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Team 07: Hybrid Rocket Competition

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Abstract

As part of the NASA Florida Space Grant Consortium (FSGC) Hybrid Rocket Competition, the FAMU-FSU Boosters team from the FAMU-FSU College of Engineering are competing to build a rocket using a hybrid motor to achieve a maximum altitude of 2,000 feet. The Boosters team is participating in this competition to put all their learned academic engineering knowledge together and apply it to create a rocket to compete with other universities and community colleges. Other objectives of the competition include successful completion of a proposal submission, bi-weekly progress reports, a Failure Modes & Effects Analysis (FMEA) and an Engineering Notebook containing software simulations and collected data. To meet the objectives mentioned above, the team has set forth the following goals: design the rocket, build and test prototypes, and revise the design to create a final hybrid rocket to compete in the NASA FSGC Hybrid Rocket Competition. We aim to demonstrate that an innovative rocket design, that meets all competition requirements, is achievable by the FAMU-FSU Boosters and other College of Engineering senior design or student groups such as AIAA in the future by winning the competition.

Acknowledgement

These remarks thanks those that helped you complete your senior design project. Especially those who have sponsored the project, provided mentorship advice, and materials. 4

- Paragraph 1 thank sponsor!
- Paragraph 2 thank advisors.
- Paragraph 3 thank those that provided you materials and resources.
- Paragraph 4 thank anyone else who helped you.

Table of Contents

List of Tables

List of Figures

Notation

AIAA	American Institute of Aeronautics and Astronautics
FSGC	Florida Space Grant Consortium
NEFAR	North East Florida Association of Rocketry

Chapter One: EML 4551C

1.1 Project Scope

1.1.1 Description

Develop a hybrid rocket capable of reaching an altitude of two thousand feet from launch.

1.1.2 Key Goals

1. Build and test a prototype of rocket.
2. Finalize design for competition.
3. Achieve altitude of as close to two thousand feet as possible.
4. Win the NASA Hybrid Rocket Competition.
5. Lay the groundwork for future aerospace competitions for the FAMU-FSU COE.

1.1.3 Assumptions

- Proposal for FSGC Hybrid Rocket Competition is accepted.
- Funding request is granted.
- Fuel sources/motor are able to be housed by FAMU-FSU COE.
- Final design is ready for competition.
- FMEA and Hazard Analysis meets FSGC standards to gain access to competition.
- Engineering Notebook for the competition is accepted to by FSGC to be allowed to compete.

1.1.4 Markets

1.1.4.1 Primary Markets

Aerospace Industry Corporations such as NASA, SpaceX, Lockheed Martin, Boeing, Northrup Grumman, etc.

1.1.4.2 Secondary Markets

Rocket related educational and hobby groups such as AIAA, high schools and other universities participating in rocketry projects.

1.1.5 Stake Holders

NASA, Florida Space Grant Consortium (FSGC), North East Florida Association of Rocketry (NEFAR), Dr. Chiang Shih, Dr. Shayne McConomy, FAMU-FSU College of Engineering, FAMU-FSU AIAA.

1.2 Customer Needs

The NASA Florida Space Grant Consortium (FSGC) and the North East Florida Association of Rocketry (NEFAR) have sponsored a competition involving the design and launch of hybrid motor rockets. The competition has been divided into two optional categories. The first category consists of launching a hybrid rocket to the maximum altitude. The second is involves teams rocket closest to 2,000 feet in altitude; our team chose to compete in the latter.

1.2.1 Project Needs

The specifications provided for the hybrid motor rocket competition are very concise and make up the following guidelines for this project:

- The rocket will be purposed to reach apogee of 2,000 feet.
- The rocket will utilize a hybrid motor rated "G" or from a lower class.
- This translates to the rockets having a total impulse up to 160 N*s (Newton seconds).
- The rocket will be able to be fired from a distance of 300 feet from launch rails/pad.
- Both the launch rails and the firing electronics must be provided by the respective teams.
- Firing electronics incorporate at least one safety switch to prevent accidental ignition of rocket during setup.
- Launch equipment meet safety standards of the North East Florida Association of Rocketry.
- A recording barometric altimeter will record altitude data for the competition.
- The launch site should be considered zero altitude and the altimeter should be calibrated to zero.

1.2.2 Deliverable Needs

Furthermore, this competition requires various deliverables be submitted as additional documentation to the project. While these are not strictly needs pertaining to the functionality of the product, they are still required by the sponsor.

- A Failure Modes & Effects Analysis (FMEA) report will be submitted by November 17, 2017.
  - "The Hazard Analysis should focus on the handling and use of the nitrous oxide and any pyrotechnic systems or materials. The Failure Modes & Effects Analysis should focus on what kinds of things could go wrong with your launch equipment and rocket, as well as, what you have done to mitigate or reduce the identified failure modes. These reports should be no more than four text pages in length, tables and graphs are not included in page count. They should be updated and resubmitted as your designs evolve. The reports are to show that you are ready to test and fly your rockets and motors safely. Failure to submit these reports may result in your being removed from the competition."[1]
- A three to four page report will be submitted every two weeks detailing the progress of the team detailing the progress and achievements of the team.
  - The report will be submitted via PBWorks as requested by the sponsors.

- An engineering analysis notebook will be submitted by the team two weeks prior to the launch date of the competition detailing the calculations done to prepare for the physical rocket's flight.

1.3 Functional Decomposition

1.3.1 Body

- Protect other Subsystems from harm
- Store other Subsystems
- Ensure stability during flight

1.3.2 Motor

- Provide thrust to allow rocket to gain altitude
- Use solid fuel grain with liquid or gas oxidizer as fuel sources (Hybrid motor)

1.3.3 Launch System

- Rail system to point the rocket within 30 degrees of straight up
- Have a backup safety switch to prevent accidental ignition
- Capable of being launched from 300 ft away

1.3.4 Electronics

- Read from Altimeter
- Store Data
- Activate Recovery System

1.3.5 Recovery System

- Decelerate the body/motor to a safe speed before landing

1.4 Target Summary

The targets featured in the appendix allow us to quantify specific metrics as a means of measuring the success of this product.

According to the decomposition of the body, several functions must be achieved. This includes storing internal components, keeping them protected during flight, and maintaining stability. While these have respective metrics, specific targets cannot be given until a design is generated. This is due to the variance of the metrics depending on the geometry of the body.

Following this section, the motor is introduced. Ideally our motor will have a thrust of 160 N·s. This is a target that was specified by the sponsors of the competition and must be followed. With a max thrust of 160 N*s, our rocket must have a thrust time of around 3-5 seconds to to reach a peak close to 2000ft.

The electronic portion of our system must also meet certain targets, the sourcing of the current shows a target of 2 Amps (a minimum threshold) needed to be provided to a heating element to set of the parachute deployment charge. The 2 Amps are estimated for a Nichrome wire to produce enough heat to create combustion of gunpowder in the charge. The altimeter sensor is also required from the sponsor and must measure the altitude reached through pressure; this allows us to set the target of our sensor with reference to the maximum altitude, to be able to read as low as a 0.78 atm or 79.495 kPa.

