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Midterm I Report

Team 24: Intercollegiate Rocket Engineering Competition

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Abstract

Team 24 of the 2016-2017 Senior Design class has committed to designing and building a competitive rocket for the Experimental Sounding Rocket Association's Intercollegiate Rocket Engineering Competition (IREC). This competition requires that a sounding rocket be designed, built, and flown to 10,000 ft above ground level; and be safely recovered. For this purpose, we have determined that a rocket with fixed fins and composed of fiberglass, should be created. Housed inside of this should be two recovery systems, our payload and our flight computer. This should all be propelled by a solid grain rocket motor and the delayed black powder gas generator should be used for our recovery system with a CO_2 canister as a backup. Testing shall be done via a scale model and eventually flight testing of our system. Once all things have been deemed satisfactory, Team 24 will participate in the IREC held at Spaceport America.

Acknowledgements

Team 24 would like to acknowledge the different people and organizations that have assisted throughout this venture:

Firstly, this team would like to thank Dr. Rajan Kumar for his assistance in developing concepts for the research experiment to fly on our rocket. We would also like to thank John Hansel for introducing the team to a number of launch and safety procedures specified by the NAR and Tripoli rocket organizations. Additionally, Team 24 would like to express our appreciation of Dr. Nikhil Gupta and Dr. Chiang Shih for oversight and advisement of the senior design projects.

1. Introduction

The Experimental Sounding Rocket Association (ESRA) was founded in 2003 and aims to further the development of sounding rockets, which are designed to carry scientific payloads. The ESRA hosts a yearly competition known as the Intercollegiate Rocket Engineering Competition (IREC). This competition requires teams from over a dozen universities to design, build, and launch experimental sounding rockets. A key point of the competition is that the vehicles must carry a payload which performs a scientific experiment.

It is the goal of Team 24 to create a competitive rocket capable of reaching an apogee of 10,000 ft above ground level (AGL), while simultaneously performing a useful scientific experiment. Team 24 aims to conduct all activities as safely and professionally as possible, while delivering a vehicle with truly outstanding performance.

2. Background and Literature Review

2.1 Early History

Experimental rocketry can be traced back to 1806, when Claude Ruggieri created rockets to carry animals into the atmosphere. However, sounding rockets in their current use and configuration can be attributed to a Russian rocketry pioneer by the name of Mikhail Tikhonoravov. In 1933, Tikhonoravov launched a liquid fueled rocket carrying scientific instrumentation [1]. Later in 1946, the V2 rocket, famous for causing devastation during the second World War, was used by both American and Russian scientists for atmospheric experimentation [2].

Use of sounding rockets exploded during the International Geophysical Year, from 1957 to 1958. During this period approximately 200 rockets were launched. Upper atmospheric and space experiments were being performed at a rapid rate. Some notable activities during this time frame include the launching of the first probes to the moon, along with the discoveries of the Van Allen belts and the magnetosphere [1] [2].

2.2 Modern Sounding Rockets

Currently, sub-orbital sounding rockets are used world wide for a vast expanse of disciplines and studies. There are several reasons for this, but the most compelling is their large range of testing altitude. Weather balloons are primarily limited by their speed and their maximum altitude of roughly 120,000 ft. Satellites in orbit around the Earth operate in the vacuum of space and cannot study atmospheric phenomenon directly. Thus, sounding rockets deliver a unique capability to do direct atmospheric measurements at high altitudes and at very high mach numbers. [1]

2.3 Sounding Rocket Composition

A series of subsystems composes the sub-orbital sounding rocket: the payload, recovery system, flight control system, propulsion system and telemetry system. All of these systems possess unique hardware, however, of most interest to this project is the payload. This system is typically housed inside of the nose cone. As such, the payload can be separated from the launch vehicle, allowing for it to be used multiple times for different experiments. [3].

3. Project Details

3.1 Needs Statement

This team's objective is to design and develop a recoverable rocket that safely delivers a payload to an apogee of 10,000 ft AGL. The payload needs to have a scientific or engineering purpose, and every component must be recoverable. Additionally, the rocket and payload should conform to the rules of the Experimental Sounding Rocket Association's 2017 Intercollegiate Rocket Engineering Competition.

3.2 Goal Statement and Objectives

Successfully design, build, and fly a vertical take-off, single-stage, rocket powered launch vehicle to an apogee of 10,000 ft AGL, and deploy a scientifically useful payload as part of the Intercollegiate Rocket Engineering Competition sponsored by the Experimental Sounding Rocket Association.

In order to accomplish this goal, the following objectives are set by our team:

- Brainstorm concepts for launch vehicle and for payloads that may be useful to the scientific or engineering community
- Conduct substantial background research into launch vehicle aerodynamics, materials, controls, and structural mechanics

- Benchmark the rocket-payload system using previous competition entries as case studies
- Develop a set of engineering characteristics using engineering parameters, design variables, and constraints
- Utilize engineering tools such as a house of quality chart to select parts and materials that best meet our goal
- Develop scale prototype to validate initial engineering design
- Reiterate on prototype to improve performance
- Design, fabricate, and assemble necessary parts for both test and flight articles
- Develop flight software and integrate into avionics sensors to control rocket functions
- Conduct flight testing of recovery system and flight controller
- Compete at the IREC

3.3 Constraints

The Basic Category of the Intercollegiate Rocket Engineering Competition has a set of rules and requirements pertaining to the design of the vehicle and its payload. In addition there are numerous safety requirements imposed for the launch of the vehicle.

3.3.1 Vehicle & Payload Requirements

- The vehicle must attain an altitude of 10,000 ft AGL
- The payload must be at least 8.8 lbs
- The vehicle and payload must be recoverable
- The payload must not be used to alter the stability of the rocket
- The vehicle must have an altimeter and record data using a fight computer
- A maximum of one propulsive stage is allowed
- Propulsion must use non-toxic fuels
- Payload may not contain hazardous materials or live animals

3.3.2 General Requirements

In addition to the rules regarding the design of the vehicle and payload, several other rules should be observed regarding the flight and launch preparation.

- The vehicle must be able to return to a safe-mode after arming
- The vehicle should attain a speed of 100 ft/s before leaving the launch rail
- The vehicle and payload must have a recovery system
- Main parachute should slow rocket to at least 30 ft/s by 1,500 ft AGL

4. Project Scope

The sounding rocket developed through the course of this project should fulfill the competition requirements imposed by the IREC. Additionally, the research payload should provide useful data for researchers at the FAMU-FSU College of Engineering. Nearly all components of the rocket shall be recoverable and reusable for any subsequent flights, if additional experimental flights are desired.

A number of elements of the launch vehicle can be purchased, however the body, fins, nose cone, software, and experimental payload will require design, development, and some components may require in-house manufacturing. Our major purchases will be the rocket motors required for test flights and validation.

As per the IREC evaluation criteria, the launch vehicle produced by Team 24 will be evaluated based upon the altitude the rocket is capable of reaching as well as the damage levels to components during flight. Our vehicle development process will be completed when, following a thorough test flight program, (1) the rocket consistently reaches the target altitude, and (2) all components are recovered without damage. Beyond that point, group resources will largely be dedicated to optimizing the data obtained through the experimental payload of the rocket, which will be evaluated based upon the quality and accuracy of the data obtained.

In June of 2017 the team will travel to participate in the Intercollegiate Rocket Engineering Competition held at Spaceport America and hosted by the Experimental Sounding Rocket Association. It is our aim to place highly at this competition and bring further prestige to our university.

Finally, it is the hope of Team 24 that successful participation in the Intercollegiate Rocket Engineering Competition will result in an increased level of enthusiasm and usher forth a wave of interest in rocketry and spaceflight at the FAMU-FSU College of Engineering. We sincerely hope that this project will become a yearly venture for the College of Engineering and that, in later years, more advanced vehicles can be developed and entered into competitions.

5. Methodology

To accomplish the previously stated goals and objectives, the design team has envisioned a methodology to be adhered to in all aspects of the design process. These methodologies are described in detail in the following sections.

5.1 Team Schedule

A consistent weekly schedule will be helpful to the team and conducive to achieving the stated goals and objectives. Below is a table of the planned weekly schedule for the team. Other meetings and events will be in addition to this:

Type	**Day**	**Time**
Team	Thursday	8:15 am - 8:50 am
Team	Saturday	10:00 am - 12:00 pm
Team + Mentor	Wednesday	1:00 pm - 2:00 pm
Team + Mentor	Friday	9:20 pm - 9:50 pm

Table 1: Table of team meeting times.

