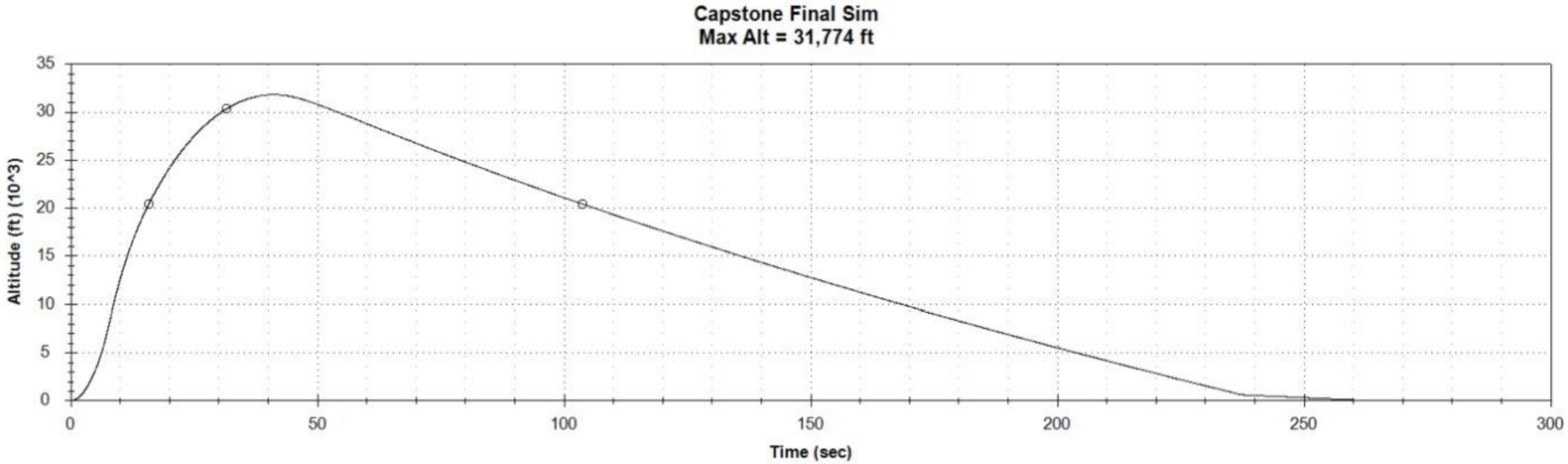
- Assumptions: Coefficient is of a flat plate at turbulent flow, the density of air is at an elevation of 20,000ft, the area used is the planform area. Some error due to compressiblility at Mach 2.

Engineering Calculations: Rocksim Simulations



Simulation	Results	Engines loaded	Max. altitude Feet	Max. velocity Miles / Hour	Max. acceleration Gees	Velocity at deployment Miles / Hour	Velocity at launch guide departure Miles / Hour	Time to apogee	Total flight time
32		[N4800T-0] [N1000W-P]	35160.11	1031.52	15.17	67.11	83.41	43.98	167.26
33		[N1000W-0] [N4800T-P]	37464.90	1736.92	24.68	37.46	45.75	51.42	126.51
34		[N1000W-0] [N4800T-P]	37074.15	1726.73	24.67	39.13	45.75	51.14	126.23
35		[N1000W-0] [N3300R-P]	33637.47	1453.03	16.54	35.58	48.00	49.17	120.88
36		[N1000W-0] [N3300R-P]	34243.44	1461.02	16.54	24.77	48.00	49.65	121.95
37		[N1000W-0] [N3300R-P-1]	34496.06	1456.19	16.62	34.18	48.00	50.50	122.87
38		[N1000W-0] [N4000-0]	35465.22	1566.36	16.94	49.42	43.40	51.70	121.52

Engineering Calculations: RASAero Simulations



Flight

Options Simulations

	Motor(s) Loaded	Max Alt (ft)	Max Vel (ft/sec)	Time to Apogee (sec)
▶	N3300 (AT) | N3300 (AT)	31,774	2,267.0	41.2

Predicted Performance

- Flight Altitude
  - 31,774 ft AGL
- Velocity
  - Mach 2.015
- Acceleration
  - 431.9 ft/s^2
- Flight Time
  - 256 Seconds

Failure Modes and Effective Analysis (FMEA)

Table 2: FMEA

Item #	Item	Failure	Root Cause	Likelihood 1 = least 5 = most	Severity 1 = least 5 = most	Precaution	Performance 1 = least 5 = most	Schedule 1 = least 5 = most	Cost 1 = least 5 = most
1.1	Separation System (Staging)	Fails to Separate, buckling, thermal,	Electrical Failure, Mechanical failure	3	5	Ground Testing before launch to certify system	1	3	3
1.2	Separation System (Structural)	Failure in flight of sep. system, impact, thermal	System detaches mid-flight/ aero forces exceed limits	2	4	Ensure system is secured before flight.	1	3	3
1.4	Body (Structural)	Body bending, cracks, deformities	Forces during flight/temperatur e	2	5	Visual/NDT inspections	2	2	3
1.5	Fins (Structural)	Bending, cracks, deformities	Material deformation, adhesive epoxy failure	2	5	Visual/ NDT inspections	2	2	3
1.6	Avionics	Flight computers do not set off energetics	Battery failure, electrical short, match failure	2	5	Ground testing with energetics	4	2	3

