Designing and Flying an Experimental Sounding Rocket

TEAM 24
ALEX MIRE
TARIQ GRANT
WILLIAM POHLE
BRANDON GUSTO

10/13/2016
SPONSOR: FAMU-FSU
COLLEGE OF ENGINEERING
ADVISOR: DR. RAJAN KUMAR

Problem Statement & Scope

Design and construct a rocket capable of carrying an experimental payload to be launched and safely recovered within the parameters of the 2017 Intercollegiate Rocket Engineering Competition hosted by the Experimental Sounding Rocket Association.

Figure 1: 2015-2016 Intercollegiate Rocket Engineering Competition [1]

Goals

- Successfully design, build and fly a single stage rocket
- Reach an apogee of 10,000 ft AGL
- Deploy a scientifically useful payload
- Safely recover all rocket components
- Win the competition

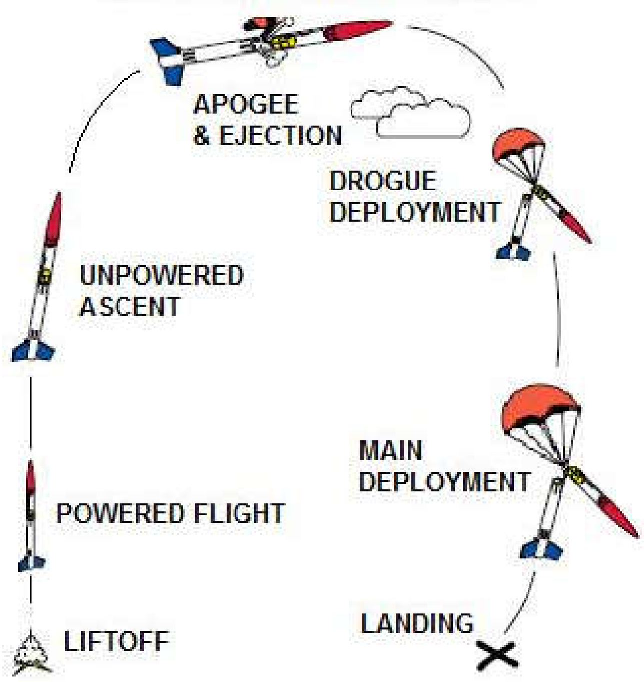


Figure 2: General Flight Profile[2]

Objectives

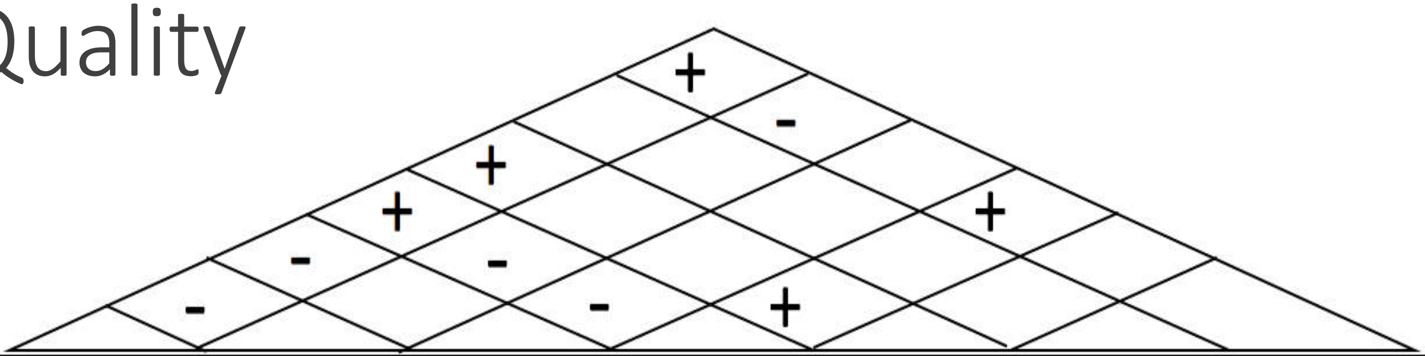
1. Conduct Background Research
2. Develop Engineering Characteristics
3. **Conceptual Design**
4. Detailed Design
5. Scale Prototype
6. Full Size Prototype
7. Flight Testing
8. Final Design
9. Compete

Figure 3: Conducting Background Research

Vehicle & Payload Constraints

- Payload must weigh 8.8 lb. minimum
- Vehicle & payload must be recoverable
- Must have an altimeter and flight controller
- Single stage only
- Non-toxic propellant
- No hazardous or live material