5.2 Safety and Logistics

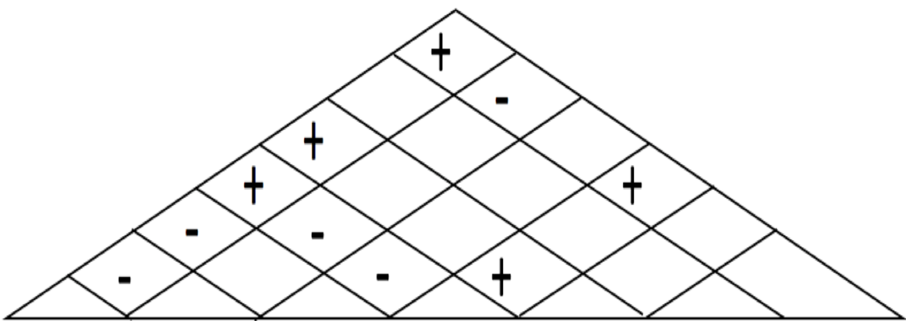
- Comply with legal requirements associated with high power rocketry and the Intercollegiate Rocket Engineering Competition
- Develop risk assessment and safety plan to ensure safety of design team and reduce liability risks
- Perform certification tests and attain rocketry organization membership to ensure launch site access and high-power motor access

5.3 Launch Vehicle

Before beginning the main launch vehicle design, the features that would be most important to focus on were determined. This was done by defining the characteristics of sounding rockets, as shown below.

- Stability : The ability of the rocket to maintain a straight flight path
- Rocket Weight : The amount of mass that the rocket motor would be required to lift
- Total Impulse : The culmination of the burn time and force output of the motor selected
- Reliability : The probability that the components will perform as designed
- Scientific Value : The usefulness of the experiment being performed
- Material Strength : The ability of the material to withstand the forces it will be subject to
- Avionics : The flight controller and sensor package

By weighting the correlation between these features and the competition requirements and constraints, the following table was produced.



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

Figure 1: House of Quality comparing engineering values with the requirements.

The House of Quality implies that, in order to produce a competitive vehicle, the most critical aspects of the design are stability, avionics, and reliability. With the ranking of characteristics performed, the actual design can be completed according to the following steps:

1. Develop a mathematical model to simulate the flight profile of the vehicle
2. Select a rocket motor to determine target vehicle weight
3. Select vehicle outer mold material
4. Determine aerodynamic shape, fin geometry, and other parameters related to flight stability
5. Determine internal components for recovery, payload and avionics systems
6. Determine if the final design meets the necessary performance and safety specifications; if not, return to step 1 and make adjustments.

5.4 Verification

A number of tests are to be conducted by the design team to ensure that the final design meets each and every criteria across the board. The proceedings for each of the following tests will be outlined in the safety plan and risk assessment. These tests will be scheduled and performed under the appropriate supervision at predetermined locations. All test results will be documented and any discrepancies will be reported to the advisory staff.

- Payload Test : The payload will be tested for functionality
- Aerodynamic Drag test : Perform sub-scale wind test on model of launch vehicle to verify flight characteristics
- Recovery Test : Test parachute deployment systems for reliability with ground and flight tests
- Flight Test : Test the fully integrated, final design for functionality

5.5 Expected Results

At the end point of this project, it is expected that a competitive rocket capable of carrying an 8.8 lbs payload will be created by Team 24. In addition to this, Team 24 expects to launch this rocket at the ESRA's IREC competition in 2017. For the purposes of Senior Design, there are also other expectations.

The results of this project will amount to a number of deliverables:

- All documentation pertaining to the Senior Design curriculum
- All documentation pertaining to the ESRA IREC rules and regulations
- All documentation pertaining to NAR and Tripoli rocket certification

- Final flight hardware to be flown in competition
- Final poster for Senior Design

6. Vehicle Development

The development cycle of this rocket will include a fairly detailed conceptual design. Due to the enormous challenge of designing a launch vehicle from scratch, we intend to be as detailed as possible during the early conceptual stage.

6.1 System Overview

The launch vehicle is composed of several subsystems which are all integral to a safe and stable flight. The figure below details the approximate layout of our launch vehicle[4]. As can be seen in the figure, the payload will be housed in the nose cone with a secondary recovery system behind it. After this comes the majority of the flight control system, which will be contained in the main tube of the vehicle body with the primary recovery system aft of it. Finally, the motor will be housed at the tail end of the rocket and surrounding it will be the stabilization system.

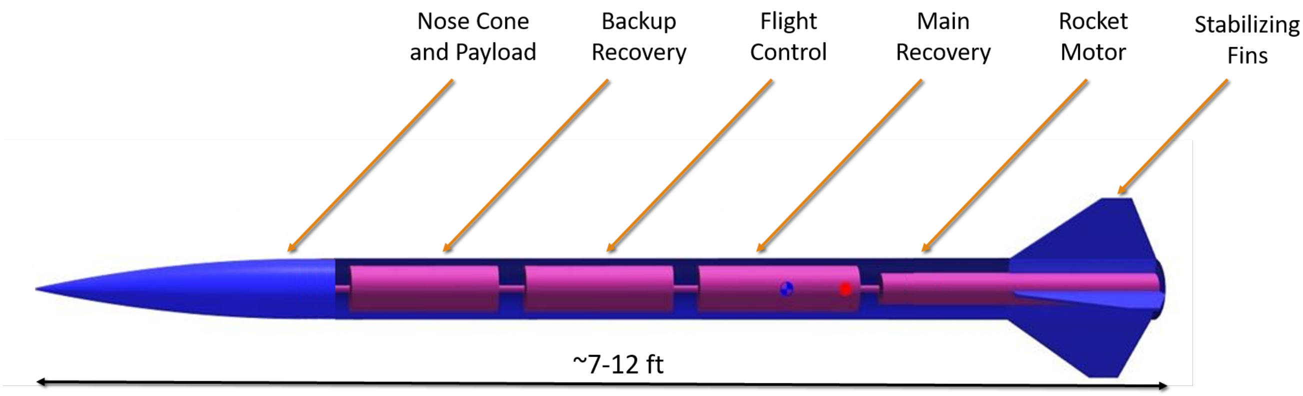


Figure 2: Rocket Subsystems in their approximate location.[4]

6.2 A Simplified Mathematical Model

Before a clean-sheet design of a rocket can be started, a simplified model must be created to describe the flight of the vehicle. The model must take into account the forces and varying parameters that affect the vehicle during the flight. This is necessary to determine the type of motor needed; specifically its necessary thrust profile and total impulse can be estimated. From this, an estimate of the maximum weight of the vehicle systems can be made and thus many elements of the vehicle can be decided.

A model was created which uses Newton's Laws and the classical equations of motion iteratively to simulate the trajectory of the rocket up to the point of apogee. The basis of the code is Newton's second law,

$$F = \frac{dp}{dt} = \frac{d(mv)}{dt}. \tag{1}$$

Given that the mass of the vehicle is changing constantly due to the loss of propellant, the previous equation (1) would be unwieldy to use in practice. However, by taking finite (sufficiently small) time steps $dt \approx \Delta t$, the mass can assumed to be constant within each interval without much loss of accuracy. Then (1) becomes

$$F_i = m_i a_i, \tag{2}$$

which is a more familiar and manageable form. Then separating each component of the vehicle by its mass, namely the fixed-mass motor casing, the fixed weight associated with the airframe and internal components, and the variable mass of the propellants, the model represents the total mass as

$$m_{\text{tot}_i} = m_{\text{fixed}} + m_{\text{propellant}_i}. \tag{3}$$

Then given the initial conditions of the vehicle before launch, the acceleration, velocity and position at each time step can be determined. This is done using

$$a_i = \frac{F_{\text{tot}_i}}{m_{\text{tot}_i}} \tag{4}$$

$$v_{i+1} = v_i + a_i \Delta t \tag{5}$$

$$r_{i+1} = r_i + v_i \Delta t + \frac{1}{2} a_i (\Delta t)^2. \tag{6}$$

While these simple equations form the basis of the model, the determination of the total force on the rocket at each time step is the most exacting part of the model. Summarized in the table below is a list of assumptions that the model makes in order to estimate the total force on and mass of the vehicle at each time step.

