The Terra Nova Project
Preliminary Design Review

NASA University Student Launch Proposal

Florida State University - Panama City
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Table of Contents

Table of Tables

Table of Figures

Acronym Bank

ATF – Bureau of Alcohol, Tabacco, Firearms and Explosives

AHJ – Authority Having Jurisdiction

CAD – Computer Aided Design

CAM – Computer Aided Manufacturing

CDR – Critical Design Review

CFR – Code of Federal Regulations

CNC – Computer Numerical Control

DDS – Digital Design Studio

FAA – Federal Aviation Administration

FMEA – Failure Modes and Effects Analysis

FRR – Flight Readiness Review

FSU – Florida State University

GCSC – Gulf Coast State College

HAUS – Habitat for Agricultural Utilization Study

HOL – Holley Building

HPR – High Powered Rocketry

ICT – In-Circuit Testing

InSPIRE - Innovation, Sustainability, and Preeminent Research & Education

LRR – Launch Readiness Review

NAR – National Association of Rocketry

NASA – National Aeronautics and Space Administration

NFPA – National Fire Protection Association

OSHA – Occupational Safety and Health Administration

PC – Panama City

PCB – Printed Circuit Board

PDF – Payload Demonstration Flight

PDR – Preliminary Design Review

PhD – Doctor of Philosophy

PLA – Polylactic Acid

PLAR – Post Launch Analysis Report

PPE – Personal Protective Equipment

RSO – Range Safety Officer

SDS – Safety Data Sheet

SEARS – SouthEast Alabama Rocketry Society

STEM – Science Technology Engineering and Math

TRA – Tripoli Rocketry Association

UAS – Unmanned Aircraft System

USLI – University Student Launch Initiative

AGL – Above Ground Level

1. Summary

Team Summary	
The Terra Nova Project	4750 Collegiate Dr. Panama City, FL 32405
Elizabeth Gildersleeve – Mentor	NAR #: 119990 HPR Certification Level: Level 2 Email: Elizabeth.gildersleeve00@gmail.com Phone: (850) -775-8483 FSU PC Mechanical Engineering Alumni
Launch Week Plans:	Planning to attend NASA Launch Week

Social Media				
Instagram	LinkedIn	YouTube	X	Facebook

Launch Vehicle Summary				
Primary Motor	Secondary Motor	HAUS Section Weight	Avionics Section Weight	Propulsion Section Weight
L2200G-0	L1420P-R	16.375 lb.	16.438 lb.	Wet: 24.375 lb. Dry: 19.375 lb.
Drogue Parachute	Main Parachute	Altimeter	Black Powder	CO_2 Canisters
Fruity Chutes 15” Compact Elliptical16.375 Parachute	120” Fruity Chutes Iris Ultra 120” Compact Parachute	Egg Timer Proton	Estimated < 0.1g. Charges Located In Avionics Bay.	16 oz CO_2 Canisters. 2 for Each Separation, 2 for Redundancy.
Proj. Descent Rate (Landing)	Drogue	Reefed Main	Full Main	Reefing-Line Cutter
15.9 ft/s	Deployment at Apogee. 154 ft/s Descent Rate.	Deployment at 1500 ft.	Deployment at 600 ft.	No Energetics Used.

Payload

The payload of the Terra Nova Project is the Terra Inquisitor meaning earth investigator. The Terra Inquisitor’s experiment is to autonomously deploy from the mechanically separated HAUS section of the rocket, collect a minimum soil sample size of 60ml, and test that sample for pH. The testing data will be logged with proper timestamps for the conducted experiment.

2. Changes Since Proposal

2.1. Launch Vehicle Design and Systems

Multiple changes have been made to both the design and systems of the launch vehicle, including overall dimensions, separation locations, location of the Living Quarters for the STEMnauts, shock cord design, and main parachute deployment.

Shock Cord

In the first deliverable, the concept of a Kevlar-elastic shock cord was proposed as a method to mitigate the peak forces caused by deceleration during deployment. While a specific cord method has not been chosen (pending results of cord material testing), the initial idea is under further review. An alternative option has been presented via the 1200lb TS Paramax paracord sold by the Paracord Store. Should the testing of this cord prove it to be a suitable option for the shock cord, its simplicity would be more beneficial than the initially proposed Kevlar-elastic hybrid shock cord.

Main Parachute Deployment

In the proposal, the concept of using a pilot parachute to lessen the exerted force during deployment of the main was proposed. This is a good option, but a better one was found with the use of a reefing line on the main to control the main parachute's effective area. This method will achieve a similar result in terms of drag force, since it is primarily a function of area. The difference between these two methods is that reefing the main parachute achieves the same effect but only uses a single parachute. The use of two parachutes in series posed the logistical challenge of properly packing them in a way that would not cause interference or tangling, while also adding another subsystem to control their sequential deployment. While the reefed parachute will also require a subsystem to cut the line, the challenge of a sequential deployment will not be posed, thus making the system as a whole more simplistic and achievable.

Primary & Secondary Motor Selections

The primary and secondary selected motors in the proposal were the L1420R-P & L2200G-0, respectively. Since then, these two motors have swapped in ranking, with the L2200G-0 being our preferred choice. Increased weight in the rocket design has caused lower overall apogee estimations, and the L2200G-0 is the best choice for our goals given this new data.

Living Quarters Location

In the proposal, the Living Quarters for the STEMnauts was in the nosecone of the Terra Nova. The primary purpose was to decrease the mass of the HAUS section of the rocket to ensure the safe landing of all sections. In addition to this, changes in overall rocket weight shifted the center of gravity, and thus the stability margin of the rocket. To mitigate this change, the habitat was moved down the rocket and is now located forward of the avionics bay, before the airframe transition.

Payload

Since the submission of the proposal the Terra Nova team has found it necessary based on the capabilities of the small team to reduce the testing scope of the Terra Inquisitor to only pH. The initial goal to test for both pH and conductivity was ambitious and beyond the capabilities of the teams limited resources. Other changes to the payload design include the design of the mechanical separation no longer being a geared rack and pinon, but instead a power screw. The power screw has the capability to be self-locking and amplifies the input torque to produce the needed separation.

Changes to Timeline

Due to the change in due date of the PDR, the overall schedule was moved back slightly. All changes were a result of this due date change, and the project is on schedule.

3. Vehicle Criteria

3.1. Selection, Design, and Rational of Launch Vehicle

3.1.1. Mission Statement

The mission of the Terra Nova Project is to design and manufacture a high-powered rocket able to successfully carry and deploy the HAUS payload, the Terra Inquisitor. The Terra Inquisitor will then collect and test a sample of soil. This will achieve be with commercially available and in-house manufactured components. The design of the recovery system is to safely reach ground level within 80 seconds of apogee. The safety of the landing is based on all individual rocket sections sustaining no more than 65 ft-lb of energy and not irreparable damages. The design and manufacturing of all recovery system components shall meet all specified safety criteria and NASA launch rules and guidelines. Custom bulkheads will be used to absorb forces imparted on the recovery system and manufactured using the new form of additive manufacturing, 3D metal printing.

3.1.2. Launch Vehicle Design and Rationale

For the creation of the optimal design for any system requires brainstorming different ways to achieve the mission and design criteria. After brainstorming, these different designs and ideas are compared and combined for the formation of the optimal design. The design of all systems in the Terra Nova rocket are based off the comparison of many different design ideas. These designs were then compared based on their unique pros and cons to achieving our mission.

The selection of the optimal component and/or material of construction of the rocket design was based on the employment of decision matrices. These matrices compare each material or component based on the particular selection criteria for each component and a weight factor associated with each criteria. The scoring was then created by multiplying the rating of the particular material for each criteria and its weight factor. All these scores are then summed up to produce the overall score. The material and/or component with the highest score will be selected for the construction of the rocket.

Technical Design Score Table 3.1	
Definition	Value
Poor	2
Fair	4
Good	6
Great	8
Excellent	10

Table 3-1 Technical Design Scoring

All designs were be based off design requirements (further outlined in 6.1 Derived Requirements) the usage of a primary ID of 6” and the usage of a Aerotech 75/5120 RMS (currently in supplies). This diameter was selected because any larger, weight and drag will become major concerns for a rocket motor that fits a 75/5120 RMS and is an L-class, any smaller and the payload design will be significantly constrained.

3.1.3. Alternate Rocket Vehicle Designs:

Nose Cone

Geometry

The primary considerations for the selection of the nose cone geometry are drag and availability. There are many different geometries to consider for the nose cone. The primary considerations include parabolic, elliptical, ogive, Von Karman, and conical. Overall, the drag forces associated do not show extreme variance for speeds below Mach 1 (1 and 3). However, there are minor differences that will affect the optimization of the rocket. These minor differences are not fully agreed upon by rocketeers. According to experimental data in “Drag of Nose Cones” by Ashley Milligan, the nose cone order from least drag to most drag is the long elliptical, parabolic, long cone, and ogive (a Von Karman was not included in the test). Though this experiment points to elliptical nose cones being the optimal design, it was limited in scope only testing each geometry at a speed of 39.28 MPH ≈ 57.6 fps. Thus, it is best to further consider other data and calculations before the determination of the nose cone geometry. According to calculations from “TR-11 Model Rocket Technical Report” by Dr Gregorek the ogive nose cone would outperform the conical for velocities below Mach 1. The other nose cone shapes were not included in Dr Gregorek’s report. Due to the variance in the data concerning the optimal nose cone geometry, the selection of the nose cone will be primarily based on commercial availability, weight, and cost. No elliptical nose cones were found commercially available for a 6” ID. Ogive and conical were available on multiple rocketry sites including Madcow Rocketry, Wildman Rocketry, and LOC 40 Precision. The Von Karman was only found available on Wildman Rocketry. Due to the larger availability and the direct calculations comparing conical to ogive conducted by Dr Gregorek, the ogive nose cone will be used for the design of the Terra Nova. The nose cone will have a fineness ration of 4:1 due to no commercially available smaller ratio.

Material of Construction and Cost

The decision matrix used to evaluate nose cone materials (Table 3-2) incorporated scores calculated by the multiplication of the criteria weight and the rating of the material. The ratings are based on a scale of 10 out of 10; the material that performs the best will receive a rating of 10. All other material scores for the particular criteria were rated relative to the best. In the event of all material ratings tie for a particular category, the rating for all will be 10.

4:1 Ogive Nose Cone			Fiberglass			Carbon Fiber		
Criteria	Weight	Parameter	Magnitude	Rating	Score	Magnitude	Rating	Score
Cost	.25	USD	191	10	2.5	239	7	1.75
Strength	.3	ksi	80.6	9	2.7	87.0	10	3
Density	.25	$\frac{lb}{in^3}$	.0650	9	2.25	.0578	10	2.5
Handling Safety	.2	Safety Score	6	10	2	6	10	2
Overall Score:					9.45			9.25

Table 3-2 Ogive Nose Cone Material Decision Matrix

Cost is the price of the component in USD. Cost was taken into consideration as a criteria due to the need to keep the overall cost of the vehicle low. Thus, the weighing factor for cost is 25%. Rating for this criteria was based on the lowest cost being optimal and so receiving a rating of 10.

Strength is the maximum strength in ksi the material can withstand in uniaxial tension. Strength was taken into consideration as a material criteria due the nose cone needing to withstand all the forces of flight and the impact of landing. If the nose cone material were to fail, the rocket would be considered unrecoverable. Hence, the weighing factor for material strength is 30%. Rating for this criteria was based on the highest strength material being considered optimal and thus receiving a score of 10.

Density is weight per unit volume of the material of construction in $\frac{\text{lb}}{\text{in}^3}$. Density was taken into consideration as a criteria due to the need to keep the overall weight of the vehicle low. This is especially true for all rocket components in the front most section of the rocket since the lower the weight the less restriction must be placed on the payload design without exceeding the impact energy requirement. Weight will also effect the center of gravity (CG) of the rocket and so effect rocket stability. Thus, the weight factor for density is 25%. Rating for this criteria was based on the lowest density being considered optimal and so receiving a rating of 10.

Boat-tailing

Justification

One of the greatest contributors to overall rocket drag is base drag. This drag is an imbalance of pressure forces at the base of the rocket that resist its motion. For a rocket the largest pressure differential is from the nose cone to the base of the rocket. This pressure differential is due to the flow separation at the aft of the rocket. This flow separation is a partial vacuum or vortex causing a wake at the base to be a low-pressure zone and thus an imbalance in pressure. Due to these factors, base drag is a function of the area at the base of the rocket and the pressure differential due to the sudden transition at the base of the rocket. According to research conducted by the authors of "SRT-2 Phoenix", base drag accounts for 35-40% of total rocket drag. They note that the incorporation of a diameter reduction has the potential to reduce this drag by nearly 60% (3). This is also corroborated in "TR-11 Model Rocket Technical Report" by Dr. Gerald Gregorek who notes that base drag can account for 30% of total rocket drag (4). Boat-tailing is a common method used to reduce the drag at the base of a rocket by reducing the diameter at the tail end of the rocket. This not only reduces the area the low-pressure wake acts upon, it also lessens flow separation and thus the decreases the pressure differential between the nose cone and base. Dr. Gregorek estimates the % reduction of drag through empirical correlations from experiments outlined in his report. Through this data, he created a figure outlining the percentage of original base drag compared to the ratio of the diameters with a transition angle less than 5 degrees (to ensure the flow will not separate along the boat-tail).

$$Diameter\ Ratio = \frac{diameter\ at\ end\ of\ boat - tail}{original\ diameter}$$

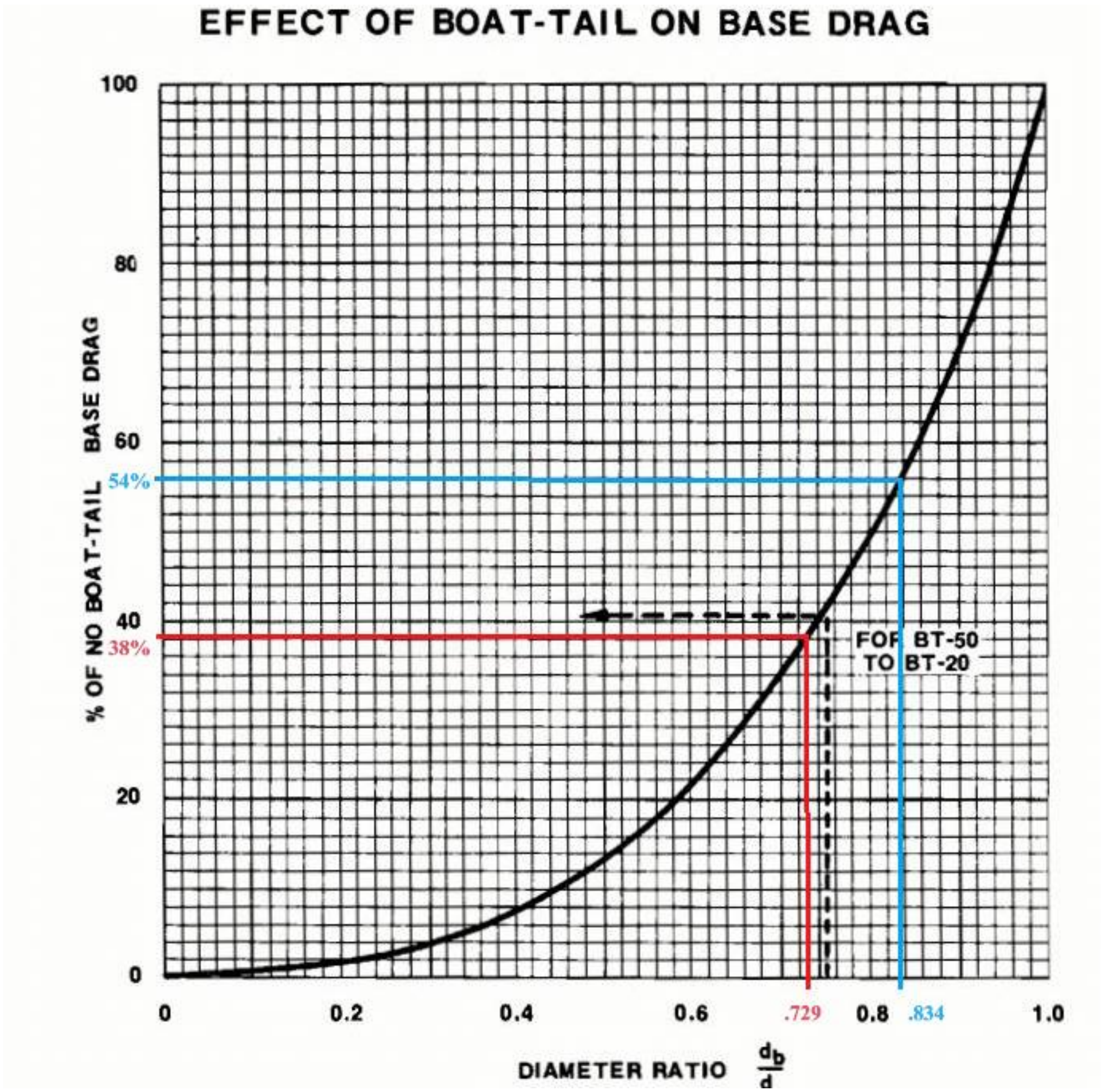


Figure 3-1 Effect of Boat-tail on Base Drag (4).

Using a boat-tail design with a of $Diameter\ ratio = \frac{5.15"}{6.17"} = .834$. According to Figure 3-1, when following the lines in blue lines, this diameter reduction equates to 54% of original base drag. Thus, by using this boat-tail design, the base drag is reduced by 46%. It is important to note that this this reduction of drag is true only for the coasting phases of rocket ascent (after motor burnout). This is due to the exhaust of the motor acting to break the low-pressure vortex attempting to form (3).

Disadvantages to boat-tailing are additional weight, cost, and fabrication time. Overall, with the significant reduction in base drag as well as the fire protection capabilities for the body of the rocket, a boat-tail will be incorporated in the design of both the full-scale and sub-scale rocket vehicles.

Material of Construction

Now that the inclusion of a boat-tail has been selected for the design of the Terra Nova's launch vehicle, the material of construction must be selected. The decision matrix used to evaluate nose cone materials (Table 3-3) incorporated scores calculated by the multiplication of the criteria weight and the rating of the material. The ratings are out of 10; the material that performs the best will receive 10 out of 10. All other material scores for the particular criteria were rated relative to the best. In the event of all material ratings tie for a particular category, the rating for all will be 10.

Boat-Tail			Fiberglass			Carbon Fiber		
Criteria	Weight	Parameter	Magnitude	Rating	Score	Magnitude	Rating	Score
Cost	.15	USD/Volume	1.10	10	1.5	11.7	4	.6
Tensile Strength	.1	ksi	80.6	5.5	.55	87.0	7	.7
Density	.25	$\frac{lb}{in^3}$	.0650	9	2.25	.0578	10	2.5
Manufacturing and Handling Safety	.15	Safety Score	6	6	.9	6	6	.9
Flame Retardant	.2	Flammability Class	B	6	1.2	B	6	1.2
Machinability/ Fabrication	.15	Experience/Available Equipment	3	3	.45	3	3	.45
Overall Score:			6.85					5.17

Boat-Tail			Inconel 718			Aluminum 6061		
Criteria	Weight	Parameter	Magnitude	Rating	Score	Magnitude	Rating	Score
Cost	.15	USD/in^3	13.5	3	.45	1.90	9	1.35
Tensile Strength	.1	ksi	139	10	1	51.6	4	.4
Density	.25	$\frac{lb}{in^3}$	.296	3	.75	.0982	8	2
Manufacturing and Handling Safety	.15	Safety Score	3	10	1.5	3	10	1.5
Flame Retardant	.2	Flammability Class	A	10	2	A	10	2
Machinability/ Formability	.15	Experience/Available Equipment	7	7	1.05	10	10	1.5
Overall Score:					6.75			8.75

Boat-Tail			Steel 1020		
Criteria	Weight	Parameter	Magnitude	Rating	Score
Cost	.15	USD/Volume	9.5	8	1.2
Tensile Strength	.1	ksi	81	6	.6
Density	.25	$\frac{\text{lb}}{\text{in}^3}$	.284	3.5	.875
Manufacturing and Handling Safety	.15	Safety Score	3	10	1.5
Flame Retardant	.2	Flammability Class	A	10	2
Machinability/ Formability	.15	Experience/Available Equipment	8	8	1.2
Overall Score:					7.375

Table 3-3 Boat-tail Material Decision Matrix

Cost is the price of the material in USD/volume. Cost was taken into consideration as a criteria due to the need to keep the overall cost of the vehicle low. Thus, the weighing factor cost is 15%. Rating for this criteria was based on the lowest cost being optimal and so receiving a rating of 10.

Tensile Strength is the maximum strength the material can withstand in uniaxial tension in ksi. Strength was taken into consideration as a material criteria due the boat-tail needing to withstand all forces of flight and the impact of landing. If the boat-tail material were to fail during the recovery of the rocket, the rocket would be considered unrecoverable. However, it is not expected that the boat-tail will be subjected to extreme forces. The greater concern for the material construction is flammability. Hence, the weighing factor for material strength is 10%. Rating for this criteria was based on the highest strength material being considered optimal and thus receiving a score of 10.

Density is weight per unit volume of the material of construction in $\frac{\text{lb}}{\text{in}^3}$. Density was taken into consideration as a criteria due to the need to keep the overall weight of the launch vehicle low. This is true for the boat-tail as its primary function is to decrease base drag. Thus, the heavier the boat-tail is the less advantage is gained by the usage of a boat-tail. The weight will also effect the center of gravity (CG) of the rocket and so effect rocket stability. Since the boat-tail is at the base of the rocket it will lower the CG and thus reduce the stability of the rocket the heavier it is. Based on all these factors, the weight factor of density is 25%. Rating for this criteria was based on the lowest density being considered optimal and so receiving a rating of 10.

Manufacturing and Handling Safety is the safety hazards from the inherent toxicity of the materials of construction and the safety of the various machines required form the material. This is measured based on the Safety scores outlined in Section 5.4.4. Safety Data Sheets (SDS): Chemicals and Materials. Safety is always an important factor for the usage of any components or materials. Thus, the weighing factors 15%. The material with the lowest safety score is considered the safest material and will receive a rating of 10.

Flame Retardant is the flammability class of the material based on classes outline in Appendix C of "Material Selection in Mechanical Design" by Michael Ashby (**Error! Reference source not found.**). Flammability of the material of the boat-tail is important due to the boat-tail being in direct contact with the exhaust of the rocket motor. Due the importance of this criteria to ensure the boat-tail does not receive permanent damage, it was weighted at 20%. The material that received the best class (A) received a rating of 10.

Machinability/Fabrication is measured by experience using the material and available equipment to form the material. This criteria was included due to the materials of construction either requiring the Terra Nova team to custom fabricate the boat-tail or to outsource the fabrication to the Terra Nova team's local machining shop, Maritech Machining Inc. Thus, the formability of the material based on previous experience, available equipment, and available equipment at Maritech Machining is important for the selection of the boat-tail material and so the weight factor is 15%. Rating for this criteria was based on the material that the Terra Nova team has the most experience with and/or Maritech is the best equipped to machine receiving a rating of 10.

Reducing Transition Airframe

Justification

There are many advantages and few disadvantages to the usage of a reducing transitional airframe. The primary disadvantage is availability and hence fabrication time. For the current set requirement of a primary ID of 6" (6.1.1 Derived Vehicle Requirements), there are no available transitions to any other diameter. Thus, the transition would need to be fabricated by the Terra Nova team.

The are four primary advantages to using a reducing transitional airframe weight reduction, streamlining/drag reduction, stability, and payload space. The weight reduction when using a transitional airframe can be calculated by summing the volumes of all body tubes from transition to the aft of the rocket and multiplying those volumes by the density of the material of construction. According to our calculations, there is a 2.2 lb reduction when using the transition. This is a significant weight reduction, but on its own it does not fully justify the usage of a transition due to time required for custom-fabrication.

In addition to the weight reduction, the addition of a transition would reduce base drag similarly to boat-tailing. This is because the underlying principle of boat-tailing is the reduction of the area at the base of the rocket. By transitioning from a 6.17" OD to a 5.15" OD with a transitioning angle less than 5 degrees, the area at the base of the rocket would be reduced and so the base drag associated would be reduced. Due to the similarity between boat-tailing and reducing transitions, Dr Gregoreks diameter ratio vs % original base drag graph can be used to estimate the reduction of the base drag. Referencing the Figure 3.1 above, with a $\text{Diameter ratio} = \frac{5.15''}{6.17''} = .834$, the reduction in base drag would equate to 54% of the original drag or 46% reduction in base drag. Combining the transition and boat-tail would achieve a $\text{Diameter ratio} = \frac{4.5}{6.17} = .729$. Following the red lines on Figure 3-1 above with the new Diameter ratio, the new base drag will be 38% of the original drag or 62% less bases drag.

Material of Construction

Based in the base drag and weight reduction capabilities of a reducing transition, it will be included in the design of the Terra Nova's launch vehicle, thus its material of construction must be selected. The decision matrix used to evaluate nose cone materials (Table 3-4) incorporates scores calculated by the multiplication of the criteria weight and the rating of the material. The ratings are out of ten; the material that performs the best will receive 10 out of 10. All other material scores for the particular criteria were rated relative to the best. In the event of all material ratings tie for a particular category, the rating for all will be 10.

Reducing Transition			Fiberglass			Carbon Fiber		
Criteria	Weight	Parameter	Magnitude	Rating	Score	Magnitude	Rating	Score
Cost	.15	$\frac{USD}{in^3}$	1.10	7	1.05	11.7	2	.3
Strength	.30	ksi	80.6	9.75	2.93	87.0	10	3.0
Density	.25	$\frac{\text{lb}}{\text{in}^3}$	.0650	6	1.5	.0578	7.5	1.13
Handling Safety	.15	Safety Score	6	5	.75	6	5	.75
Formability	.15	Experience / Available Equipment	5	5	.75	5	5	.75
Overall Score:					6.98			5.93

Reducing Transition			Creality PETG			Creality PLA		
Criteria	Weight	Parameter	Magnitude	Rating	Score	Magnitude	Rating	Score
Cost	.15	$\frac{USD}{in^3}$	.387	9.75	1.46	.370	10	1.5
Strength	.30	ksi	7.25	3.5	1.05	7.69	3.75	1.13
Density	.25	$\frac{\text{lb}}{\text{in}^3}$	.0448	10	2.5	.0452	9	2.25
Handling Safety	.15	Safety Score	2	10	1.5	2	10	1.5
Formability	.15	Experience / Available Equipment	10	10	1.5	9.5	9.5	1.35
Overall Score:					8.01			7.73

Reducing Transition			Creality PETG & Fiberglass Composite		
Criteria	Weight	Parameter	Magnitude	Rating	Score
Cost	.15	$\frac{USD}{in^3}$	.637	8.5	1.28
Strength	.30	ksi	80.6	9.75	2.93
Density	.25	$\frac{\text{lb}}{\text{in}^3}$	.0512	8.5	2.13
Handling Safety	.15	Safety Score	6	5	.75
Formability	.15	Experience / Available Equipment	7	7	1.28
Overall Score:					8.13

Table 3-4 Reducing Transition Material Decision Matrix

Cost is the price of the material in USD/in^3. Cost was taken into consideration as a criteria due to the need to keep the overall cost of the launch vehicle as low as possible. Thus, the weighing factor cost is 15%. Rating for this criteria was based on the lowest cost being optimal and so receiving a rating of 10.

Strength is the maximum strength the material can withstand in uniaxial tension in ksi. Strength was taken into consideration as a material criteria due the transition to withstand the forces during of flight and the impact of landing. If the reducing transition material were to fail during the recovery or launch of the rocket, the rocket would be considered unrecoverable and have great safety concerns. As the transition is an inherent stress concentration, is custom fabricated, and is must be able to absorb considerable energy during all stages of the rocket flight, the material strength is crucial. Also, the overall design of the transition is very constrained to the OD's of both the connecting body tubes and couplers. Thus, the overall selected material must have considerable strength. Based on all these factors, the material strength was weighted as 30%. Rating for this criteria was based on the highest strength material being considered the optimal and thus receiving a score of 10.