A significant metric needed in the recovery system to have a good performance is the descent speed. This dictates the impact force the rocket will face and whether or not this will allow it to be reused. An ideal target for this project would be about 15 ft/s to 20 ft/s this allows the rocket to have a fairly quick descent without damaging the internals of the system.
Finally, the main metric and target of the hybrid motor rocket competition team is for the system to have an apogee of exactly 2000 ft. This makes for a very difficult goal to reach so an error metric was added as well with a value of ±50 ft. The scoring of the competition does not correlate to the bulk of our personal metrics but it was noted specifically that 80% of the points earned comes from launching and landing the rocket safely. Following this, the official point category is split into the following:

1. 100 pts for highest or closest to altitude
2. 90 pts for 2ndhighest or closest to altitude
3. 80 pts or 3rdhighest or closest to altitude
4. 70 pts for 4thhighest or closest to altitude
5. 0-10 pts for self-built motor
6. 0-5 pts for self-built rocket

1.5 Concept Generation

System	Concept Type	Concept
1. Body	1.1 Body Material	1.1.1 Thin Cardboard Body
		1.1.2 Thick Cardboard Body
		1.1.3 Blue Tube Body
		1.1.4 Fiberglass Body
	1.2 Engine Mount	1.2.1 2 Centering Rings
		1.2.2 Long Centering Rings
		1.2.3 Disc-Type Centering RIngs
2. Fins	2.1 Fin Material	2.1.1 Balsa Wood
		2.1.2 Plastic
		2.1.3 Fiber Glass
		2.1.4 Basswood
		2.1.5 Plywood
		2.1.6 3D Printed Material
	2.2 Number of Fins	2.2.1 None
		2.2.2 Two
		2.2.3 Three
		2.2.4 Four
		2.2.5 Five
	2.3 Fin Geometry	2.3.1 Elliptical
		2.3.2 Trapezoidal
		2.3.3 Square
		2.3.4 Clipped Delta
	2.4 Angle of Attack	2.4.1 0°
		2.4.2 5°
		2.4.3 10°
	2.5 Airfoil Shape	2.5.1 Teardrop
		2.5.2 Squared
		2.5.3 Tapered

3. Nose Cone	3.1 Nose Cone Shape	3.1.1 Conical
		3.1.2 Spherically blutned Cone
		3.1.3 Bi-Cone
		3.1.4 Hemispherical
		3.1.5 Parabolic
		3.1.6 Ogive
	3.2 Nose Cone Material	3.2.1 Balsa Wood
		3.2.2 Plastic
		3.2.3 3D Printed
4. Electronics	4.1 Boards	4.1.1 myRio
		4.1.2 BeagleBone Blue
		4.1.3 Arduino Uno RV3
	4.2 Altimeter	4.2.1 MPL3115A2 Altimeter
		4.2.2 BMP183 Altimeter
	4.3 Accelerometer	4.3.1 MPU-6050 Accelerometer
		4.3.2 Grove Accelerometer
	4.4 Storage Devices	4.4.1 HiLetgo Stackable SD Card Shield
5. Recovery System	5.1 Rocket Recovery	5.1.1 Parachutes
	5.2 Dynamic Altitude Limiter	5.2.1 Secondary Parachutes
		5.2.2 Retractable Fins
6. Motor	6.1 G Class	6.1.1 G-100
		6.1.2 G-130
		6.1.3 G-300
		6.1.4 G-123
		6.1.5 G-234

System 1: Body

Concept Type 1.1: Body Material

Concept 1.1.1: Thin Cardboard Body

Thin cardboard is a popular material for the body of the model rockets. It is extremely light, cheap and easy to cut. However, this is usually used for lower classes of rockets, such as classes A-D.

Figure 1.1.1 Multiple thin walled cardboard tubes to be used for rocket body.

Concept 1.1.2: Thick Cardboard Body

Thick cardboard is also a popular material for model rockets and it is relatively cheap. This material is cheap, easy to cut and paint and is moderately light. The main advantage of thick walled cardboard is that it is much stronger than thin walled cardboard. It is appropriate in use for medium class rockets, such as F and G.

Figure 1.1.2 Multiple thick walled cardboard tubes to be used for rocket body.

Concept 1.1.3: Blue Tube Body

Blue tube is quite light and is very strong. However, it is expensive and is only really necessary on larger motor applications.

Figure 1.1.3 Blue tube stock to be used for rocket body.

Concept 1.1.4: Fiberglass Body

Fiberglass tube for rocket applications is a common high performance material. This material is very light and strong, but brittle under certain loading. This material is moderately expensive.


Figure 1.1.4 Fiberglass rocket body (right) with a cardboard nose cone (left).

Concept Type 1.2: Engine Mount

Concept 1.2.1: 2 Centering Rings

The engine is in the tube body of the rocket. This needs to be held in place by engine mounts, an engine block and engine hook. The engine mount consists of a mount tube and (a) centering ring(s). This centering ring system consists of two centering rings, one towards the front on the engine mount tube and one towards the back. This method of engine mounting is easy to work with and as there are two relatively thick rings this ensures the motor is aligned with the body of the rocket. Additionally, these centering rings are moderately light.

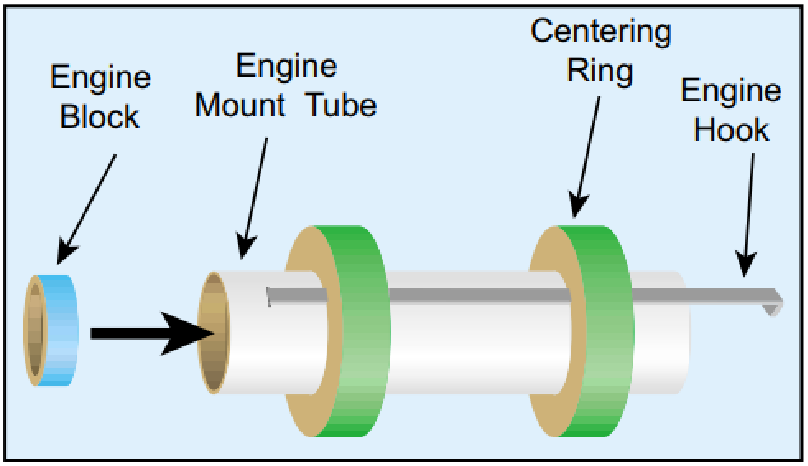

Figure 1.2.1 Two centering rings holding engine mount tube.

Concept 1.2.2: Long Centering Rings

The long centering ring is the simplest and easiest centering ring to use for the engine mounting. The centering ring must be long enough to ensure correct engine alignment. This ring is the heaviest option.

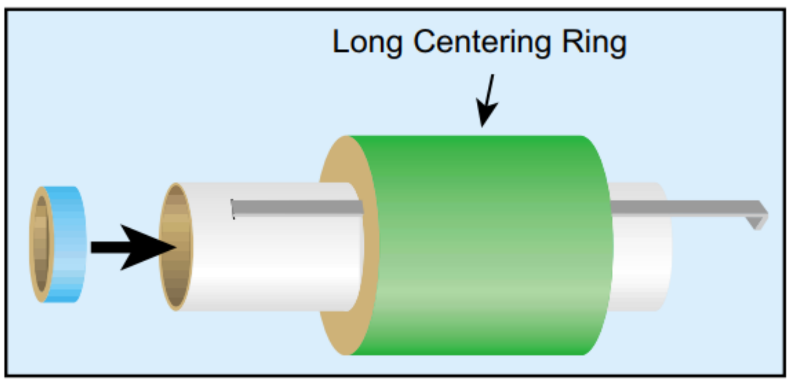

Figure 1.2.2 A long centering ring holding engine mount tube.

Concept 1.2.3: Disc-Type Centering Rings

Two disc-type centering rings can be used similarly to the two centering rings in concept 1.2.1, but the rings are replaced with the discs. The engine hook is not so highly held in place and so additional means may have to be employed to ensure stability, such as making tape. This concept is the lightest of all, but does not provide such high stability as the others and is usually employed in rockets with larger diameters.

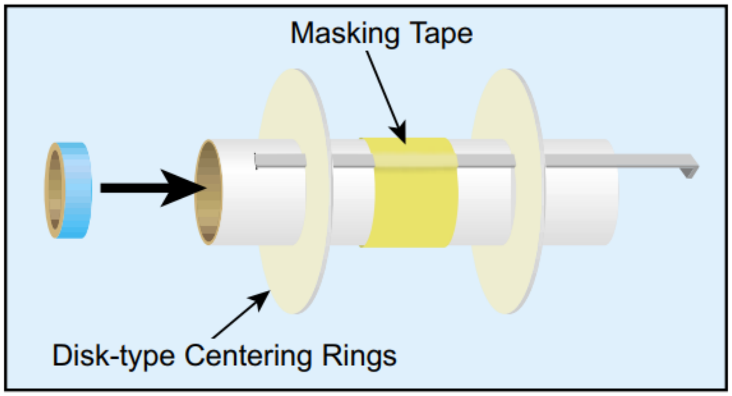

Figure 1.2.3 Disc-type centering rings holding engine mount tube.