Term	Equation	Explanation
ρ	$\rho = \rho_0 \exp(-r/r_0)$	The sea-level air density is ρ_0 and r is present altitude while r_0 is maximum atmospheric altitude
F_{thrust}	None	For each rocket motor analyzed, the thrust profile data is used at each time step during the burn
F_{form}	$F_{\text{form}} = \frac{1}{2} C_d \rho A_{\text{front}} v^2$	Standard equation for form drag on a bluff body
F_{friction}	$F_{\text{friction}} = \frac{1}{2} C_f \rho A_{\text{wetted}} v^2$	Standard equation for drag caused by friction of the air moving over the vehicle surface
C_f	$C_f = (1.5 \log \text{Re} - 5.6)^{-2}$	Empirical relationship used to estimate the coefficient of skin friction for a body in turbulent flow
$m_{\text{propellant}}$	$m_{\text{propellant}} = m_{\text{prop init}} - b\Delta t$	Letting b be a constant burn rate of the propellant, this model assumes the loss of propellant mass is linear

Table 2: List of assumptions in the model.

The code developed using this model takes in performance data from commercial rocket motors, an arbitrary fixed mass (not including the motor casing), and information about the dimensions of the motor in order to determine the minimum diameter of the vehicle's airframe. The output of the program is information about each motor's overall performance as well as the forces acting on the vehicle during the flight, which is important for other design aspects.

6.3 Propulsion & Flight Analysis

As mentioned in the previous section, the simulation that was developed has the ability to predict the trajectory of the rocket throughout the entire flight; from liftoff, burnout, coast phase and finally apogee. Since one of the main criteria in designing the vehicle is mass, it is important to know how much a particular motor can lift to the target altitude. In order to determine what the maximum fixed airframe mass could be, the simulations were run with a locus of potential masses. As can be seen in Figure (3), six different motors were analyzed for a range of potential masses. Their predicted apogees are plotted along the ordinate. Following the intersection of the target altitude of 10,000 ft and each curve downward, it is clear what the target weight of the airframe should be for each particular motor.

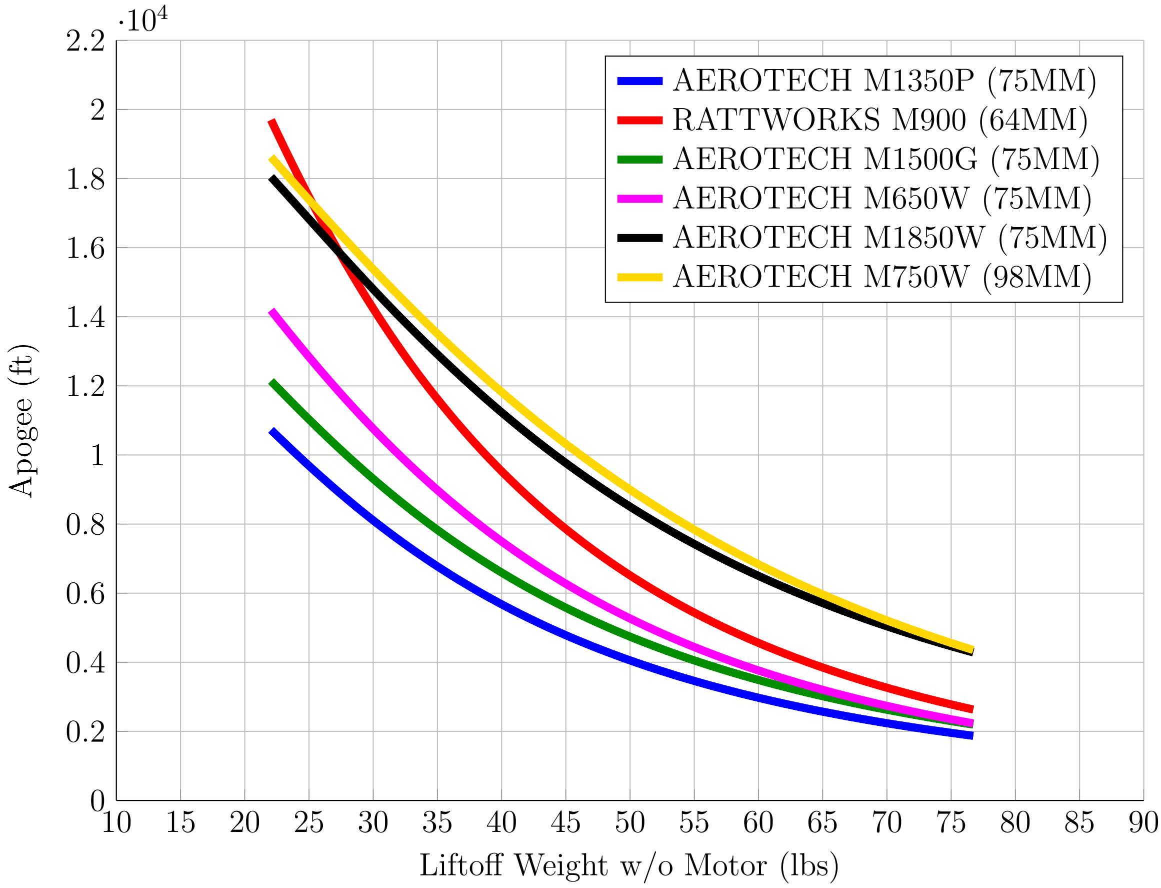


Figure 3: Flight apogee based on mass of rocket for six motors, including five solid fuel and one hybrid fuel motor.

Since the code calculates the entire trajectory, the simulation also has the added functionality of calculating the maximum theoretical Mach number encountered by the vehicle. These results are shown in Figure 4. By combining the information from Figure 3 with that of Figure 4, Table 3 details the expected Mach number for weights which allow a 10,000 ft apogee.

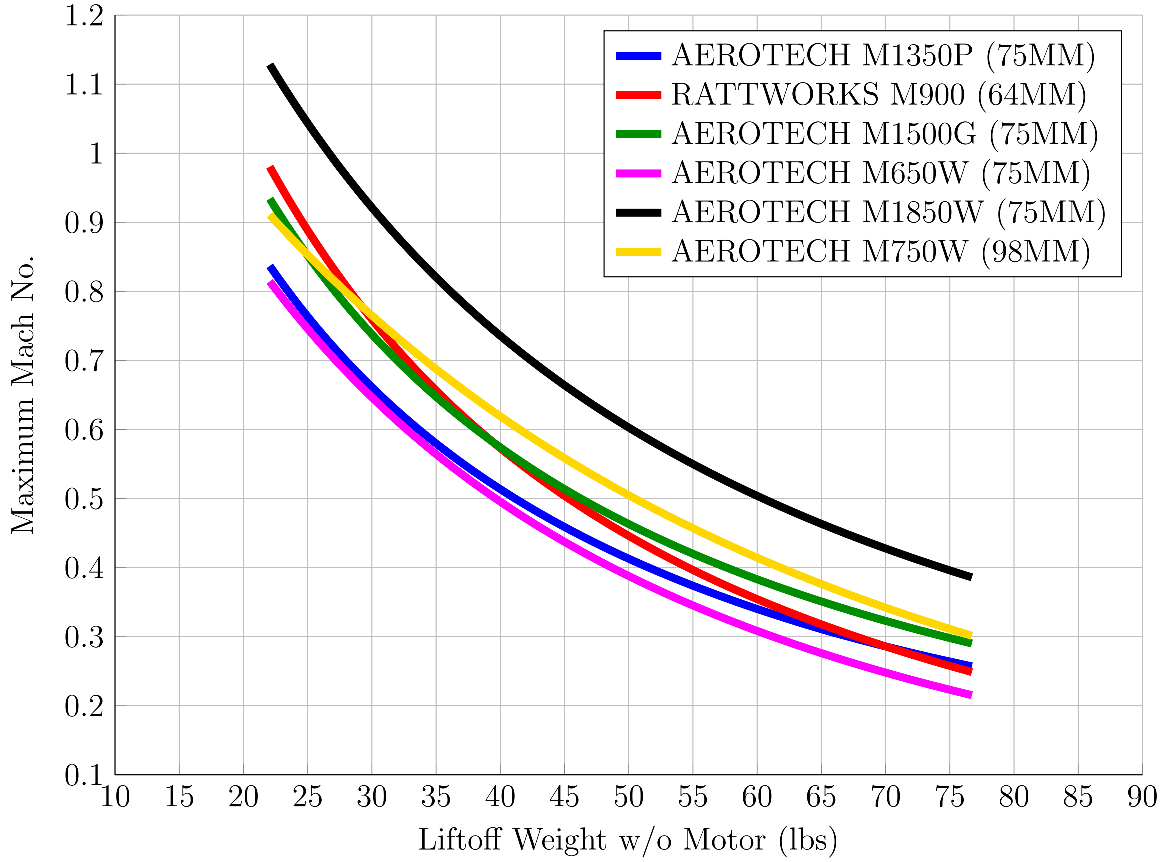


Figure 4: Maximum Theoretical Mach number based on mass of the rocket for the six motors analyzed.