Density is weight per unit volume of the material of construction in $\frac{\text{lb}}{\text{in}^3}$. Density was taken into consideration as a criteria due to the overall need to keep the weight of the launch vehicle as low as possible. This allowing room for the weight of other components. The weight of the transition will also effect the center of gravity (CG) of the rocket and so effect rocket stability. Thus, the weight factor density is 25%. Rating for this criteria was based on the lowest density being considered optimal and so receiving a rating of 10.

Handling Safety is the safety hazards from the inherent toxicity of the materials of construction. This is measured based on the Safety scores outlined in Section 5.4.4. Safety Data Sheets (SDS): Chemicals and Materials. Safety is always an important factor for the usage of any components or materials. Thus, the weighing factors 15%. The material with the lowest safety score is considered the safest material and will receive a rating of 10. For composite materials, the safety rating was assumed to be the rating of the least safe material of construction.

Formability is measured by experience using the material and available equipment to form the material. This criteria was included since the Terra Nova team will be custom fabricating this reducing transition. Thus, the formability of the material based on previous experience and available equipment is important for the selection of the transition material and so the weight factor is 15%. Rating for this criteria was based on the material that the Terra Nova team has the most experience with and the most equipment to form receiving a rating of 10.

Based on all these selection criteria, the composite of Creality PETG and Fiberglass will be used as the material of construction for the transition with the highest overall score of 8.13. However, there is one important note that must be made. For this matrix, it was assumed that the tensile strength of the composite was the same as the fiberglass. To ensure this composite does have sufficient strength, the Terra Nova team will need to fabricate and test some composite samples.

Body Tubes and Couplers

No matter the rocket design, body tubes and couplers will be required. Therefore, the primary consideration for the body tubes and couplers will be the material of construction based on commercially available components. The material of construction will be assumed to be the same for both the couplers and the body tubes to ensure they are designed and fabricated to fit together.

To effectively select a material of construction a decision matrix will be employed. The decision matrix will be evaluating the available components for a 6" ID of body tube. It is important to note there was no available phenolic, pre-glassed phenolic, or cardboard tubing for both the required IDs of the Terra Nova launch vehicle design. The decision matrix used to evaluate body tube and coupler materials (Table 3-5) incorporates scores calculated by the multiplication of the criteria weight and the rating of the material. The ratings are out of ten; the material that performs the best will receive 10 out of 10. All other material scores for the particular criteria were rated relative to the best. In the event of all material ratings tie for a particular category, the rating for all will be 10.

Body Tube and Coupler			Fiberglass			Carbon Fiber		
Criteria	Weight	Parameter	Magnitude	Rating	Score	Magnitude	Rating	Score
Cost	.35	$\frac{USD}{in}$	8.26	10	3.5	18.8	4	1.4
Strength	.30	ksi	80.6	8	2.4	87.0	10	3.0
Density	.25	$\frac{\text{lb}}{\text{in}^3}$	.0650	8.5	2.13	.0578	10	2.5
Handling Safety	.10	Safety Score	6	10	1.0	6	10	1.0
Overall Score:					9.03			7.9

Table 3-5 Body Tube and Coupler Material Decision Matrix

Cost is the price of the component per linear inch or USD/in. Cost was taken into consideration as a criteria due to the need to keep the overall cost of the launch vehicle as low as possible. Since the primary components for the Terra Nova launch vehicle are the body tubes and the couplers. Minimizing the cost of the components will significantly reduce the overall cost of the launch vehicle and thus allow for the various costs of other components more niche to the design of the Terra Nova Project. The cost magnitude for the Body Tube and couplers was calculated by summing the costs of both components after each was divided by their particular lengths. All costs were obtained from the Wildman Rocketry site for a consistent comparison. Due to all these considerations, the weighing factor cost is 35%. Rating for this criteria was based on the lowest cost being optimal and so receiving a rating of 10.

Strength is the maximum strength the material can withstand in uniaxial tension in ksi. Strength was taken into consideration as a material criteria due the all body sections and couplers needing to withstand the forces during of flight and recovery. If any body tube or coupler were to fail during the recovery or launch of the rocket, not only would the rocket be considered unrecoverable, there would also be significant safety concerns. As the body tubes and couplers are the required to be the primary absorbers of the considerable energy during all stages of the rocket flight, the material strength is crucial. Based on all these factors, the material strength was weighted as 30%. Rating for this criteria was based on the highest strength material being considered optimal and thus receiving a score of 10.

Density is weight per unit volume of the material of construction in $\frac{\text{lb}}{\text{in}^3}$. Density was taken into consideration as a criteria due to the overall need to keep the weight of the launch vehicle as low as possible. The weight of the body tubes and couplers are the primary contributors to the overall weight of the launch vehicle weight. Reducing the weight of the body and couplers allows room for the weight of other components. The weight of these components will also effect the center of gravity (CG) of the rocket and so effect rocket stability. Thus, the weight factor density is 25%. Rating for this criteria was based on the lowest density being considered optimal and so receiving a rating of 10.

Handling Safety is the safety hazards from the inherent toxicity of the materials of construction. This is measured based on the Safety scores outlined in Section 5.4.4. Safety Data Sheets (SDS): Chemicals and Materials. Safety is always an important factor for the usage of any components or materials. However, since the safety factors for both materials were exactly the same, the overall relative effect of this criteria on material selection is minimal. Thus, the weighing factor is 10%. The material with the lowest safety score is considered the safest material and will receive a rating of 10.

Based on all these selection criteria, fiberglass is the selected material for the design of the body tubes and couplers with the highest score of 9.03.

Bulkheads

Bulkheads will be required for any rocket design; the primary considerations are material of construction and the particular requirements set by the Terra Nova team. Before the material can be defined, the derived requirement by the Terra Nova team is to use 3D printed bulkheads. The particular form of 3D printing being considered is metal 3D printing. Metal 3D printing is a newer form of additive manufacturing. The only material accessible to the Terra Nova team is Inconel 718. Not only is this form of manufacturing available to the team, the material is also available through Florida State University Panama City’s InSPIRE program. Through this program both the costs associated with manufacturing and inherent material costs are covered; there would be no incurred cost to the Terra Nova Project through the usage of this additive manufacturing. This design includes the testing of 3D printed Inconel 718 to ensure the material properties based the particular methodologies of printing employed by Maritech are sufficient for the Terra Nova. To further evaluate the usage of this material, a decision matrix will be employed comparing the various 3D printable materials available to the Terra Nova team. Then a comparison of the strength to weight characteristics between Inconel 718 and Aluminum 6061-T6 will be conducted to ensure the usage of Inconel does not increase the overall weight of the rocket as compared to a lighter weight metal. The decision matrix used to evaluate bulkhead materials (Table 3-6) incorporates scores calculated by the multiplication of the criteria weight and the rating of the material. The ratings are out of ten; the material that performs the best will receive 10 out of 10. All other material scores for the particular criteria were rated relative to the best. In the event of all material ratings tie for a particular category, the rating for all will be 10.

Bulkheads			Creality PETG			Creality PLA		
Criteria	Weight	Parameter	Magnitude	Rating	Score	Magnitude	Rating	Score
Cost	.25	USD/Volume	.387	2	.4	.370	2	.4
Tensile Strength	.3	ksi	2	3.5	1.05	2	3.75	1.05
Density	.3	$\frac{lb}{in^3}$	.0448	10	3	.0452	9	2.7
Handling Safety	.15	Safety Score	2	10	1.5	2	10	1.5
Overall Score:					5.95			5.65

Bulkheads			Inconel 718		
Criteria	Weight	Parameter	Magnitude	Rating	Score
Cost	.25	USD/in^3	N/A	10	2.5
Tensile Strength	.3	ksi	139	10	3
Density	.3	$\frac{lb}{in^3}$	.296	2	.6
Handling Safety	.15	Safety Score	3	8	1.2
Overall Score:					7.3

Table 3-6 Bulkhead Material Decision Matrix

Cost is the price of the material per volume or USD/in^3 of material. Cost was taken into consideration as a criteria due to the need to keep the overall cost of the launch vehicle as low as possible. Due to this, the weighing factor cost is 25%. Rating for this criteria was based on the lowest cost incurred by the Terra Nova team being optimal and so receiving a rating of 10.

Strength is the maximum strength the material can withstand in uniaxial tension in ksi. Strength was taken into consideration as a criteria since the bulkheads are the primary component that must directly absorb the forces of recovery. If any bulkhead were to fail during the recovery or launch of the rocket, not only would the rocket be considered unrecoverable, there would also be critical safety concerns. Based on all these factors, the material strength was weighted as 30%. Rating for this criteria was based on the highest strength material being considered optimal and thus receiving a score of 10.

Density is weight per unit volume of the material of construction in $\frac{\text{lb}}{\text{in}^3}$. Density was taken into consideration as a criteria due to the overall need to keep the weight of the launch vehicle as low as possible. The weight bulkheads, depending on the material of construction, can become significant contributors to the overall weight of the launch vehicle weight. Reducing the weight of the bulkheads allows room for the weight of other components. The weight of these components will also effect the center of gravity (CG) of the rocket and so effect rocket stability. Thus, the weight factor density is 25%. Rating for this criteria was based on the lowest density being considered optimal and so receiving a rating of 10.

Handling Safety is the safety hazards from the inherent toxicity of the materials of construction. This is measured based on the Safety scores outlined in Section 5.4.4. Safety Data Sheets (SDS): Chemicals and Materials. Safety is always an important factor for the usage of any components or materials. However, since the safety factors for both materials were exactly the same, the overall relative effect of this criteria on material selection is minimal. Thus, the weighing factor is 10%. The material with the lowest safety score is considered the safest material and will receive a rating of 10.

Based on all these selection criteria, Inconel 718 is the selected material for the design of the bulkheads with the highest score of 7.3.

Further justification of Inconel 718 must be provided by comparing this material to other metal lighter weight metals. This will ensure that usage of Inconel does not increase weight in comparison to the ensuring strength. Inconel 718, when un-heat-treated, has an ultimate tensile strength of 958 MPa (15), and a density of around .296 $\frac{\text{lb}}{\text{in}^3}$ (16). Aluminum 6061-T6 has an ultimate tensile strength of 260 MPa (17) and a density of around .0982 $\frac{\text{lb}}{\text{in}^3}$ (this density was calculated using the percentages of all alloying elements (17) and the densities of each element (18)). Assuming a 1in cube of material:

The strength to weight ratio of Inconel 718 = $\frac{958\ MPa\ x\ \frac{1\ ksi}{6.895\ MPa}}{.296\ \frac{\text{lb}}{\text{in}^3}\ x\ 1\ in^3} = 469\,\frac{ksi}{lb}$.

The strength to weight ratio of Aluminum 6061-T6 = $\frac{260\ MPa\ x\ \frac{1\ ksi}{6.895\ MPa}}{.0982\ \frac{\text{lb}}{\text{in}^3}\ \text{x}\ 1\ \text{in}^3} = 384\,\frac{ksi}{lb}$.

The ratio between the two materials = $\frac{469\,\frac{ksi}{lb}}{384\frac{\text{ksi}}{\text{lb}}} = 1.22$.

Based on these calculations, Inconel 718 is 1.22 times stronger per pound than a heat-treated aluminum. Therefore, using Inconel 718 for our bulkheads would reduce the overall weight of the rocket without compromising its strength.

The last consideration for the usage of Inconel 718 is whether the material should be heat-treated. Heat-treating of this material is an important consideration because of the inherent porosity of 3D printed metals for power bed fusion. Heat-treating would greatly increase the strength and isotropy of the Inconel and thus less material would be required for the same strength. However, there is shrinkage of the material. According to Maritech the Inconel can be expected to shrink by 20%. Thus, dimensional accuracy of the printed material will be a consideration when selecting heat-treated vs non-heat-treated. However, this will depend on the experimental mechanical properties determined from the research of two of the Terra Nova's team, Safety Officer Jonathan Serbest and Payload Systems Officer Case Dyer. They are engaged in a separate project to determine the mechanical properties of Inconel 718 in uniaxial tension and the more application based properties of Inconel 718 in torsion. Further details regarding this project are included in Appendix C: Additional Documentation.

Fin Design

Alternate Designs

The design and fabrication of the Terra Nova's fins is essential in ensuring a successful flight. The primary considerations for fin design is due to its effects on rocket stability, drag, and structural integrity. Stability is measured by the distance between the center of pressure (CP) and the center of gravity (CG) with the CP being below the CG for a stable rocket. It is required by HB Req. 2.3 that the stability of the rocket be above 2 Cal. There are many different fin shapes including ellipsoidal, delta, clipped delta, trapezoidal, swept, tapered swept, etc. The theoretical best fin shape for stability and lowest induced drag is the ellipsoidal (5). However, it was noted that after simulations combining the fins with a rocket nose cone and body, the ellipsoidal performed worse than trapezoidal and clipped delta (5). Structurally trapezoidal fins are superior to both the delta, clipped delta and swept with minimal loss in stability (6). Considerations of weight of the fins will primarily be due to material construction not selected geometry.

The number of fins used in model rocketry is generally 3-4 (6). More can be used but are often unnecessary. The number of fins will be determined by the desired stability margin and selected fin geometry. One primary consideration for the number of fins is pertaining to the fabrication and affixing the fins to the rocket. More fins requires more fins to be cut, post-processed, possibly additional weight, more fin slots (if fin slots are used), more time fixing fins to rocket body, etc. Thus, as the number of fins increases the more likely there will be variance fabricated fin shape and also the position of the fin on the body tubes.

With all these factors noted, the selected fin design is a "clipped" trapezoid. The overall trapezoidal shape was selected due to is simple geometry, structural integrity, and sufficient lift and drag affects. The simple geometry ensures the fin design is feasible using the facilities available (listed in Appendix A). The "clipping" of the trapezoidal geometry was to reduce the weight of the fins and due to the observed superior stability and drag performance based on simulation data in OpenRocket.

Material of Construction

Now that the fin shape is selected, the material of construction for the fins must be defined. To define the material of construction for the fins a decision matrix was employed. The decision matrix to evaluate the materials (Table 3-7) incorporates scores calculated by the multiplication of the criteria weight and the rating of the material. The ratings are out of ten; the material that performs the best will receive 10 out of 10. All other material scores for the particular criteria were rated relative to the best. In the event of all material ratings tie for a particular category, the rating for all will be 10.

Custom Fins			Fiberglass			Carbon Fiber		
Criteria	Weight	Parameter	Magnitude	Rating	Score	Magnitude	Rating	Score
Cost	.15	$\frac{USD}{in^3}$	1.10	7	1.05	11.7	2	.3
Strength	.40	ksi	80.6	9.75	3.9	87.0	10	4
Density	.20	$\frac{\text{lb}}{\text{in}^3}$	.0650	6	1.2	.0578	7	1.4
Handling Safety	.15	Safety Score	6	5	.75	6	5	.75
Formability	.10	Experience / Available Equipment	7.5	7.5	.75	7.5	7.5	.75
Overall Score:					7.65			7.2

Custom Fins			Creality PETG			Creality PLA		
Criteria	Weight	Parameter	Magnitude	Rating	Score	Magnitude	Rating	Score
Cost	.15	$\frac{USD}{in^3}$	.387	9.75	1.46	.370	10	1.5
Strength	.40	ksi	7.25	3.5	1.4	7.69	3.5	1.4
Density	.20	$\frac{\text{lb}}{\text{in}^3}$	.0448	10	2	.0452	9	1.8
Handling Safety	.15	Safety Score	2	10	1.5	2	10	1.5
Formability	.10	Experience / Available Equipment	10	10	1.0	9	9	.9
Overall Score:					7.36			7.1

Table 3-7 Custom Fin Material Decision Matrix

Cost is the price of the material in USD/in^3. Cost was taken into consideration as a criteria due to the need to keep the overall cost of the fins as low as possible. However, there are only four fins thus the overall effect of the cost of the fins is less significant than other criteria. Thus, the weighing factor cost is 15%. Rating for this criteria was based on the lowest cost being optimal and so receiving a rating of 10.

Strength is the maximum strength the material can withstand in uniaxial tension in ksi. Strength was taken into consideration as a material criteria since the fins are a critical component of the rocket for stability. If the fins were to fail during the flight to apogee the flight of the rocket would become unpredictable and thus risk the success accuracy of the predicted rocket height. If the fins were to fail upon impact of the ground the rocket would be considered unrecoverable and thus fail its mission. Thus, the material strength for the fins was weighted as 40%. Rating for this criteria was based on the highest strength material being considered optimal and thus receiving a score of 10.

Density is weight per unit volume of the material of construction in $\frac{\text{lb}}{\text{in}^3}$. Density was taken into consideration as a criteria due to the overall need to keep the weight of the launch vehicle as low as possible. The weight of the fins will have a significant but not large effect on the weight of the rocket. Optimizing the weight of the fins allows room for the weight of other components. The weight of these components will also effect the center of gravity (CG) of the rocket and so have an additional effect rocket stability. Thus, the weight factor density is 20%. Rating for this criteria was based on the lowest density being considered optimal and so receiving a rating of 10.

Handling Safety is the safety hazards from the inherent toxicity of the materials of construction. This is measured based on the Safety scores outlined in Section 5.4.4. Safety Data Sheets (SDS): Chemicals and Materials. Safety is always an important factor for the usage of any components or materials. Thus, the weighing factors 15%. The material with the lowest safety score is considered the safest material and will receive a rating of 10.

Formability is measured by experience using the material and available equipment to form the material. This criteria was included due to the fins being custom fabricated by the Terra Nova team. Thus, the formability of the material based on previous experience and available equipment is important for the selection of the fin material. However, since the overall shape of the fins are not complex difficulty of forming the fins will not be a major challenge, hence, the weighing factor is 10%. Rating for these criteria was based on the material that the Terra Nova team has the most experience with and the most equipment to form receiving a rating of 10.

Based on all these selection criteria, fiberglass is the selected material for the design of the fins with the highest score of 7.65.

Recovery System Location

The avionics bay is the center of the recovery system with both separations happening at either end of the bay. Initially it was set to be in the middle of the rocket, just aft of the transition. This location is fine, but we have found an issue with the impact energy of the forward section and the only way we see to solve this is by rearranging the placement of mass in the body of the rocket. Doing this required the rearrangement of several components, but in terms of the avionics bay, it was moved slightly forward from just aft of the transition, to inside the transition. This change will effectively decrease the mass in the forward separating section enough to keep our ground impact energy within the constraints of the competition without increasing the mass of any other section beyond what is acceptable.

Centering Rings

The centering rings of the rocket are an important component. They are used to hold the motor tube for the RMS. The important consideration for the centering ring design is its material of construction. To evaluate which material should be used a decision matrix was employed. The decision matrix to evaluate the materials (Table 3-8) incorporates scores calculated by the multiplication of the criteria weight and the rating of the material. The ratings are out of ten; the material that performs the best will receive 10 out of 10. All other material scores for the particular criteria were rated relative to the best. In the event of all material ratings tie for a particular category, the rating for all will be 10.

Centering Rings			Fiberglass			Carbon Fiber		
Criteria	Weight	Parameter	Magnitude	Rating	Score	Magnitude	Rating	Score
Cost	.25	$\frac{USD}{in^3}$	1.10	7	1.75	11.7	2	.5
Strength	.20	ksi	80.6	9.75	1.95	87.0	10	2
Density	.30	$\frac{\text{lb}}{\text{in}^3}$	.0650	6	1.8	.0578	7	2.1
Handling Safety	.15	Safety Score	6	5	.75	6	5	.75
Formability	.1	Experience / Available Equipment	7.5	7.5	.75	7.5	7.5	.75
Overall Score:					7.0			6.1
Centering Rings			Creality PETG			Creality PLA		
Criteria	Weight	Parameter	Magnitude	Rating	Score	Magnitude	Rating	Score
Cost	.25	$\frac{USD}{in^3}$	.387	9.75	2.44	.370	10	2.5
Strength	.20	ksi	7.25	3.5	.7	7.69	3.5	.7
Density	.30	$\frac{\text{lb}}{\text{in}^3}$	.0448	10	3	.0452	9	2.7
Handling Safety	.15	Safety Score	2	10	1.5	2	10	1.5
Formability	.1	Experience / Available Equipment	10	10	1.0	9	9	1.0
Overall Score:					8.64			8.4

Table 3-8 Centering Ring Material Decision Matrix

Cost is the price of the material in USD/in^3. Cost was taken into consideration as a criteria due to the need to keep the overall cost of the centering rings as low as possible. Thus, the weighing factor cost is 15%. Rating for this criteria was based on the lowest cost being optimal and so receiving a rating of 10.

Strength is the maximum strength the material can withstand in uniaxial tension in ksi. Strength was taken into consideration as a material criteria since the ability for the centering rings to hold the motor tube in place is critical. However, the forces during flight and recovery acting on the centering rings is minimal since most of the forces will be exerted on the bulkheads and airframe. Thus, the material strength was weighted as 20%. Rating for this criteria was based on the highest strength material being considered optimal and thus receiving a score of 10.

Density is weight per unit volume of the material of construction in $\frac{\text{lb}}{\text{in}^3}$. Density was taken into consideration as a criteria due to the overall need to keep the weight of the launch vehicle as low as possible. The weight of the centering rings will have a significant but minimal effect on the weight of the rocket. Optimizing the weight of all the components allows room for the weight of other components. The weight of these components will also effect the center of gravity (CG) of the rocket and so have an additional effect rocket stability. Thus, the weight factor density is 30%. Rating for this criteria was based on the lowest density being considered optimal and so receiving a rating of 10.

Handling Safety is the safety hazards from the inherent toxicity of the materials of construction. This is measured based on the Safety scores outlined in Section 5.4.4. Safety Data Sheets (SDS): Chemicals and Materials. Safety is always an important factor for the usage of any components or materials. Thus, the weighing factor is 15%. The material with the lowest safety score is considered the safest material and will receive a rating of 10.

Formability is measured by experience using the material and available equipment to form the material. This criteria was included due to the centering rings being fabricated by the Terra Nova team. Thus, the formability of the material based on previous experience and available equipment is important for the selection of the centering ring material. However, since the overall geometry of the centering rings is not complex, the forming the centering rings will not be a major challenge, hence, the weighing factor is 10%. Rating for these criteria was based on the material that the Terra Nova team has the most experience with and the most equipment to form receiving a rating of 10.

Based on all these selection criteria, PETG is the selected material for the design of the centering rings with the highest score of 8.64.

Motor Tubing

Similarly to the centering rings, the motor tube of the rocket primarily depends on material construction. The motor tube is important for the proper installation of the RMS. Hence, to effectively select the material of construction a decision matrix was employed based on commercially available components based on the 75/5120 RMS. The decision matrix to evaluate the materials (Table 3-9) incorporates scores calculated by the multiplication of the criteria weight and the rating of the material. The ratings are out of ten; the material that performs the best will receive 10 out of 10. All other material scores for the particular criteria were rated relative to the best. In the event of all material ratings tie for a particular category, the rating for all will be 10.

Motor Tube			Fiberglass			Cardboard		
Criteria	Weight	Parameter	Magnitude	Rating	Score	Magnitude	Rating	Score
Cost	.35	$\frac{USD}{in}$	2.10	4	1.4	.682	10	3.5
Strength	.20	ksi	25.4	10	2.0	4.21	4	.8
Density	.30	$\frac{\text{lb}}{\text{in}^3}$	.0650	6	1.8	.0450	10	3
Handling Safety	.15	Safety Score	6	6	.9	2	10	1.5
Overall Score:					6.1			8.8

Motor Tube			Phenolic		
Criteria	Weight	Parameter	Magnitude	Rating	Score
Cost	.25	$\frac{USD}{in^3}$	.716	9	2.25
Strength	.20	ksi	13.5	7.5	1.5
Density	.30	$\frac{\text{lb}}{\text{in}^3}$	.0450	10	3
Handling Safety	.15	Safety Score	2	10	1.5
Overall Score:					8.25

Table 3-9 Motor Tube Material Decision Matrix

Cost is the price of the component per linear unit in USD/in. Cost was taken into consideration as a criteria due to the need to keep the overall cost of the motor tube as low as possible. Due to this, cost was considered the most important criteria relative to the others with a weighing factor is 35%. Rating for this criteria was based on the lowest cost being optimal and so receiving a rating of 10.

Strength is the maximum compressive strength the material can withstand in uniaxial compression in ksi. Strength was taken into consideration as a material criteria since the ability for the motor tube to hold the RMS in place is critical. However, the motor tube is not the primary support for the RMS and so will experience minimal forces during flight. This is because the RMS will be supported against the Propulsion bulkhead. Thus, the material strength for the motor tube was weighted as 20%. Rating for this criteria was based on the highest strength material being considered optimal and thus receiving a score of 10.

Density is weight per unit volume of the material of construction in $\frac{\text{lb}}{\text{in}^3}$. Density was taken into consideration as a criteria due to the overall need to keep the weight of the launch vehicle as low as possible. The weight of the motor tube will have a significant but minimal effect on the weight of the rocket. The weight of the motor tube will also effect the center of gravity (CG) of the rocket and so have an additional effect rocket stability. Thus, the weight factor density is 30%. Rating for this criteria was based on the lowest density being considered optimal and so receiving a rating of 10.

Handling Safety is the safety hazards from the inherent toxicity of the materials of construction. This is measured based on the Safety scores outlined in Section 5.4.4. Safety Data Sheets (SDS): Chemicals and Materials. Safety is always an important factor for the usage of any components or materials. Thus, the weighing factors 15%. The component with the lowest safety score is considered the safest material and will receive a rating of 10.

Based on all these selection criteria, cardboard is the selected material for the design of the motor tube with the highest score of 8.8.

Separation Points

The Terra Nova Rocket will separate at 3 different locations: 2 during recovery and 1 after landing (for the payload, no pyrotechnics involved). Initially, these locations were aft of the transition and forward of the motor housing. With the potential changes listed above, the new separation points would be forward, rather than aft, of the transition, while the aft separation point would not change.

Location of Payload

The payload will be housed in Body Tube 1 and the HAUS coupler located above the reducing transition. This location of the payload was part of the justification for the usage of the reducing transition. This transition allows the rocket design to achieve its required apogee using the predetermined RMS without further limitations being imposed on the payload design.

Rail Buttons

Rail buttons are a critical component of the rocket to ensure the initial flight trajectory as close to desired as possible. The rail buttons are necessary protrusions from the body of the rocket and will be located beneath the CG of the rocket per Handbook Req. 2.13. Overall, there are many different possible locations for the rail buttons. The first rail button will be located a diameter's length (for the larger ID) below the CG as is commonly recommended by rocketeers. The second will be located within 4 inches of the last airframe of the rocket. Due to the usage of the reducing transition, the usage of standoffs will be necessary to offset the rail buttons from the airframe by half an inch. This will ensure the larger diameter airframe will not make significant contact with the launch rail and reduce the risk of both ripping off the rail buttons or strange flight trajectories.