House of Quality



Customer Requirements	Customer Importance	Stability	Rocket Weight	Total Impulse	Reliability	Scientific Value	Material Strength	Avionics
Accurate	7	8		10		7		9
Lightweight	1	6	10				4	4
Recoverable	8	10	7		9	9	7	8
Safe	10	9	3	6	10		8	9

Score	232	96	130	172	121	140	221
Relative Weight	0.209	0.086	0.117	0.155	0.109	0.126	0.199
Rank	1	7	5	3	6	4	2

Most Important Factors: Stability Reliability Avionics

Rocket Subsystems

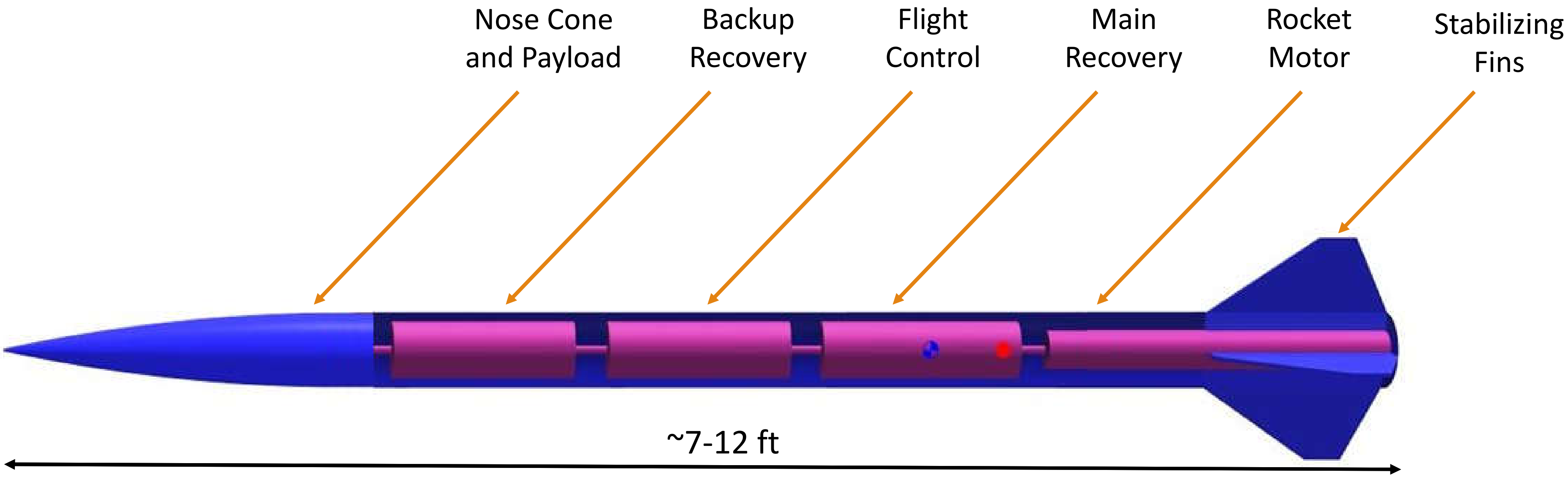


Figure 4: Rocket Subsystems [3]