From Table 3 we can see that, by utilizing any one of the six motors, our rocket will likely be moving somewhere from Mach 0.5 to Mach 0.8. It is most likely that our rocket will be flying at subsonic speeds for the majority of the motors we could utilize. With this information, the process of optimizing flow characteristics and selecting materials can begin.

Motor	Mach Number	Liftoff Weight
M1350P	0.80	23 lbs
M1500G	0.80	27 lbs
M650W	0.60	33 lbs
M900	0.60	38 lbs
M1850W	0.65	44 lbs
M750W	0.60	46 lbs

Table 3: Combinations of Mach number and weight for 10,000 ft apogee rockets.

6.4 Nose Cone Shape Optimization

Nose cone design is influenced greatly by the intended speed of the moving body. For subsonic flights, domal shaped rocket noses have lower drag characteristics than cone shaped noses. The opposite is true once the rocket enters the supersonic regime. Since our rocket will be moving at a subsonic velocity, a domal shape is desired.

Extensive research has been done on this subject, and the following figure details the ideal shapes for given mach numbers based on emprical data. By following the information presented in "The Descriptive Geometry of Nose Cones,"[5] it was determined that the simplest and most effective cone shape would have a profile proportional to $x^{0.5}$.

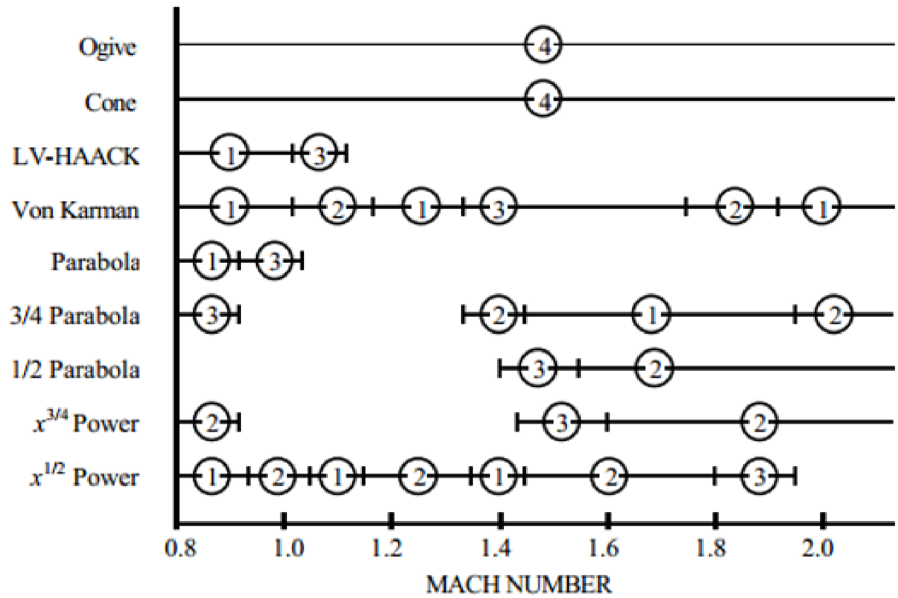


Figure 5: Nose cone profile as a function of mach number.[5]
1-ideal 2-good 3-acceptable 4-unacceptable

In order to create a profile that matches $x^{0.5}$, the surface of the cone must follow Equation (7). After the surface profile of the cone has been developed, the ideal length must be determined using the fineness ratio defined in Equation (8). The fineness ratio dictates the magnitude of wave drag experienced by the rocket as velocity increases. A high fineness ratio indicates a minimization in wave drag, however raising the fineness ratio requires making the rocket longer; a longer nose cone has increased surface area and thus a higher magnitude of surface drag is produced. As such optimization must be done to determine a specific nose cone length.

$$Y = Radius\ of\ tube * (x/length\ of\ nose\ cone)^{0.5} \tag{7}$$

$$Fineness = Length/Base\ Diameter \tag{8}$$

6.5 Airframe Material Selection

Material selection for a rocket is crucial to its performance. Materials used for the body are required to withstand high speed ground impacts and undergo large changes in acceleration. As an added issue, the thrust to weight ratio is extremely important for a high power rocket; lighter rockets allow for the use of smaller motors and can potentially reduce overall cost. Meeting all of these conditions requires a high-performance material.

According to our background research, there are at least three materials which could be used in our design: carbon fiber, fiberglass, and aluminum. All of these materials have high strength-to-weight ratios. Currently, our budget does not allow for use of carbon fiber in our design. Therefore, due to the predominance of fiberglass in the low-power rocketry field, it is probable that this will be the material out which we construct the main body of our rocket.

Another extensive computer code was developed to determine if the material could meet our requirements for safety and performance. This code analyzes the main tube of the vehicle as a beam in compression. Data about the flight of the vehicle, including the maximum thrust from the motor, the maximum drag force on the nose of the rocket, and the maximum force of the hefty payload at maximum acceleration. These forces, with the latter two on top and the thrust force on the bottom, can be combined to determine the factors of safety for buckling of the beam based on expected load and the theoretical maximum compression the airframe may undergo before failure.

Given a hollow, cylindrical airframe cross-section, a number of parameters related to buckling failure can be determined. The slenderness ratio of the airframe (beam) is given by

$$S_r = \frac{l}{k}, \tag{9}$$

where l is the estimated length of the vehicle [**?**] and k is the radius of gyration given by

$$k = \sqrt{\frac{I}{A}}. \tag{10}$$

In (10), I is the second moment of area and A is the cross-sectional area bearing the load. Using these parameters as well as the values for the compressive yield strength, S_{yc}, and compressive modulus, E, the critical loading of the airframe can be determined. The critical load is given by the Euler-column formula as

$$P_{\mathrm{cr}} = \frac{\pi^2 EA}{S_r^2}. \tag{11}$$

A typical critical stress curve based on the Euler equation is shown in Figure (6). When

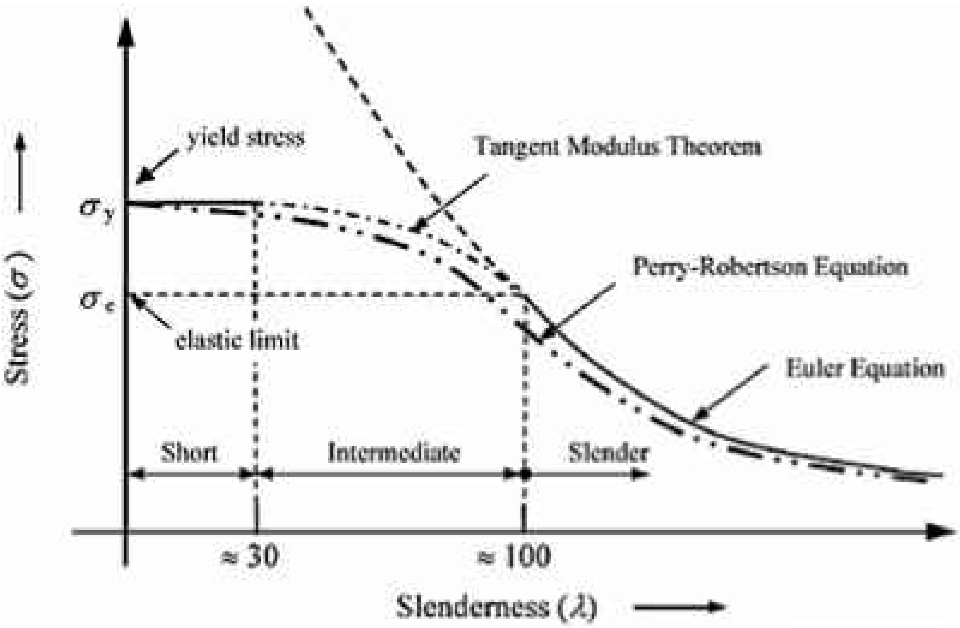


Figure 6: Stress vs slenderness ratio curve showing regions of safety known as Euler and Johnson regions.

the slenderness ratio S_r is greater than a parameter given by

$$(S_r)_D = \pi\sqrt{\frac{2E}{S_{yc}}}, \tag{12}$$

which is determined from the intersection of the compressive yield stress and the stress curve, the Euler-column stress equation is used:

$$\sigma_{\text{cr}} = \frac{P_{\text{cr}}}{A} = \frac{\pi^2 E}{S_r^2}. \tag{13}$$

However if $S_r \leq (S_r)_D$ then the Johnson equation is used to determine the critical stress, given by

$$\sigma_{\text{cr}} = \frac{P_{\text{cr}}}{A} = S_{yc} - \frac{1}{E}\left(\frac{S_{yc}S_r}{2\pi}\right)^2. \tag{14}$$

Using these equations for a fiberglass body it was determined that the factor of safety for the worst-case scenario in flight was approximately 8. This was using an airframe material thickness of just 1.5 mm. The corresponding airframe weight was well within the team's margins, so this initial result is quite promising.