Gantt Chart (1st Semester)

TASK	ASSIGNED TO	PROGRESS	START	END
Stage 1	Team		1/22/24	2/5/24
Team Selection	Team	100%	1/22/24	1/22/24
Staff/Team Meeting 1	Team	100%	1/22/24	1/22/24
Client Meeting 1	Team	100%	1/26/24	1/26/24
Team Charter	Team	100%	1/22/24	1/26/24
Staff/Team Meeting 2	Team	100%	1/29/24	1/29/24
Client Meeting 2	Team	100%	1/30/24	1/30/24
Presentation 1	Team	100%	1/29/24	2/5/24
Stage 2	Team		1/29/24	2/5/24
Client Meeting 3	Team	100%	2/6/24	2/6/24
Staff/Team Meeting 3	Team	100%	2/12/24	2/12/24
Client Meeting 4	Team	100%	2/13/24	2/13/24
CG - Separation, Parachute	Avery	100%	2/12/24	2/18/24
CG - Nose Cone, Payload bay	Lindsey	100%	2/12/24	2/18/24
CG - Avionics, Motors	Austin	100%	2/12/24	2/18/24
CG - Body Design, Fin design	Koi	100%	2/12/24	2/18/24
Black Box Model / Functional Decomposition	Avery/Austin	100%	2/12/24	2/22/24
Engineering Calcuations - Moments	Avery	100%	2/19/24	2/25/24
Engineering Calcuations - Von Karman Ratio	Lindsey	100%	2/19/24	2/25/24
Engineering Calcuations - rocksim	Austin	100%	2/19/24	2/25/24
Engineering Calcuations -	Koi	100%	2/19/24	2/25/24
Concept Eval. - Decision Matix	Team	100%	2/20/24	2/21/24
Concept Eval. - Pugh Chart	Team	100%	2/20/24	2/21/24
Client Meeting 5	Team	100%	2/20/24	2/20/24
Staff/Team Meeting 4	Team	100%	2/19/24	2/19/24
CAD - Separation, Parachute	Avery	100%	2/18/24	2/25/24
CAD - Nose Cone, Payload bay	Lindsey	100%	2/18/24	2/25/24
CAD - Avionics, Motors	Austin	100%	2/18/24	2/25/24
CAD - Body Design, Fin design	Koi	100%	2/18/24	2/25/24
Budget	Lindsey	100%	2/19/24	2/25/24
Gantt Update	Koi	100%	2/24/24	2/25/24
Fundrasing	Lindsey	100%	2/19/24	2/25/24
BOM	Austin	100%	2/12/24	2/25/24
Sponsorship Proposal	Team	100%	2/12/24	3/15/24
Presentation 2	Team	100%	2/12/24	2/26/24

Gantt Chart (1st Semester) Cont.

TASK	ASSIGNED TO	PROGRESS	START	END
Stage 3				2/26/24
Website check - 1	Austin, Avery	100%	2/26/24	3/15/24
Background	Avery	100%	3/4/24	3/16/24
Requirements	Koi	100%	3/4/24	3/16/24
Lit Review Individual	Individual	100%	3/4/24	3/16/24
Mathematical Modeling	Individual	100%	3/4/24	3/16/24
Functional Decomposition	Austin	100%	3/4/24	3/16/24
Concept Generation	Individual	100%	3/4/24	3/16/24
Concept Selection and Selection Critera	Lindsey	100%	3/4/24	3/16/24
Benchmarking	Austin	100%	3/4/24	3/16/24
Report 1 - Total	Team	100%	3/4/24	3/16/24
Memo topic	Avery	100%	3/18/24	3/22/24
Memo topic	Austin	100%	3/18/24	3/22/24
Memo topic	lindsey	100%	3/18/24	3/22/24
Memo topic	Koi	100%	3/18/24	3/22/24
Analysis Memo - Total	Team	100%	3/18/24	3/22/24
Indepth CAD	Team	100%	3/25/24	3/30/24
InDepth Drawings	Team	100%	3/25/24	3/30/24
QFD Update	Koi	100%	3/25/24	3/30/24
FMEA	Team	100%	3/25/24	3/30/24
Design Validation	Team	100%	3/25/24	4/1/24
Schedule	Team	100%	3/29/24	4/1/24
Budget	Lindsey	100%	3/29/24	4/1/24
Prototype 1 Demo	Team	100%	3/25/24	4/1/24
Presentation 3	Team	100%	3/25/24	4/1/24
Stage 4				3/4/24
Prototype 1 Revision and Testing	Team	100%	4/1/24	4/26/24
Report 2	Team	100%	4/1/24	4/23/24
Final CAD and BOM	Team	100%	4/1/24	4/26/24
Prototype 2 Demo	Team	100%	4/5/24	4/29/24
Analysis Report	Individual	100%	4/1/24	5/1/24
Website Check 2	Team	100%	4/1/24	5/5/24

Gantt Chart (2nd Semester)