System 2: Fins

Concept Type 2.1: Fin Material

Concept 2.1.1: Balsa Wood

This material was looked at because it is fairly cheap, lightweight and workable. This being said at high forces balsa wood is not particularly strong.

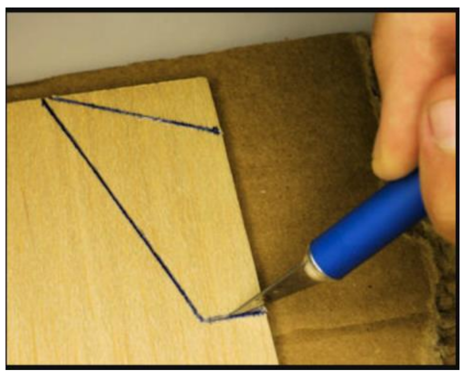

Figure 2.1.1: Balsa Wood Fins

Concept 2.1.2: Plastic

Plastic can be formed into almost any shape possible. Although it is very pliable and workable once it is set there isn't much modifying it. It is very lightweight and very cheap but isn't as strong other possibilities.

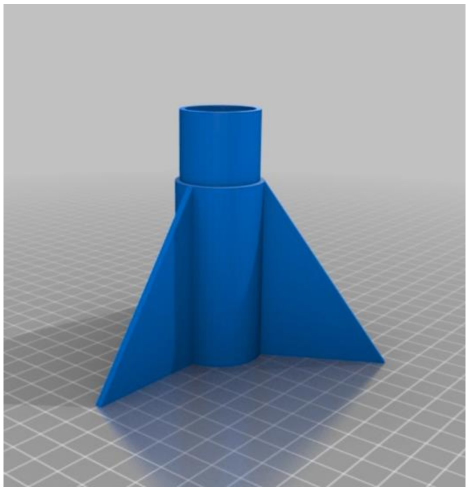
Figure 2.1.2 Plastic Fins

Concept 2.1.3: Fiberglass

Fiberglass is both very strong and lightweight but it is hard to work. It is possible to mold fiberglass into whatever shape you need to. Although this being said, fiberglass is a brittle material which won't plastically deform much before breaking.


Figure 2.1.3 Fiberglass Fins from a mold

Concept 2.1.4: Basswood

Basswood is similar to Balsa wood where it is lightweight, easily available, and workable. The main difference between Basswood and Balsa wood is that Basswood is a bit stronger and can take greater forces before deforming.

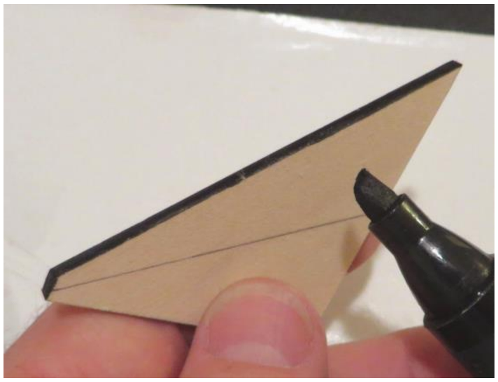
Figure 2.1.4 Basswood Fins

Concept 2.1.5: Plywood

Plywood is another type of wood which is lightweight and easily available. Unlike the other woods mentioned plywood is not nearly as workable or as strong as a solid piece of wood like Basswood or Balsa.


Figure 2.1.5 Plywood Fins

Concept 2.1.6: 3D Printed Material

3D printed material is probably the most versatile material in terms of making shaped because there aren't any shapes out of the question. It is generally pretty hard, which is good for fins. There aren't many drawbacks other than the actual process of printing it which would be out of our control anyways.

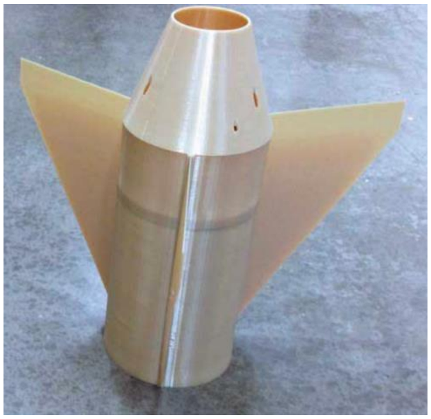

Figure 2.1.6 3D Printed Fins

Concept Type 2.2: Number of Fins

Concept 2.2.1-5

It is possible that we don't have any fins, although this would be good for the total weight of our system, it isn't ideal for stability. For the number of fins we could have anywhere from 2-5. Any number more than 6 would induce too much drag. When deciding on how many fins there should be the fewer amount of fins would cause the least amount of drag and the least amount of lift. As the number of fins increase the amount of drag, lift and weight of the whole rocket would increase as well, although so should stability.

Concept Type 2.3: Fin Geometry

Concept 2.3.1: Elliptical

The most ideal fin shape. Since the shape has less area as it gets farther from the body it induces the least amount of drag possible.

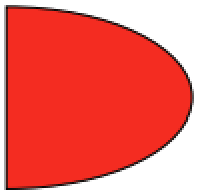

Figure 2.3.1 Elliptical Fin Shape

Concept 2.3.2: Trapezoidal

Similar to the elliptical fin the trapezoidal fin has less area towards the end of the fin creating less induced drag but since the ends are not rounded like the elliptical fin it creates more drag.

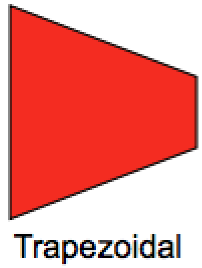

Figure 2.3.2 Trapezoidal Fin Shape

Concept 2.3.3: Rectangular

Since this design has just as much area at the edge then it does at the side where it joins to the rocket this would be the worst design. Although this may be the worst for aerodynamics it is aesthetically pleasing and the easiest to produce.

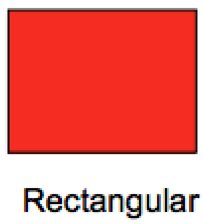

Figure 2.3.3 Rectangular Fin Shape

Concept 2.3.4: Clipped Delta

The clipped delta shape is somewhere in between the rectangular and the trapezoidal. It is both aesthetically pleasing but still has good aerodynamic qualities.

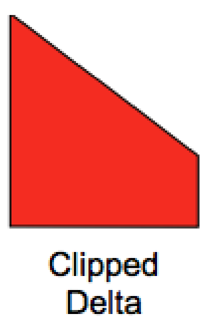

Figure 2.3.4 Clipped Delta Fin Shape

Concept Type 2.4: Angle of Attack

Concept 2.4.1: 0°

The angle of attack is the angle in which the axis of symmetry of the fin differs from the direction of the wind. This angle of attack can be 0 degrees which would create no lift and have the least amount of drag.

Concept 2.4.2: 5°

The angle of attack can be changed to 5 degrees which would create some lift from the fins, causing the rocket to spin on its longitudinal axis. This would make the rocket travel in more of a straight line due to centrifugal force. This also comes at a price because the tilted fin would also have more area facing the wind which would produce more drag.

Concept 2.4.3: 10°

The angle of attack can be changed to 10 degrees which would create even more lift and more drag than the 5 degree angle of attack.

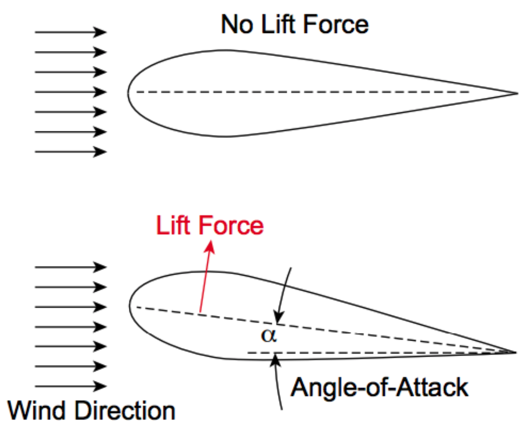

Figure 2.4 Angle of Attack

Concept Type 2.5: Airfoil Shape

Concept 2.5.1: Teardrop

The teardrop shaped airfoil is the most efficient type of airfoil that there is in the sense that it creates most amount of lift with the least amount of drag.