Flight Model & Simulation

What the model includes

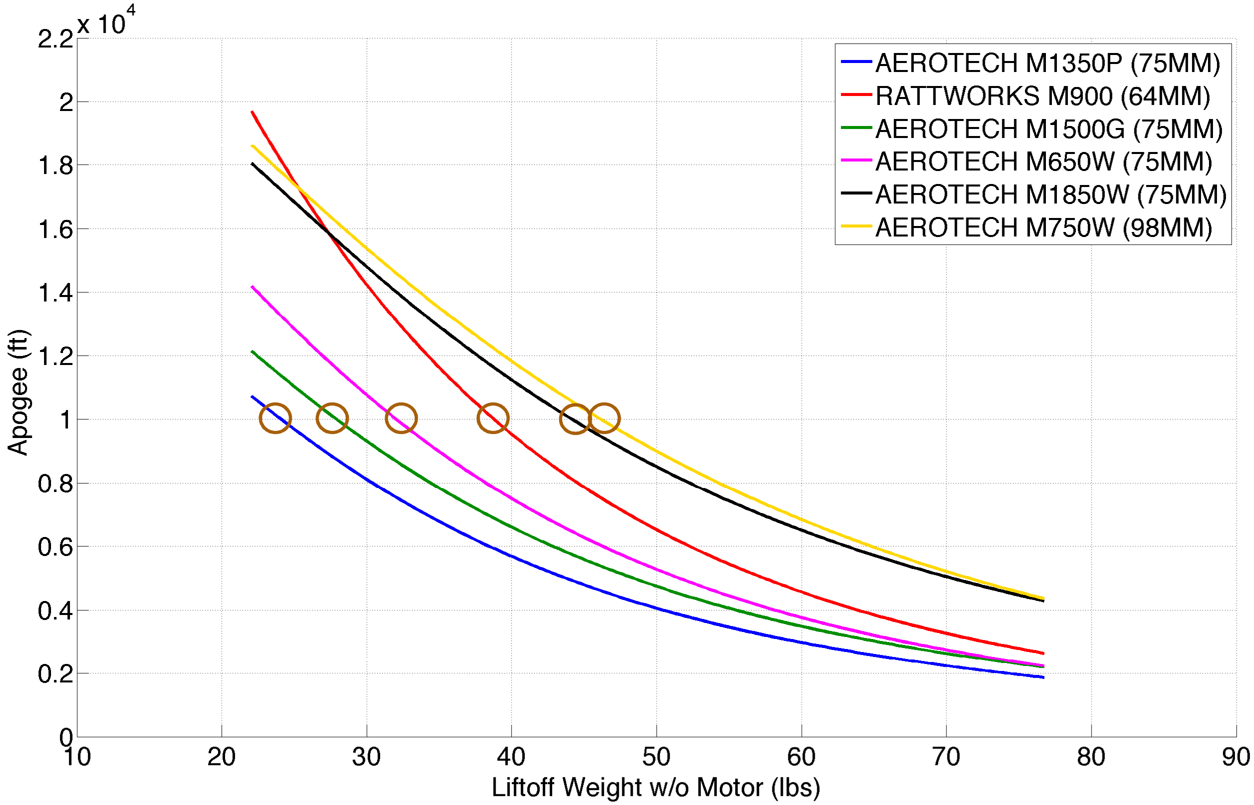
- Form drag
- Skin friction drag
- Variable atmospheric pressure
- Variable thrust
- Variable vehicle mass

What it doesn’t

- Complex geometry
- Lift induced drag
- Compressibility effects
- Vehicle rotation or instability
- Nonlinear propellant burn rate

The model shows that of any single subsystem, the propulsion element has the greatest impact on overall system performance

Motor Performance Comparison [4-5]



To reach our target altitude:

M1350P ~ 23 lbs. vehicle weight

M1500G ~ 27 lbs. vehicle weight

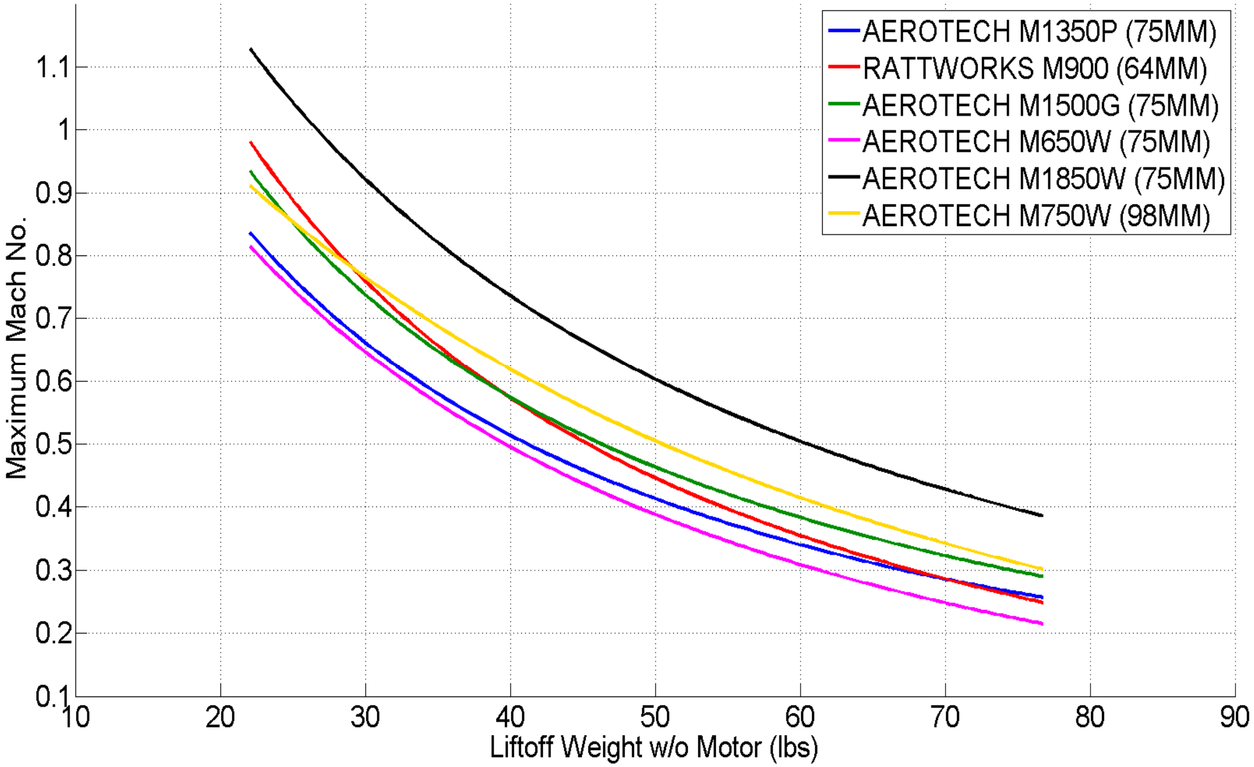
M650W ~ 32 lbs. vehicle weight

M900 ~ 38 lbs. vehicle weight

M1850W ~ 44 lbs. vehicle weight

M750W ~ 46 lbs. vehicle weight

Mach Regime Comparison[4-5]



Expected Mach number:

M1350P ~ 0.8 at 23 lbs.

M1500G ~ 0.8 at 27 lbs.

M650W ~ 0.6-0.7 at 32 lbs.

M900 ~ 0.6 at 38 lbs.

M1850W ~ 0.6-0.7 at 44 lbs.

M750W ~ 0.5-0.6 at 46 lbs.

Nose Cone Shape Optimization

- Cone shape has an influence over the drag experienced by the rocket.
- Ideal Cone shape varies based upon the speed of the rocket
  - If subsonic a more domed shape is preferred.
  - If supersonic a more coned shape is preferred.
- For our expected velocity, a cone with $x^{\frac{1}{2}}$ profile would be desired

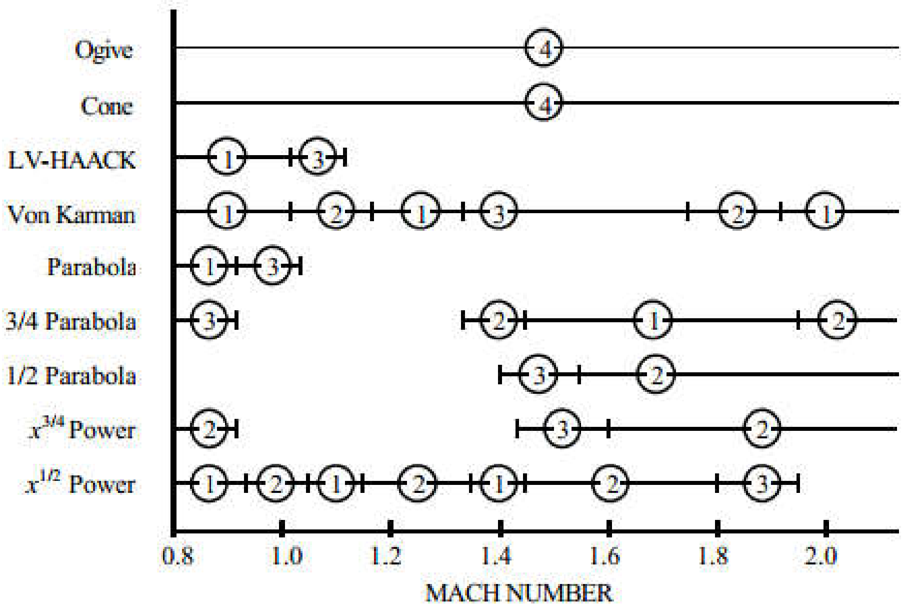


Figure 5: Drag characteristics of various nose shapes in the transonic-to-low Mach regions [6]

Nose Cone Shape Optimization — $X^{\frac{1}{2}}$

- To create this profile, a plot is made by graphing the following equation and revolving it around the x axis.

$$Y = Radius\ of\ tube\left(\frac{x}{Length\ \ of\ nose\ cone}\right)^{0.5}$$

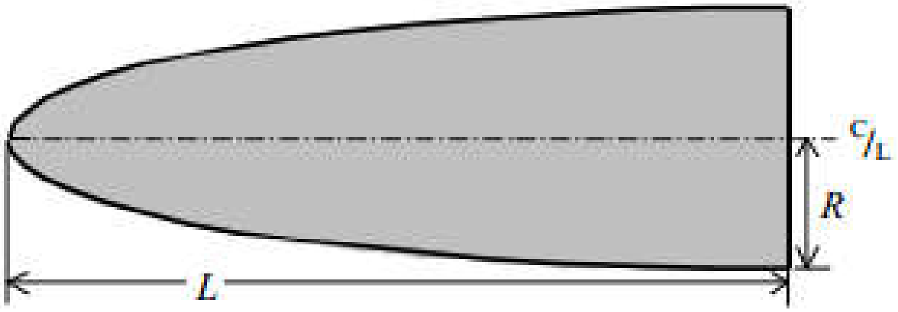


Figure 6: Nose Profile Optimization Curve [7]