TASK	ASSIGNED TO	PROGRESS	START	END
Stage 1	Team		8/26/24	
Kickoff Meetings (team/staff) 1	Team	100%	8/29/24	8/29/24
HW 00	Individual	100%	8/29/24	8/29/24
Project Management Assignment	Team	100%	8/26/24	8/31/24
Sep. Sys. Rev 5 update	Avery, Austin,Koi	100%	8/29/24	9/3/24
Fin Canster Rev 2 update	Koi	100%	8/29/24	9/4/24
Team/Staff Meeting 2	Team	100%	9/5/24	9/5/24
Engineering Calculations Summary	Team	100%	9/4/24	9/11/24
Sep. Sys. Testing Pass/Fail	Koi, Austin	100%	9/9/24	9/13/24
Sep. Sys. Testing Plan Rough Draft	Koi	100%	9/13/24	9/16/24
Body Tube Rev 2 update	Koi, Lindsey	100%	9/14/24	9/17/24
BOM Update - 50%	Lindsey	100%	9/16/24	9/20/24
Sep. Sys. Rev 7 Drawing update	Avery, Koi	100%	9/16/24	9/18/24
Fin Canster Rev 2 Drawing update	Koi, Lindsey, or Avery	100%	9/16/24	9/18/24
Coupler Design Rev 2 update	Austin	100%	9/20/24	9/22/24
ANSYS Fluid Flow Model - Full Rocket	Koi	100%	9/12/24	9/15/24
Self Learning or Individual Analysis	Individual	100%	9/2/24	9/13/24
Team/Staff Meeting 3	Team	100%	9/12/24	9/12/24
Manufacturing Plan - Body Tubes	Avery, Lindsey	100%	9/14/24	9/16/24
Mandrel Parts Procurement	Austin	100%	9/13/24	9/16/24
Material Procurement - 50%	Lindsey, Avery	100%	9/16/24	9/21/24
Team/Staff Meeting 4	Team	100%	9/19/24	9/19/24
Mandrel Construction	Austin	100%	9/15/24	9/17/24
BOM Update - 100%	Avery, Lindsey	100%	9/23/24	9/27/24
Hardware Status Update - 33% Build	Team	100%	9/23/24	9/27/24
Peer Eval 1	Team	100%	9/23/24	9/27/24

Gantt Chart (2nd Semester) Cont.

TASK	ASSIGNED TO	PROGRESS	START	END
Stage 2				
Flight computer Procurement Check up	Austin, Lindsey, Avery	100%	9/23/24	10/4/24
Fin Canster material aquirement	Avery, Lindsey	100%	9/30/24	10/4/24
Motor assembly material Procurement	Avery, Lindsey, Austin	100%	9/30/24	10/4/24
Sep Sys material Procurement	Avery, Lindsey, Austin	100%	10/2/24	10/4/24
Team/Staff Meeting 5	Team	100%	9/26/24	9/26/24
Nose Cone Mold Procurment/Machine	Lindsey	100%	10/2/24	10/4/24
Sep. Sys. Test Plan - Final	Koi	100%	9/30/24	10/4/24
Flight Computer Order	Austin, Avery	100%	10/2/24	10/4/24
Fin Construction	Avery, Lindsey	100%	10/7/24	10/11/24
Body Tube Construction	Avery, Lindsey	100%	10/7/24	10/11/24
Nose Cone Construction	Lindsey	100%	10/7/24	10/11/24

Coupler carbon construction	Lindsey, Avery	100%	10/7/24	10/11/24
Team Staff Meeting 6	Team	100%	10/3/24	10/3/24
Coupler hardware Procurement	Team	100%	10/9/24	10/12/24
Sep Sys manufacture	Team/Perry	100%	10/7/24	10/17/24
Full Coupler Construction	Team	100%	10/7/24	10/17/24
Fin canster manufacture	Austin, Koi	100%	10/7/24	10/17/24
Website Check 1	Avery	100%	10/7/24	10/11/24
Hardware Status Update - 67% Build	Team	100%	10/14/24	10/17/24
Assembly hardware Procurement	Lindsey, Avery	100%	10/9/24	10/11/24
Parachute 1 Initial Procurement	Linsdey, Avery	100%	10/9/24	10/11/24
Parachute 2 Initial Procurement	Lindsey, Avery	100%	10/9/24	10/11/24
Launch Testing Plan	Team	100%	10/21/24	10/23/24

Gantt Chart (2nd Semester) Cont.

TASK	ASSIGNED TO	PROGRESS	START	END
Stage 3				
Team Staff Meeting 7	Team	100%	10/10/24	10/10/24
Assembly hardware Procurement Checkup	Lindsey, Avery	100%	10/21/24	10/23/24
Parachute 1 Procurement Checkup	Lindsey, Avery	100%	10/21/24	10/23/24
Parachute 2 Procurement Checkup	Lindsey, Avery	100%	10/21/24	10/23/24
UGRADS Registration	Team	100%	10/18/24	10/24/24
Peer Eval 2	Individual	100%	10/21/24	10/25/24
Team Staff Meeting 8	Team	100%	10/17/24	10/17/24
Booster Assembly	Team	100%	10/14/24	11/12/24
Main Rocket Assembly	Team	100%	10/14/24	11/12/24
Draft of Poster	Team	100%	10/18/24	10/31/24
Finalized Testing Plan	Team	100%	10/21/24	11/1/24
Hardware Status Update - 100% Build	Team	100%	11/1/24	11/12/24