Fasteners

Fasteners will be used throughout the entire rocket but are primarily relevant in attaching bulkheads and other primary components to the airframe. The highest exerted force on the fasteners will be during deployment, so the material selected must not come within a safety factor of rupture during recovery. The forces exerted during deployment of the reefed main, and the reefing line rupture are calculated in section 3.3 but will be refenced here for justification. The force created by the drogue deployment was neglected in calculations because the force created is significantly lower than either of those created by the main events.

$$F_{main,reefed} = 282.74\ lbs$$
$$F_{main,unreefed} = 643.58\ lbs$$

The highest force exerted during deployment is 643.58 lbs. Assuming the entire load is applied to a single bolt presents the absolute worst-case scenario. The selected fasteners will likely be 0.25" bolts, though a force analysis will allow specific material justification. Materials up for consideration are 2024 Al, 6061 Al, and stainless steel 316. With Mohr's Circle, it can be estimated that the maximum shear strength is half that of the maximum tensile strength

Fastener Material			2024 Aluminum			6061 Aluminum		
Criteria	Weight	Parameter	Magnitude	Rating	Score	Magnitude	Rating	Score
Cost	.20	$\frac{USD}{fastener}$	Quote Pending	6	1.2	Quote Pending	6	1.2
Strength	.40	ksi	34.0	7	2.8	22.5	5	2
Density	.25	$\frac{\text{lb}}{\text{in}^3}$	0.1	8	1.6	0.0975	10	2
Handling Safety	.15	Safety Score	3	10	1.5	3	10	1.5
Overall Score:					7.1			6.7

Fastener Material			Stainless Steel 316		
Criteria	Weight	Parameter	Magnitude	Rating	Score
Cost	.20	$\frac{USD}{fastener}$	$15.0	10	2
Strength	.40	ksi	42	10	4
Density	.25	$\frac{\text{lb}}{\text{in}^3}$	0.289	5	1.25
Handling Safety	.15	Safety Score	3	10	1.5
Overall Score:					8.63

Cost is the price of the component in USD. Cost was taken into consideration as a criteria due to the need to keep the overall cost of the launch vehicle as low as possible. Since there will be many fasteners used throughout the rocket, cost was given a weighing factor of 20%. Rating for this criteria was based on the lowest cost being optimal and so receiving a rating of 10.

Strength is the maximum shear strength the material can withstand in ksi. Strength was taken into consideration as a material criteria since the fasteners must be able to withstand the forces of recovery and flight. Since the fasteners will be critical in absorbing and transferring the forces of flight, the material strength received a weight of 40%. Rating for this criteria was based on the highest strength material being considered optimal and thus receiving a score of 10.

Density is weight per unit volume of the material of construction in $\frac{\text{lb}}{\text{in}^3}$. Density was taken into consideration as a criteria due to the overall need to keep the weight of the launch vehicle as low as possible. The weight of all the combined fasteners will be significant in the overall weight of the rocket and thus the weighing factor for density is 25%. Rating for this criteria was based on the lowest density being considered optimal and so receiving a rating of 10.

Handling Safety is the safety hazards from the inherent toxicity of the materials of construction. This is measured based on the Safety scores outlined in Section 5.4.4. Safety Data Sheets (SDS): Chemicals and Materials. Safety is always an important factor for the usage of any components or materials. Thus, the weighing factors 15%. The material with the lowest safety score is considered the safest material and will receive a rating of 10.

This decision matrix identifies stainless steel 316 as the ideal fastener selection. It has the highest strength, but also the highest density. The cost parameter of the two aluminum bolts is pending a quote from the manufacturer, so the rating was defaulted to 6. Until a competitive price is specified for the two aluminum options, stainless steel 316 will be the selection.

Since these bolts will be in double shear (applied load via both the bulkhead and body tube) the deployment stress can be calculated with the force of the un-reefed main to confirm this bolt can withstand these forces with the following equation.

$$\tau = \frac{F}{A}$$

$$\tau = \frac{643.58\ lbs}{\frac{\pi(0.25")^2}{4}}$$

$$\tau = 13.1\ ksi$$

Therefore, the use of all three bolts is justified. Stainless still 316 will be the selection for now, though 2024 aluminum would be a better option due to its lower density and comparable strength should the cost be reasonable.

3.2. Recovery System

Drogue Parachute

The Drogue parachute is in a usual configuration for high powered rocketry. It will be placed below the avionics bay (toward the tail) and will deploy after the first separation at apogee. Currently sized at a diameter of 15”, the goal of the drogue is to stabilize & slow the descent of the Terra Nova rocket while keeping speed relatively high in pursuit of our time goal.

Staged Main-Pilot Recovery System

Our derived goal of reaching ground from apogee in less than 80 seconds requires a late and forceful deployment to safely reach the ground while keeping a high descent speed for as long as possible. A method to achieve this safely is a staged main opening that involves a pilot parachute in series with the main parachute. The task of the pilot chute is to slightly decelerate the rocket, acting as a second drogue just before the opening of the main. This will drastically decrease the peak load created by the opening of the main parachute from an acceleration greater than 1100 ft/s^2 down to 800 ft/s^2 with a 24” diameter pilot parachute. After the deployment of the pilot parachute, the main will deploy at another specified altitude. Since we want the pilot and main parachutes to deploy along the same shock cord, the cord will be threaded through a hole in the roof of the main, which is held into the body of the rocket by a tender descender. This device (to be described in more depth in the following section) will hold the main parachute within the rocket until the specified altitude is reached, where the device will intentionally fail. The Main parachute has the task of decelerating the rocket from nearly 109 ft/s (mean OpenRocket simulation “velocity at deployment”) to an acceptable velocity that keeps impact energy below 60 ft-lbs. To accomplish this, the main parachute is sized at a 120” diameter to maximize drag on descent while keeping time to ground from apogee low. This design is promising but presents several challenges. Running two parachutes in series runs the risk of tangling parachute wires during deployment, unanticipated failure of the tender descender, and a moderately complex design. For these reasons, another option is being considered. It is worth noting that even in an unanticipated failure of the tender descender, the main parachute will still deploy, though it would jeopardize our derived goal. For redundancy, two e-matches will be wired to the tender descender.

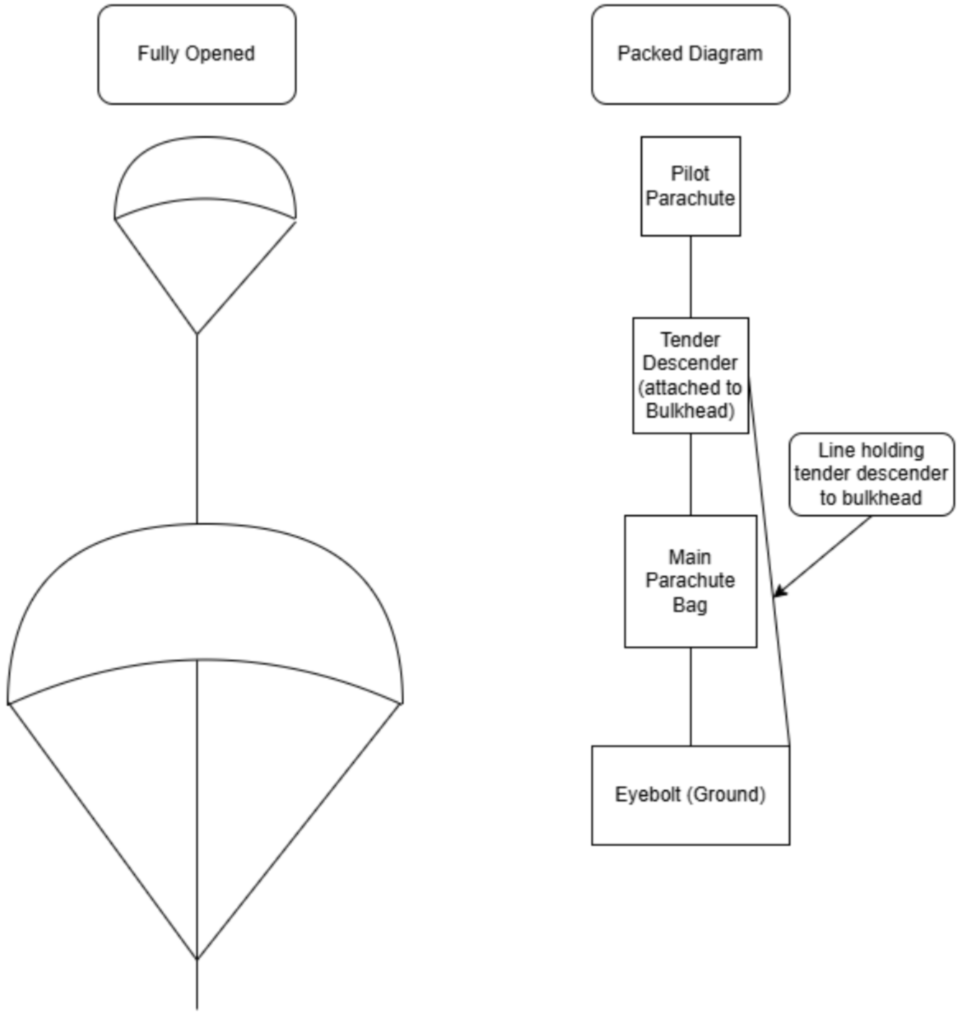


Figure 3-2 Pilot-Main Line Diagram

Tender Descender

The Tender Descender is a key component in the pilot-main staged opening. The main-pilot and main parachutes will be on the same line, and the tender descender is the device chosen to stage the release of the two coincident parachutes. After the second separation, the main-pilot parachute will deploy, leaving the main behind inside the body of the rocket. Along the length of the shock cord and between the main-pilot and main parachutes, the tender descender will be attached to the shock cord and the local bulkhead, effectively preventing any cord between itself and the bulkhead (the main parachute) from deploying until the tender descender intentionally fails via a small pyrotechnic event (electrically ignited black powder charge).

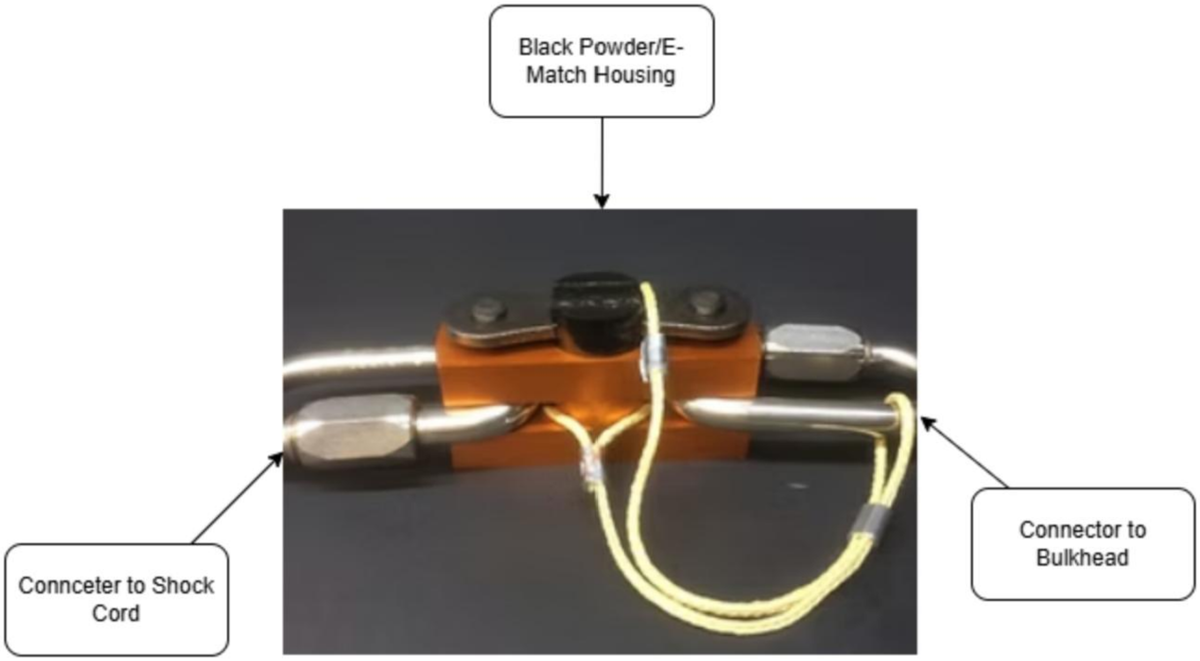


Figure 3-3 Tender Descender Visualization (2).

Main Parachute Reefer

Another method for peak force mitigation is reefing the main parachute. This effects recovery similarly to the pilot-main concept and can be used either in series with or instead of the pilot-main. This system involves a reefing line wrapped around either the base of the parachute or the parachute lines and prevents the parachute from opening fully until the line is severed. This, in effect, decreases the effective surface area and thus the drag created by the parachute until the reefing line is cut and the parachute acts as normal. This concept is a new addition since the PDR, and further study will be needed before it can be implemented. The design inspiration came from a website posted by MIT students who pursued the same goal [2]. This research proposed 3 methods for reefing the parachute, the best one being along the skirt of the parachute. Cutting the line would require one of two options. Option 1 would involve a series of rings attached around the skirt of the parachute for the reefing line to feed through, with the reefing line running all the way down to the bulkhead, where it would be severed at the body of the rocket. Option 2 would involve the same series of rings and line, but a device would be planted on the skirt of the parachute that can detect altitude and severing the line by itself. Option 1 would likely be the better one, as it involves fewer total systems and doesn't require a component being attached to the parachute, possibly interfering with its stability.

Shock Cord

Kevlar-Elastic

The Kevlar-Elastic shock cord involves a continuous line of Kevlar with several sections of bungee cord to damp the deployment force along the length of the cord. The Kevlar cord to be used in this design would be Kevlar Cord 1500# sold by Apogee Rockets. With a diameter of 0.137" and a given tensile strength of 1500 lbs, this cord provides a strong and heat-resistant option. The length of the cord would be sized at 40x the diameter (6") of the rocket, giving a 20 ft cord. This cord provides the strength needed to withstand deployment forces, but its rigidity creates the potential issue of transferring the instantaneous deployment loads into the body of the rocket. To combat this, the proposed design of damping the cord throughout its length with bungee cords. The bungee cord is yet to be chosen, and a related project is underway to test several options for material properties to determine the best option. The proposal for this project can be viewed in the appendix. The specific properties to be tested for are the spring constants, which will be used to determine how much force it will take to fully elongate them. The number and length of sections will then be determined based on these calculations, estimating their behavior in series with one another. This design is unique and useful in theory, but test results could prove other cords sufficient for our goals. Attachment points between Kevlar and elastic sections will be weaker than the rest of the cord (some options: knots, carabiners), and these areas of stress concentration could prove to be problematic. The cords would be connected to the body of the rockets via eye bolts on the bulkheads placed at the ends of each separating section.

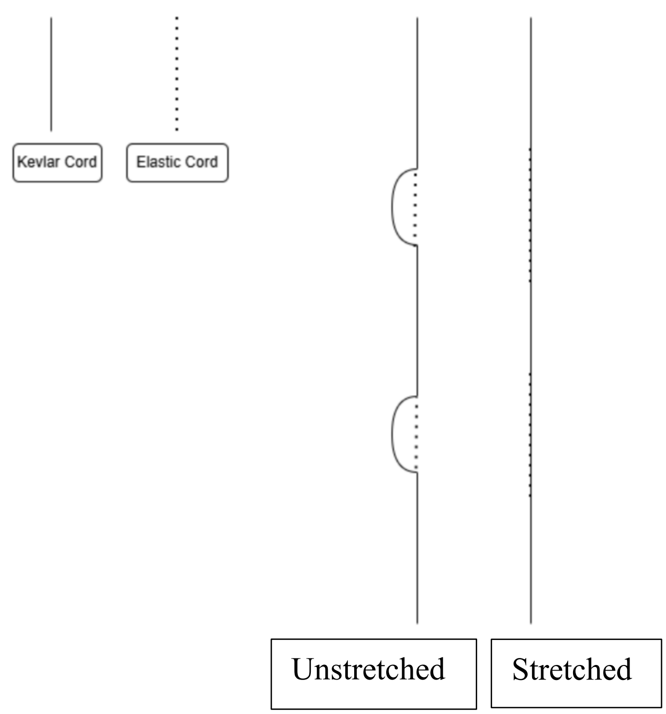


Figure 3-4 Kevlar-Elastic Shock Cord.

PARAMAX

Another option for the shock cord of the Terra Nova rocket is the PARAMAX paracord sold by The Paracord Store. With a 0.25” diameter and a 1200lb tensile strength, this cord could provide a simpler and more practical solution to the recovery problem. While it is weaker than the Kevlar cord, it is still above the maximum instantaneous force our OpenRocket simulations predict. This paracord will be tested in the project referenced in the appendix, though it is expected that this cord will be far more elastic than Kevlar cord. This cord could solve Kevlar’s rigidity issue, though elastic sections could still be used as previously described should this cord be chosen. The same length rule (40x the diameter of the rocket) will be applied for a 40” cord. These cords would be connected to the body of the rocket via the bulkheads placed at the ends of each separating section of the rocket. This concept could provide a superior alternative to the Kevlar-Elastic cord with comparable material traits and a more simplistic design.

3.3. Selected Rocket Concepts

Nose Cone

The nose cone’s primary purpose is to minimize drag at the front of the rocket. A fiberglass Ogive nose cone with a 6” ID, and a fineness ratio of 4:1 was selected in the preliminary design for two main reasons. First, it is commercially available through many sites including Loc 40 Precision and Wildman Rocketry. Second, according to the calculations of Dr Gregorek, the ogive nose cone is superior to the other widely available nose cone shape, the conical.

Transition

Though the transitional airframe will bring some fabrication challenges to the Terra Nova Team, overall, it was selected due to its three primary advantages. These advantages are one weight reduction, two base drag reduction, and payload space. The selected material of the transition is a composite of 3D printed PETG with a reinforcing coating of Fiberglass cloth and epoxy. The current design of the Full-scale transition is detailed in Figures 3-5 to 3-8.

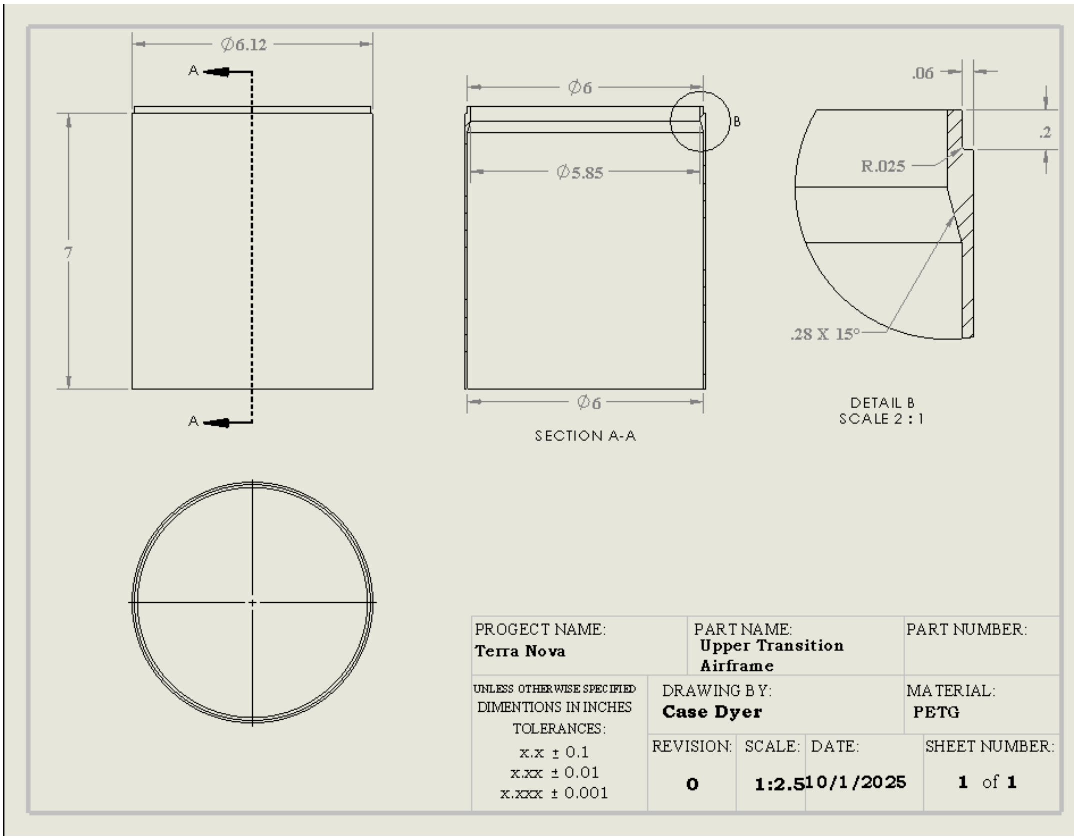


Figure 3-5 Detailed Upper Transition Design

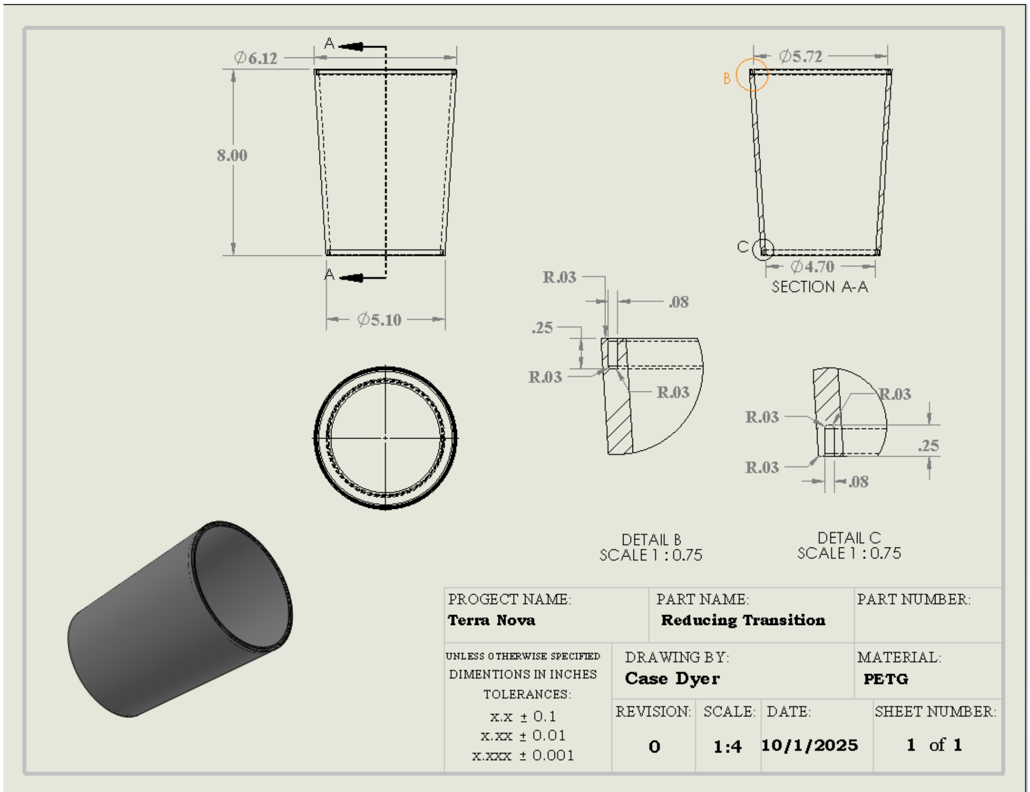


Figure 3-6 Detailed Reducing Transition Design

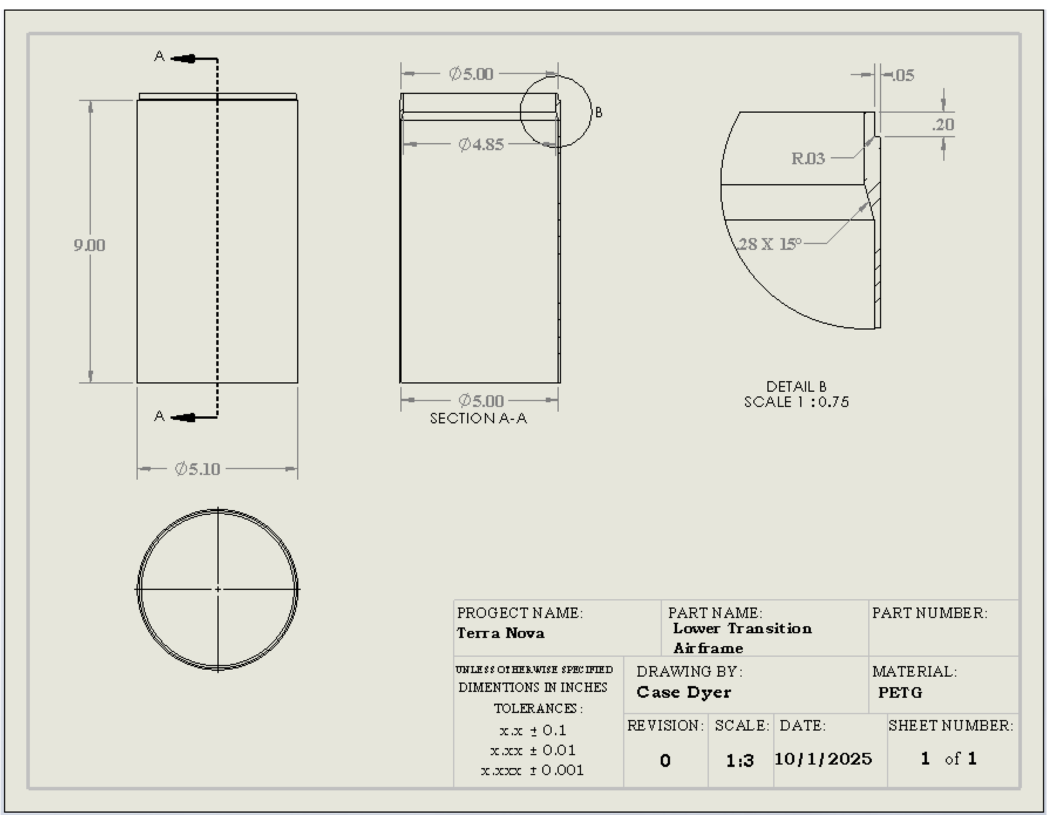


Figure 3-7 Detailed Lower Transition Design

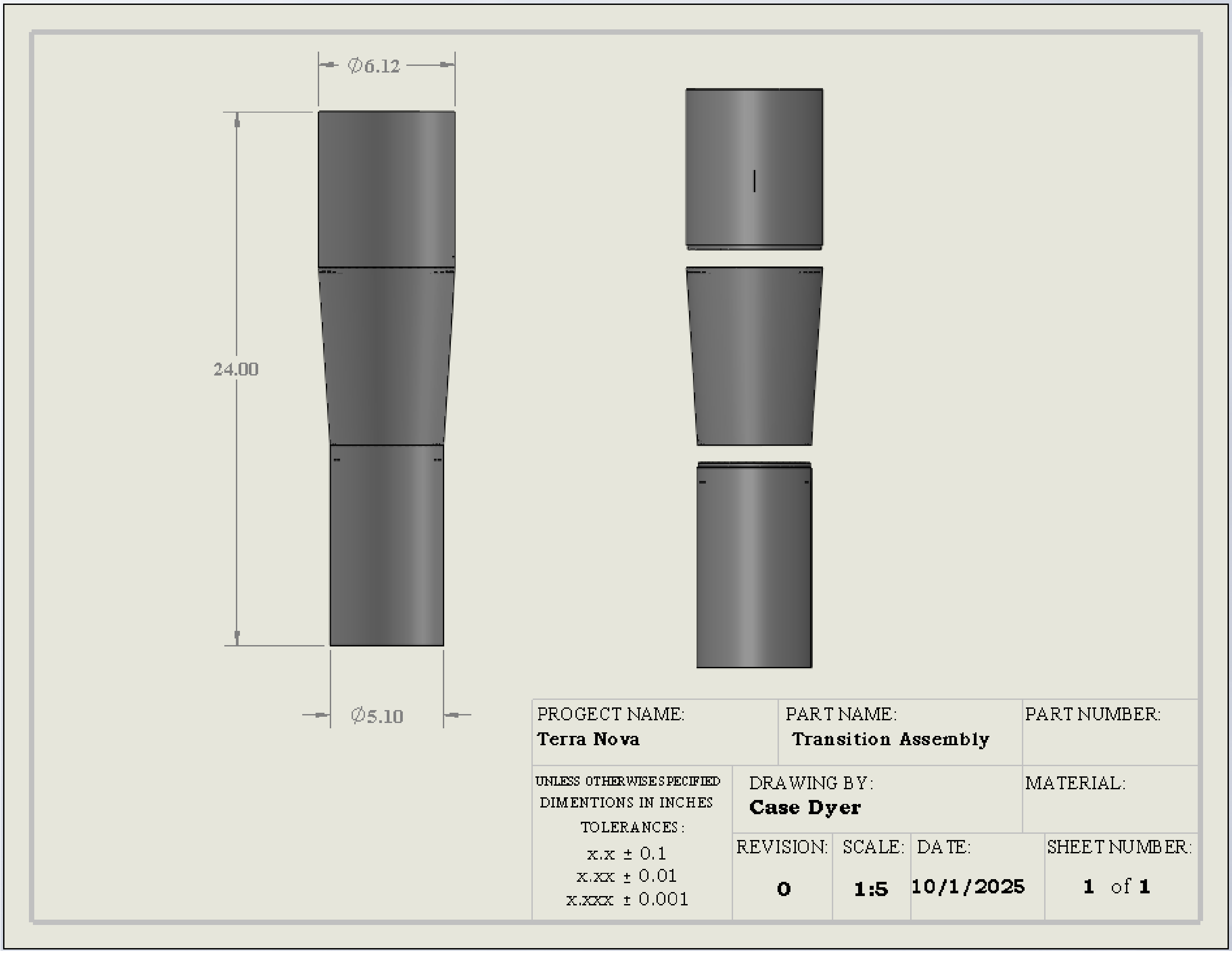


Figure 3-8 Detailed Transition Airframe Assembly

Boat-Tail

The inclusion of the boat-tail was an important selection to the design of the Terra Nova launch vehicle to reduce the base drag. The material that scored the highest in the boat-tail decisions matrix was Aluminum 6061-T6 and therefore will be the utilized material. The current design of the Full-scale boat-tail is detailed in Figure 3-9. This boat-tail design will require modification after the receiving of the motor retainer that will be inserted and fixed to the boat-tail using interference fitting.