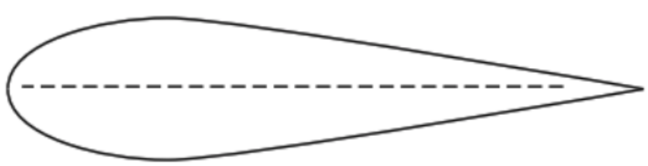
Figure 2.5.1 Teardrop Airfoil- Cross Section

Concept 2.5.2: Squared (No airfoil)

This design is the most basic design where you would not have to modify the fin. It would be the easiest to produce and the sharp corners would be aesthetically pleasing, but this is the most inefficient in the aerodynamic sense.

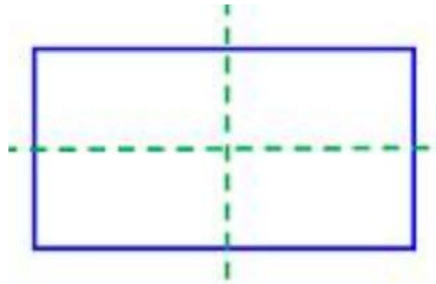

Figure 2.5.2 Squared Airfoil- Cross Sectional Area

Concept 2.5.3: Tapered

This design makes the fin root thicker than the fin tip which creates less drag. This design does make the fin thinner at the tip so it would be less likely to withstand forces at high speeds due to the thinner cross sectional area.

Figure 2.5.3 Tapered Fin Airfoil

System 3: Nose Cone

Concept Type 3.1: Nose Cone Shape

Concept 3.1.1: Conical

The nose cone can have many different shapes. This conical shaped nose cone is very simple, cheap and easy to manufacture or buy. This shape offers little of storage space in the nose cone.

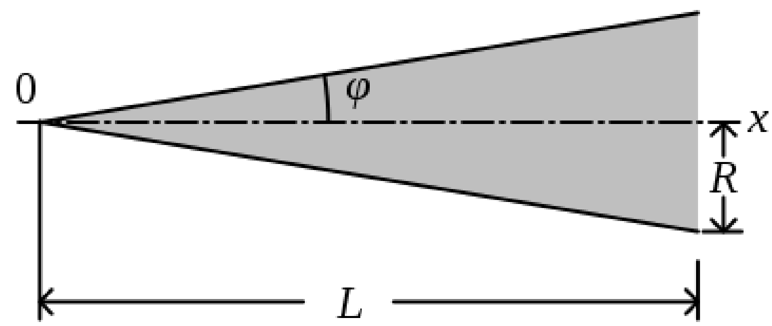

Figure 3.1.1 Cross section of nose cone in the shape of a cone.

Concept 3.1.2: Spherically Blunted Cone

The spherically blunted cone shaped nose cone is similar to the conical shaped nose cone, but has a spherical shape to the tip of the nose. This offers better aerodynamics for the rocket and promotes laminar flow over the body of the rocket. This option is slightly more expensive and is more complicated than the conical shaped nose cone.

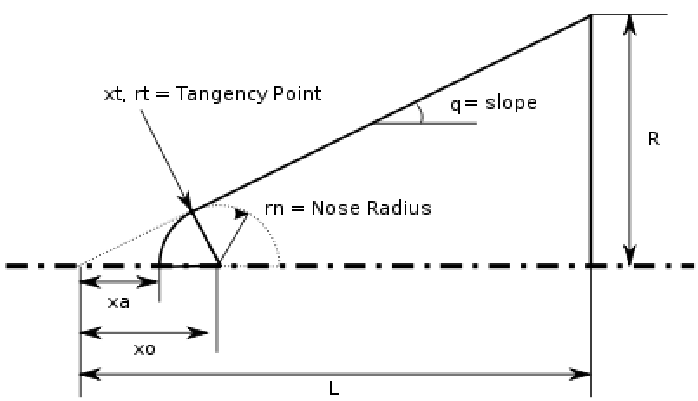

Figure 3.1.2 Cross section of nose cone in the shape of a cone with a rounded tip.

Concept 3.1.3: Bi-Cone

The bi-cone nose cone is similar to the conical shaped nose, but has an additional taper. This allows for a lighter nose cone and is better for storing larger items in the nose. This is an uncommon design for nose cones.

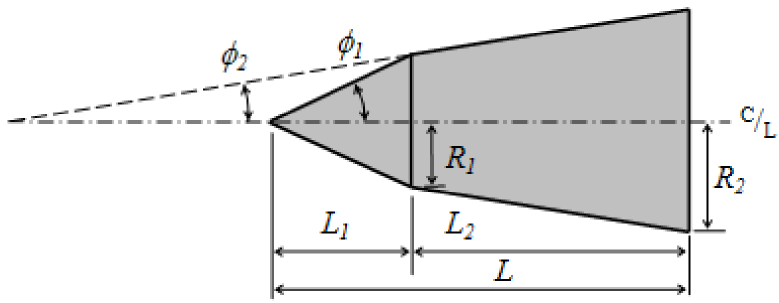

Figure 3.1.3 Cross section of nose cone in the shape of an initial and final cone with different angles/slopes.

Concept 3.1.4: Hemispherical

This nose cone consists of a straight circular tube with a hemispherical point. This shape is beneficial as it is a shorter nose cone to save weight, but also allows large payloads to be carried in the nose cone whilst remaining relatively aerodynamic.

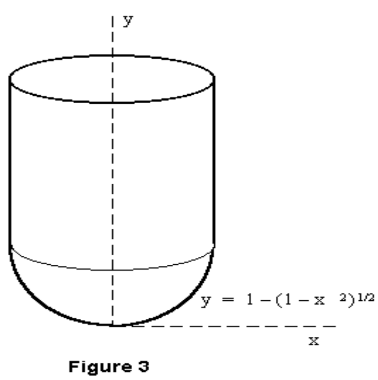

Figure 3.1.4 Nose cone with constant circular tube section with a hemispherical point..

Concept 3.1.5: Ogive

This design is similar to the hemispherical design as is allows for large payloads to be stored in the nose cone, saving weight and remaining aerodynamic. This design sacrifices aerodynamics for more storage space. To maximize this space, a smaller hemispherical-like shape is placed on top of the initial curved shape and is called the “ogive” shape.

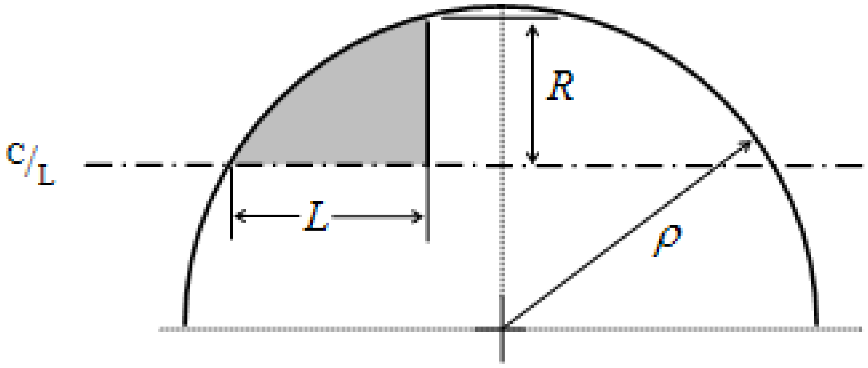

Figure 3.1.5.1 Cross section of nose cone of the Ogive shape.

Figure 3.1.5.2 Nose cone of the Ogive shape being applied on the Blue Origin spacecraft.

Concept Type 3.2: Nose Cone Material

Concept 3.2.1: Balsa Wood

Nose cones are commonly made of balsa wood in model rocketry applications. This material is very light, easy to machine and very cheap. However, balsa wood is not very strong and is difficult to hollow out and store items in.

Figure 3.2.1 Examples of different nose cones made of balsa wood.

Concept 3.2.2: Plastic

Plastic is strong, cheap and easy to buy in many different shaped nose cones. Additionally, plastic has low skin drag and will reduce drag of the rocket.

Figure 3.2.2 Nose cones made of plastic.