Stage 4				
Team Staff Meeting 9	Team	100%	10/24/24	10/24/24
Peer Eval 3	Individual	100%	11/11/24	11/15/24
Final Poster and PPT	Team	20%	11/11/24	11/17/24
Initial Testing Results Video	Team	0%	11/11/24	11/21/24
Final CAD Packet	Team	0%	11/4/24	11/22/24
Product Demo and Testing Results in class	Team	0%	9/27/24	11/27/24
Final Report	Team	0%	11/18/24	12/3/24
Final Website Check	Team	0%	11/18/24	12/4/24
Final Product Demo	Team	0%	11/18/24	12/5/24
Operation/Assembly Manual	Team	0%	11/25/24	12/5/24
Expo PPT and Poster Presentation Delivery F	Team	0%	12/6/24	12/6/24
Practice Presentations	Team	0%	12/2/24	12/5/24
Peer Eval 4	Individual	0%	12/9/24	12/12/24
Client handoff	Team	0%	12/9/24	12/11/24
Secondary Launch Date (Emergency)	Team	0%	12/14/24	12/15/24

Bill of Materials (BOM)

SUBSYSTEM	ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	QTY.	PRICE ($)	TOTAL PRICE ($)	ACQUISITION METHOD	PRIMARY VENDOR
NOSECONE	1	1	Nose Cone Shell	Carbon Fiber	1	N/A	N/A	Manufacture	NovaKinetics
	2		Nose Cone Coupler	Carbon Fiber	1	N/A	N/A	Manufacture	NovaKinetics
	3		Nose Cone Bulkhead	6061 Aluminum	1	N/A	N/A	Manufacture	IMS
	4		eyebolt-type2_ai	Steel	1	N/A	N/A	Donated	NAU Rocket Club
	5		Metal Nose Cone Tip	Steel	1	N/A	N/A	Donated	NAU Rocket Club
	6	92949A347	Button Head Hex Drive Screw	18-8 SS	2	$3.79	$3.79	Order	McMaster Carr
BODY	7		2nd Stage Body Tube (50in. X 6.17in.)	Carbon Fiber	1	N/A	N/A	Manufacture	NovaKinetics
	8		Payload Body Tube	Carbon Fiber	1	N/A	N/A	Manufacture	NovaKinetics
	9		Lower Body Tube	Carbon Fiber	1	N/A	N/A	Manufacture	NovaKinetics
FIN CANISTERS	10		Aft End Centering Ring with Sep Brace	6061 Aluminum	2	N/A	N/A	Manufacture	IMS
	11		Centering Ring	6061 Aluminum	4	N/A	$88.65	Manufacture	IMS
	12		Fin Bracket	6062 Aluminum	6	N/A	N/A	Manufacture	IMS
	13		Corner Bracket	6063 Aluminum	24	N/A	N/A	Manufacture	IMS
	14	92095A196	M4 Button Head Hex Drive Screw	Passivated 18-8 Stainless Steel	36	$8.69	$17.38	Order	McMaster Carr
	15	91263A516	Hex Drive Flat Head Screw	Zinc-Plated Alloy Steel	26	$8.82	$17.64	Order	McMaster Carr
	16	94645A101	M4 Nylon Lock Nut	Zinc-Plated Steel	60	$14.05	$28.10	Order	McMaster Carr
	17	94645A210	M8 Nylon Lock Nut	Zinc-Plated Steel	6	$11.16	$11.16	Order	McMaster Carr
	18	91292A213	18-8 Stainless Steel	Stainless Steel	12	$7.94	$23.82	Order	McMaster Carr
	19	1556A65	Stainless Steel Bracket	Stainless Steel	18	$2.59	$2.59	Order	McMaster Carr
	20	97483A095	Aluminum Flush Mount Rivets	6061 Aluminum	32	$15.35	$15.35	Order	McMaster Carr
	21		Fin	Carbon Fiber	6	$340.21	$340.21	Order	Composite Envisions
	22		2nd Stage End Cap	6061 Aluminum	1	N/A	N/A	Manufacture	IMS

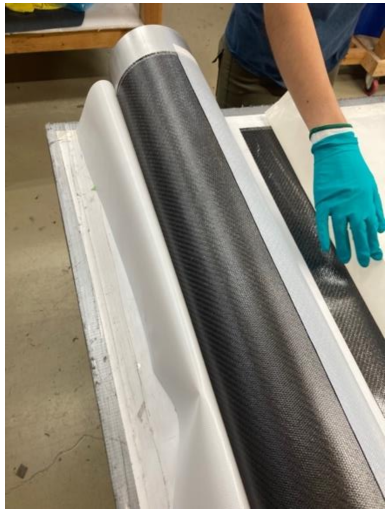
Bill of Materials (BOM)