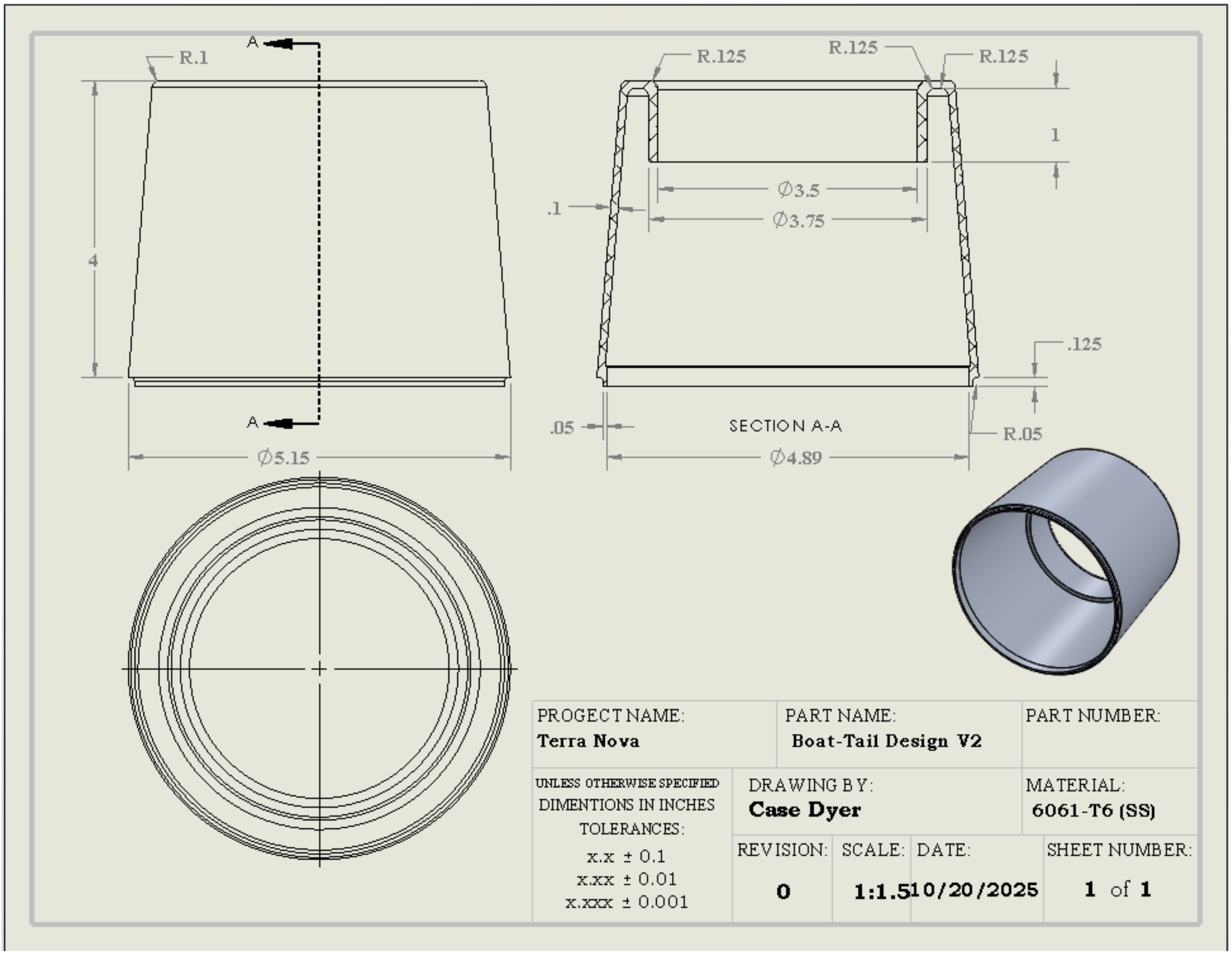


Figure 3-9 Detailed Boat-Tail Design

Body

The body of the rocket connects and houses all components of the rocket. It was crucial that the selected material be lightweight, strong, cost effective and commercially available. A decision matrix was employed to select the material that ranked the highest. The material that scored the best was G-12 Fiberglass and so it will be the material of construction for the commercial purchased body tubes. Figures 3-10 to 3-12 detail the body tubes to be used.

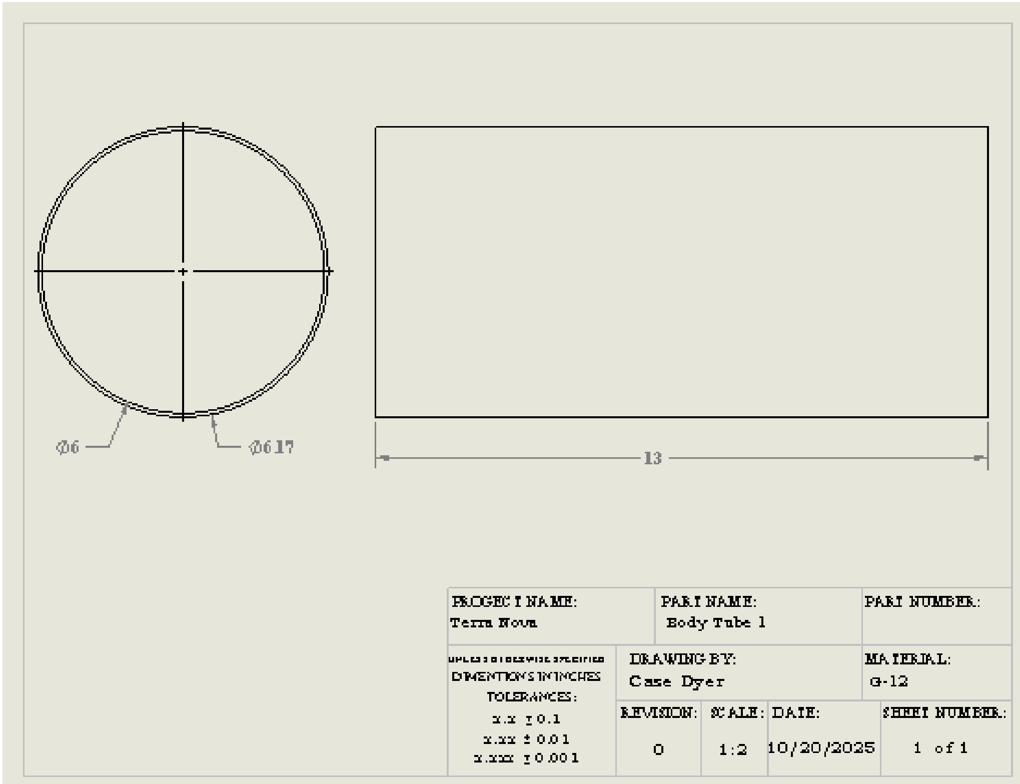


Figure 3-10 Detailed Body Tube 1

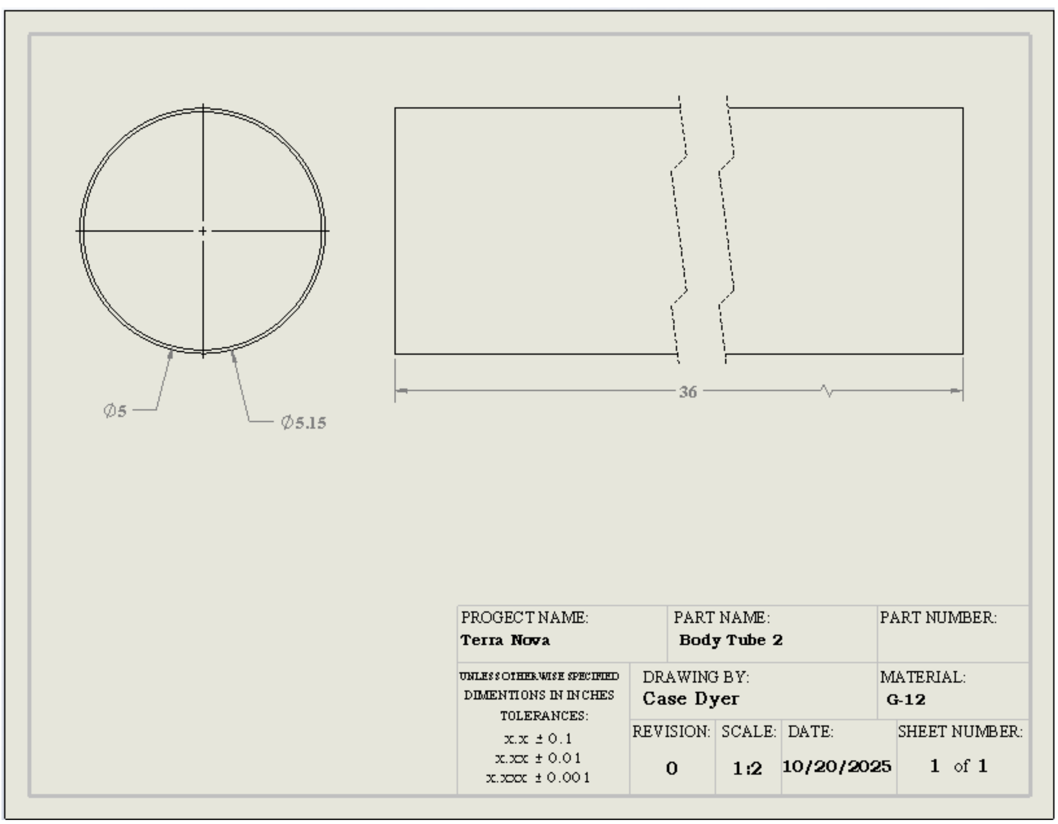


Figure 3-11 Detailed Body Tube 2

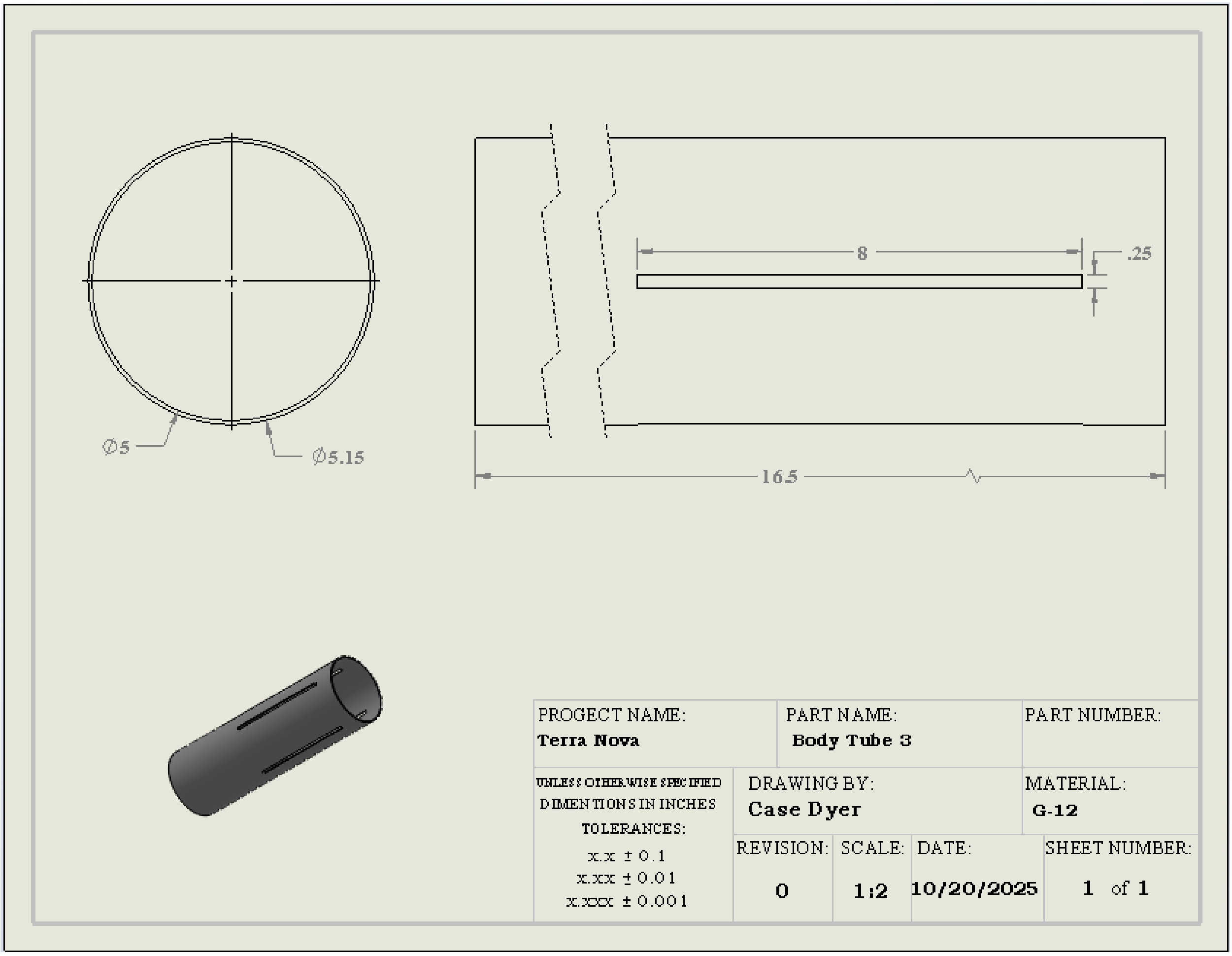


Figure 3-12 Detailed Body Tube 3

Fins

The fins of the rocket are crucial for stabilizing the rocket. The Terra Nova's fin design is based on the strength and stability characteristics of the trapezoidal fins. However, based on simulations in OpenRocket the trapezoidal fin shape was further modeled to reduce drag to a "clipped trapezoidal" fin with the front face of the fins being rounded. The selected material based on the fin material decision matrix was cut to shape fiberglass sheets. Figure 3-13 details the specific design of the Terra Nova's clipped trapezoidal fins.

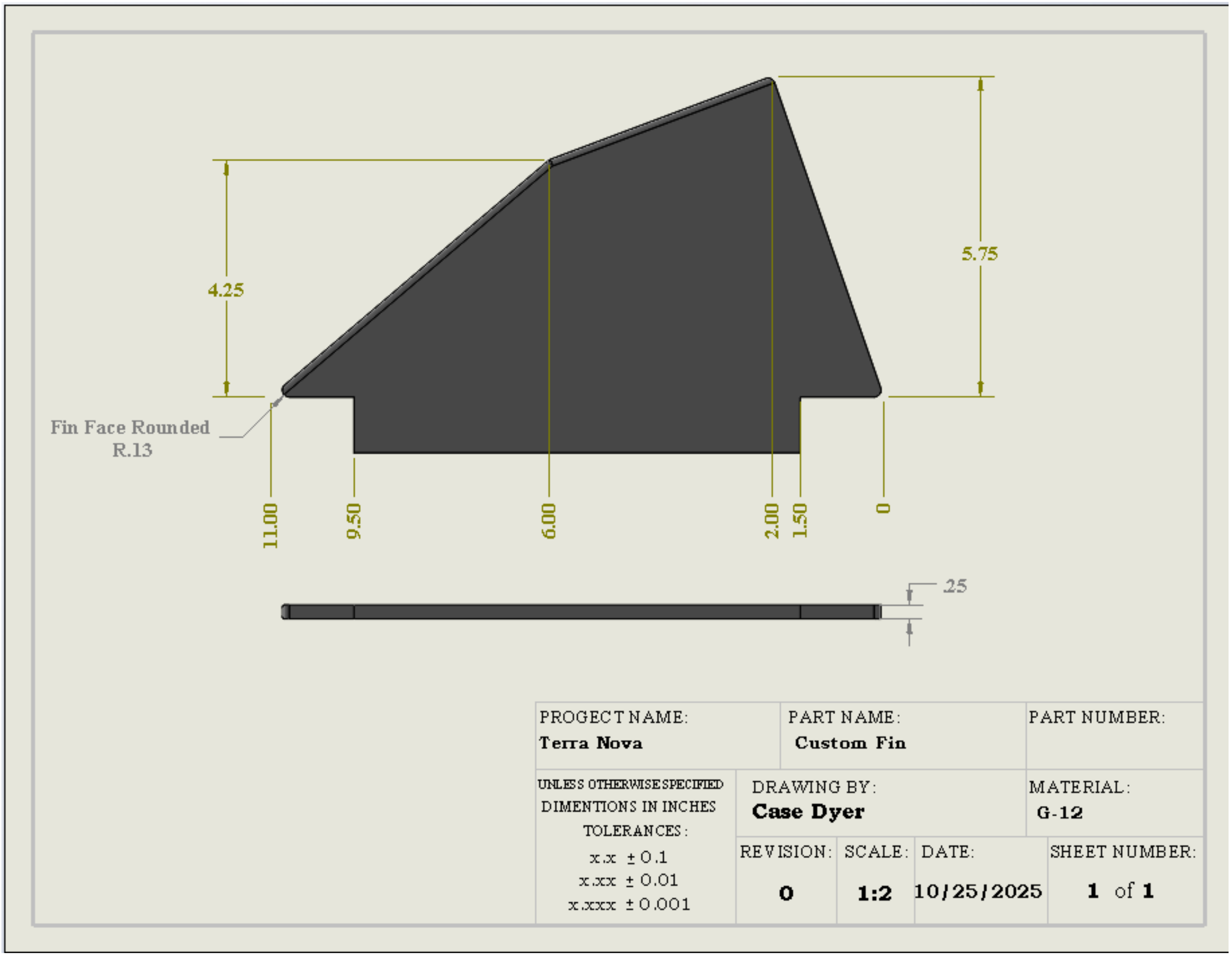


Figure 3-13 Custom Fins.

Full Terra Nova Launch Vehicle

The fully assembled Terra Nova launch vehicle based on all the leading concepts is detailed in Figures 3-14 to 3-17. This includes the locations of all separation points during and after flight. Figure 3-14 outlines the names of the 3 primary sections of the rocket that will be separating. Using only three separating sections meets the requirement per Handbook Req. 2.5 of a maximum of 4 independent sections.

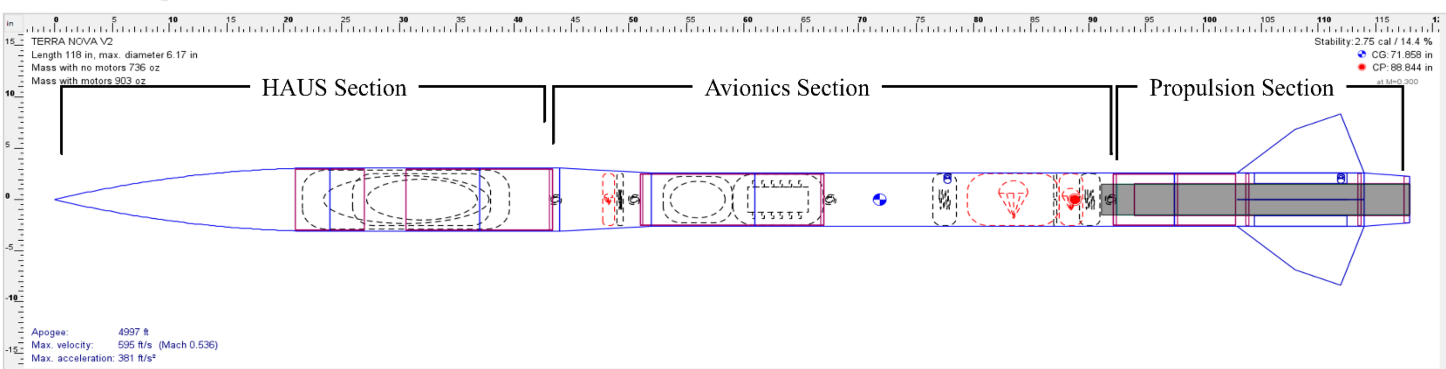


Figure 3-14 Terra Nova Sections

Figure 3-15 details the location of various external components and separation locations for the launch vehicle.

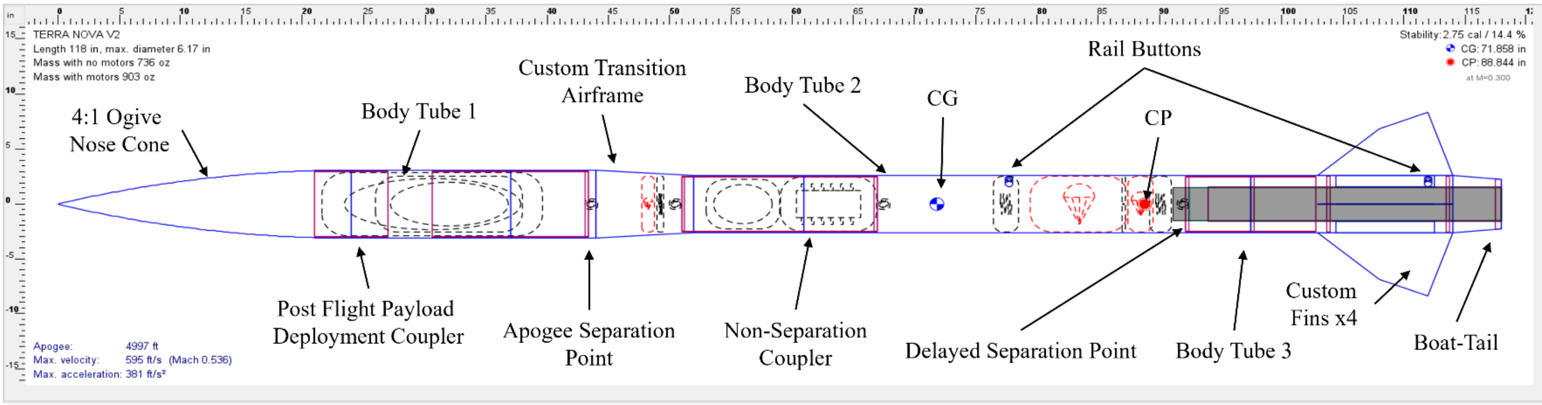


Figure 3-15 Terra Nova Exterior Components

Figure 3-16 details the location of various interior components for the launch vehicle.

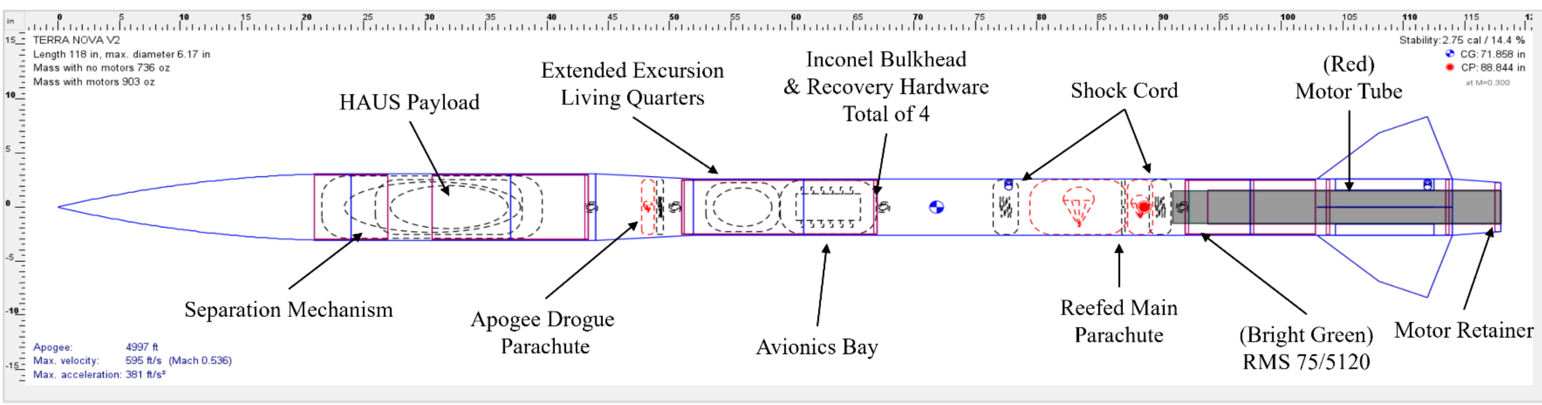


Figure 3-16 Terra Nova Interior Components

Figure 3-17 and Table 3-10 are the exploded view of the Terra Nova launch vehicle and its associated bill of materials (BOM).