Concept 3.2.3: 3D Printed

3D printed nose cones have many of the same advantages as plastic nose cones that would be bought online. With a 3D printed nose cone could be made exactly to our specification, dimensions and application. A great advantage to 3D printing is that if the nose cone were to be filled the printing will automatically print in a honeycomb structure, increasing the compressive strength of the structure and saving weight. If the high range 3D printers in HPMI could be employed to make the nose cone, the resolution of the printed piece could be very high, making the piece very smooth and aerodynamic

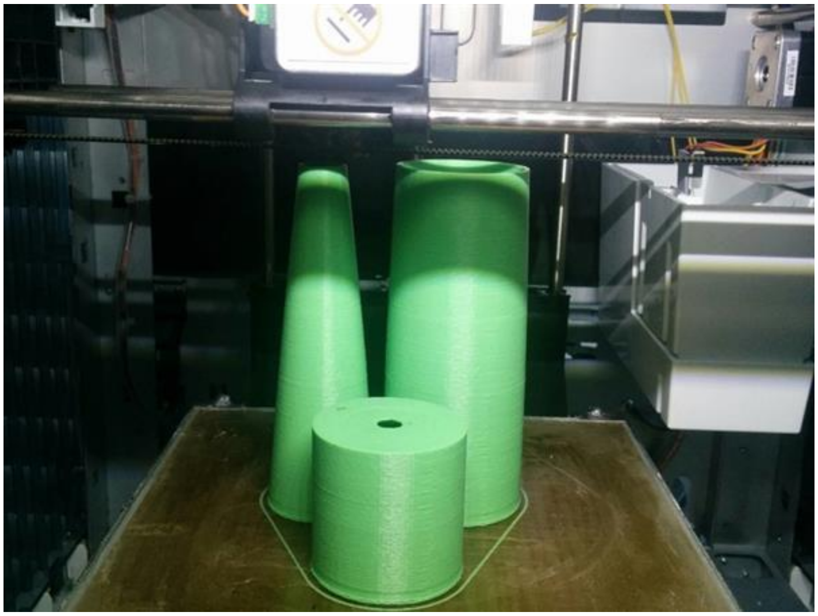

Figure 3.2.3.1 Three different nose cones being 3D printed.

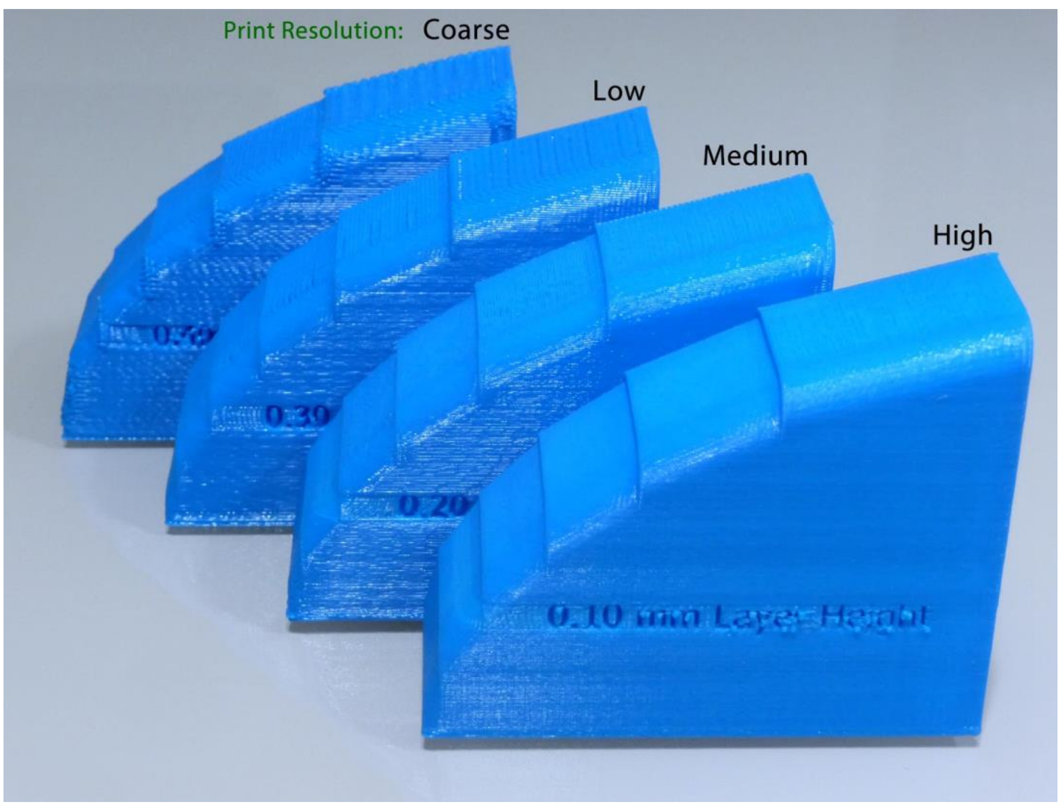

Figure 3.2.3.2 Effect of a higher or lower printing resolution.

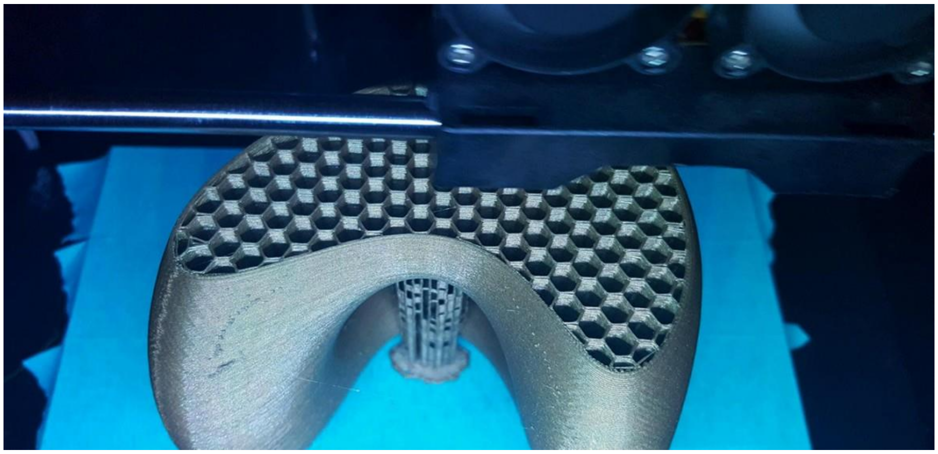

Figure 3.2.3.3 Natural honeycomb fill in a 3D printed piece.

System 4: Electronics

Concept Type 4.1: Board

Concept 4.1.1: myRIO Student Embedded Device

The myRio board is the most expensive and heaviest board; but it widely used in the industry of robotics and engineering.

Figure (4.1.1) myRio board

Concept 4.1.2: BeagleBone Blue

The BeagleBone Blue is moderately expensive board and is not widely compatible; but has greater processing power and storage.

Figure (4.1.2) BeagleBone Blue board

Concept 4.1.3: Arduino Uno RV3

The Arduino Uno is the cheapest most reliable and adaptable board on the market currently. The drawback is low processing speed and buying add-ons known as shields to increase functionality.

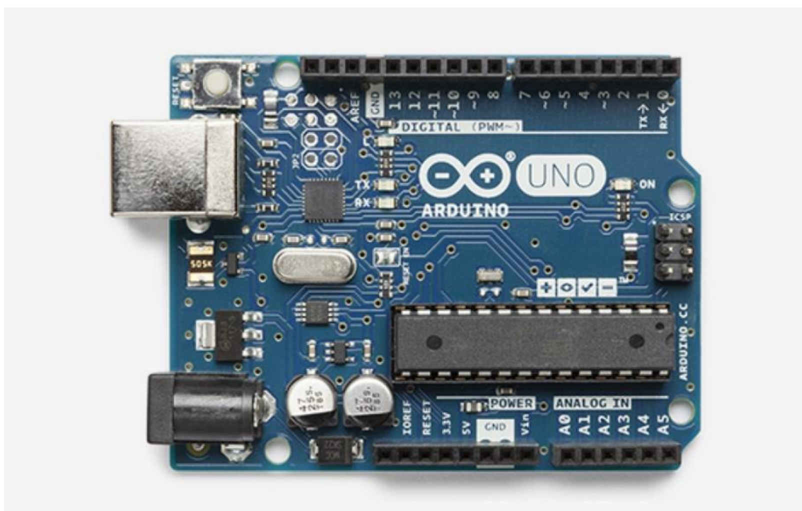

Figure (4.1.3) Arduino Uno RV3

Concept Type 4.2: Altimeter

Concept 4.2.1: MPL3115A2 - I2C Barometric Pressure/Altitude/Temperature Sensor

This sensor has compatibility for a wide range of boards and is slightly larger and heavier than other altimeters.