AVIONICS	23		Avionics Coupler 2nd Stage	Steel	1	N/A	N/A	Manufacture	NAU Rocket Club
	24		Avionics Bulkhead	6061 Aluminum	2	N/A	N/A	Manufacture	NAU Rocket Club
	25		flat washer type a narrow_ai	6062 Aluminum	12	N/A	N/A	Donated	NAU Rocket Club
	26		eyebolt-type2_ai	Steel	2	N/A	N/A	Donated	NAU Rocket Club
	27		Avionics Sled (3D Printed)	3D Polymer	2	N/A	N/A	Manufacture	
	28		Raven 4 v9		4	N/A	N/A	Donated	NAU Rocket Club
	29		GPS Tracker v15		2	N/A	N/A	Donated	NAU Rocket Club
	30	92001A321	18-8 Stainless Steel Wing Nut	18-8 SS	8	N/A	N/A	Donated	NAU Rocket Club
	31	90322A657	High-Strength Steel Threaded Rod	Steel	4	N/A	N/A	Donated	NAU Rocket Club
	32		Switch Band	Carbon Fiber	1	N/A	N/A	Donated	NAU Rocket Club
	33		hex thick nut_ai	Steel	2	N/A	N/A	Donated	NAU Rocket Club
RECOVERY	34		Main Parachute	Nylon	1	N/A	N/A	Donated	NAU Rocket Club
	35		Drogue, Booster	Nylon	1	N/A	N/A	Donated	NAU Rocket Club
	36		Drogue, SS	Nylon	1	N/A	N/A	Donated	NAU Rocket Club
	37		Main parachute, Booster	Nylon	1	N/A	N/A	Donated	NAU Rocket Club
	38		Aerotech 98/15360 Motor casing	6061 Aluminum	2	N/A	N/A	Donated	NAU Rocket Club
	39		Aerotech N1000W	Propellant	1	$1,257.99	$1,257.99	Order	Aerotech
	40		Aerotech N3300R	Propellant	1	$1,153.99	$1,302.69	Order	Aerotech
	41		Shock Cord 8800lbs	Kevlar	2	N/A	N/A	Donated	NAU Rocket Club
	42		Tender Decender	6061 Aluminum	2	N/A	N/A	Donated	NAU Rocket Club
				Total Parts Needed	352			Total Parts Received	349
SEPERATION SYSTEM OMITTED DUE TO NDA BUT INCLUDED IN FINAL CALCULATIONS				Total Cost ($):		$3,314.18		Parts On Hand (%)	99.15%
				Total Spent			$3,503.30	Assembled (%)	95.00%

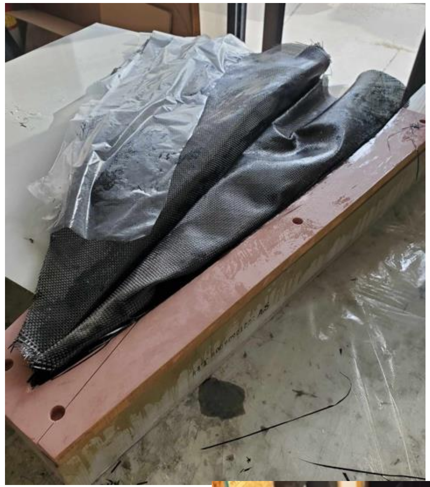
Budget

Funding/Expense	Description	Amount
Client Funding	Northrop Grumman	+$7,000
Fundraising	Donations, GoFundMe	+$938.78
First Semester Expenses	Prototype	-$191.05
Second Semester Expenses	Hardware, material, PPE, tools, motors	-$3,312.25
Future Expenses	Travel, +reimbursements	~$1,500
Total Remaining:		$1,864.52

Manufacturing Process

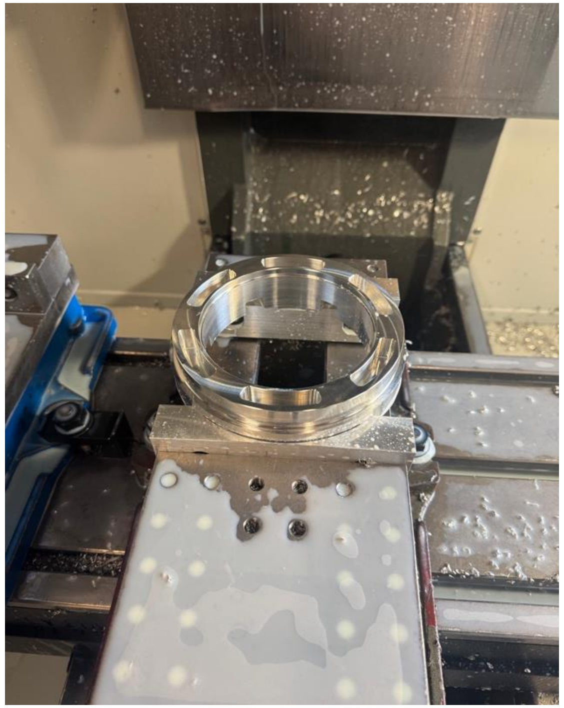


Manufacturing Process Cont.