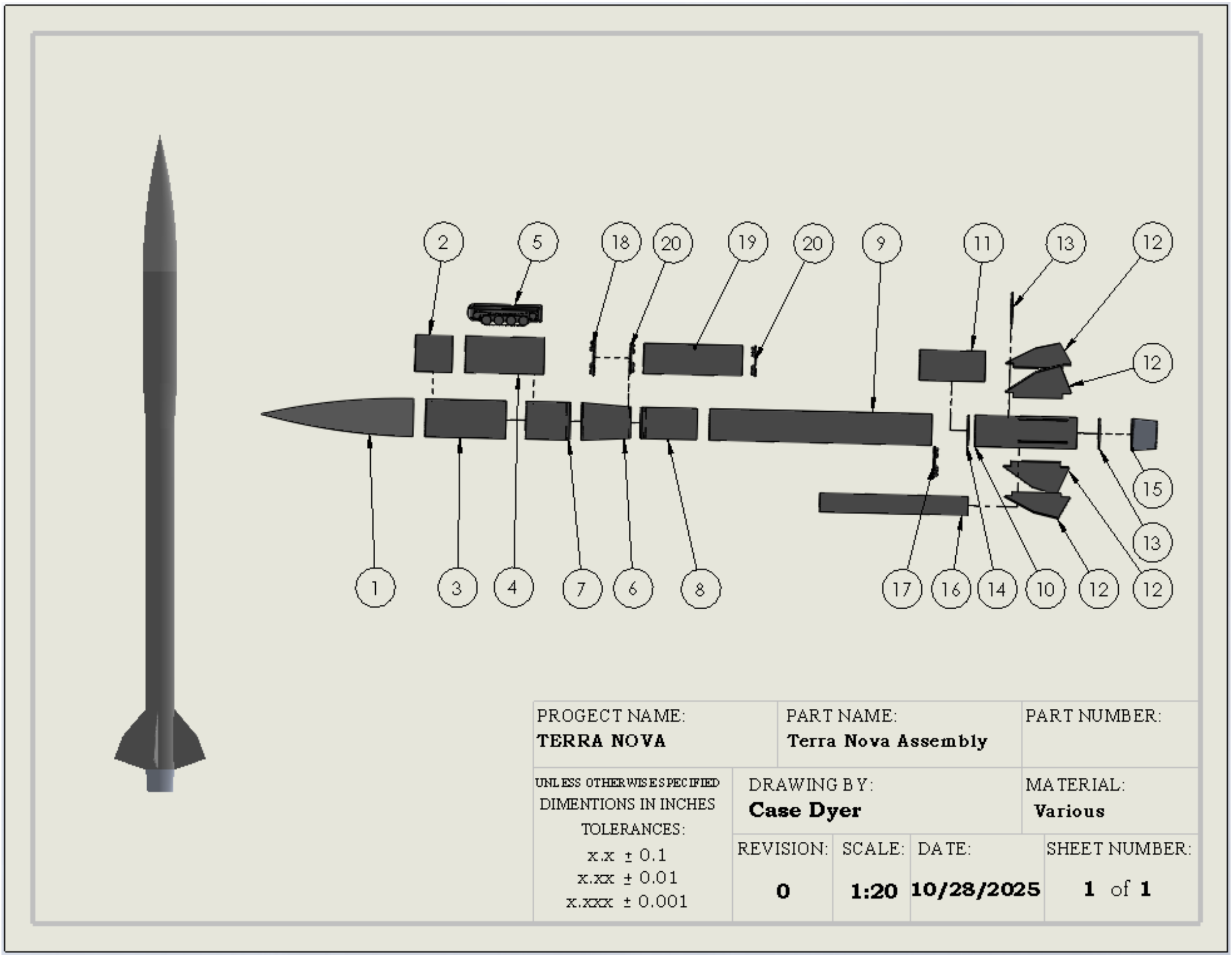


Figure 3-17 Terra Nova Assembly

Terra Nova Launch Vehicle BOM		
Part Number	Part Name	Quantity
1	4:1 Ogive Nose Cone	1
2	Nose Cone Coupler	1
3	Body Tube 1	1
4	Payload Coupler	1
5	Terra Inquisitor	1
6	Reducing Transition	1
7	Upper Transition Airframe	1
8	Lower Transition Airframe	1
9	Body Tube 2	1
10	Body Tube 3	1
11	Propulsion Separation Coupler	1

12	Clipped Trapezoidal Fins	4
13	Motor Tube to Body Tube 3 Centering Rings	2
14	Motor Tube to Propulsion Coupler Centering Ring	1
15	Boat-Tail	1
16	Motor Tube	1
17	RMS Bulkhead	1
18	HAUS Section Bulkhead	1
19	Avionics Bay Coupler	1
20	Avionics Bay Bulkheads	2

Table 3–10 Terra Nova Launch Vehicle BOM

Launch Vehicle Dimension and Weight Overview

The dimensions of all the Terra Nova launch vehicle components are detailed in Table 3-11 below.

General Dimensions		
Airframe Component	Measurement	Weight
HAUS Section		Primary ID: 6” Primary OD:6.17”
Nose Cone	• Shape: 4:1 Ogive • Base OD: 6.17” • Length: 24”	24 oz
Nose Cone Coupler	• Length: 6”	10.6 oz
Body Tube 1	• Length: 13”	22.6 oz
HAUS Section Coupler	• Length: 12.75”	22.5 oz
HAUS Bulkhead	• Thickness: .25”	31.5 oz
Avionics Section		Primary ID: 5” Primary OD:5.15”
Apogee Drogue Parachute	• Diameter: 15”	2.64 oz
Custom Transition Airframe	• Overall length: 24” • Transitions OD from 6.17” to 5.15” OD • Transitions from 6” ID to 5” ID • Transition length: 8”	35.7 oz

	• Transition angle: 3.68°	
Avionics Bay Coupler	• Length: 16”	15.7 oz
Avionics Bay Bulkhead x2	• Thickness: .25”	22.1 oz
Body Tube 2	• Length: 36.5”	46.7 oz
Main Parachute	• Diameter: 120”	23.7 oz
Reef Mechanism	• Diameter: 30”	8.0 oz
Propulsion Section		Primary ID: 5” Primary OD:5.15”
RMS Bulkhead	• Thickness: .25”	22.1 oz
Propulsion Coupler	• Length: 10.625”	10.4 oz
Aerotech RMS	• RMS size: 75/5120	65.1 oz
Body Tube 3	• Length: 16.5”	21.1 oz
Clipped Trapezoidal Fin Set	• As detailed	50.9 oz
Centering Rings x3	• Thickness: .25”	3.23 oz
Motor Retainer	• RMS Diameter: 75mm	4.47 oz
Boat-Tail	• Length: 4” • Transitions: 5.15” OD to 4.5” OD	16 oz
Overall Vehicle Length		118”
Overall Launch Vehicle Weight		32.1 lb
Assumed Weight of Additional Components and Payload		13.9 lb
Vehicle Weight (Excluding Primary Motor)		46 lb
Total Vehicle Weight		56.4 lb

Table 3–11 General Dimensions

Propulsion

The rocket will be propelled by a L2200G-0 Aerotech motor, providing an impulse of 5104. The diameter of this motor is 2.95” and is fitted to the Aerotech 75/5120 RMS system, which already in the supplies of the Terra Nova team. Simulations indicate this motor will take the rocket to a mean apogee of 4833 ft. Should this motor become unavailable, our secondary motor, the L1420R-P is also fitted to the RMS system we possess. This secondary choice is simulated to take the rocket to a mean apogee of 3903 ft at an impulse of 4616. This motor does not propel our current rocket design to the minimum apogee of 4000 ft specified by NASA but is the only other viable option given our current RMS setup. Should we be forced to use this motor, we will need to reduce the overall weight of the rocket.

Recovery System Location

The recovery system will consist of the avionics bay, recovery hardware, parachutes, and the reef line cutting mechanism. These components will all be housed in the midsection of the rocket body.

Separation Points

The rocket will separate at two different locations, one at apogee and one at 1500 ft AGL. At Apogee, the top of the transition will separate from the nosecone where the drogue parachute will be deployed. Then, at 1500 feet the second separation will occur in the aft section of the rocket, between the body tube housing the avionics/HAUS/parachute, and the body tube housing the motor and related hardware.

Reefed Main Parachute

The current leader for the parachute deployment system is the reefed main parachute. Both the reefed main and pilot-main work at the most basic level by deploying parachute area at different stages of recovery to minimize peak force while still leading to a safe descent. Where these two concepts differ is the method of deploying area. The reefed main involves two parachutes in series which creates a serious risk of tangling the parachute lines, as well as the complexity of design required to successfully attach two parachutes to the same cord. The reefed main parachute concept eliminates both concerns while still achieving the end goal. It will require a separate line running to the body of the rocket, and a device to detect altitude and cut the line at the correct height above ground level. A line can be ran from the eyebolt on the bulkhead to and around the skirt of the parachute, back down through the cutting device, and grounded again at the eyebolt. The device will then use a spring-loaded knife edge to cut through the line. The spring will be placed under load and held via a physical limit, which will be moved by a linear actuator at the proper altitude. This device will use its own altimeter and a second will be used for redundancy. The line would run through several loops along the skirt of the parachute, holding it at an open diameter of 30” (the same as the pilot parachute). After severing the line, the parachute will open to its full diameter of 120” (the diameter of the pilot concept plus the main). This allows us to simulate the reefed parachute as two separate deployments for simplicity, and in turn provides the same effect as the pilot-main concept with less components and weight than the initially proposed design of a pilot-main and main parachute being deployed sequentially.

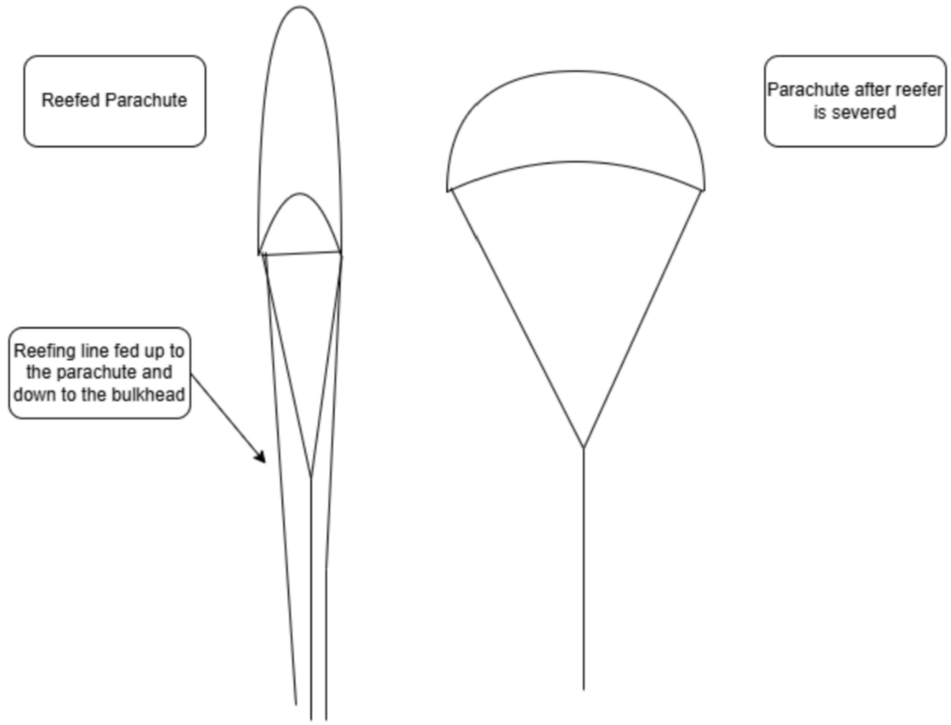


Figure 3-18 Reefed Main Parachute.

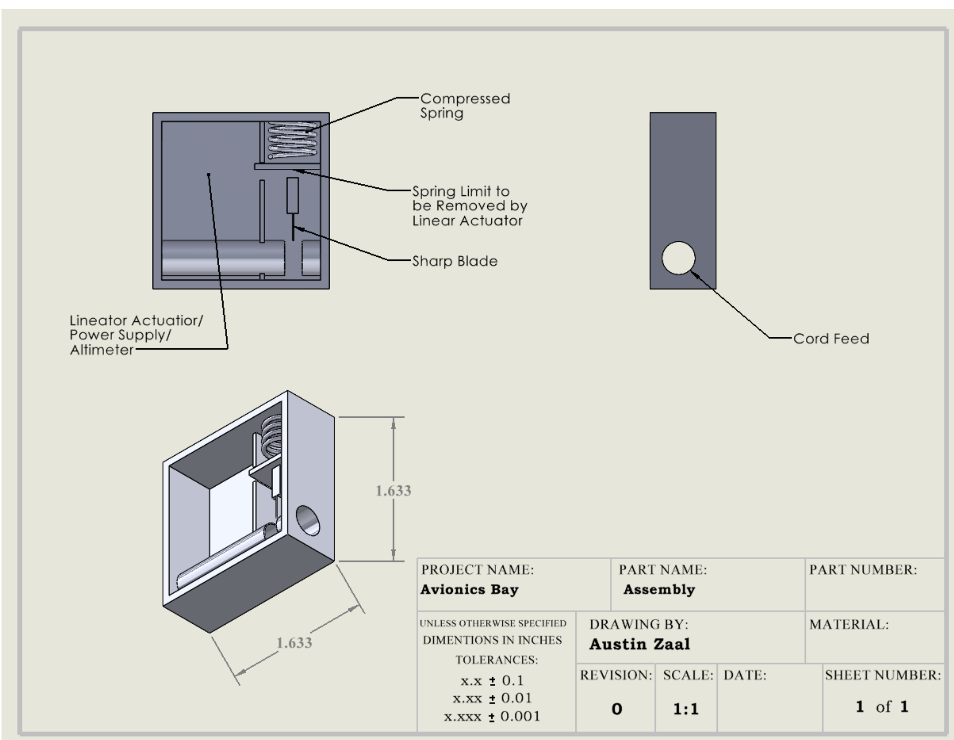


Figure 3-19 Reefing Line Cutter

Shock Cord

The selection of a shock cord is pending the results of cord testing but should the Paramax paracord prove to have good ductility, it could provide a superior alternative to the initial Kevlar-elastic hybrid. Initially the Kevlar-elastic cord was proposed from the concern that the forces of recovery would sever the shock cord line or the body of the rocket, but here, a more concrete force analysis will be conducted. The release of the drogue parachute will occur at apogee and create a minimal deployment force since the rocket will have almost no velocity at this point. Because of this, it can be neglected entirely, as the deployment of the main will exert the most force during deployment. The main will deploy in two stages. In stage one, the reefed main parachute will deploy, only allowing an opening diameter of 30”. Stage two will begin when this reefing line is severed, allowing the main to open to its full 120” diameter. Openrocket simulation results will be used to determine accelerations, and thus deployment forces. The acceleration caused by the reefed main is 180 ft/s^2, and adding a 10% error margin, it comes to 198 ft/s^2. Using this value and the mass of the full rocket without motors, the deployment force can be calculated.

$$F_{main,reefed} = ma$$

$$F_{main,reefed} = (1.427\ slug)(198\frac{ft}{s^2})$$

$$F_{main,reefed} = 282.74\ lbs$$

Calculating the drag force when the reefing line requires the same approach. The simulated acceleration from this event is 410 ft/s^2. Adding that same 10% error margin, it becomes 451ft/s^2.

$$F_{main,unreefed} = ma$$

$$F_{main,unreefed} = (1.427\ slug)(451\frac{ft}{s^2})$$

$$F_{main,unreefed} = 643.58\ lbs$$

Both the Paramax paracord and Kevlar cord will be tested in tension for strength and elasticity, but some initial values can be provided. Paramax paracord is rated by the supplier to 1200 lbs of tensile force (0.25” diameter; 24446 psi tensile strength). The tensile strength of Kevlar varies, but until testing of the samples is complete a 1500 lbs tensile strength can be assumed. In any case either cord can withstand these forces, though it is expected that the elasticity of the paracord will prove it to be superior to the Kevlar-elastic design. This is because the connection points of the originally proposed cord would likely require the use of carabiners, adding a significant amount of potentially unnecessary mass to the recovery system.

Parachute Sizing

Calculating the optimum parachute size involves a trial-and-error process of calculating the drag force from several parachute options until acceptable terminal velocity values are found. Assuming:

$$W = F_D$$

This states that the force of drag is equal to the weight of the rocket, presenting a static analysis. Given the weight of our current rocket concept to be 47.125 lbs, and the equation for drag force:

$$F_D = \frac{\rho v^2 C_D A}{2}$$

where:

$\mathrm{A} = \text{Area of the Parachute}; \rho = \text{Air Density}; \quad \mathrm{v} = \text{terminal velocity}$
$\& \ \mathrm{C_D} = \text{Coefficient of Drag}$

This equation can be used with commercially available parachutes' sizes and coefficient of drag to estimate the terminal velocity caused by a particular parachute. The two most important parameters to set when solving this equation are:

1. The landing velocity (found from the impact energy equation $E = 0.5mv^2 \leq 60$ ft-lbs.)
2. Time to ground from apogee (derived goal of 80s)

With these two parameters set, the first step is to find the desired landing velocity. The rockets weight of 47.125lbs can be converted to slugs via the following equation:

$$m = \frac{W}{g}$$

$$m = \frac{47.125lbs}{32.17lbs/slug} = 1.465\ slug$$

In the current configuration of the rocket, it is safe to assume each of the three separating sections have equal mass, therefore:

$$m_{1\ section} = 0.4883\ slug$$

With this parameter and the derived goal of $E \leq 60$ft-lbs, the desired landing velocity can be calculated.

$$60\ ftlbs \geq \frac{(0.4833slug)v_{land}^2}{2}$$

$$v_{land} \leq 15.68\ \frac{ft}{s}$$

With the desired landing velocity set, different parachute sizes and their respective drag coefficients were used to solve for velocity using the drag force equation. The found velocities were then used to determine the descent time for each stage of separation, given the deployment altitudes. First, the drogue is to be deployed at an average simulated apogee of 4848.7 ft. With the average ground level of Huntsville AL being roughly 600 feet, air density is referenced at the actual height (+600ft from simulation data). The air density at 5448.7 ft is extrapolated to be 20.19*$10^{-4}\,\frac{slug}{ft^3}$. The selected drogue parachute is Fruity Chutes' 15" Compact Elliptical Parachute with a drag coefficient specified at 1.5-1.6 (1.55 will be used for calculations).

$$W = F_D$$

$$47.125 = \frac{v_1^2\left(20.19 * 10^{-4}\frac{slug}{ft^3}\right)(1.55)(1.227ft^2)}{2}$$

Thus,

$$v_1 = 156\,\frac{ft}{s}$$

This parachute will be deployed at apogee (4848.7 ft AGL) and the reefed main parachute will be deployed at 1500 ft AGL, so the rocket will fall 3347.7 ft with only the drogue. This distance at the found velocity grants a descent time of stage 1

$$t_1 = 21.5\,sec$$

Moving onto the deployment of the reefed main parachute, the method is the same, but the coefficient of drag and area of the drogue must also be accounted for, since both parachutes will be contributing to the descent rate. The main parachute will be 120", reefed down to 30". This is stage 2 and 3 of the recovery process. Stage two will be initiated at 1500 ft AGL or 2100 ft above sea level, so the air density $\rho = 22.39 * 10^{-4}\frac{slug}{ft^3}$. The calculations for stage 2 descent velocity are as follows:

$$W = F_D$$

$$W = \frac{\rho v_2^2[(C_{D,reefed\ main})(A_{reefed\ main}) + (C_{D,drogue})(A_{drogue})]}{2}$$

$$47.125 = \frac{v_2^2\left(22.39 * 10^{-4}\frac{slug}{ft^3}\right)[(2.2)(4.908ft^2) + (1.55)(1.227ft^2)]}{2}$$

$$v_2 = 57.6\frac{ft}{s}$$

Using the same method as before, the descent time of stage 2 (from 1500 to 600 ft) can be found.

$$t_2 = 15.5\,sec$$

Finally, stage three is calculated using the full area of the main parachute after the reefing line is severed as well as the drogue area. Stage three will be initiated at 600 ft AGL, which is within the rules since severing the reefing line does not require the use of any pyrotechnics. The actual altitude will be closer to 1200 ft, where the air density $\rho = 22.72 * 10^{-4} \frac{slug}{ft^3}$. Calculations for stage three are as follows:

$$W = F_D$$

$$W = \frac{\rho v_3^2[(C_{D,main})(A_{main}) + (C_{D,drogue})(A_{drogue})]}{2}$$

$$47.125 = \frac{v_3^2\left(22.39 * 10^{-4} \frac{slug}{ft^3}\right)[(2.2)(78.54ft^2) + (1.55)(1.227ft^2)]}{2}$$

$$v_3 = 15.4 \frac{ft}{s}$$

Again, solving for the descent time form 600 ft to ground

$$t_3 = 39\ sec$$

Given the derived goal of landing at a velocity less than or equal to 15.68 ft/s, this meets the requirements for impact energy. Summing t_1 t_2 & t_3, the total estimated apogee to ground time can be found

$$t_1 + t_2 + t_3 = t_{A2G}$$
$$t_{A2G} = 76.0\ sec$$

This meets our goal of apogee to ground time less than or equal to 80 seconds without jeopardizing the safety of recovery via an unacceptable ground impact energy. The parachute configuration that achieves this goal is as follows:

1. 15” Fruity Chutes Compact Elliptical Parachute, deployed at apogee
2. 120” Fruity Chutes Iris Ultra 120” Compact Parachute, reefed to 30” effective diameter, deployed at 1500 AGL
3. 120” Fruity Chutes Iris Ultra 120” Compact Parachute, de-reefed at 600 ft AGL

Shear Pin Selection

Before a specific shear pin can be selected, the forces it must withstand must first be understood. When the rocket is assembled at ground level, the internal pressure inside the body will be equal to the atmospheric pressure around it; however, as the rocket increases altitude, the atmospheric pressure will decrease while the rocket’s internal pressure will stay mostly constant. This increasing pressure differential will create a force that grows in magnitude as the rocket ascends.

The weight of the rocket's components will also attempt to separate the different sections of the rocket, while friction between the body tubes and couplers will act to prevent this action. Based on hand solved calculations, the worst-case scenario of these forces will happen when the rocket is perfectly vertical, just as it hits apogee.

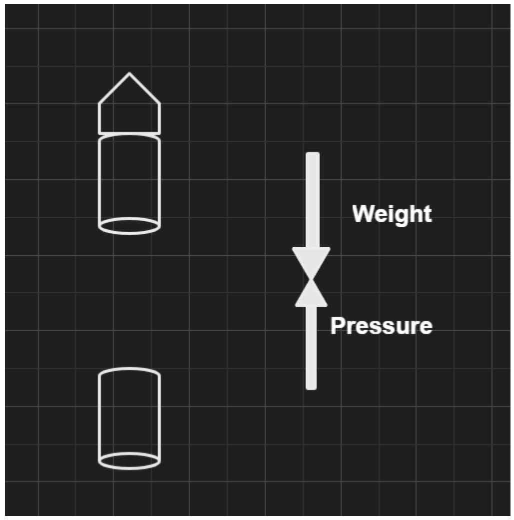


Figure 3-20 Nosecone FBD.

This free body diagram demonstrates the forces acting to separate the nose cone (Section 1) from sections 2&3. Simulating the worst-case scenario, friction is neglected, thus providing no assistance to the shear pins to keep the rocket together. With the air pressure at ground level set to 14.696 psi, and the air pressure at apogee (roughly 5500 ft, more than +600 of the simulated 4848.7 ft to account for Huntsville's average ground level of 600 ft above sea level) is 12.016 psi. This creates a pressure differential:

$$\Delta P_{apogee} = P_{ground,inside} - P_{air,apogee}$$
$$\Delta P_{apogee} = 2.68\, psi$$

With this estimated pressure differential, a force is created:

$$F_{P,apogee} = \Delta P_{apogee} * A_c$$

Since the nosecone separation occurs at the top of the transition, the diameter of the rocket this force will be acting on at its greatest is 6". Thus:

$$F_{P,apogee} = (2.68psi) * (\frac{\pi(6)^2}{4})$$
$$F_{P,apogee} = 75.775\, lbs$$

The weight of sections 2 & 3 of the rocket will also contribute to a natural separation in this exercise. Sections 2 & 3 weigh 16.4375 lbs and 13.875 lbs, respectively. The minimum force the shear pins must withstand can be modeled by the maximum force created in this scenario. Thus:

$$F_{pin} = F_{P,apogee} + W_{2,3}$$
$$F_{pin} = (106.09lbs) + (16.4375lbs + 13.875lbs)$$
$$F_{pin} = 106.09\ lbs$$

This solution demonstrates that the minimum force the shear pins must be able to withstand is roughly 107 lbs. This parameter led to the selection of Apogee Rocket's Small Nylon Shear Pins. The properties of these pins were not specified in the catalog, but after referencing MatWeb's database on Nylon 6 Cast [13] (not the exact material, but provides a rough estimate), the shear strength of this material was reported between 6500-11000 psi. Taking the worst case scenario of a shear strength of 6500 psi, and the size of the screws being 2-56 (diameter of 0.086"), their strength in lbs can be found.

$$P_{max,shear} = \frac{F_{max}}{A_c}$$
$$F_{max} = 37.757\ lbs$$

Alone, this is not enough to withstand the calculated forces, but using 4 of these pins and assuming equal distribution of load, the maximum force shoots up to:

$$F_{max} = 151.03\ lbs$$

This is more than capable of withstanding the forces calculated in this exercise, so this selection is justified.

CO2 Cartridge Sizing

With the shear pins selected, the force needed to separate can be determined. Our selected method of separation is a pressure separation created by the ejection of CO2 from pressurized canisters. The worst case of several calculations will be specified again here. There will be two separations during the recovery of the Terra Nova rocket. First, at apogee (4848.7 ft), and second, at 1500 ft. The air pressures used will be the same as in the previous calculations:

$$F_{sep,1} = \Delta P_{apogee} * A_{c,bulkhead}$$
$$P_{air,apogee} = 12.016\ psi$$

Since the force to separate must be greater than the maximum strength of the shearpins,

$$F_{sep} > 152lbs$$

With these parameters set, the pressure needed to separate at apogee via CO2 canisters can be calculated.

$$F_{sep} < \Delta P * A_{c,bulkhead}$$
$$152 < (P_{internal} - 12.016) * (\frac{\pi(6)^2}{4})$$
$$P_{internal} > 17.392psi$$

The pressure needed to separate is 17.392 psi. Assuming the worst case scenario of a vented body tube (external pressure = internal pressure) at least an additional 5.376 psi must be created. To determine how much CO2 this requires, the ideal gas law can be employed. The area to be pressurized here is the transition, which presents a complex volume. For both simplicity and safety factors, it will be assumed that the entire transition is consistently 6" in diameter, and 8" in length. Temperature will also be taken to be 20°C. All of these parameters will be converted to SI units for this calculation.

$$PV = nRT$$
$$(37066.23Pa)\left(\left(\frac{\pi(0.1524m)^2}{4}\right)(0.2032m)\right) = n(8.314\frac{J}{Kmol})(293.15°K)$$
$$n = 0.056\, mol$$

Thus, half a mol of CO2 must be deployed. Converting this to grams is as follows. Note: M_{CO2} is the molar mass of carbon dioxide.

$$m = n * M_{CO2}$$
$$m = (0.056mol)(44.009\frac{g}{mol})$$
$$m = 2.48g$$

Since CO2 cartridges are available in 8, 12, or 16 grams, a single 12-gram cartage can be employed for this separation at a minimum.

For the second separation, the same method will be used. The only major differences are that the diameter of this section of the rocket is down to 5", the pressurized portion is much longer, and the air pressure at this separation (1500 ft) is 13.956 psi.

$$F_{sep,1} = \Delta P_{1500ft} * A_{c,bulkhead}$$
$$P_{1500ft} = 13.956\ psi$$
$$F_{sep} > 152lbs$$
$$F_{sep} < \Delta P * A_{c,bulkhead}$$
$$152 < (P_{internal} - 13.956) * (\frac{\pi(5)^2}{4})$$
$$P_{internal} > 21.70\ psi$$

Thus, a much greater internal pressure of 21.70 psi must be achieved for this second separation. Assuming the internal pressure to be the same as the external pressure, an additional 7.741 psi must be created. To calculate the mass of CO2 required, the ideal gas law will be used again. Note: the length of this separating section is 29”. All of these parameters will be converted to SI units for this calculation.

$$PV = nRT$$
$$(53372.34Pa)\left(\left(\frac{\pi(0.127m)^2}{4}\right)(0.737m)\right) = n(8.31146\frac{J}{Kmol})(293.15°K)$$
$$n = \ 0.204mol$$

Converting moles into the mass of CO2 required:

$$m = n * M_{CO2}$$
$$m = (0.2046mol)(44.009\frac{g}{mol})$$
$$m = 8.99g$$

Thus, a single 12g cartridge should suffice at a minimum for this separation as well. For an increased factor of safety, 16g CO_2 cartridges will be used for both separations at a minimum.