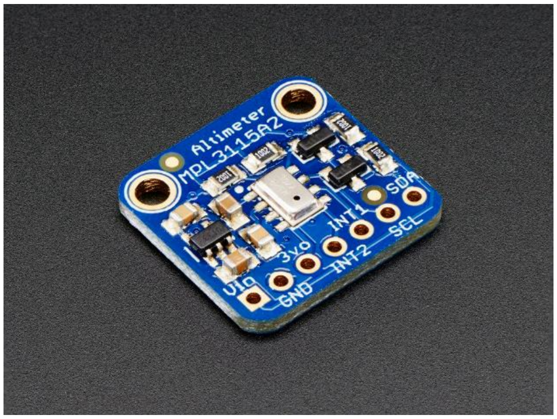

Figure (4.2.1) MPL3115A2 Altimeter

Concept 4.2.2: Adafruit BMP183 SPI Barometric Pressure & Altitude Sensor
This sensor is compatible with the arduino and is slightly smaller and lighter than other sensors.

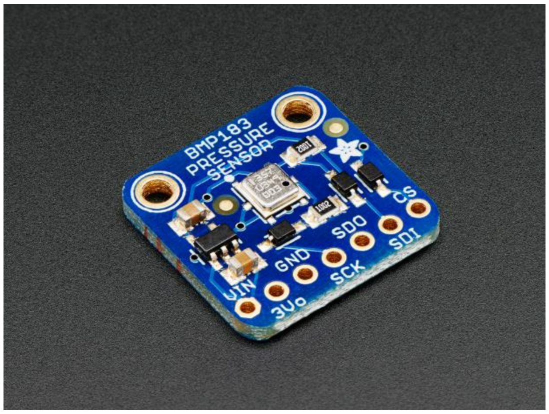

Figure (4.2.2) BMP183 Altimeter

Concept Type 4.3: Accelerometers

Concept 4.3.1: GY-521 MPU-6050 MPU6050 3 Axis Accelerometer Gyroscope Module 6 DOF 6-axis Accelerometer Gyroscope Sensor Module 16 Bit AD Converter Data Output IIC I2C

This accelerometer is compatible with most boards and has a high resolution while being low cost.

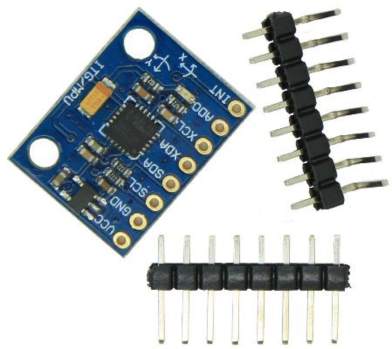

Figure (4.3.1) MPU-6050 Accelerometer

Concept 4.3.2: Grove - 6-Axis Accelerometer&Compass v2.0
This accelerometer is compatible with all boards and has a high resolution while being high cost.

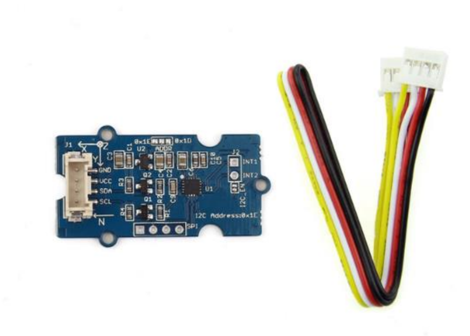

Figure (4.3.2) Grove Accelerometer

Concept Type 4.4: Storage devices
Concept 4.4.1:HiLetgo Stackable SD Card Shield for Arduino
This shield adds extra compatibility for storing data onto an SD card for Arduino products.

Figure (4.4.1) SD storage shield for Arduino

System 5: Recovery System

Concept Type 5.1: Rocket Recovery

Concept 5.1.1: Parachutes

The selection of parachutes ranges depending on the weight of the rocket and is dependent on design selection.


Figure (5.1.1) Parachute deployed on rocket

Concept Type 5.1: Dynamic Altitude Limiter

Concept 5.2.1: Secondary Parachutes

This parachute is used to slow down the rocket midflight to achieve the desired altitude. The benefit is these parachutes are cheap and reusable materials but require extra design to incorporate into the body.

Figure (5.2.1) Parachute altitude limiter concept

Concept 5.2.1: Retractable fins

The retractable fins can be used to slow the rocket the downside is increased design time and more modifications to the body.

Figure (5.2.2) Retractable Fin concept on an airplane

System 6: Motor

Concept Type 6.1: G Class

Concept 6.1.1: G-100

The G-100 motor uses PVC grains, ⅛ in injector and a slow feed nozzle. This motor was tested to have a total weight of 511 g, maximum oxidizer volume of 140 cc, burn time of 1.43 sec and a total impulse of 146 Ns.

Figure (6.1.1) 38mm motors of varying lengths

Motor Manufacture	Contrail Rockets	Test Date	14-25 Sep 05
Motor Designation	G100PVC	Certified Until	Indefinitely
TMT Metric Designation	G101 (81%)	Samples per Second	480
Metric Dimensions	38 X 406MM	Burn Time	1.43 seconds
Total Weight	511 g	Total Impulse	146 NS
Recovery Weight	499 g	Maximum Thrust	230 N
Fuel Grain Weight	93 g	Average Thrust	101 N
Nitrous Oxide Volume	140cc		

Figure (6.1.2) G-100 Test Data

Concept 6.1.2: G-130

The G-130 motor uses PVC grain, 3/16 in injector and a medium feed nozzle. This motor was tested to have a total weight of 516 g, maximum oxidizer volume of 140cc, burn time of 0.86 sec and a total impulse of 100Ns.

Motor Manufacture	Contrail Rockets	Test Date	24-25 Sep 05
Motor Designation	G130PVC	Certified Until	Indefinitely
TMT Metric Designation	G115 (24%)	Samples per Second	480
Metric Dimensions	38 X 406MM	Burn Time	.86 seconds
Total Weight	516 g	Total Impulse	100 NS
Recovery Weight	505 g	Maximum Thrust	706 N
Fuel Grain Weight	93 g	Average Thrust	130 N
Nitrous Oxide Volume	140cc		

Figure (6.1.3) G-130 Test Data

Concept 6.1.3: G-300

The G-300 motor uses PVC grain, ¼ in injector and a fast feed nozzle. This motor was tested to have a total weight of 535 g, maximum oxidizer volume of 90 cc, burn time of 0.25 sec and a total impulse of 100 Ns.

Motor Manufacture	Contrail Rockets	Test Date	5-6 Nov 05
Motor Designation	G300PVC	Certified Until	Indefinitely
TMT Metric Designation	G288 (24%)	Samples per Second	480
Metric Dimensions	38 X 406 MM	Burn Time	.25 seconds
Total Weight	535 g	Total Impulse	100 NS
Recovery Weight	498 g	Maximum Thrust	689 N
Fuel Grain Weight	125 g	Average Thrust	288 N
Nitrous Oxide Volume	90 cc		

Figure (6.1.3) G-300 Test Data

Concept 6.1.4: G-123

The G-123 motor uses HP grain, ⅛ in injector and a slow feed nozzle. This motor was tested to have a total weight of 511 g, maximum oxidizer volume of 140 cc, burn time of 1.15 sec and a total impulse of 142 Ns.