Nose Cone Shape Optimization — Length

- To determine appropriate length of the nose cone the fineness ratio must be considered.

$$Fineness = \frac{Lengt}{Base\ Diameter}$$

- As Velocity increases, the fineness ratio of the nose cone affects wave drag
- Higher Fineness ratios cause more surface friction drag.

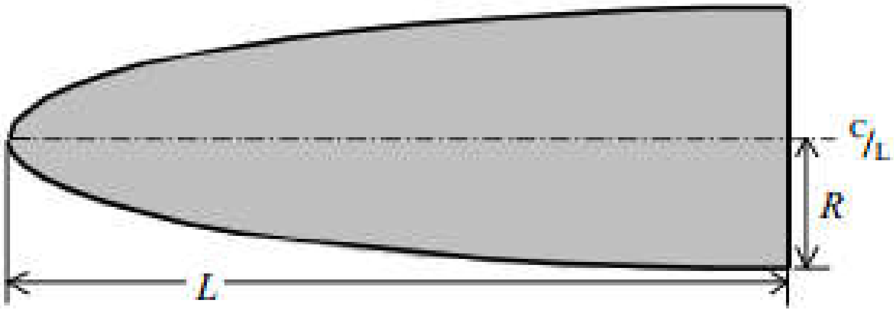


Figure 6: Nose Profile Optimization Curve [7]

Material Selection for Rocket Body

CARBON FIBER

- High Strength
- High Price
- Rough Surface
- Light Weight

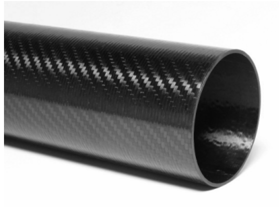


Figure 7: Carbon Fiber [8]

PLASTIC

- Low Strength
- Low Price
- Smooth Surface
- Light Weight

Figure 8: Plastic [9]

FIBERGLASS

- Medium Strength
- Low Price
- Rough Surface
- Light Weight

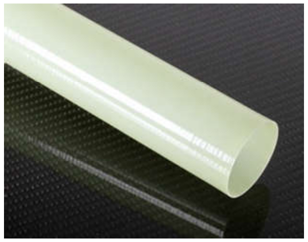


Figure 9: Fiberglass [10]

ALUMINUM

- High Strength
- High Price
- Smooth Surface
- High Weight

Figure 10: Aluminum [11]

Stabilization

FIXED FINS

- Simple
- Cheap
- 3 fins
- Light Weight

STEERABLE FINS

- Complex
- 3 fins
- Requires actuators
- Heavier than fixed

THRUST VECTORING

- Complex
- Expensive
- Long Development
- Reduced drag
- Accurate flight trajectory

SPIN STABILIZATION

- 3 angled fins
- cheap
- Could affect payload
- Could affect recovery

Recovery

DUAL DEPLOYMENT

Apogee

Drogue parachute deployment

Main Parachute deployment

Landing

Figure 11: Dual Deployment [12]

REEFED PARACHUTE

Apogee

Main parachute opens partially

Ripcord unreefs main parachute

Landing

Figure 12: Reefed Parachute [13]

STEERABLE PARAFOIL

Apogee

Drogue parachute deployment

Parafoil is released

Landing

Figure 13: Steerable Parafoil [14]