6.6 Stability

Many different options exist for stabilizing the flight of a rocket. Of all possible options, it was deemed that fixed fins would be a cheap effective solution to the problem. Since our rocket has an intended altitude of 10,000 ft AGL and a short flight time, the developmental cost and time required for any other stabilization systems would be unnecessary. Furthermore an increase in complexity of the stabilization system would add additional points of failure and would not be desired.

Although stabilizing fins work to align the rocket in a straight, steady flight, they also serve an additional function. In rocketry, the proximity between the center of gravity and the center of pressure is crucial to obtaining a stable flight; for desirable flight characteristics the center of pressure needs to be beneath the center of gravity by approximately 1 to 1.5 diameters of the rocket. Should the center of pressure lie any closer to the center of gravity, the fins are designed with increased surface area to move the center of pressure closer to the rear of the rocket. For this reason, exact fin geometry can not be determined until after the majority of the sounding rocket has been developed.

6.7 Recovery Systems

The recovery system of a launch vehicle is a very important subsystem if a sub-orbital rocket flying over land. In this competition the team has the dual purpose of ensuring that the vehicle comes down safely without harming anyone, and also protecting the valuable flight computer and payload sensors.

The recovery system of this rocket is split into two components: a drag device (parachute or parafoil) which slows the descent of the rocket, and the deployment system which is responsible for ejecting the parachute from the rocket body reliably. The two components are separate entities which work in conjunction to bring the vehicle down safely.

6.7.1 Parachute System

There are three parachute systems that are currently the most often used in the amateur rocketry field: These are a dual deployment parachute system, a reefed parachute system, and a steerable parafoil system.

A dual deployment system includes a small drogue parachute which is ejected from the rocket at apogee. The drogue parachute slows the rocket initially and minimizes lateral drift from the launch site. When the rocket has reached a substantially lower altitude (1,500 ft AGL for the competition) the larger main parachute is deployed, and slows the rocket to an acceptable landing velocity. An example is illustrated in the figure below.

Figure 7: A dual deployment parachute system after deployment.
[7]

A reefed parachute system deploys a parachute at apogee, however the parachute is not fully developed until much later. It remains in a half-opened state for the majority of the descent. This allows the rocket to continue down at a high velocity, reducing drift substantially. Once the desired altitude has been reached, a ripcord is cut, which unreefs the parachute, allowing full expansion, and slows the rocket. An example is shown below.

Figure 8: A large-scale reefed parachute system after deployment, still in its reefed stage.
[9]

Steerable parafoils are much more complex. They work similarly to a dual deployment system, however instead of a main parachute, a parafoil is used. Small servos adjust the length of cables attached to the foil and steer the rocket down. However, in order for this system to work the rocket must have substantial mass. A steerable parafoil system is shown in the figure below.

Figure 9: A steerable parafoil guiding an experimental flight vehicle.
[8]

In order to select a parachute system, a Pugh matrix was employed. Dual deployment is the most prevalent of the three systems in use and was chosen as the baseline.

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 10: Pugh Selection Matrix for Recovery System showing that with the selected engineering characteristics, the reefed parachute narrowly scores more points than the baseline.

By comparing how each system performs according to the team's desired characteristics, it was determined that a steerable parachute would be unreasonable and inefficient. Therefore, it was decided that the main system will be a reefed parachute system and our backup recovery system will be a common dual deployment system.

6.7.2 Deployment System

Multiple methods exist to eject a recovery system from the rocket body. The system must be reliable, not just on the ground but at the high altitude with lower atmospheric pressure that it will be deployed. There are two leading systems that the team is looking at currently.

In the first design, a cartridge of compressed gas is punctured and the escaping gas is used to propel the parachute out of the vehicle. A commercial product is available and shown below for reference.

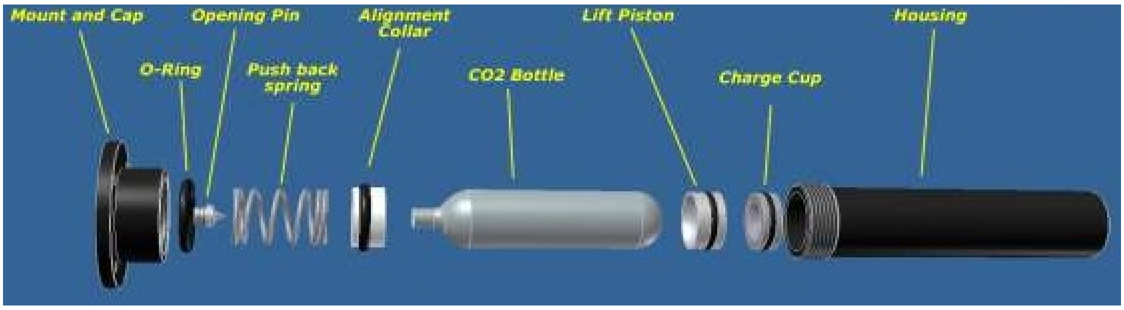


Figure 11: Exploded view of the Peregrine compressed CO_2 ejection system. [10]

An alternative method is a black powder gas generator. This works by using a delay grain that holds a flame between the time of engine shutdown and apogee. Then the fuse strikes a powder charge, producing a high temperature, high pressure gas that can eject the parachute out of the vehicle.

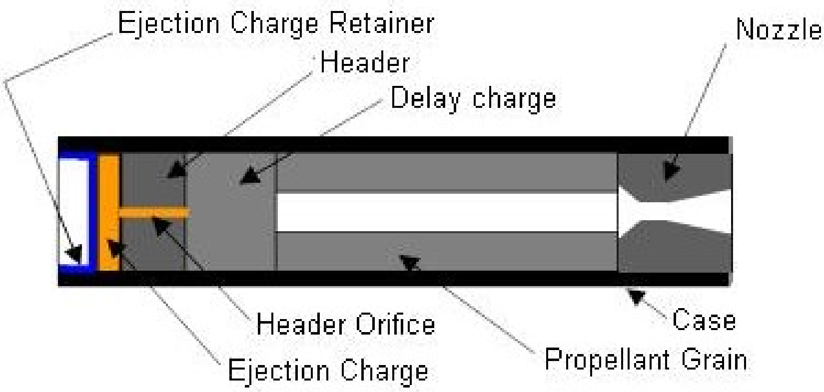


Figure 12: A simple diagram of a rocket motor with the gas generator on the left side at the forward end of the motor. [11]

For the sake of maintaining utmost reliability, the team has decided to use both of these systems. The black powder gas generator will be used for the main parachute as it can be used independently of the flight computer, making it possibly more reliable. The compressed gas system will be used for the reserve dual deployment parachute near the sensitive electronics near the top of the rocket. The lack of hot gases makes the compressed gas system an attractive option for placing near avionics systems.

6.8 Avionics

For the avionics package, the team has decided to program its flight computer. Currently, commercial options are limited in their functionality. The Intercollegiate Rocket Engineering Competition requires that the vehicle include an experimental payload. For this payload, the team currently intends to have the main flight computer run the experiment and record the data. By only having a single system do both, it reduces unnecessary mass in the vehicle. Team 24 also intends to program the flight computer manually.

For the vehicle altimeter options, the team has considered the use of either a barometric pressure sensor or an accelerometer. In order to effectively decide, a decision matrix was created based upon several parameters of importance. As can be seen below, each parameter has been assigned a weight based upon its importance to the vehicle's success in the IREC. From Table (4) it can be seen that using just a barometric pressure sensor will provide the most effective option for altitude measurement.