Motor Manufacture	Contrail Rockets	Test Date	24-25 Sep 05
Motor Designation	G123HP	Certified Until	Indefinitely
TMT Metric Designation	G123 (76%)	Samples per Second	480
Metric Dimensions	38 X 406MM	Burn Time	1.15 seconds
Total Weight	511 g	Total Impulse	142 NS
Recovery Weight	499 g	Maximum Thrust	413 N
Fuel Grain Weight	83 g	Average Thrust	123 N
Nitrous Oxide Volume	140cc		

Figure (6.1.4) G-123 Test Data

Concept 6.1.5: G-234

The G-234 motor uses HP grain, ¼ in injector and a fast feed nozzle. Thise motor was tested to have a total weight of 544 g, maximum oxidizer volume of 90 cc, burn time of 0.53 sec and a total impulse of 117.95 Ns

Motor Manufacture	Contrail Rockets	Test Date	28-29 Jan 06
Motor Designation	G234HP	Certified Until	Indefinitely
TMT Metric Designation	G221 (47%)	Samples per Second	480
Metric Dimensions	38 X 414 MM	Burn Time	.53 seconds
Total Weight	544 g	Total Impulse	117.95 NS
Recovery Weight	498 g	Maximum Thrust	606.5 N
Fuel Grain Weight	110 G	Average Thrust	221 N
Nitrous Oxide Volume	90 cc		

Figure (6.1.5) G-234 Test Data

1.6 Concept Selection

Concept selection for the rocket design was completed using tools such as the House of Qualities and Pugh Matrix. By focusing initially on creating a house of quality, component selection was narrowed down based on engineering parameters and their respective influence on the system as a whole. Following this, we utilized the Pugh matrix to compare various components to a reference product: The Apogee "G-Force" Rocket. The G-Force rocket is an industry standard model rocket that is readily available on the market. Project needs were selected using the G-Force rocket as a reference or datum of an effective design as the G-Force rocket is designed for and commonly used in G class motor competitions. We originally tried employing a House of Quality, but determined that it wasn't feasible for every single component and subsystem. However, it was useful in determining parameters for various parts of the rocket and the relationships between them. Below is an example of a house of quality for the entire rocket. Pugh Matrices were then used for the concept selection; information is presented in the format of the following: what design parameters are impactful for the subsection, the Pugh Matrix for that subsection and then which design was selected (bolded and highlighted in green) and reasoning for the selection.

Nearly all concepts are affected by the design parameters: cost and fire resistance. The cost of components for the rocket is relatively minimal compared to the overall budget funding this project. Therefore, whilst cost is an important design parameter to consider during concept selection, it does not have as much weight as others such as durability, drag, etc. The same applies for fire resistance; fire resistance is an important factor in a material in the unlikely event of a fire, but this is very unlikely to occur and therefore fire resistance does not have a lot of impact in the selection process.

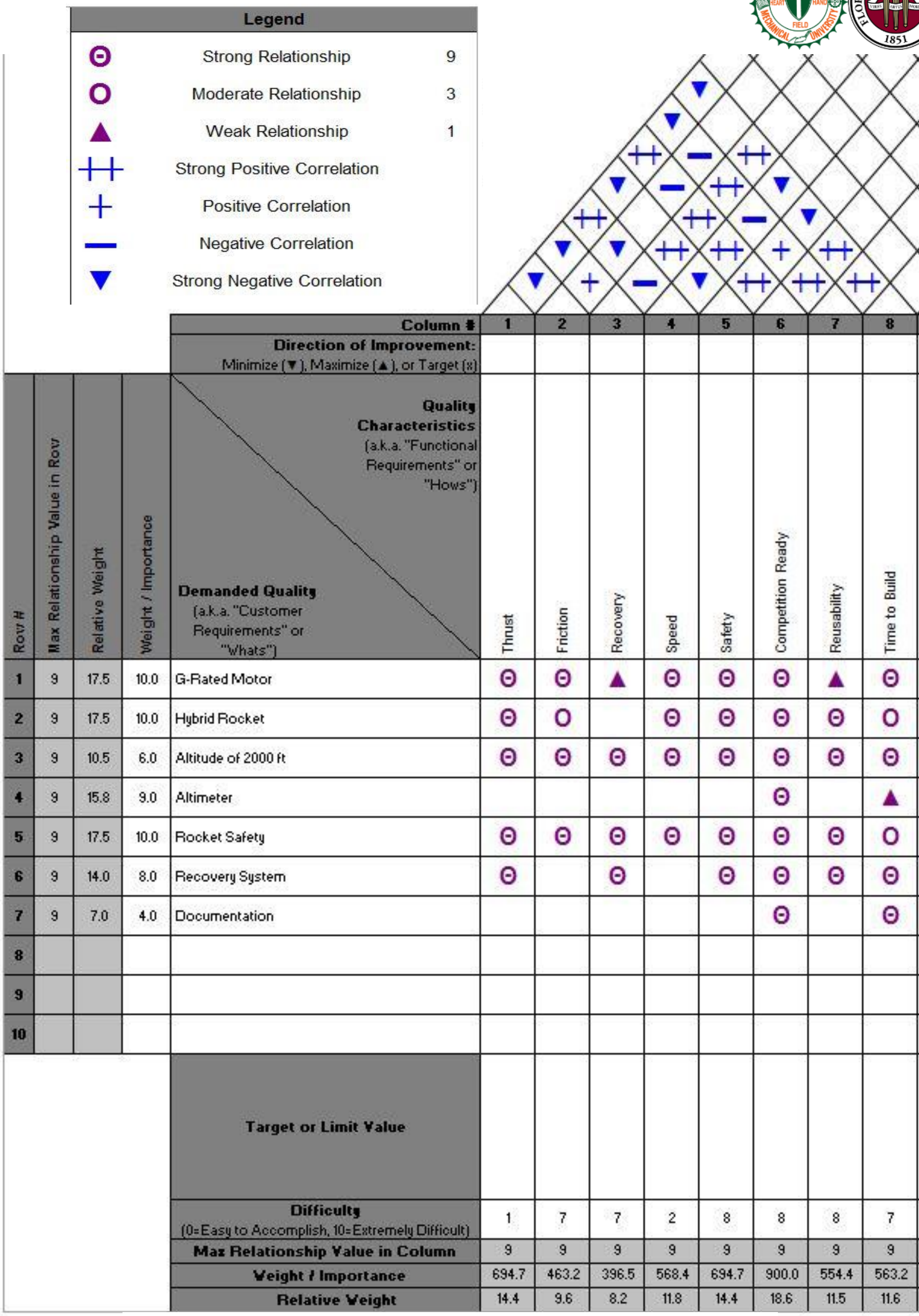

Figure 7. House of Quality applied to the entire rocket.

1. Body

The body of the rocket is what houses all the components and keeps the rocket together. During concept selection we looked at various body materials and different engine mounting styles would be the most beneficial.

1.1 Body Material

The body of our rocket can be made from numerous different materials, including Blue Tube, Fiberglass, etc. These were all considered and weighed against the body material used in the G-Force rocket which uses a thin cardboard as its body material. Therefore concept 1.1.1, thin cardboard body material is equivalent to the G-Force rocket and is given ratings of 0. It is important for the material of the rocket to be durable to sustain forces during flight and experience as little skin drag as possible.

Table 1.1

Pugh Matrix of different body materials referencing thin cardboard of the G-Force rocket.

Body Material					
Design Parameters	Datum	Concepts			
	G-Force	1.1.1	1.1.2	**1.1.3**	1.1.4
Durability	0	0	1	1	1
Fire Resistance	0	0	0	1	1
Friction coefficient	0	0	0	1	1
Cost	0	0	-1	-1	-1
Total	**0**	**0**	**0**	**2**	**2**

Concept selected: **1.1.3** – Blue Tube

We selected the blue tube as our body material after checking the Pugh Matrix and recognizing it was tied for first with fiberglass. We then compared other qualities of both components the ability to manufacture our own body with fiberglass for example. In the end, we decided that it would be cheap enough to order custom sized bodies that we could machine rather easily. If it proves to be unsuitable for prototyping we can iterate a body design with fiberglass.

1.2 Engine Mount

The engine mounts are a crucial component are they hold in place the motor during firing and must withstand high forces during launch. The durability and the reliability of the engine mount is very important because if a failure occurs in the mounting system (misalignment or slip) then the rocket's trajectory will be significantly altered and could result in a critical failure.