Recovery Concept Selection

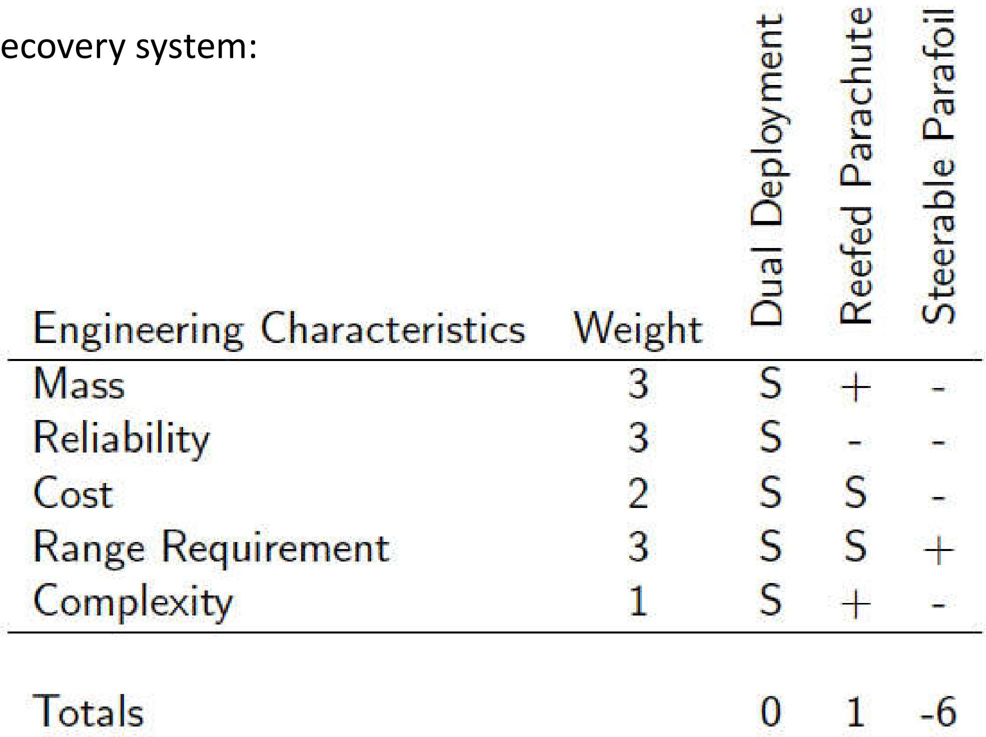
A Pugh Selection Matrix is used to determine the optimal recovery system:

Primary Recovery System

- Reefed Parachute

Secondary Recovery System

- Dual Deployment



Engineering Characteristics	Weight	Dual Deployment	Reefed Parachute	Steerable Parafoil
Mass	3	S	+	-
Reliability	3	S	-	-
Cost	2	S	S	-
Range Requirement	3	S	S	+
Complexity	1	S	+	-
Totals		0	1	-6

Figure 14: Recovery System Pugh Selection Matrix

Recovery System Deployment

Compressed CO_2

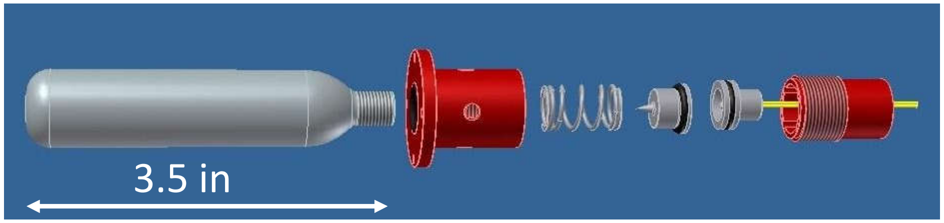


Figure 15: CO_2 Recovery System [15]

Black Powder Gas Generator

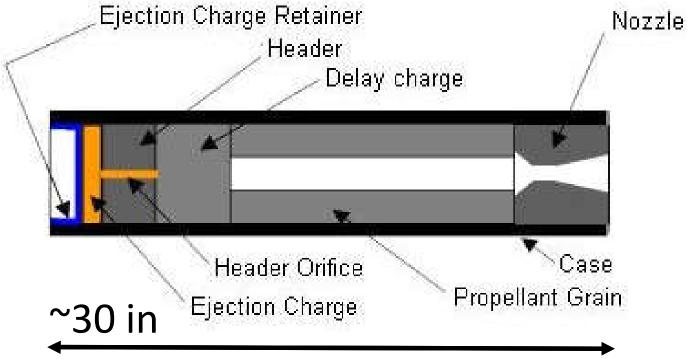


Figure 16: Black Powder Recovery System [16]

Avionics

• Flight Computer	• Altimeter	• Batteries

Flight Computer				
Criterion (Weight)	Ease of Use (3)	Cost (5)	Versatility (4)	Total
Purchased	5	3	2	38
Self-Programmed	3	5	5	54

Altimeter Decision Matrix					
Criterion (Weight)	Weight (1)	Ease of Use (4)	Accuracy (5)	Cost (2)	Total
Barometric Sensor	5	5	3	5	50
Accelerometer	4	4	2	3	36
Combined	3	3	5	2	44

Battery Decision Matrix						
Criterion (Weight)	Weight (4)	Dimensions (3)	Charge/Discharge (2)	Safety (5)	Cost (2)	Total
Lithium Polymer	5	5	5	3	4	68
Nickel-Metal Hydride	4	4	3	5	4	67
Nickel-Cadmium	4	4	4	4	5	66