Sensor Type	Weight(1)	Ease of Use(4)	Accuracy(5)	Cost(2)	Total Score
Barometric Sensor	5	5	3	5	50
Accelerometer	4	4	2	3	36
Combined	3	3	5	2	44

Table 4: Altimeter Decision Matrix

6.9 Payload Design

The launch vehicle must carry an experimental payload. Through discussions with the team's mentor, a leading concept has been proposed. To leverage the ongoing research by the team's mentor and others at the Aero-Propulsion, Mechatronics and Energy (AME) Center, it is likely that the team's experiment will consist of an active flow control testbed. This experiment will study the effects of injecting momentum in a fluid. Specifically, the intention is to separate the airflow downstream from the nose of the vehicle, and then inject fluid via injectors embedded in small ports around the circumference of the airframe in order to reattach the flow and modify the wake characteristics of the vehicle. This has the potential to improve drag characteristics for launch vehicles of this kind. The idea is also widely applicable in the field of aeronautics. Such experiments have been done before at the AME to modify the stall characteristics of aircraft, as seen in the figure below.

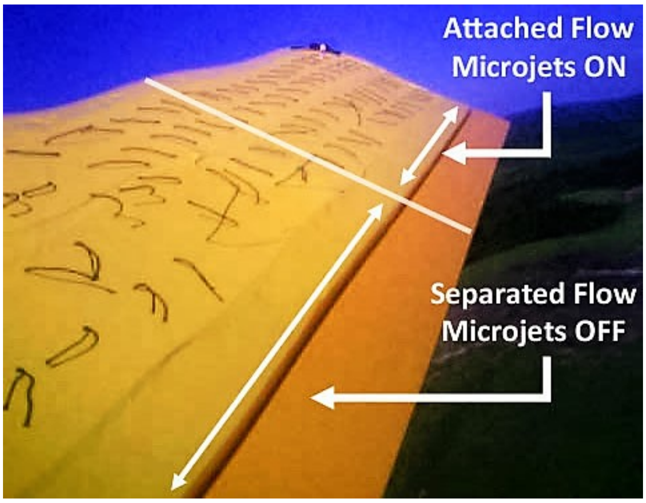


Figure 13: Flow injectors modify the stall characteristics of an experimental aircraft. [12]

To meet the requirements of the competition, the components of the payload designed must be able to fit in a standardized size. The competition uses the CubeSat, or U-class spacecraft, standard for the dimensions of the payload. These are denoted by

Size	Dimensions (cm^3)
1U	$10 \times 10 \times 10$
1.5U	$10 \times 10 \times 15$
2U	$10 \times 10 \times 20$
3U	$10 \times 10 \times 30$

Table 5: Standard cubesat dimensions that the payload components must fit within.

For reference, a rendering is provided of the cubesat frames in the figure below

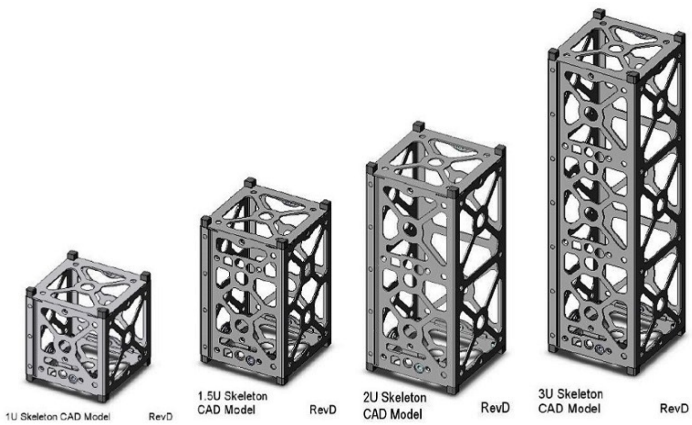


Figure 14: Comparison of standard cubesat frames. [13]

6.10 Launch Vehicle Overview

All of the conceptual decisions made for the launch vehicle have been summarized into the following table.

Subsystem Selection	
Nose Cone	$x^{1/2}$ Profile
Airframe Material	Fiberglass
Stabilization	Fixed Fins
Recovery System	Reefed Deployment and Dual Deployment
Deployment System	Compressed CO_2 and Black Powder Gas Generator
Flight Computer	Self-programmed
Altimeter	Barometer
Experimental Payload	Active Flow Control Testbed

Table 6: Overview of launch vehicle subsystem decisions.

To help visualize the vehicle, a model was made using CAD software. The concept vehicle is shown in the figures below.

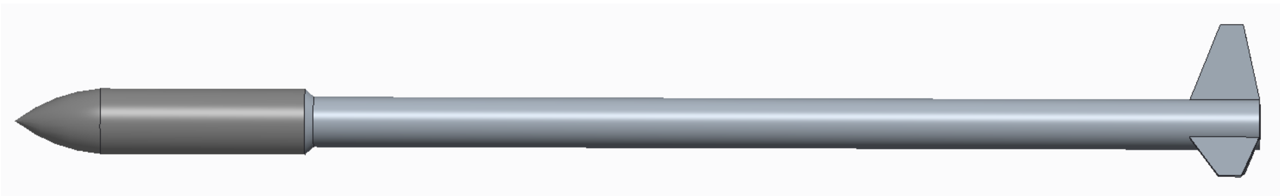


Figure 15: View 1 of the concept vehicle.

The enlarged diameter of the nose section relative to the body of the vehicle is to produce the separation effect necessary for the active flow control experiment that the team intends to fly.

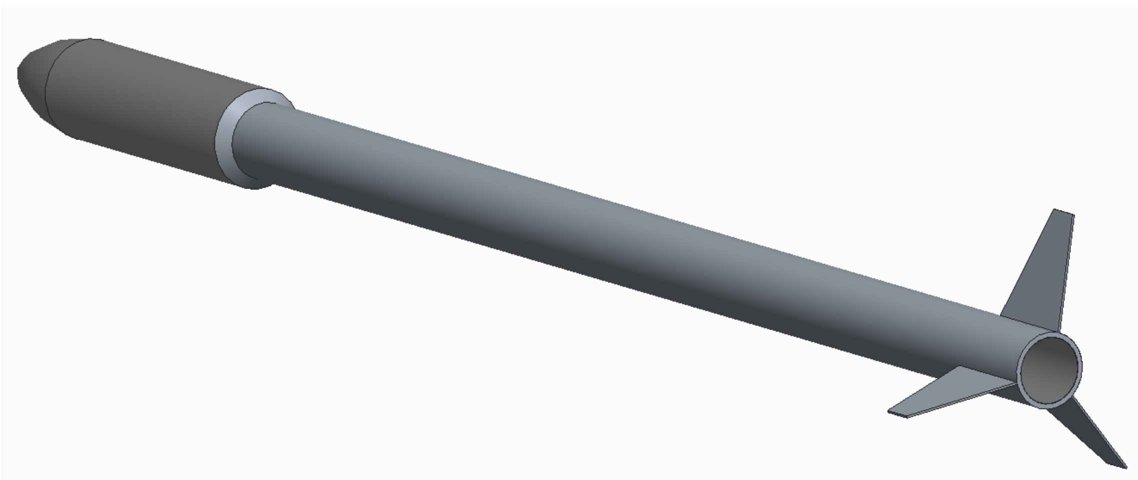


Figure 16: View 2 of the concept vehicle.

7. Project Planning

Team 24 plans to have a design finalized and have orders for components placed by the end of the Fall 2016 semester. A Gantt chart showing the breakdown and dates of tasks for this semester can be found in the Appendix. The work outlined for this project can be broken down into five phases: Background Research and Concept Generation, Detail Design and Analysis, Design Implementation, Test and Revise, and Competition Due Dates.

7.1 Background Research and Concept Generation

This phase consists of detailed background research on rocket motors, fin design, recovery systems, nose cone profiles, potential payloads, and avionics. Background research of the competition was also performed to become more familiar with the competition requirements that our design is to meet. Additionally, this initial stage was used as a time for brainstorming and concept generation for the components required for the rocket and payload.

7.2 Detailed Design and Analysis

This phase will be used to select, refine, and analyze our design. Based on the concepts generated during the first phase an initial design will be chosen and raw material used for the components will be selected. The exact specifications for this design will be refined when an initial CAD model is made, and the model will be updated as the design changes. As the initial CAD model is being made, a flight controller and recovery system will be developed. Next, an initial payload for the rocket will be selected and integrated into the initial rocket design. Once all the components of the initial rocket design are known analysis of the design will begin. The results of the analysis will be used to determine which components of the rocket have to be redesigned. This leads into a tentative final design. An FMEA and H-FMEA will then be performed to analyze the potential failure modes of this design. Based on the results of the FMEA and H-FMEA the design may require updating. This leads into the final design, bill of materials, and cost analysis.