Top Level Testing

Success Levels	Goals
Complete Mission Success	- Separation system works as expected, successful separation and second stage motor ignition. (CR1, CR2, ER2) - Payload safely delivered and landed. Data captured. (CR4, CR7, CR6, CR10, ER1, ER3, ER6) - Launch vehicle performance meets altitude goal. (CR5, CR6, CR9, ER2, ER3, ER4, CR3) - Launch vehicle recovered in reusable condition, no damage to vehicle at all. (CR3, CR5, CR8, CR10, ER6, ER5) - Recovery system performs as expected and designed. (CR1, CR2, CR10, ER2, ER6) - No anomalies (durastic angle change, bird strike, etc.) during full flight and payload mission until completed flight and recovery (All CRs and ERs)
Partial Mission Success	- Flight success (All CRs and ERs) - Velocity and altitude requirements met (CR4, CR6, CR7, CR9, ER1, ER3) - Payload flown but no data recorded. (CR5, ER4) - All components are recovered and reusable with minor damage. (CR1, CR3, CR10, ER4, ER6)
Partial Mission Failure	- Failure of payload or launch vehicle performance (All CRs and ERs) - Successful flight with failure of payload data recording or delivery (CR5, ER4) - Velocity or altitude requirement missed. (CR5, CR6, CR9, ER2, ER3, ER4, CR3) - Vehicle or payload systems damaged during flight or landing (CR1, CR3, CR10, ER4, ER6)
Complete Mission Failure	- Failure of both launch vehicle and payload systems (CRs and ERs) - Failure of recovery system deployment and beyond reasonable repair state (CRs and ERs) - Failure of vehicle before, during, or after flight (All CRs and ERs)

Detailed Testing Plan

Success Levels	Goals
Complete Mission Success	• Separation system works as expected, successful separation and second stage motor ignition. (CR1, CR2, ER2) • Payload safely delivered and landed. Data captured. (CR4, CR7, CR6, CR10, ER1, ER3, ER6) • Launch vehicle performance meets altitude goal. (CR5, CR6, CR9, ER2, ER3, ER4, CR3) • Launch vehicle recovered in reusable condition, no damage to vehicle at all. (CR3, CR5, CR8, CR10, ER6, ER5) • Recovery system performs as expected and designed. (CR1, CR2, CR10, ER2, ER6) • No anomalies (drastic angle change, bird strike, etc.) during full flight and payload mission until completed flight and recovery (All CRs and ERs)
Partial Mission Success	• Flight success (All CRs and ERs) • Velocity and altitude requirements met (CR4, CR6, CR7, CR9, ER1, ER3) • Payload flown but no data recorded. (CR5, ER4) • All components are recovered and reusable with minor damage. (CR1, CR3, CR10, ER4, ER6)
Partial Mission Failure	• Failure of payload or launch vehicle performance (All CRs and ERs) • Successful flight with failure of payload data recording or delivery (CR5, ER4) • Velocity or altitude requirement missed. (CR5, CR6, CR9, ER2, ER3, ER4, CR3) • Vehicle or payload systems damaged during flight or landing (CR1, CR3, CR10, ER4, ER6)
Complete Mission Failure	• Failure of both launch vehicle and payload systems (CRs and ERs) • Failure of recovery system deployment and beyond reasonable repair state (CRs and ERs) • Failure of vehicle before, during, or after flight (All CRs and ERs)

Procedures

Assembly prep at Launch site:

1. Set the Altimeter and GPS prior to putting the vehicle together completely.
2. Inspect all connections of the vehicle to ensure connections are secure. Should be done with the required tool.
3. Prep the propellant to be inserted into the motor casing.
4. Insert propellent into the motor casing into the main vehicle motor.
5. Insert propellent into the motor casing of the booster stage.
6. Depending on if the motor casing is not inserted into the rocket, insert motor casings into each stage of the vehicle. Securing the motor casing by screwing it in.
7. Ensure igniter is connected to the flight computer and the motor on both stages.
8. Ensure there is no play in the fin canister assembly
9. Connect both stages at the separation device connections.

Pre-flight setup

1. Assemble and secure the launch tower.
2. Ensure rail is secured to the launch tower.
3. Ensure rail connectors are secured tightly to the launch vehicle.
4. Connect the launch vehicle by the rail connectors to the launch tower.
5. Visually check to make sure the launch vehicle has no anomalies on the rocket body. All fins are connected securely.
6. The launch vehicle should be angled 90 degrees from the ground, aligning with azimuth.
7. The launch vehicle should be resting on the blast plate of the tower.

Procedures (Cont.)

Launch

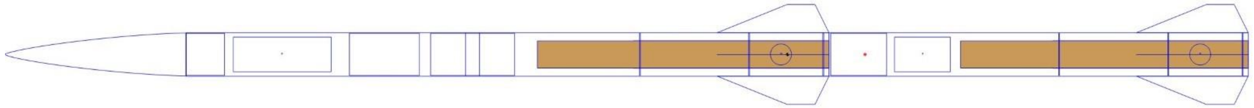
1. Turn on and connect to flight computers and GPS.
2. Last visual inspection of the launch vehicle.
3. Retreat to a minimum safe distance of 1,000 ft or 300m.
4. Before launch, check to see if vehicle is connected to device running the flight computers.
5. Last visual inspection of minimum safe distance red zone. Radius of 1,000 ft or 300m.
6. Last visual inspection of near by air space. If there is a visible entity within the air space wait to launch.
7. After all last check and visual inspection, launch vehicle is ready.

Launch Day!

Will updated with Launch Photo

Results/Goals

- The vehicle is expecting to reach 30,000ft AGL, reach Mach 2.0, and have a separation event. Along with return to the ground safely with not damage. The result should be successfully reached, both flight simulation software used show all flight goals being achieved and vehicle being recovered safely with no damage.