Morphological Chart

Component	Option 1	Option 2	Option 3	Option 4
Nose Cone	$x^{\frac{1}{2}}$ Profile			
Material	Carbon Fiber	Fiberglass	Plastic	Aluminum
Stabilization	Fixed Fins	Steerable Fins	Thrust Vectoring	Spin Stabilization
Recovery System	Dual Deployment	Reefed Deployment	Steerable Parafoil	
Recovery Deployment	Compressed CO_2	Black Powder		
Flight Computer	Purchased	Self-made		
Altimeter	Barometer	Accelerometer		

Risk Assessment & Safety

Modes of Failure

- Errant Rocket Trajectory
- Motor Rupture
- Recovery Failure

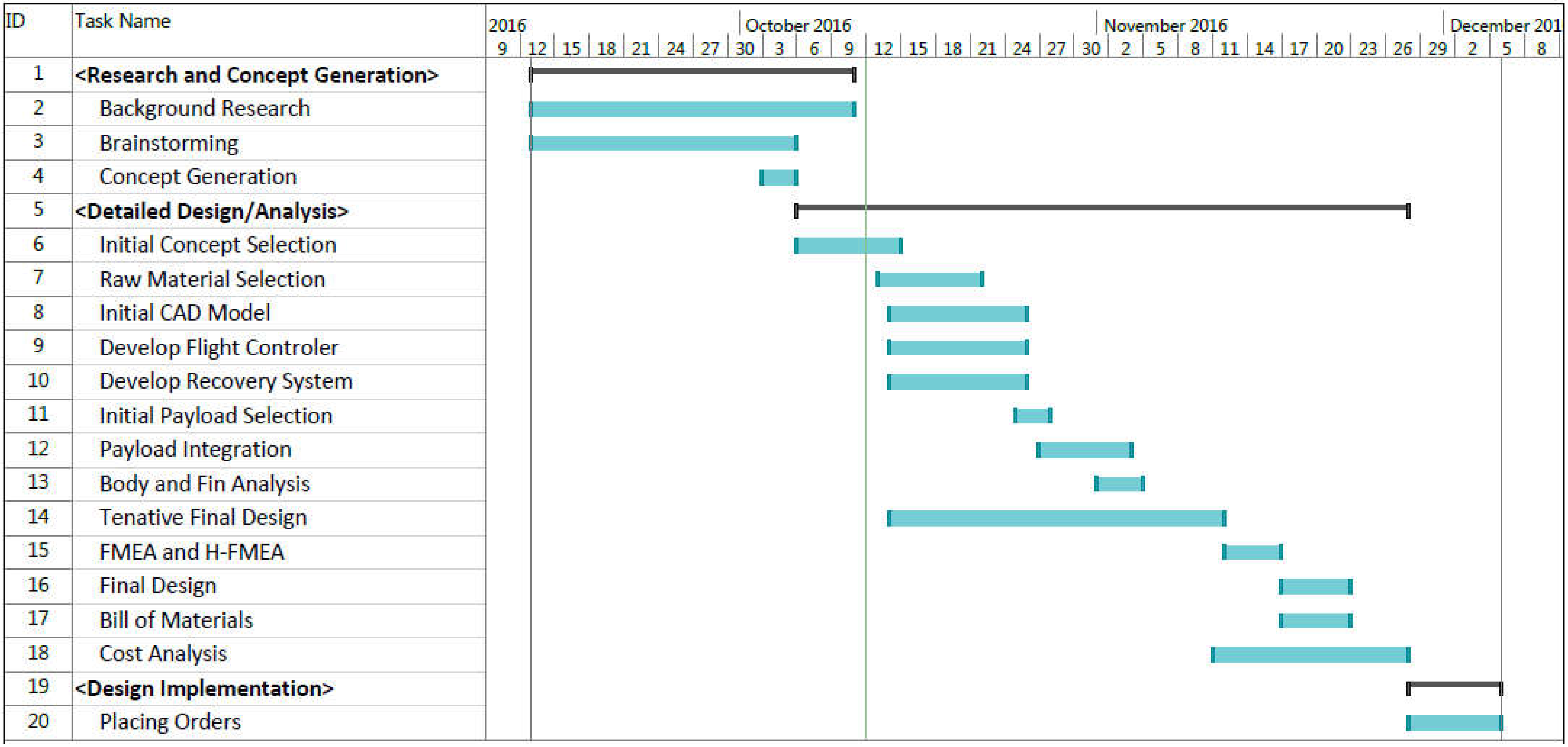
Potential Damage

- Personal Injury
- Vehicle Loss
- Payload Loss

Mitigation Strategy

- Safety Distance
- Redundant Recovery System
- Safety Protocol Review

Gantt Chart



ID	Task Name
1	**<Research and Concept Generation>**
2	Background Research
3	Brainstorming
4	Concept Generation
5	**<Detailed Design/Analysis>**
6	Initial Concept Selection
7	Raw Material Selection
8	Initial CAD Model
9	Develop Flight Controler
10	Develop Recovery System
11	Initial Payload Selection
12	Payload Integration
13	Body and Fin Analysis
14	Tenative Final Design
15	FMEA and H-FMEA
16	Final Design
17	Bill of Materials
18	Cost Analysis
19	**<Design Implementation>**
20	Placing Orders

References

- [1] "ESRA - Latest News," in *Sounding Rocket*, 2016. [Online]. Available: http://www.soundingrocket.org/latest-news. Accessed: Oct. 10, 2016.
- [2] “Albuquerque Rocket Society”. [Online].*Information for the New Rocket Hobbyist*. Availablehttp://www.arsabq.org/images/Flight_Sequence.jpg October 10, 2016 [date accessed].
- [3] Spaceforest.pl, “Demonstrator Rocket,” *SpaceForest / Demonstrator rocket*. [Online]. Available: http://spaceforest.pl/demonstrator-rocket. [Accessed: 13-Oct-2016].
- [4] J. C. (john@jcsw.com), “ThrustCurve Home,” *ThrustCurve Hobby Rocket Motor Data*. [Online]. Available: http://www.thrustcurve.org/. [Accessed: 12-Oct-2016].
- [5] “BuyRocketMotors.com,” *The Fastest and Most Reliable and Transparent Way to Buy High Power Rocket Motors*. [Online]. Available: http://buyrocketmotors.com/. [Accessed: 12-Oct-2016].