Avionics Bay

The avionics bay will be housed in the center of the rocket within the coupler connecting the non-separating midsection body tubes. The role of this component will be to measure altitude throughout the flight and direct the recovery system. The reef line cutter and payload systems will operate independently of this system, so the avionics bay’s primary task is to fire the CO_2 canisters to create separation. The avionics bay will need to be vented in order for the barometric altimeter to work properly, but the volume to be pressured (outside the avionics bay) will need to be sealed to properly pressurize and create separation. This seal will be accomplished via O-rings around the bulkheads on either side of the avionics bay. The components of the avionics bay will include 2 barometric altimeters/flight computers, 2 power sources, and 2 e-matches running to each of the two CO_2 cartridges (specified above). At the nozzle of each CO_2 cartridge, an isolated black powder charge will be contained with a firing pin. Upon ignition, the charge will set off and rupture the seal of the cartridge. This gas ejection will create the force needed to rupture the shear pins and create both separations at the proper timing. Attached below is an electrical diagram for the avionics operations and a drawing of the current avionics bay configuration.

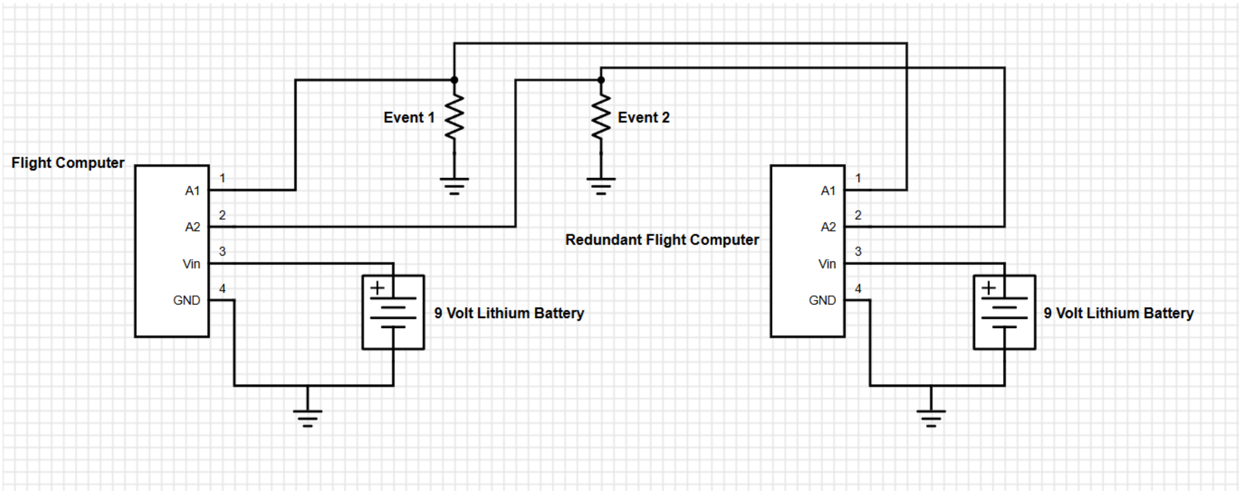


Figure 3-21 Avionics Electrical Schematic.

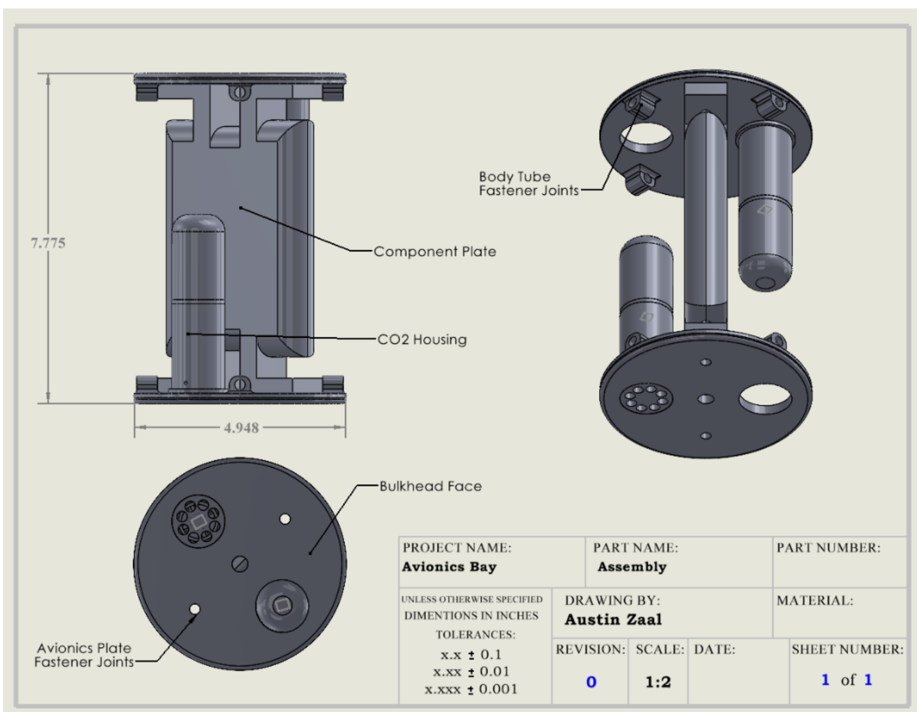


Figure 3-22 Avionics Bay Assembly.

Separation Event

Both separations will be initiated by the release of CO_2 from pressurized canisters. These canisters will be housed inside the avionics bay, directing outward into the volumes housing recovery hardware. As specified above, a 16g CO_2 canister will be sufficient to create both separations, with an additional unit for redundancy. The canisters will be held in a casing that orients them in the proper direction and houses a firing pin and black powder charge to rupture the seal and release the gas into the recovery compartments. Drawings for this casing can be referenced below. Since the powder charge is only being used to rupture the canisters, a minute amount will be needed. It is expected that 0.1g or less should be sufficient, though a specific amount will be decided during testing. All proper safety protocols will be strictly adhered to when handling/testing this substance.

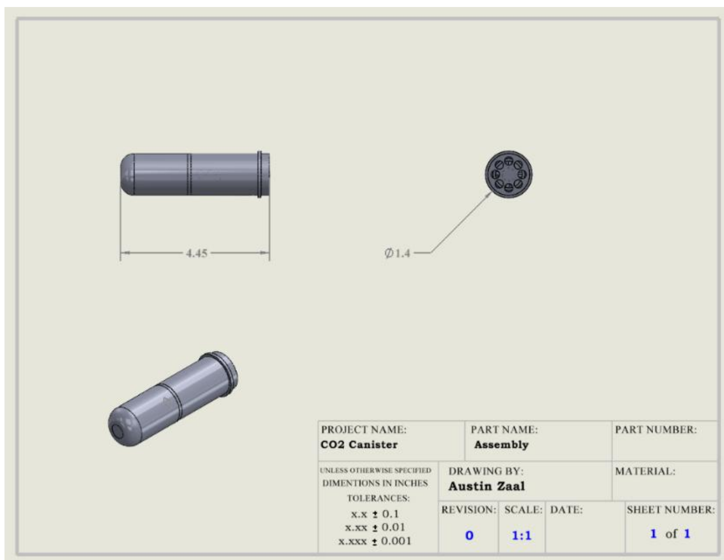


Figure 3-23 CO_2 Canister Assembly

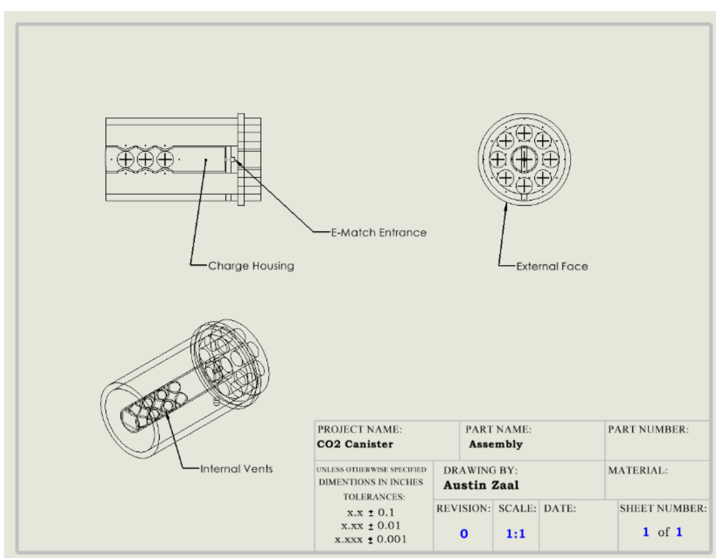


Figure 3-24 CO_2 Venting/Energetics

3.4. Mission Performance Predictions

Full-Scale Rocket the Terra Nova

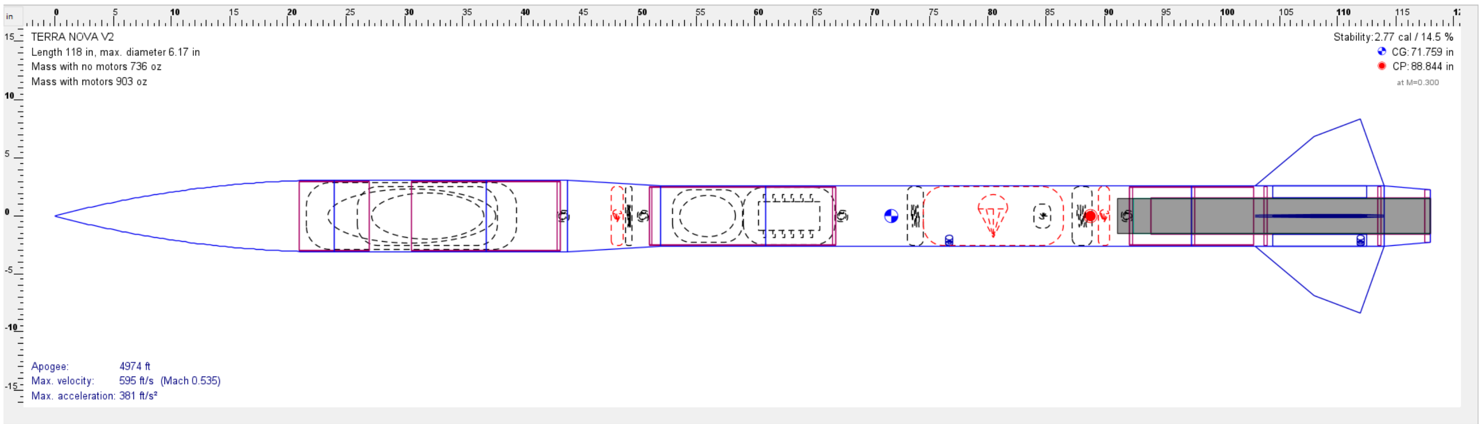


Figure 3-25 Terra Nova V2.8.

The figure above displays the current design of the full scale Terra Nova rocket. The rocket has a length of 118” and weights with and without motors of 56.38 lbs & 45.94 lbs, respectively. The stability margin of 2.71 cal meets the NASA requirement. The center of gravity is located at 71.51” aft of the nose, and the center of pressure follows 16.91” further at 88.43” aft of the nose. Along with the fin design, these locations are a large contributor to the high stability margin.

In section 3.3, these deployment forces were calculated based on the accelerations caused by the main parachute. The force created by the drogue deployment was considered negligible, since it is much smaller than that of the main deployment.

$$F_{main,reefed} = 282.74\ lbs$$
$$F_{main,unreefed} = 643.58\ lbs$$

The worst case of these two events is the full opening of the main after the reefing line is severed. This value of 643.58 lbs will be used to calculate the force exerted on the frame of the rocket to prove it can withstand the forces of recovery. Assuming the full load is applied to the bulkhead and equally distributed on each of the 4 attachment points (bulkhead to the body of the rocket). This would put the attachment points in shear with this load, and the body tube/coupler into tension. It will also be assumed that the body tube/coupler takes all the applied load without help from each other. The tensile strength of fiberglass is 80.6 ksi or 80600 psi. It was calculated earlier in this document that the shear stress applied entirely to a single bolt from the main opening is 13.1 ksi. Assuming this load is directly transferred to the body tube/coupler in tension, the fiberglass frame can withstand this load with a safety factor of 6.

Primary Motor

The primary motor selection has been redefined to the L2200G-0 Aerotech motor. After further solidifying the design of the Terra Nova, an increase in weight from the previously proposed rocket led to the need for a more powerful motor to achieve the goals of this launch. The secondary and primary motors were swapped in ranking. The vehicle's apogee is now predicted to be 4850 ft with a max velocity of 596 fps. The highest instantaneous acceleration experienced by the launch vehicle and the STEMnauts is 408 ft/s^2 or 12.7 G's at the full deployment of the un-reefed main. The rocket is expected to reach ground from apogee in 75 seconds and land at a speed of 15.7 fps. Both parameters are consistent with the calculations in sections above and the derived requirements set by the Terra Nova team to ensure the safe launch and landing of the STEMnauts. The figures outlined below are one of several OpenRocket simulations for the predicted performance of the Terra Nova at various launch angles (from 5°-10° in 2.5° in7559.8tervals) and wind speeds. Landing at 15.7 fps is very close to the calculated 15.6 fps, and the impact energy calculated for each respective section is as follows:

$$E_{HAUS\ Section} = 59.8 \text{ ft-lb}$$
$$E_{Avionics\ Section} = 58.4 \text{ ft-lb}$$
$$E_{Propulsion\ Section} = 49.5 \text{ ft-lb}$$

Each of these calculated values meet both the NASA requirement and our derived goals. It should also be noted that the velocity of the rod averages 77.7 fps, which meets the NASA requirement of 52 fps.

Flight Simulations

The figures below are based on the flight conditions outlined in Table 3-12 and conducted using OpenRocket software.

Flight Simulation Conditions Huntsville, Alabama	
Criteria	Magnitude
Wind	0 MPH
Launch Rail Angle	5°
Launch Rail Length	12 ft
Temperature	70 °F
Altitude	600 ft
Latitude	34.6 °N
Longitude	-86.7 °E
Pressure	1 atm

Table 3–12 Flight Simulation Conditions

Altitude

The apogee expected based on these conditions is 5105 ft. With a predicted total flight time of 93.2 seconds, time to apogee of 18.1 seconds, and hence a tine from apogee to ground of 75.1 seconds. Figure 3-26 illustrates the flight of the rocket and the deployment of the recovery system. The apogee drogue is expected to deploy 1 second after apogee, followed by the reefed main deployment at an altitude of 1500 ft. Lastly, the main fully deploys at an altitude of 600 ft.

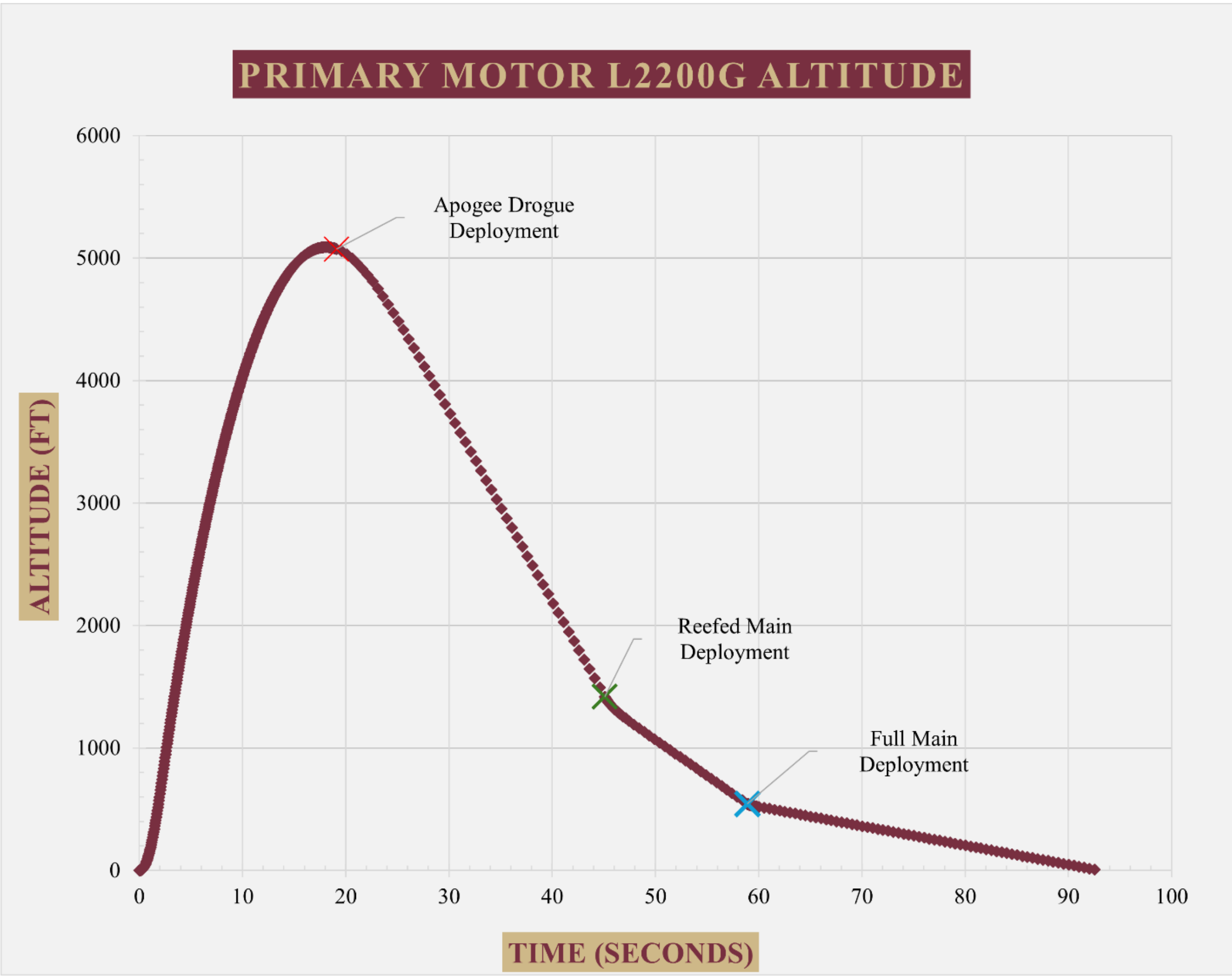


Figure 3-26 Primary Motor Predicted Flight Altitudes.

Velocity

The velocities experience by the Terra Nova during flight is shown in Figure 3-27on the next page. The peak velocity is due to the thrust of the rocket motor. The velocity off the rail is anticipated to be 77.7 fps with the L2200G motor accelerating the rocket till motor burnout at which the rocket achieves the maximum anticipated velocity of 596 fps. The velocity at the deployment of the reefed main is 154 fps, with the full deployment of the main occurring at a velocity of 59.1 fps bringing the rocket to its landing velocity of 15.9 fps.

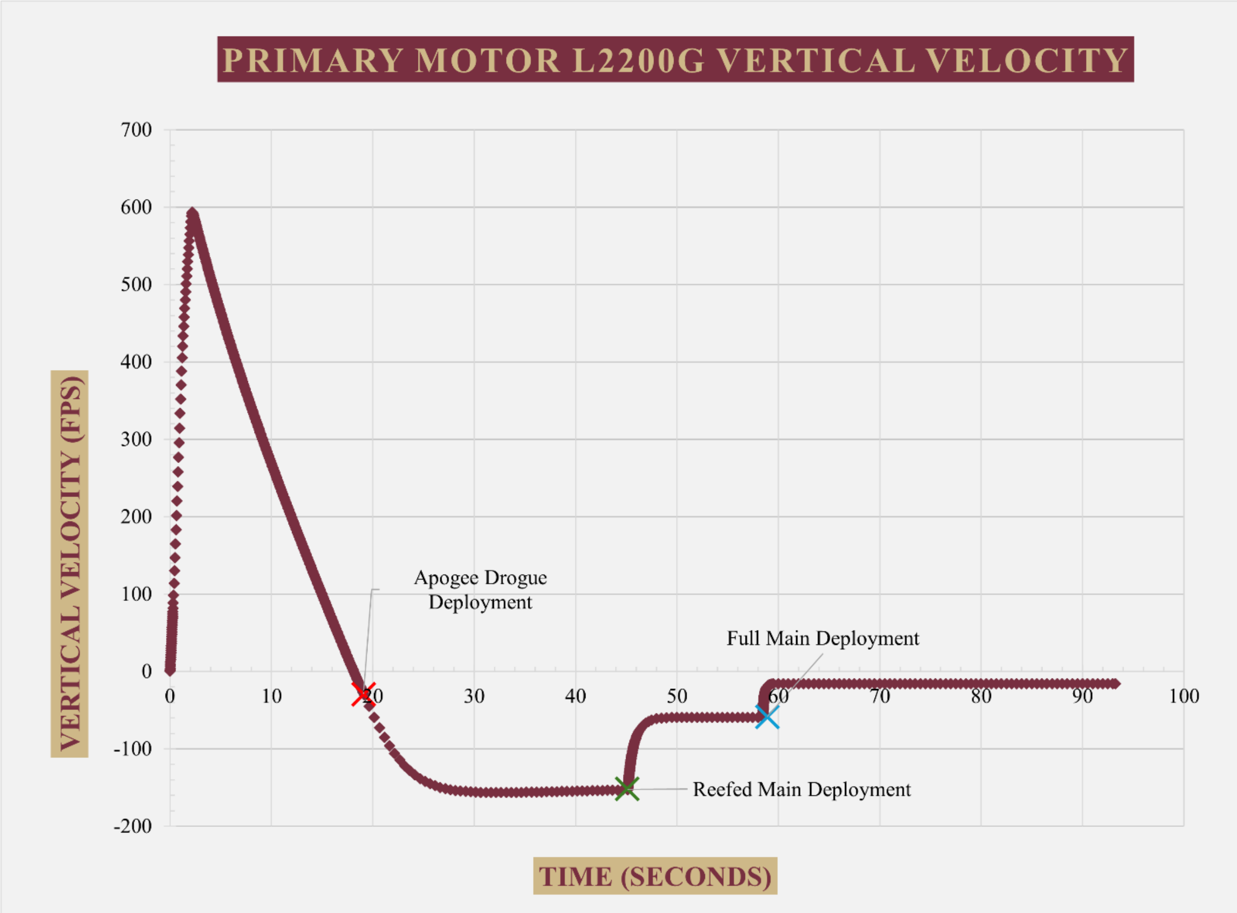


Figure 3-27 Primary Motor Predicted Flight Velocity

Accelleration

The accelerations experienced by the Terra Nova are outlined in Figure 3-28. The peak instantaneous acceleration due to motor thrust is 381 ft/s^2 or 11.8 G's. The instantaneous acceleration of the rocket at the deployment of the reefed main is 180 ft/s^2 or 5.6 G's and a the final and greatest acceleration of 408 ft/s^2 or 12.7 G's at the full deployment of the main.

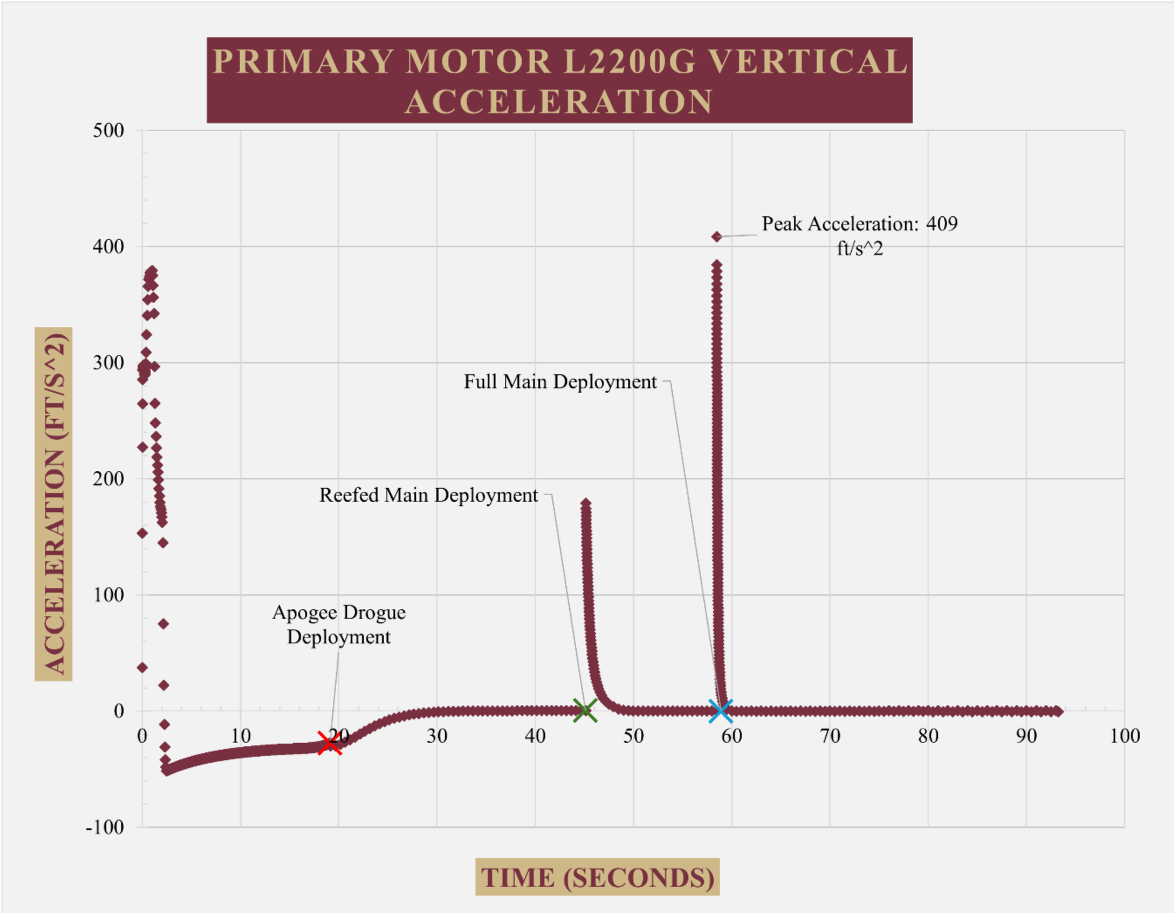


Figure 3-28 Primary Motor Predicted Flight Acceleration

Thrust

The predicted thrust of the L2200G is shown in Figure 3-29. The maximum anticipated thrust of the motor is 3099 N with a total impulse of 5104 Ns. The average thrust of the motor is 2243 N. Motor burnout occurs after 2.4 seconds using 2518 g of propellent. The thrust to weight ratio for the Terra Nova design and the L2200G is 8.94:1.0 exceeding the minimum requirement of 5.0:1.0 weight ratio per Handbook Req. 2.12.

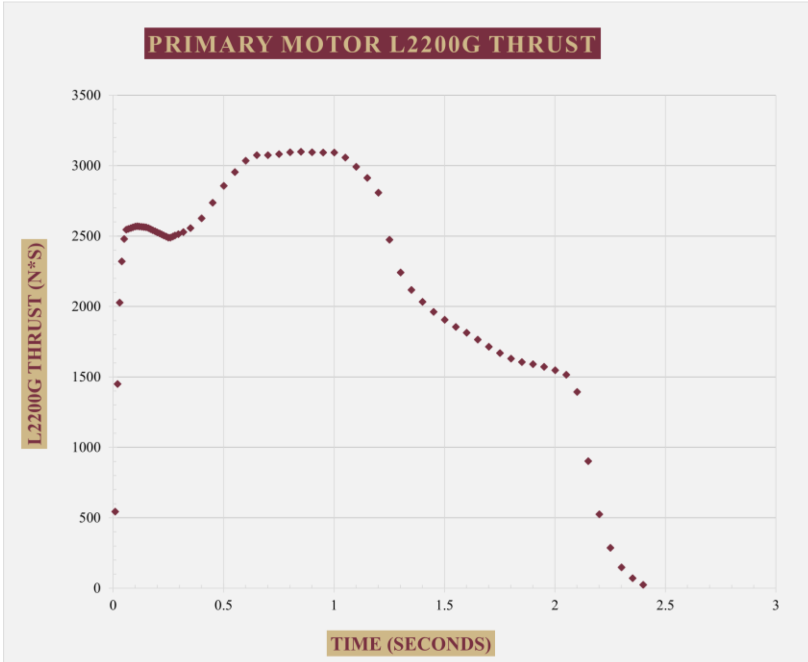


Figure 3-29 Primary Motor Predicted Flight Acceleration

Stability

The static stability of the Terra Nova is required per Handbook Req. 2.11 to be above 2 calibers. The Terra Nova's static stability on the launch pad is 2.71 calibers meeting the requirement of 2. The stability of the rocket at rail exit is 2.8 calibers. However, the stability of the rocket changes with velocity, weight, and angle of attack. Figure 3-30 details the expected stability of the launch vehicle over the course of its flight to apogee.