7.3 Design Implementation

Once the design is finalized, orders will be placed for components of the rocket. Our team will place these orders before the end of the Fall semester. When the components of the rocket are received the team can begin assembly and payload integration.

7.4 Test and Revise

The recovery system, data acquisition, and the experiment will require strenuous ground testing. Additional orders can then be placed if required for better operation of a rocket subsystem. Once all subsystems are performing nominally, a verification launch will be performed, and modifications to the design will be made if necessary.

7.5 Competition Deadlines

- Project Entry Form
- 1^{st} Progress Update
- 2^{nd} Progress Update
- 3^{rd} Progress Update
- Project Technical Report
- Poster Session Materials
- School Participation Letter
- SAC NMSA Waiver and Release of Liability Form
- SAC ESRA Waiver and Release of Liability Form
- IREC Consent to Limited PII Release Form
- Competition (June 20-24, 2017 in Las Cruces, New Mexico)

8. Conclusion

Sounding rockets have been used for the majority of the last century to further scientific knowledge and engineering goals. It is the aim of Team 24 to continue this by creating a sounding rocket capable of reaching 10,000 ft AGL while performing a scientific or engineering experiment safely. To achieve this goal it is imperative that we focus on the stability, reliability, and avionics package of our rocket. These features will maximize the scientific usefulness of the final product as well as emphasize the importance of safety to this group. Design of the overall system will happen in 4 general steps: pre-design, launch vehicle design, payload integration, and finally, verification and validation. Each of these steps contain the most pertinent requirements to proceed to the next. It is the goal of Team 24 that by completing each step, the final product will be adequate for the competition and provide useful scientific data.

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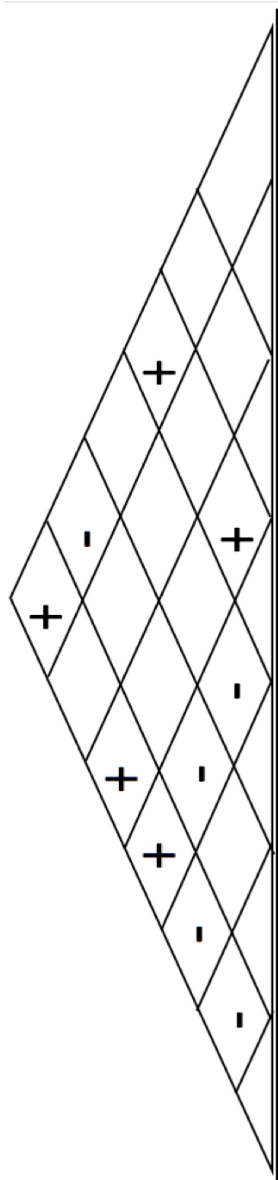
Appendix A



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

	Stability	Rocket Weight	Total Impulse	Reliability	Scientific Value	Material Strength	Avionics
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

Figure 17: House of Quality comparing Engineering Values with Requirements

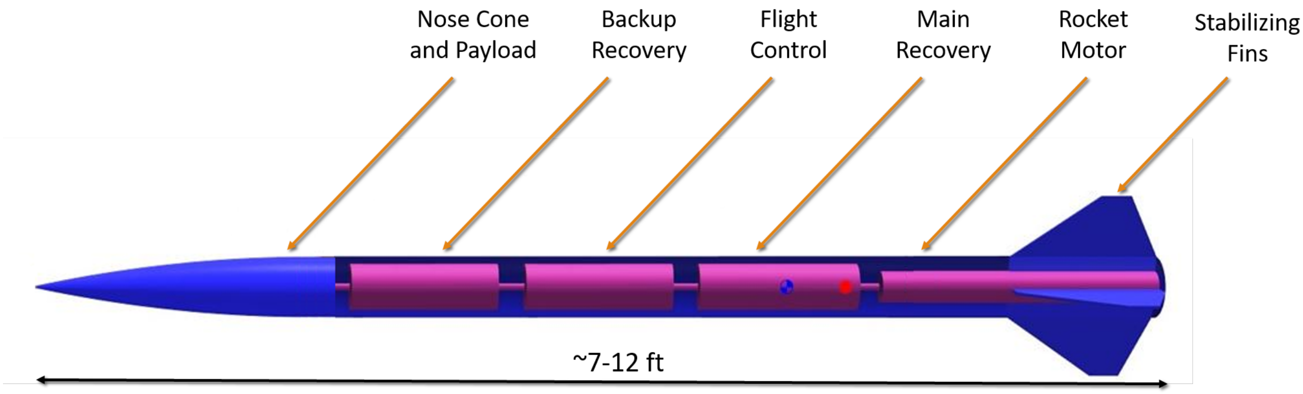


Figure 18: Rocket Subsystems in their approximate location.[4]

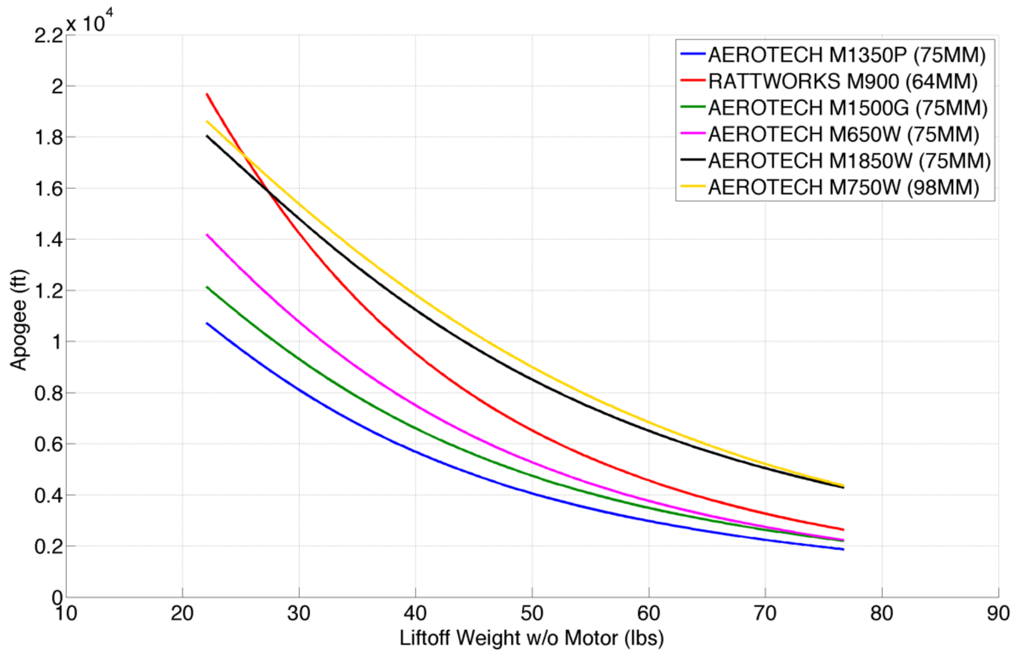


Figure 19: Flight apogee based on weight of rocket for six motors.

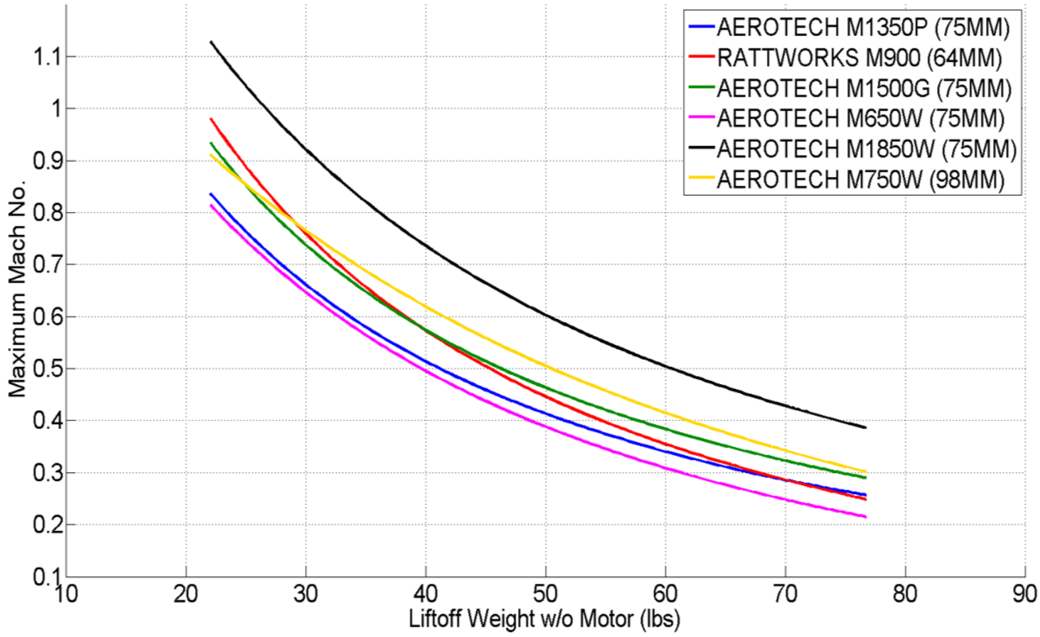


Figure 20: Maximum Theoretical Mach speed based on weight of rocket for six motors.