- [6] Nose Cone Selection Chart – Geometry of nose cones 1996 Gary Crowell Sr. (drag chart&nose cone)
- [7] G. A. Crowell, “The Descriptive Geometry of Nose Cone,” Scribd. [Online]. Available:https://www.scribd.com/doc/60921375/the-descriptive-geometry-of-nose-cone. [Accessed: 12-Oct-2016]
- [8] “Carbon Fiber Tube 3K Matte 22X1000mm,” *Carbon Fiber Rods Carbon Fiber Tubes Dublin Ireland*. [Online]. Available: http://www.radiocontrolledshop.ie/599-carbon-fiber-rods-an*and* d-carbon-fiber-tubes-dublin-ireland. [Accessed: 12-Oct-2016].
- [9] “8 Foot Plastic Pipe,” *MSC Industrial Supply Co.* [Online]. Available: http://www.mscdirect.com/industrialtools/8-foot-plastic-pipe.html. [Accessed: 12-Oct-2016].
- [10] "Round fiberglass tubing," in *Rock West Composites*. [Online]. Available: https://www.rockwestcomposites.com/round-tubing/fiberglass-tubing. Accessed: Oct. 10, 2016.
- [11] “Maharashtra Metal (India),” *Aluminium Round Tube in Mumbai, Aluminum Round Tube Dealers & Suppliers in Mumbai*. [Online]. Available: http://dir.indiamart.com/mumbai/aluminium-round-tube.html. [Accessed: 12-Oct-2016].
- [12] "How rockets work," in *Fly Rockets*. [Online]. Available: http://www.flyrockets.com/work.asp. Accessed: Oct. 11, 2016.
- [13] Y. Gibbs, "X-38 descent with large Steerable Parafoil," NASA, 2015. [Online]. Available: https://www.nasa.gov/centers/dryden/multimedia/imagegallery/X-38/EC99-44923-102.html. Accessed: Oct. 11, 2016.
- [14] "Team for advanced flow simulation and modeling," in *TAFSM*, 2004. [Online]. Available: http://www.tafsm.org/PROJ/AS/j175STFECCFSIP/. Accessed: Oct. 11, 2016.
- [15] “Peregrine CO2 Ballistic Deployment System | Fruity Chutes!,” *Peregrine CO2 Ballistic Deployment System | Fruity Chutes!* [Online]. Available: https://fruitychutes.com/parachute_recovery_systems/co2_parachute_ejection_deployment.htm. [Accessed: 12-Oct-2016].
- [16] "Rocketry basics," in *Jacobs’ Rocketry*. [Online]. Available: http://www.jacobsrocketry.com/rocketry_overview.htm. Accessed: Oct. 10, 2016.

Thank you!
Questions?