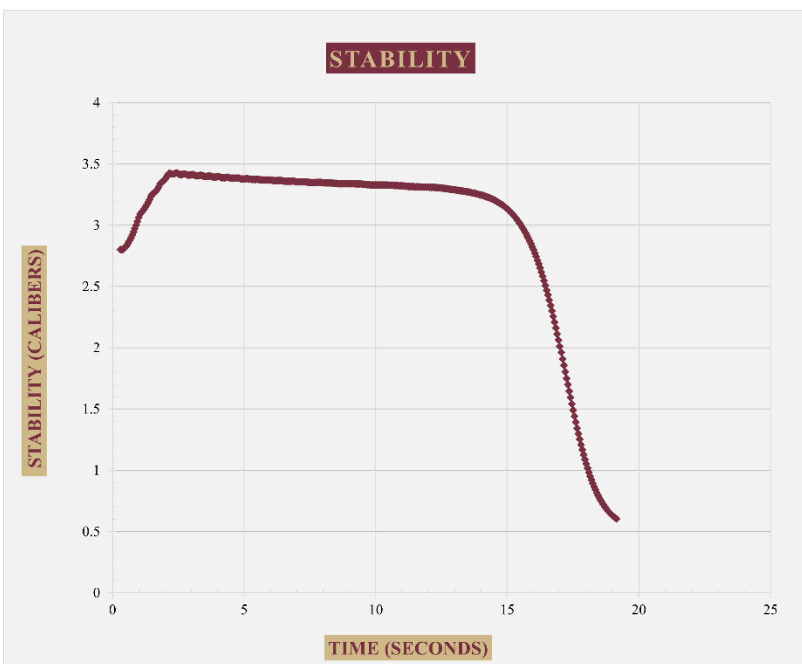


Figure 3-30 Primary Motor Predicted Stability

The maximum stability experienced during flight is 3.43 occurring just after motor burnout and peak velocity at flight time 2.45 seconds. The minimum stability during flight to apogee is .604 calibers just before the rocket reaches apogee.

Secondary Motor

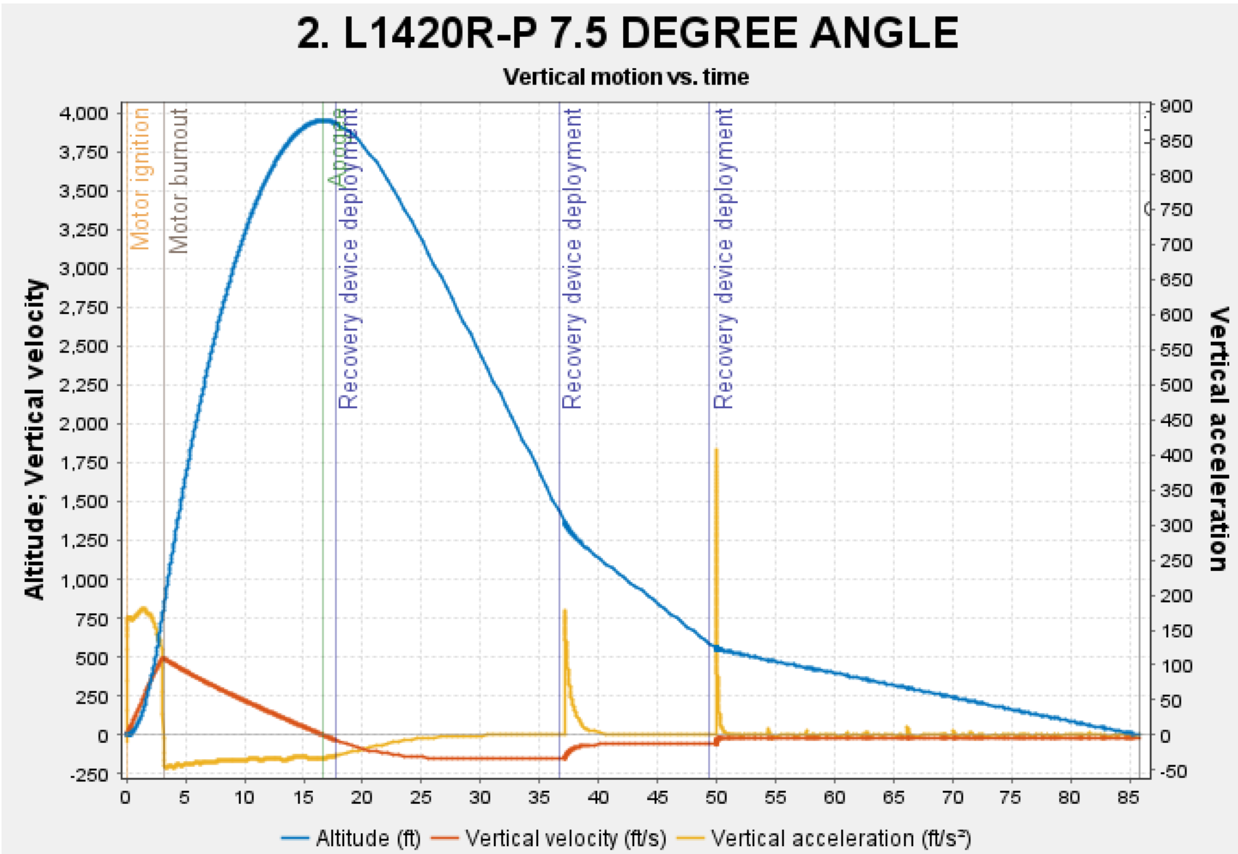


Figure 3-31 Secondary Motor Combined Simulation Data.

The secondary motor selection has been redefined to the L1420R-P Aerotech motor. The figure presented above is one of several OpenRocket sims of our predicted performance at several launch angles (from 5°-10° in 2.5° intervals). The reported predictions are the mean values of different simulations. The mean apogee altitude with this motor is 4012.33 ft. This altitude is on the edge of meeting requirement of 4000-6000ft per Handbook Req. 2.1, with the worst values falling below 4000 ft. Increased mass in the rocket decreased predicted apogee from the proposal and thus changed altered preferred motor selection. This motor is still in consideration since it is the second best available motor that fits the RMS already possessed. This motor reaches a top speed of 511 fps, and the peak deceleration of 408 ft/s^2. This motor configuration does slightly affecting the ground hit velocity/impact energy, averaging at 15.8 fps compared to the 15.7 fps with the primary motor configuration. The impact energy for each respective section in this motor configuration is as follows:

$$E_{nose\ section} = 63.50\ ft - lbs$$
$$E_{mid\ section} = 63.77\ ft - lbs$$
$$E_{tail\ section} = 53.84\ ft - lbs$$

While these values are slightly larger than in the primary configuration, they still meet both the NASA requirement and our derived goal. The velocity off the launch rod with this configuration averages out at 59.0 fps across all simulated launch angles. This meets the requirement of 52 fps per Handbook Req. 2.14. Finally, the thrust to weight ratio for this motor is 5.7:1.0 meeting Handbook Req. 2.12.

Horizontal Drift During Descent

The horizontal drift of recovery can be estimated by multiplying the velocity of the wind times the time from deployment (apogee) to ground. This calculation runs on the assumption that the rocket travels at the same horizontal velocity as the wind. This assumption is justified since the parachute drives the rocket to a steady state velocity within 1 or 2 seconds. The transient velocity in this short segment drives to equilibrium with environment, and reaches steady state at a velocity very close to that of the wind around it. In section 3.3, the time from apogee to ground was calculated. Using this total time to ground (t_{A2G} = 76.0 sec), and the horizontal wind speed, the drift of the rocket can be estimated. For the purposes of this calculation, wind speed will be considered constant and several different wind speed values will be used to model different scenarios.

$$x_{disp} = v_{wind,x} * t_{A2G}$$
$$Given: t_{A2G} = 76.0\ sec$$

Calculated Drift Estimation	
Wind Velocity (fps)	Total Drift (ft)
0	0
5	380
10	760
15	1140
20	1520
25	1900
30	2280

Table 3–13 Drift Estimation

The average wind speed in Huntsville, AL is roughly 11 ft/s, so these conditions model scenarios we will face well. Per Handbook Req. 3.10, the vessel must land within a 2500 ft radius of the launch pad. Even in the worst case of a 30 ft/s horizontal wind, the rocket meets these drift requirements.

4. Payload Criteria

4.1. Payload Objective

The objective of the Terra Nova's HAUS payload (the Terra Inquisitor) is to autonomously collect and test a 60 mL sample of soil for pH level within 12 minutes of landing. The test data from the soil sample will be time-stamped and stored in a SD card on the Inquisitor. The Inquisitor will be a rover like vehicle capable handling various terrains and obstacles. It will initiate its autonomous soil testing protocol after landing.

4.2. Payload Systems

4.2.1. Mechanical Separation

The first stage of the payload is its deployment. This will be achieved without using energetics and after the rocket has safely landed; thus, this design will not eject in the air as an unmanned aircraft system (UAS). To achieve this separation at ground level, a mechanism must be designed to overcome various frictional and weight loads and separate the HAUS Section of the rocket airframe for the deployment of the Terra Inquisitor. For the optimal design of such a mechanism, these loads need to be quantified, and various concepts must be considered.

The force required to separate can be simplified to multiple forces acting at a single point on the HAUS Section of the rocket. This single point will be assumed to be at the location of separation. The forces acting at this point include the force needed to separate (F_{min}), the weight of the section (W_{HS}), friction due to ground-airframe contact ($f_{S,GA}$), friction due to coupler-airframe contact ($f_{S,CA}$), and the normal forces acting between the coupler-airframe and the airframe-ground which would be equal (F_N). The magnitude of this force will be the derived requirement for the minimum force that a mechanism must be able to exert. This is illustrated in Figure 4-1.

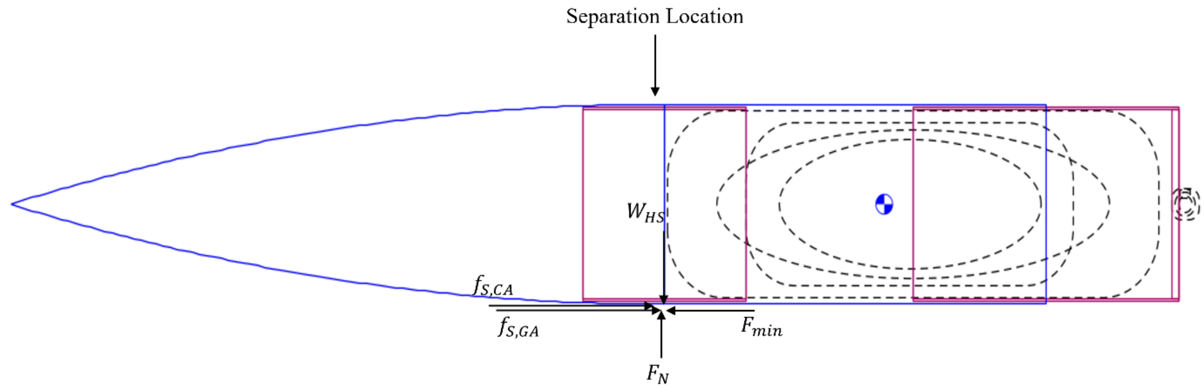


Figure 4-1 Separation FBD when θ = 0°

However, it must also be considered that the HAUS section may land on a slope, thus it is possible that there would be another orientation at which more force would be required to separate. Figure 4-2 below illustrates this alternative.

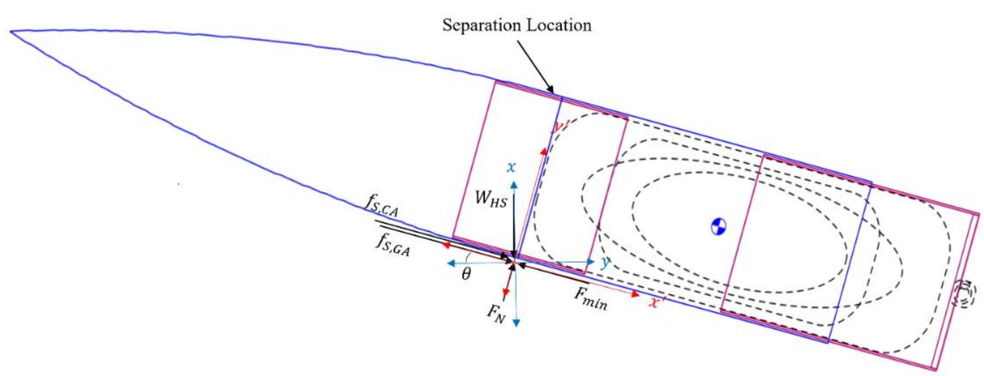


Figure 4-2 Separation FBD when θ ≠ 0°

This possibility can be simulated in MATLAB for all angles from 0-90 degrees to find the worst possible orientation of landing that requires the most force to separate. To affectively quantify a worst case-scenario landing, it will be assumed that the static coefficient of friction between the soil and the airframe is $\mu_{S,GA} = 1$ and that the static coefficient of friction between the fiberglass coupler and airframe is also $\mu_{S,CA} = 1$. These assumptions are certainly inflated, however, more accurate static coefficients of friction between these materials were not found; hence, to quantify a worst-case scenario for the required separation force, these assumptions were implemented. Using this worst-case required force, the design of the mechanical separator will be provided with sufficient redundancy to overcome a variety of other obstacles that cannot be quantified. The weight of the HAUS Section will be assumed to be maximum allowable weight per the derived requirement for the HAUS section $W_{HS} = 250$ oz (further outlined in 6.1.3 Derived Payload Requirements). Figure 4-3 below shows that the maximum force required based on the assumptions outlined is 34.9 lb when the HAUS section lands and remains on a slope of 27°. Note: Since the frictional forces due to the normal force are both equal to one, the effective force due to the sum of these forces is double the normal force for any particular landing orientation.

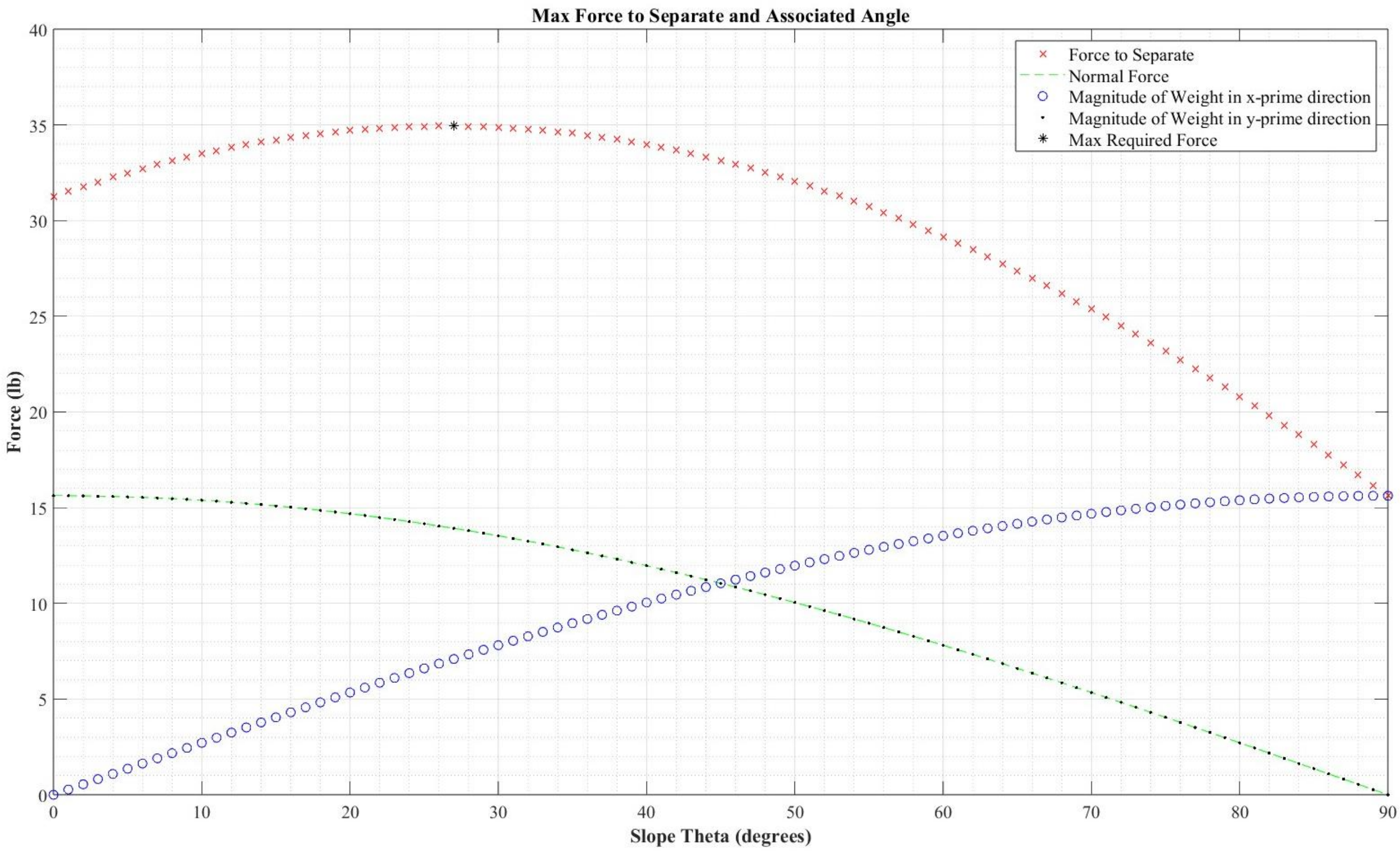


Figure 4-3 Max Force to Separate and Associated Angle

Though there are many limitations to this force estimation, it is overall, an inflated estimation of the required force to separate which is a good basis to move forward from. This is an inflated estimation due to the usage assumptions of static coefficient of friction for both the soil and coupler to the airframe being equal to one. This is most likely not the case since the rocket airframe will be smoothly painted and if necessary, there are methods to smoothen the contacting surfaces between the coupler and airframe. Also, by analyzing the CG in both figures above, it is clear that the assumption of the weight is acting fully at this point of separation is inaccurate. However, this is also an indication that the approximation of the maximum force required is an inflated value and hence is a good reference point for the design of the mechanical separation. By using this force as the minimum force that must be achieved by the mechanical separation mechanism or MSM, there is built in redundancy in the case of other factors that cannot be quantified or predicted.

Now that the derived requirement of minimum force that a MSM must achieve has been formulated, various mechanism must be considered. Since the initial reference for this design is separation after landing and thus usage of energetics is prohibited per HB Rule 4.6, there are two primary separation mechanism for consideration. One is a rail and geared rack system. The other is a power screw and nut system. Both concepts are similar, they use the mechanical advantages of geared type systems to produce linear motion from rotary motion of a motor. One advantage of the geared rack and rail is the ability for a large variety of input pinion gears. However, there are many complications with the usage of such a system. Primarily, the method of supporting the pinion gear motor assembly to maintain contact with the pinion. There are high risks of the pinion gear torquing its supporting frame till it loses contact with the rack. One major disadvantage of the rack and pinion are they do not amplify the output force to the extent that a power screw can. Thus, either a more complex gearing system would need to be implemented, or a stronger motor would be required, which would increase costs and also weight. Both systems involve some complications for the proper mounting configurations to provide sufficient separation distance for the deployment of the Terra Inquisitor. On the other hand, the power screw would not be able to slip from the separation nut and so there would be no risk of loss of contact. An example of the forcing abilities of power screws is the scissor jack. This jack is often used for car spare tire kits due to its ability to lift a portion of a car and hold its position with only the required input torque of the average person. The particular ability to be “self-locking” is a major advantage to the power screw. A self-locking screw is a screw that due to frictional forces will not rotate till those frictional forces are overcome by the input torque. A self-locking screw would ensure the HAUS Section would be held fast under the tensile or compressive forces exerted during flight without the need to implement a further means of retention. Below is a decision chart to characterize various component criteria for the furthering of an effective selection between the mechanisms. Both mechanism were compared off of commercial components found on McMaster Carr.

Mechanical Separation			Geared Rack Mech			Power Screw Mech		
Criteria	Weight	Parameter	Magnitude	Rating	Score	Magnitude	Rating	Score
Cost	.25	USD/ft	9.24	5.5	1.375	4.88	10	2.5
Tensile Strength	.10	ksi	78.3	10	1	63.8	8	.8
Weight	.30	lb/ft	.175	7	2.1	.131	10	3
Handling Safety	.10	Safety Score	3	10	1	3	10	1
Implementation	.25	Experience	7	7	1.75	10	109	2.5
Component # on McMaster Carr			6295K233			98935A205		
Overall Score:					7.225			9.8

Table 4-1 Mechanical Decision Matrix

Cost is the price of the components in USD/ft. Cost was taken into consideration as a criteria due to the need to keep the overall cost of MSM low. Thus, the weighing factor cost is 25%. Rating for this criteria was based on the lowest cost being optimal and so receiving a rating of 10.

Tensile Strength is the maximum strength the material can withstand in uniaxial tension in ksi. Strength was taken into consideration as the commercially available materials of construction must be strong enough to withstand forces from flight and separation. If these components were to fail, the payload would not be able to be deployed and hence the Terra Nova would fail its mission. However, since the commercially available materials are both steels the relative importance of the strength of the materials is less significant to the comparison of the two mechanism. Hence, the weighing factor for material strength is 10%. Rating for this criteria was based on the highest strength material considered the optimal and thus receiving a score of 10.

Weight is weight per length of the components lb/ft. Weight was taken into consideration as a criteria due to the need to keep the overall weight of the MSM as low as possible to allow more room for the design of the payload. Weight of the system will also effect the center of gravity (CG) of the rocket and so effect rocket stability. Thus, the weighing factor for the weight of the component is 25%. Rating for this criteria was based on the lightest component being considered optimal and so receiving a rating of 10.

Handling Safety is the safety hazards from the inherent toxicity of the materials of construction. This is measured based on the Safety scores outlined in Section 5.4.4. Safety Data Sheets (SDS): Chemicals and Materials. Safety is always an important factor for the usage of any components or materials. However, since both materials are very similar in both being low-carbon steels, there is not a significant difference in handling safety. In addition, since these are commercially available components, there are no manufacturing hazards for the Terra Nova team. Thus, the weighing factors 10%. The material with the lowest safety score is considered the safest material and will receive a rating of 10.

Implementation is measure of how easy it will be to create the MSM using a particular component. It is measured by experience with these systems derived from understanding how they work and what is needed to effectively and reliably integrate them to the rest of the MSM. Due to its overall importance in the selection of the system, the weighing factor is 25%. The component that is considered to be the most effective, reliable, and easy to integrate will receive a score of 10.

Based on all these considerations, the Terra Nova team will implement a power screw as the primary means of mechanical separation.

Now that the power screw is the selected mechanism, the minimum torque that a motor must provide to supply the force of 35 lb required to separate must be determined. The equation 4.1 relates the type of power screw, input torque, and output force.

$$\text{Equation 4.1: } T_{in} = \frac{F_{out} * d_m}{2} * \left(\frac{l + \pi * \mu_s * d_m * sec(alpha)}{\pi * d_m - \mu_s * l * sec(alpha)}\right)$$

$$T_{in} = \text{Torque input}$$
$$F_{out} = \text{Force output}$$
$$OD = \text{Outermost Screw Diameter}$$
$$p = \text{Screw Pitch} = \frac{1}{\text{\# of threads per inch}} \text{ for a ACME screw}$$
$$l = \text{Screw Lead} = p \text{ for ACME screw}$$
$$\alpha = \text{Lead Angle}$$
$$d_m = \text{Mean Screw Diameter} = OD - \frac{p}{2}$$
$$\mu_s = \text{coefficient of static friction}$$

Assuming the separation system incorporates the same McMaster Carr power screw in the analysis above, all the properties are outlined in Table 4-2. The coefficient of static friction will be assumed to be .5 for dry and clean steel-to-steel friction (9).

Power Screw Dimensions Table 4-2		
Dimension	Unit	Value
F_{out}	lbf	35
OD	in	1/4
Threads	# threads/in	16
p	in	0.0625
l	in	0.0625
α	°	14.5
d_m	in	0.219
μ_s	dimensionless	0.5
Part	#	98935A205

Table 4-2 Power Screw Dimensions

$$T_{min} = \frac{35\text{lb} * 0.219}{2} * \left(\frac{.0625 + \pi * .5 * .219 * sec(14.5°)}{\pi * .219 - .5 * .0625 * sec(14.5°)}\right) = 2.44\ in * lb = 39\ in * oz$$

Based on this calculation, the minimum required torque that will be required of a motor using this power screw is 39 in-oz.

4.2.2. Chassis

Overall, the design of the chassis relies more on the optimization of any particular design for weight reduction and durability. Thus, the primary considerations and alternate designs depend on the material of construction. To compare various materials, a decision matrix will be implemented. The decision matrix Table 4-3 incorporates scores calculated by the multiplication of the criteria weight and the rating of the material. The ratings are out of ten; the material that performs the best will receive 10 out of 10. All other material scores for the particular criteria were rated relative to the best. In the event that all material ratings tie for a particular category, the rating for all will be 10.

Chassis			Fiberglass			Carbon Fiber		
Criteria	Weight	Parameter	Magnitude	Rating	Score	Magnitude	Rating	Score
Cost	.20	$\frac{USD}{in^3}$	1.10	7	1.4	11.7	2	.4
Strength	.15	ksi	80.6	9.75	1.63	87.0	10	1.5
Density	.25	$\frac{\text{lb}}{\text{in}^3}$	.0650	6	1.5	.0578	7	1.75
Handling Safety	.15	Safety Score	6	5	.75	6	5	.75
Formability	.25	Experience / Available Equipment	5	5	1.5	5	5	1.5
Overall Score:					6.78			5.9
Chassis			Creality PETG			Creality PLA		
Criteria	Weight	Parameter	Magnitude	Rating	Score	Magnitude	Rating	Score
Cost	.20	$\frac{USD}{in^3}$	.387	9.75	1.95	.370	10	2
Strength	.15	ksi	7.25	4	.6	7.69	4	.6
Density	.25	$\frac{\text{lb}}{\text{in}^3}$	.0448	10	2.5	.0452	9	2.25
Handling Safety	.15	Safety Score	2	10	1.5	2	10	1.5
Formability	.25	Experience / Available Equipment	10	10	2.5	9	9	2.25
Overall Score:					9.05			8.6

Table 4-3 Terra Inquisitor Chassis Decision Matrix

Cost is the price of the material in USD/in^3. Cost was taken into consideration as a criteria due to the need to keep the overall cost of the chassis being low as possible. Thus, the weighing factor cost is 20%. Rating for this criteria was based on the lowest cost being optimal and so receiving a rating of 10.

Strength is the maximum strength the material can withstand in uniaxial tension in ksi. Strength was taken into consideration as a material criteria due the payload chassis needing to withstand the forces during of flight and the impact of landing. If the chassis of the payload were to fail it would render the mission of the rocket a failure. However, since the chassis of the payload will not be the primary absorber of all these forces, the material strength was weighted as 15%. Rating for this criteria was based on the highest strength material being considered the optimal and thus receiving a score of 10.