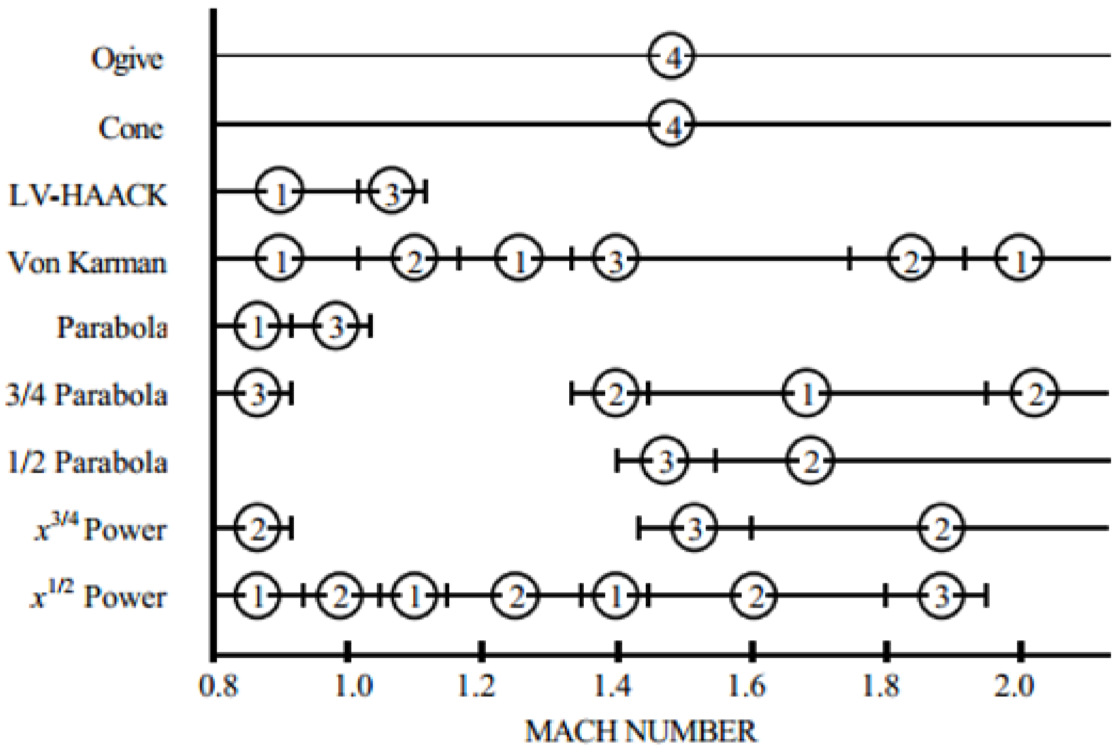


Figure 21: Nose cone profile as a function of mach number.[5]
1-ideal 2-good 3-acceptable 4-unacceptable

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 22: Pugh Selection Matrix for Recovery System

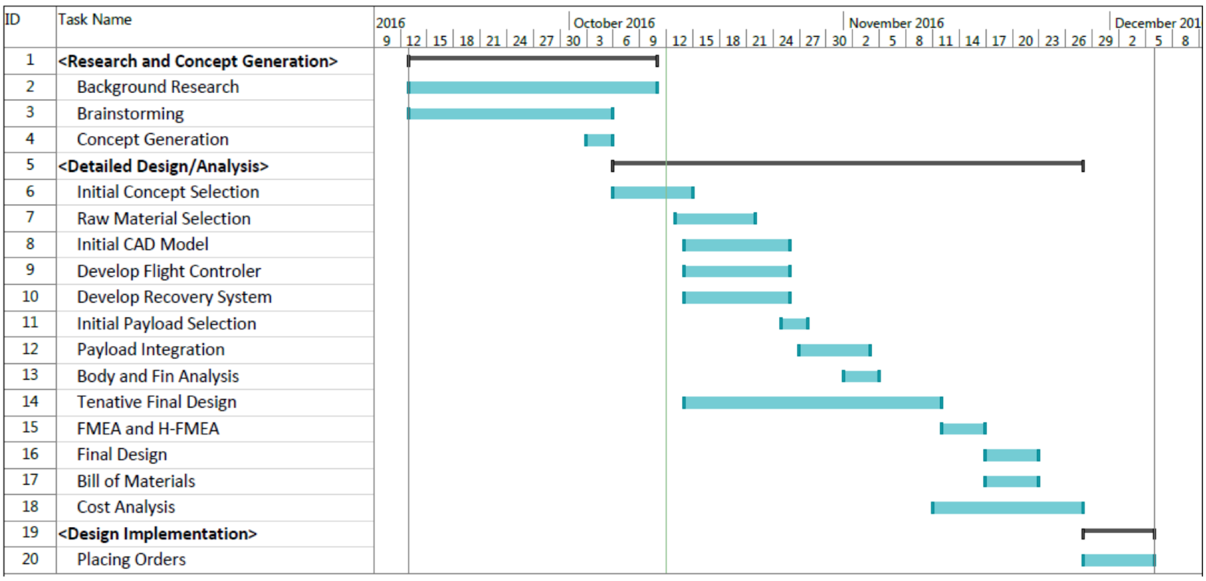


Figure 23: Gantt Chart for Fall 2016

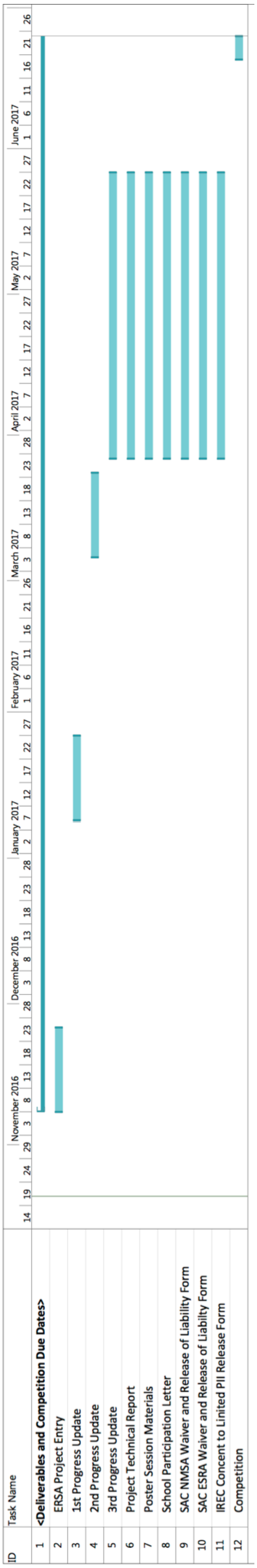


Figure 24: Gantt Chart for Competition Deadlines

Biography

Tariq Grant - Tariq is a Florida State University student in his senior year of Mechanical Engineering. He is currently a research volunteer at the Center for Intelligent Systems, Controls, and Robotics. Tariq is also the President of the American Institute of Aeronautics and Astronautics student organization at the FAMU-FSU College of Engineering.

Alexandra Mire - Alex is a Florida State University Mechanical Engineering student. For the past two summers, she has had summer internships with Jacobs Technology in the Kennedy Space Center. She is a member of the American Society of Mechanical Engineers and FSU's Flying High Circus.

Brandon Gusto - Brandon is a double major in mechanical engineering and applied mathematics at FSU. He is interested in the development of computational fluid dynamics algorithms in the field of aerospace engineering. He spent his most recent summer at the Los Alamos National Laboratory where he worked on parallelizing shock hydrodynamics codes.

William Pohle - William Pohle is a senior Mechanical Engineering student at the FAMU-FSU College Of Engineering. He spent his last summer in Indiana working for Norfolk Southern resolving repair issues and train derailments. Previously William has volunteered his time at the High Performance Materials Institute in Tallahassee where he helped develop a new composite material.