Engine Mount				
Design Parameters	Datum	Concepts		
	G-Force	1.2.1	1.2.2.	1.2.3
Durability	0	0	1	0
Fire Resistance	0	0	0	0
Reliability	0	1	-1	0
Cost	0	0	-1	0
Total	**0**	**1**	**-1**	**0**

Concept selected: 1.2.1 – Two Centering Rings

We selected the two centering rings because it is the lightest method while also keeping the stability of the one long stability ring. Additionally, our rocket body having an approximate inside diameter of 2.3 inches was not large enough to employ disc type centering rings.

2. Fins

The fins of the rocket provide stability during flight to ensure that the rocket stays to its trajectory. There are many different variations of fins to choose from; it is important that they are composed of the right material and have the optimal orientation, shape and geometry.

2.1 Fin Material

We thought of 6 different materials for the fins to be made from. When selecting a fin material, like the body material, it is important to consider durability and the drag it will induce during flight. Unlike the body, the fins would most likely be designed and manufactured by us and so manufacturability comes in to play.

Fin Material							
Design Parameters	Datum	Concepts					
	G-Force	2.1.1	2.1.2	2.1.3	2.1.4	2.1.5	**2.1.6**
Durability	0	-1	0	1	-1	-1	1
Fire Resistance	0	-1	0	1	-1	-1	0
Cost	0	1	0	-1	1	1	-1
Drag	0	-1	0	0	-1	-1	-1
Manufacturability	0	1	0	-1	1	1	1
Total	**0**	**-1**	**0**	**0**	**-1**	**-1**	**0**

Concept selected: **2.1.6** – 3D Printed Fin Material

A 3D Printed material for the fins was selected as it scored well on the Pugh Matrix and utilizing 3D printing technique allows for the design of a specific airfoil shape.

2.2 Number of Fins

Selecting the number of fins on our rocket is important as selecting too many will decrease the location of the center of gravity of the rocket because of the addition of relatively a lot of weight. However, selecting too few fins makes the rocket very unstable and can make the rocket very susceptible to wind altering the trajectory of the rocket.

Number of Fins		
Design Parameters	Datum	Concepts

	G-Force	2.2.1	2.2.2	2.2.3	2.2.4	2.2.5
Drag	0	1	1	0	-1	-1
Weight	0	1	1	0	-1	-1
Stability	0	-1	-1	0	1	1
Cost	0	1	1	0	-1	-1
Total	**0**	**2**	**2**	**0**	**-2**	**-2**

Concept selected: **2.2.3** – 3 Fins

Based on the Pugh matrix there was no large advantage for the number of fins above 2. Realistically a rocket with as few as zero or two fins will be very unstable so we made a group decision to have three fins based on research we had done to compare it to other model rockets. Three fins are generally seen as having the best stability to weight and drag ratio.

2.3 Fin Geometry

The geometry of the fin alters the aerodynamics of the rocket during flight. Generally, there is the

Fin Geometry					
Design Parameters	Datum	Concepts			
	G-Force	2.3.1	2.3.2	2.3.3	2.3.4
Stability	0	-1	0	-1	0
Drag	0	1	-1	-1	0
Manufacturability	0	1	1	1	1
Total	**0**	**1**	**0**	**-1**	**1**

Concept selected: **2.3.4** – Clipped Delta

This shape allows for an easy implementation of the airfoil design. This clipped delta shape is aerodynamic and can be easily 3D printed.

2.4 Angle of Attack

The angle of attack of the rocket fins induces a spin on the body which resists the effects of wind and increases stability.

Concept selected: **2.4.1** – Angle of Attack of 0°

We could have had an angle of attack to induce spin on the rocket but we decided that the fins themselves would be enough to keep the rocket stable. An angle of attack for the fins is usually used in larger rockets and almost never used for model rockets on the scale of our rocket and is not necessary for our application.

2.5 Airfoil shape

Airfoil shape is similar to the geometry of the fins where it affects the aerodynamics of the rocket and stability and drag must be considered during selection. Additionally, because some shapes, such as the teardrop airfoil, can be difficult to manufacture with a laser cutter when combined with the clipped delta fin geometry.

Fin Airfoil				
Design Parameters	Datum	Concepts		
	G-Force	**2.5.1**	2.5.2	2.5.3
Stability	0	0	-1	0
Drag	0	0	-1	-1
Manufacturability	0	0	1	0
Total	**0**	**0**	**-1**	**-1**

Concept selected: **2.5.1** – Teardrop Airfoil

This is the most aerodynamically efficient airfoil type. As mentioned before, this shape can be difficult to manufacture, but as we have selected 3d material to construct the fin, we can use any shape we wish.

3. Nose Cone

3.1 Nose Cone Shape

Nose Cone							
Design Parameters	Datum	Concepts					
	G-Force	3.1.1	**3.1.2**	3.1.3	3.1.4	3.1.5	3.1.6
Drag	0	-1	0	-1	-1	1	-1
Storage	0	-1	0	1	-1	0	1
Total	**0**	**-2**	**0**	**0**	**-2**	**1**	**0**

Concept selected: 3.1.2 – Spherically Blunted Cone

The overall conical shape of the nose cone is the most important part of it. We chose a spherically blunted cone because it was fairly aerodynamically efficient. It was not extremely important that we stored the recovery system in the nose cone because that could be done in the body.

3.2 Nose Cone Material

Nose Cone Material					
Design Parameters	Datum	Concepts			
	G-Force	3.2.1	3.2.2	3.2.3	
Density	0	1	0	1	
Drag	0	-1	0	0	
Manufacturability	0	1	0	1	
Durability	0	-1	0	1	
Cost	0	1	0	-1	
Total	0	1	0	2	

Concept selected: 3.2.2 – Plastic

To fit into our body tube a plastic nose cone would be the easiest to find and would be plenty strong enough to withstand forces. Along with this the overall weight could be changed simply by adding weight if it was too light.

4. Electronics

When we selected our board, we had to look for other selection points outside the Pugh Matrix and datum model rocket. This lead us to choose based on personal experience, adaptability, and compatibility with our rocket, using these parameters we came up with the Arduino Uno as our optimal board along with its accompanying HiLetGo Stackable SD Card Shield for storage. Once we selected the Arduino as our board we decided to use compatible altimeters and accelerometers which were the MPL3115A2 - I2C Barometric Pressure/Altitude/Temperature Sensor and the MPU-6050 Accelerometer + Gyro as our selections because they were specifically made for operation with an arduino board.

5. Recovery System

The only feasible option for the recovery system is a parachute for slowing the rocket down for landing. During our design process, we came up with an idea to limit the height of the rocket with an active control system that could either be retractable fins to increase drag or secondary parachutes to slow the rocket down. While both could be effective it is too early to select a concept as both control systems require prototyping and testing in wind tunnels to select one over the other or to conclude that none are needed.

6. Motor

The motor that will be purchased for this project will be the G-100 motor from Contrail Rockets. This motor was chosen for the fact that it has the longest burn time and the highest total impulse. Compared to the other motors available the G-100 is also one of the lightest motors and has one of the highest oxidizer volumes.

1.8 Spring Project Plan

Chapter Two: EML 4552C

2.1 Spring Plan

Project Plan.

Build Plan.

Appendices

Appendix A: Code of Conduct

Appendix B: Functional Decomposition

Appendix C: Target Catalog

	Metric	Target	Target Unit
Body	Impact Failure Force		N
	Drag		N
	Distance of Center of Pressure		m
Motor	Thrust	160	N·s
	Time of thrust	5-Mar	s
Electronics	Read in from altimeter	79.495	kPa
	Source current to deploy recovery system	2	A
	Store Data	10	mb
	Sampling Time	1	kHz
Launch System	Launch Cable Length	300	ft
Recovery System	Parachute Deployment Delay	5	ms
	Descent Speed	15-20	ft/s
Whole System	Apogee	2000	ft
	Maximum Error	50	ft

Appendix A:

Appendix B Figures and Tables

References

"2017-2018 Hybrid Motor High Powered Rocket Competition." *NASA Florida Space Grant Consortium* , NASA, 25 Sept. 2017, floridaspacegrant.org/programs/hybrid-motor-rocket-competition/.