Simulation	Results	Engines loaded	Max. altitude Feet	Max. velocity Miles / Hour	Max. acceleration Gees	Velocity at deployment Miles / Hour	Velocity at launch guide departure Miles / Hour	Time to apogee	Total flight time
32		[N4800T-0] [N1000W-P]	35160.11	1031.52	15.17	67.11	83.41	43.98	167.26
33		[N1000W-0] [N4800T-P]	37464.90	1736.92	24.68	37.46	45.75	51.42	126.51
34		[N1000W-0] [N4800T-P]	37074.15	1726.73	24.67	39.13	45.75	51.14	126.23
35		[N1000W-0] [N3300R-P]	33637.47	1453.03	16.54	35.58	48.00	49.17	120.88
36		[N1000W-0] [N3300R-P]	34243.44	1461.02	16.54	24.77	48.00	49.65	121.95
37		[N1000W-0] [N3300R-P-1]	34496.06	1456.19	16.62	34.18	48.00	50.50	122.87
38		[N1000W-0] [N4000-0]	35465.22	1566.36	16.94	49.42	43.40	51.70	121.52

Flight

Options Simulations

	Motor(s) Loaded	Max Alt (ft)	Max Vel (ft/sec)	Time to Apogee (sec)		Optimum Wt (lb)	Max Alt (ft)	ViewData
▸	N1000W (AT) | N3300 (AT)	46,432	1,565.5	58.9	Optimize Wt	48.750	46,670	View Data
*								

Specification Sheet Preparations (CRs)

Customer Requirement	CR Met?	Client Acceptable
CR1 – Develop Launch Vehicle	Yes	Yes
CR2 – Separation System	No	Yes
CR3 – Composite Materials	Yes	Yes
CR4 – Altitude (40,000 ft.)	Yes	Yes
CR5 – Payload (10 lb.)	Yes	Yes
CR6 – Speed (Mach 2)	Yes	Yes
CR7 – Acceleration (12+ g's)	Yes	Yes
CR8 – Trajectory Simulation	Yes	Yes
CR9 -- Com. Motors	Yes	Yes
CR10 -- Recovery	Yes	Yes

Specification Sheet Preparations (ERs)

Engineering Requirements	Target	Tolerance	Measured/Calculated Value	ER Met?	Client Acceptable?
ER1 – Max Velocity	Mach 2 or 1500 mph	±100 mph or ± 0.1 Ma	Measured	Yes	Yes
ER2 – Separation Event	Successful or unsuccessful separation	N/A	Measured	Yes	Yes
ER3 – Altitude	40,000 ft AGL	±500 ft	Measured	Yes	Yes
ER4 – Payload Weight	10 lbs	± 0.5 lbs.	Measured	Yes	Yes
ER5 – Cost of production	$7,000 USD	N/A	Measured	Yes	Yes
ER6 – Reuseable	>1	N/A	Measured/Calculated	Yes	Yes
ER7 – Payload Volume	282.7 in^3	±50 in^2	Measured	Yes	Yes

Future Works

- Future Launches with Updated Payloads
- Higher Impulse Motors for Different Flight Profiles
- Implement Different Separation Systems
- Test Active Aero Control Systems
- Design Composite Filament Winder for Tube Construction
- Simplify Fin Canister Hardware

Literature Review (Avery)

Literature Review: Staging

- Books:
  - J. D. Anderson, *Fundamentals of Aerodynamics*, 6th ed. New York, NY: McGraw-Hill Education, 2017.
  - Chandler Karp, A., & Jens, E. T. (2024). *Hybrid Rocket Propulsion Design Handbook* (First edition.). Academic Press. Chapter 10 p 232
  - D. P. MISHRA, *Fundamentals of Rocket Propulsion*. Boca Raton, FL: CRC PRESS, 2020.
- Articles:
  - L. Zhu, J. Song, B. Hu, and Z. Xu, "Numerical Investigation on the Interaction between Rocket Jet and Supersonic Inflow," *Journal of Physics: Conference Series*, vol. 2460, no. 1, p. 012066, Apr. 2023. doi:10.1088/1742-6596/2460/1/012066
  - O. Eryilmaz and E. Sancak, "Effect of Silane Coupling Treatments on Mechanical Properties of Epoxy Based High-Strength Carbon Fiber Regular (2 x 2) Braided Fabric Composites," *Polymer Composites*, vol. 42, no. 12, pp. 6233–6954, Dec. 2021. doi:https://doi.org/10.1002/pc.26311
- Website:
  - R. Nakka, "Fins for Rocket Stability," Richard Nakka's Experimental Rocketry Site, http://www.nakka-rocketry.net/fins.html (accessed Feb. 5, 2024).

Literature Review (Austin)

Literature Review: Rocket Design

Books:

- *Rocket Propulsion*. Laxmi Publications Pvt Ltd, 2016.
  - Basic rocket design textbook, goes into fundamentals of rocket science
- F. R. (Feliks R. Gantmakher, L. M. Levin, and E. T. J. Davies, *The flight of uncontrolled rockets*. Oxford, England: Pergamon Press, 1964.
  - Trajectory textbook for uncontrolled flight, will be useful in simulating vehicle in our Matlab code.

Articles:

- G. Srinivas and M. V. S. Prakash, "Aerodynamics and flow characterisation of multistage rockets," *IOP conference series. Materials Science and Engineering*, vol. 197, no. 1, pp. 12077-, 2017, doi: 10.1088/1757-899X/197/1/012077.
  - Covers aerodynamics on two-stage launch vehicle configurations
- A. Okninski, "Multidisciplinary optimisation of single-stage sounding rockets using solid propulsion," *Aerospace science and technology*, vol. 71, pp. 412–419, 2017, doi: 10.1016/j.ast.2017.09.039.
  - Can be used to optimize the second stage to get maximum performance

Dissertations:

- Z. Doucet, "Multistage 2-DOF Rocket Trajectory Simulation Program for Freshmen Level Engineering Students," ProQuest Dissertations Publishing, 2019.
  - Reference for trajectory simulation in our matlab code requirement

Websites:

- "Glenn Research Center," NASA, https://www1.grc.nasa.gov/ (accessed Feb. 4, 2024).
  - Overall source for fundamental rocketry

Literature Review (Koi)

Literature Review: Aerodynamics and rocket design

- Books:
  - W. H. Dorrance, *Viscous hypersonic flow : theory of reacting and hypersonic boundary layers*. Mineola, New York: Dover Publications, Inc, 2017.
    - This book has equations and information on how to try and calculate for hypersonic aerodynamics. Focuses on drag and friction of the rocket.
  - Sutton, *Rocket Propulsion Elements*. John Wiley & Sons, 2001.
    - This book is fundamental information on how to calculate rocket motor propulsion. Along with rocket fundamentals.
- Articles:
  - A. Iyer and A. Pant, “A REVIEW ON NOSE CONE DESIGNS FOR DIFFERENT FLIGHT REGIMES,” *International Research Journal of Engineering and Technology (IRJET)*, vol. 07, no. 08, pp. 3546–3554, Aug. 2020, Available: https://www.irjet.net/archives/V7/i8/IRJET-V7I8605.pdf
    - Information and guidance on which designs of nose cones affect supersonic flight. Along with design benefits and disadvantages of each design with calculations.
  - A. Mishra, K. Gandhi, K. Sharma, N. Sumanth, and Y. Krishna. Teja, “CONCEPTUAL DESIGN AND ANALYSIS OF TWO STAGE SOUNDING ROCKET,” *International Journal of Universal Science and Engineering*, vol. 07, pp. 53–73, Aug. 2021.
    - Information on general two stage rocket design and analysis. Used to understand how to fundamentally build two stage rockets.
  - P. Davies *et al.*, “Preliminary design and test of high altitude two-stage rockets in New Zealand,” *Aerospace Science and Technology*, vol. 128, pp. 107741–107741, Sep. 2022, doi: https://doi.org/10.1016/j.ast.2022.107741.
    - Information on how to design a high altitude two stage rocket. In depth procedures and calculations.
  - P. Żurawka, N. Sahbon, D. Pytlak, M. Sochacki, A. Puchalski and S. Murpani, "Multi-objective optimization of a fin shape for a passive supersonic rocket stage," *2023 IEEE Aerospace Conference*, Big Sky, MT, USA, 2023, pp. 1-12, doi: 10.1109/AERO55745.2023.10115859.
    - Information on how to design rocket fins. Rocket some information on rocket fin design for supersonic applications.

Literature Review (Lindsey)

Literature Review: Nose Cone Design

- Books/Chapters:
  - A Kanni Raj, "A - C F D - Applied Computational Fluid Dynamic Analysis of Thermal and Fluid Flow Over Space Shuttle Or Rocket Nose Cone". Createspace Independent Publishing Platform, 2016.
    - Analyses thermal and fluid flow over a rocket nose cone to assess what kind of nose cone would be better able to withstand high temperatures that are generated from aerodynamic heating.
  - Eugen Sänger, "Rocket Flight Engineering". 1965.
    - Discusses all components of rocketry, some chapters focusing on nose cone design best for supersonic flight.
- Papers:
  - B. Mathew, O. Bandyo, A. Tomar, A. Kumar, A. Ahuja, and K. Patil, “A review on computational drag analysis of rocket nose cone.” Available: https://ceur-ws.org/Vol-2875/PAPER_11.pdf
    - Identifies various nosecone shapes and their characteristics at different Mach numbers to determine best used for minimizing drag and heat generation.
  - Airesearc, E. Perkins, L. Jorgensen, and S. Sommer, “NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS INVESTIGATION OF THE DRAG OF VARIOUS AXIALLY SYMMETRIC NOSE SHAPES OF FINENESS RATIO 3 FOR MACH NUMBERS FROM 1.24 TO 7.4.” Available: https://ntrs.nasa.gov/api/citations/19930091022/downloads/19930091022.pdf
    - Determine best nose cone shapes for various Mach numbers with a fineness ratio of 3.
  - M. Ajuwon et al., “Optimization Design of Rocket Nosecone for Achieving Desired Apogee by Empirical Research and Simulation-Based Comparison.” Available: http://ieworldconference.org/content/SISE2020/Papers/Ajuwon.pdf
    - Determine best nose cone shapes for various Mach numbers with a fineness ratio of 3.
- Online Resources:
  - “Richard Nakka’s Experimental Rocketry Site,” www.nakka-rocketry.net. https://www.nakka-rocketry.net/RD_nosecone.html.
    - An overview of nose cone components and terms for better understand of design.

Conclusion

Thank you!

Questions?

THANK YOU

FOR MORE INFORMATION

SCAN ME