Density is weight per unit volume of the material of construction in $\frac{\text{lb}}{\text{in}^3}$. Density was taken into consideration as a criteria due to the need to keep the overall weight of the payload chassis as low as possible. This allows room for the weight of other components in the payload to keep the overall weight of the HAUS Section below the maximum 250 oz. The weight of the payload will also effect the center of gravity (CG) of the rocket and so effect rocket stability. Thus, the weight factor density is 25%. Rating for this criteria was based on the lowest density being considered optimal and so receiving a rating of 10.

Handling Safety is the safety hazards from the inherent toxicity of the materials of construction. This is measured based on the Safety scores outlined in Section 5.4.4. Safety Data Sheets (SDS): Chemicals and Materials. Safety is always an important factor for the usage of any components or materials. Thus, the weighing factors 15%. The materail with the lowest safety score is considered the safest material and will receive a rating of 10.

Formability is measured by experience using the material and available equipment to form the material. This criteria was included due to the chassis being custom fabricated by the Terra Nova team. Thus, the formability of the material based on previous experience and available equipment is important for the selection of the chassis material and so the weight factor is 25%. Rating for this criteria was based on the material that the Terra Nova team has the most experience with and the most equipment to form receiving a rating of 10.

Based on all these selection criteria, Creality PETG is the selected material for the design of the chassis with the highest score of 9.05.

4.2.3. Propulsion System

Now that the overall material for the chassis is selected, the force the chassis will be required to withstand for the payload propulsion system and also a requirement of the driving force ($F_{d,min}$) required by the propulsion must be defined. This driving force can then be used in conjunction with the radius of the system to determine the required torque (T_{min}). Theis can be defined with similar methodology to the separation force. All forces assumed to be acting at a single point. The forces the payload propulsion system will be required to overcome are the rolling resistance (f_{RR}) of the ground contact system (such as a track system) and the weight of the Terra Inquisitor (W_{TI}) when at angles $\theta \neq 0°$. Two FBDs (Figures 4-4 and 4-5 on the next page) illustrate this simplified system.

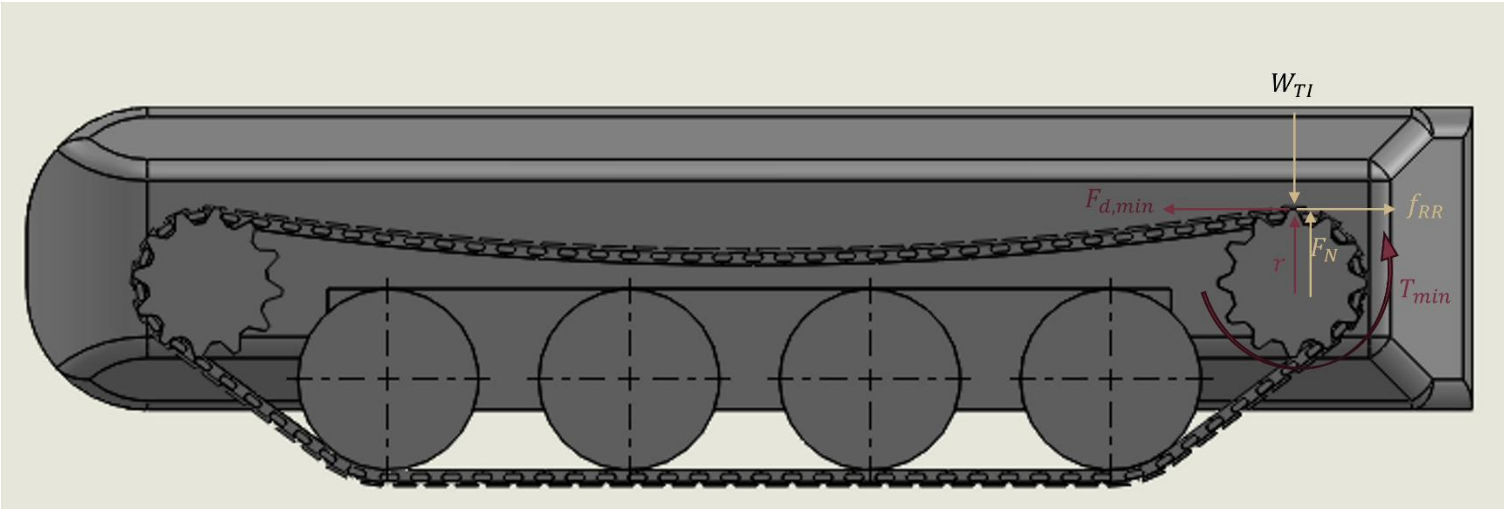


Figure 4-4 Driving FBD when θ = 0°

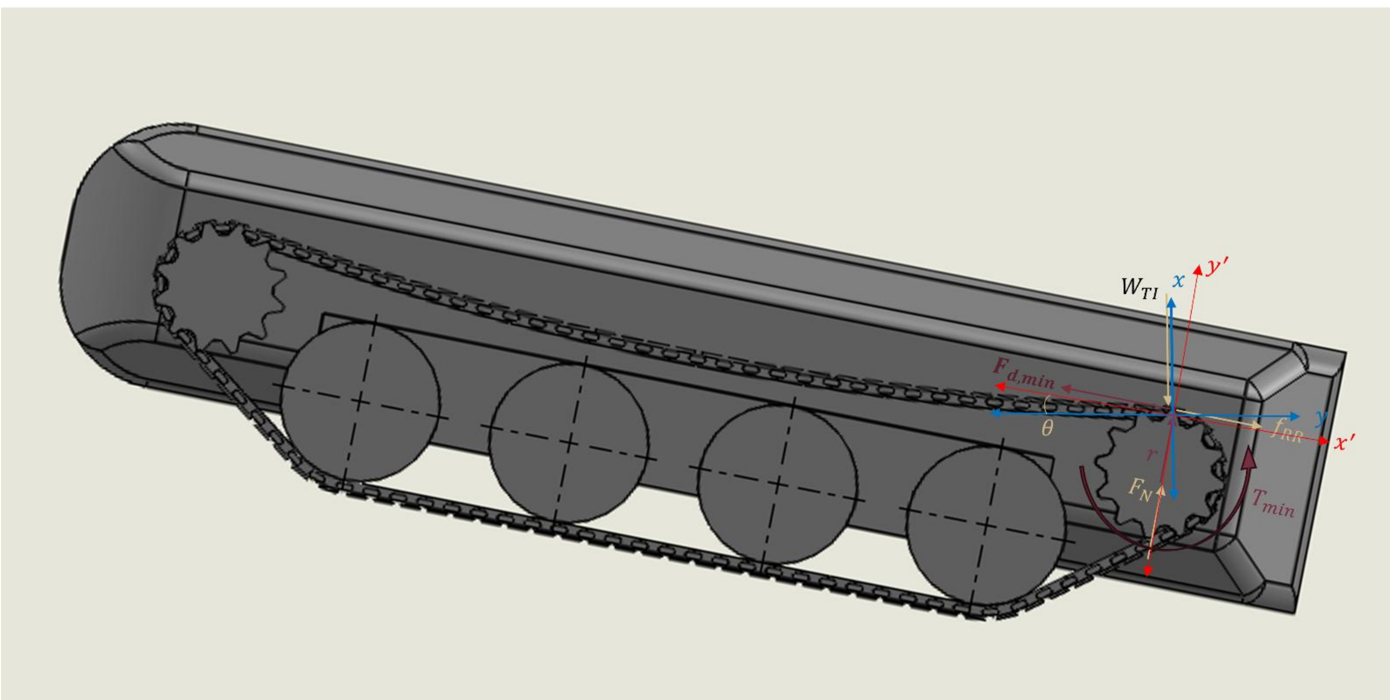


Figure 4-5 Driving FBD when θ ≠ 0°

These possibilities can be simulated in MATLAB for all angles from 0-90 degrees to find the maximum force (and thus torque for a particular radius) required for this system and at what orientation it occurs. To affectively quantify this maximum force, it will be assumed that the rolling resistance of ground contact system is .4 for tires in soft sand (9). Using this worst-case required force, the design of the Inquisitor propulsion system designed with sufficient redundancy to overcome a variety of other obstacles that cannot be quantified. The weight of the Terra Inquisitor will be assumed to be current estimated weight of 96 oz. This is based on the maximum allowable weight per the derived requirement for the HAUS section $W_{HS} = 250$ oz (further outlined in 6.1.3 Derived Payload Requirements) minus the weight of all the airframe components and the mechanical separation mechanism. Figure 4-6 below shows that the maximum force required based on the assumptions outlined is 6.5 lb when the Inquisitor drives on a slope of 68°. Note: Since rolling resistance is a function of the coefficient of rolling resistance and the normal force, the number of tires or tracks will not affect the total rolling resistance since all the normal forces will always sum to the magnitude of the weight of the payload in the y-prime direction.

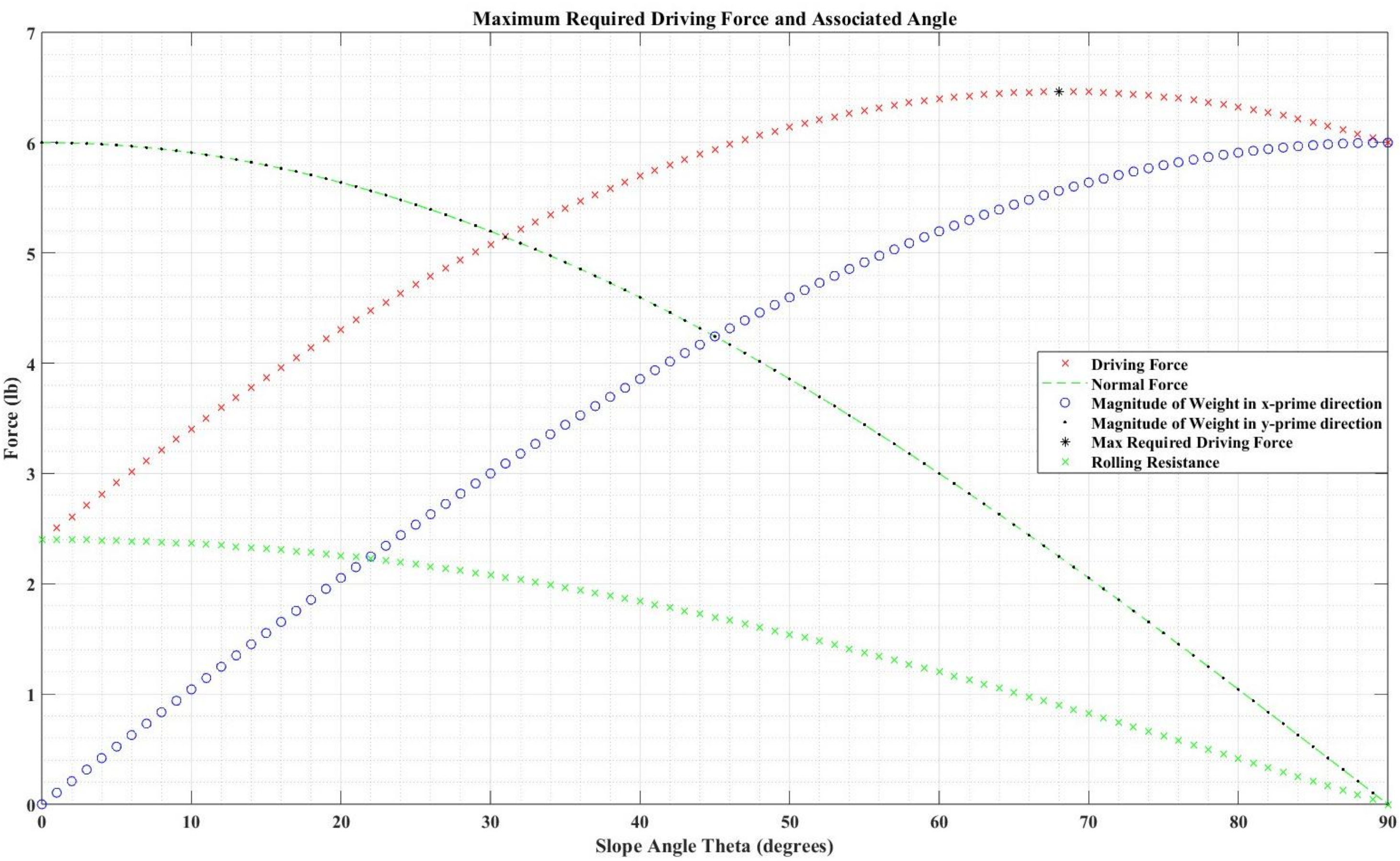


Figure 4-6 Maximum Required Driving Force and Associated Angle

Now based on this maximum force, the output torque required by a motor can be determined based on the ground traction system. There are two primary forms of ground traction systems being considered, wheels and tracks. There are many advantages and disadvantages to both. Both designs present their own unique challenges. A tire system would either require some sort of steering system or the risky usage of tank steering due to lower traction capabilities. The track system would require multiple road or roller wheels, proper sizing of the track, proper sizing of the sprockets, and a track tension system. However, the tracks reduce the pressure acting between the track and the ground thus reducing sinkage of the vehicle into the various terrains it will encounter. This reduction in interaction pressure will be critical as the Terra Inquisitor will need to be able to handle both soft sand and mud. Tracks have superior traction and therefore are much more suitable for tank steering navigation. According to experimental results completed in "The Tractive Performance of Rubber Tracks", the rubber tracks tested were found to always have less slip. Their rolling resistance was largely independent of the type and more depended on track tension and inherent power losses in track systems. The authors noted that the tires tested always proved to have deeper slots dug into the ground and their rolling resistance was very dependent on tire-soil interactions (8). Based on the analysis of this research and the need for the Terra Inquisitor's to be able to handle various terrains, a track system is the preferred system. This is because the operation of the tracks was found to be independent of the soil ensuring that the payload design will be sufficient for any soil conditions. It is also notable that the experimental data for the tracks proved that the largest measured coefficient of rolling resistance was .24. This further proves that the previous simulations to set the requirement for the minimum force that must be overcome by the motors was a worse case than can be expected using a coefficient of friction nearly double that experimentally measured. This further allows for redundancy in the design of the propulsion system in the event of other unquantifiable obstacles.

Now that both the ground traction system and the required force are outlined, an estimation of the required torque of a motor must be defined to ensure feasibility of the design. Assuming a 2-inch diameter driving sprocket, the total required torque is $\mathrm{T} = \mathrm{F} * \mathrm{r} = 6.5$ in-lb $= 75$ kg-mm. Thus, the required minimum torque that must be supplied per motor will be half the total torque assuming two motors for the propulsion system, $\mathrm{T}_m = 37.5$ kg-mm or 52 in-oz.

4.2.4. Soil Collection and Containment

The soil collection system for the Terra Inquisitor is a crucial system to the overall mission of the payload to collect and test soil. There are various systems that can be employed for the collection of soil. All the designs considered assumed that the system would be using a form of drilling. This is assumed as it is the most common form of soil collection and the most versatile for various soil conditions. Due to the limited space available in the Terra Nova, the drill must be compact and be moved from a horizontal storage location during flight to a vertical stage for soil collection. There are different methods of achieving this. Two methods under considered by the Terra Nova team are a linkage system that can achieve a fluid motion for the drilling system or a mechanism that will be rotated into each of drilling phase. The primary problems with such a mechanism is the requirement or many different motors to achieve its motion in addition to the motor for the drill. The additional motors would require more space, increase electrical power consumption, increased cost, and added weight. A linkage may be more challenging to synthesize; however, it would only require one motor to actuate the full motion of drilling and then one motor to power the drill. Based these advantages of a single linkage, the Terra Nova team undertook the effort to synthesis a linkage capable of the desire motion. This synthesis was achieved by the selection of a particular coupler curve from a symmetric four-bar coupler curve atlas in "Design of Machinery" by Robert

Norton. The coupler curve selection was based on coupler curves with two straight portions roughly 90° apart. After examining the various coupler curves, the coupler curve in Figure 4-7 was selected for further consideration and analysis.

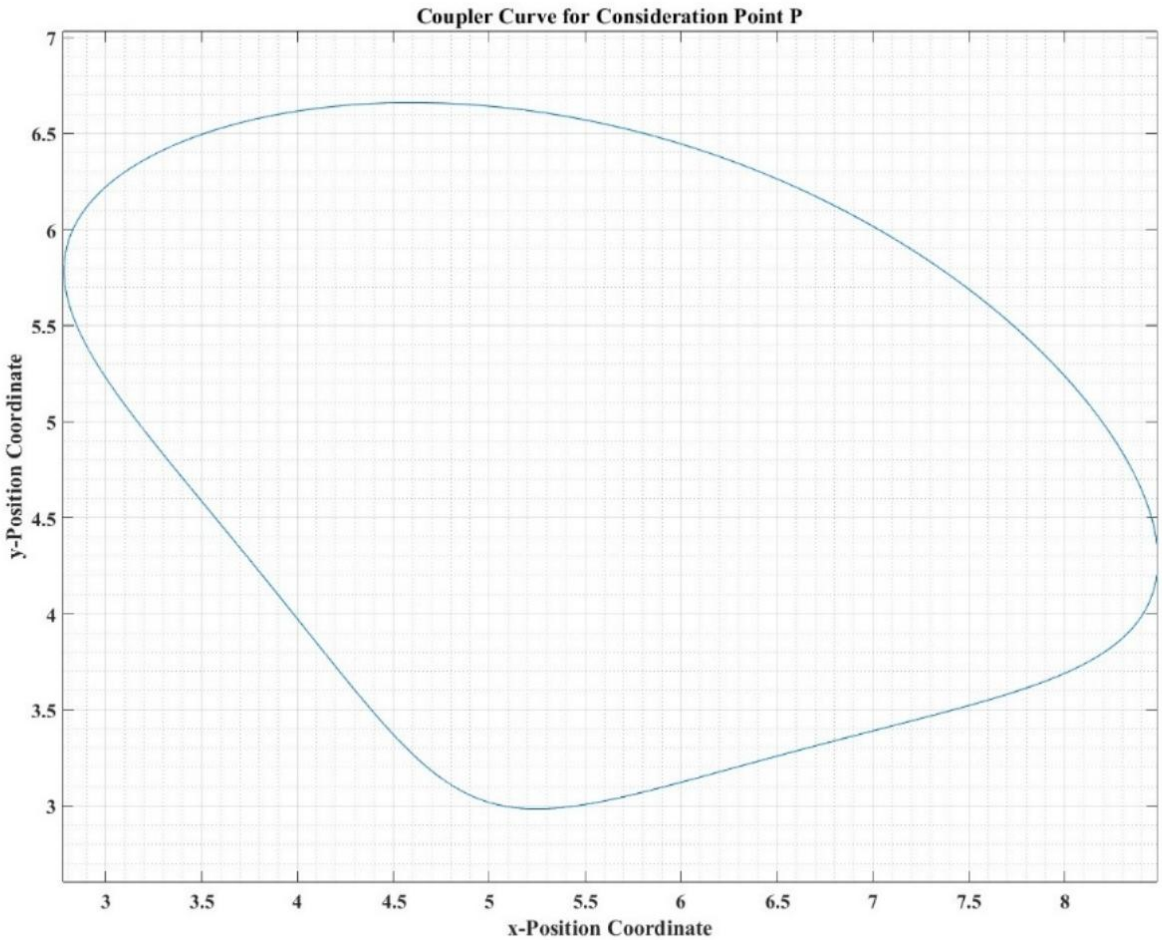


Figure 4-7 Drill Linkage Coupler Curve

The link ratios based on a crank length (L_2) of 2.0 units are L_1 (Ground Link) = L_3 (Coupler Link) = L_4(Rocker Link) = BP (line segment connecting join of coupler and crank units with point of interest P) = 4.0 with an angle (gamma) from the L_3 to BP of 216°. Since these links are proportional to the size of the crank link. Whatever length of the crank will scale the length of each other link. The coupler curve above assumed a coupler length of 2”. The basic links required for this coupler curve synthesis are as follows in Figures 4-8 to 4-14.

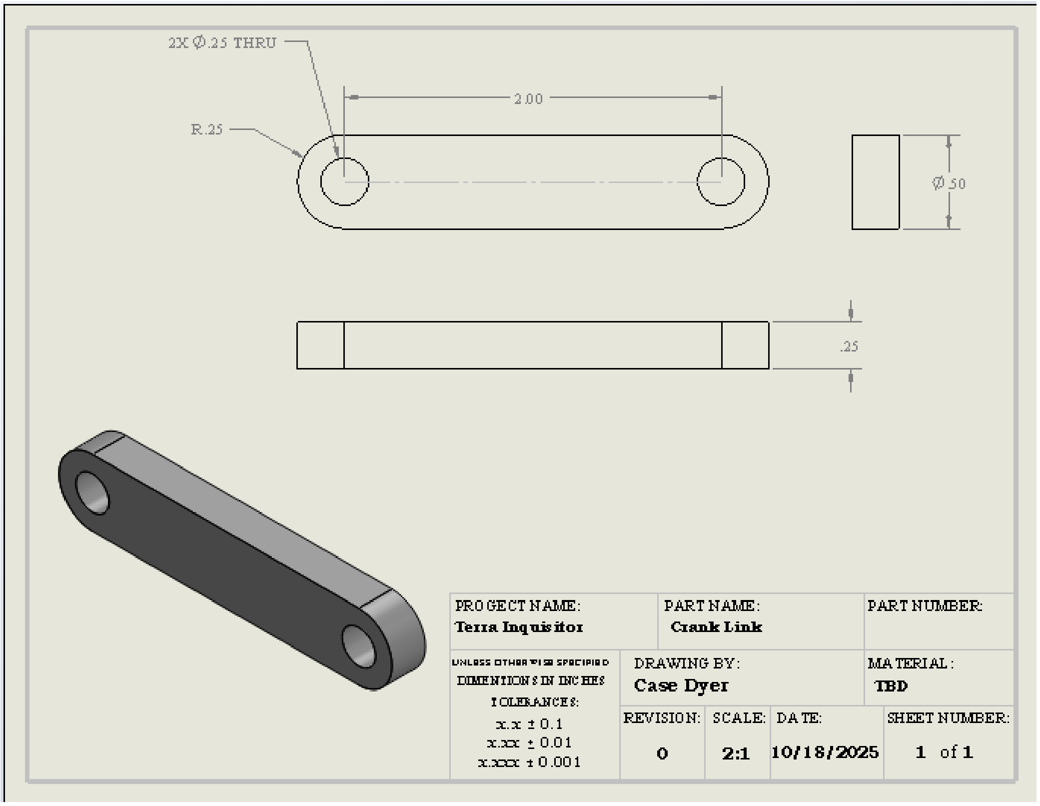


Figure 4-8 Crank

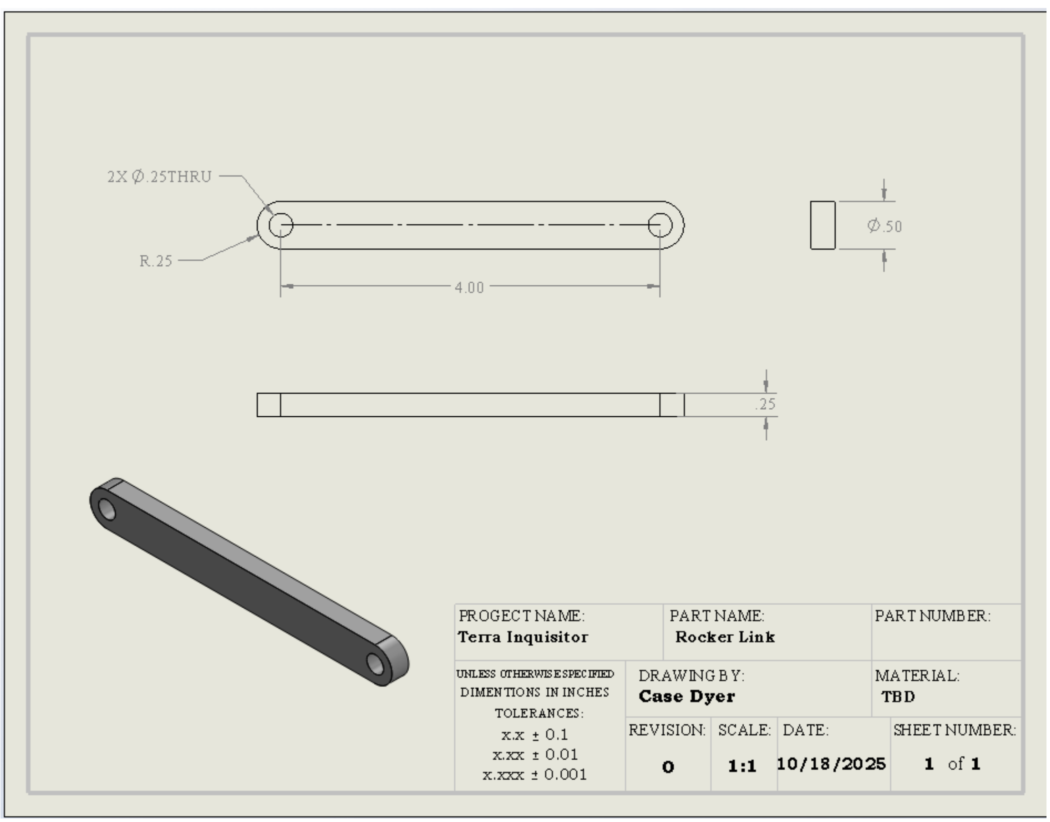


Figure 4-9 Rocker

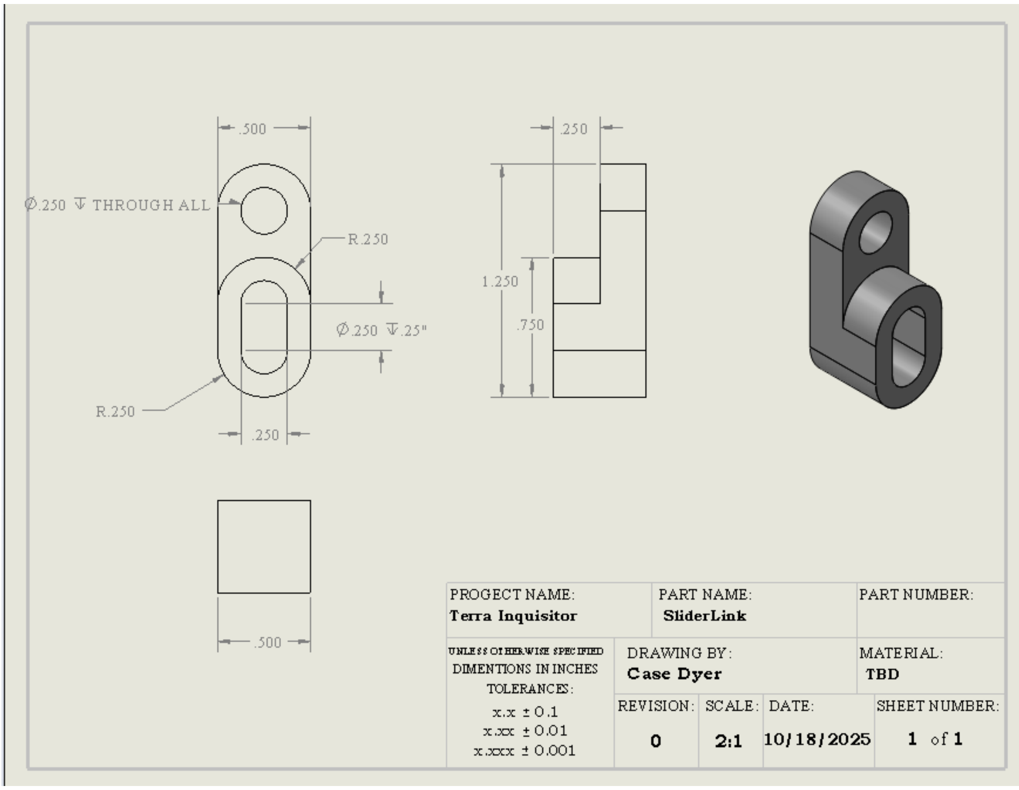


Figure 4-10 Slider

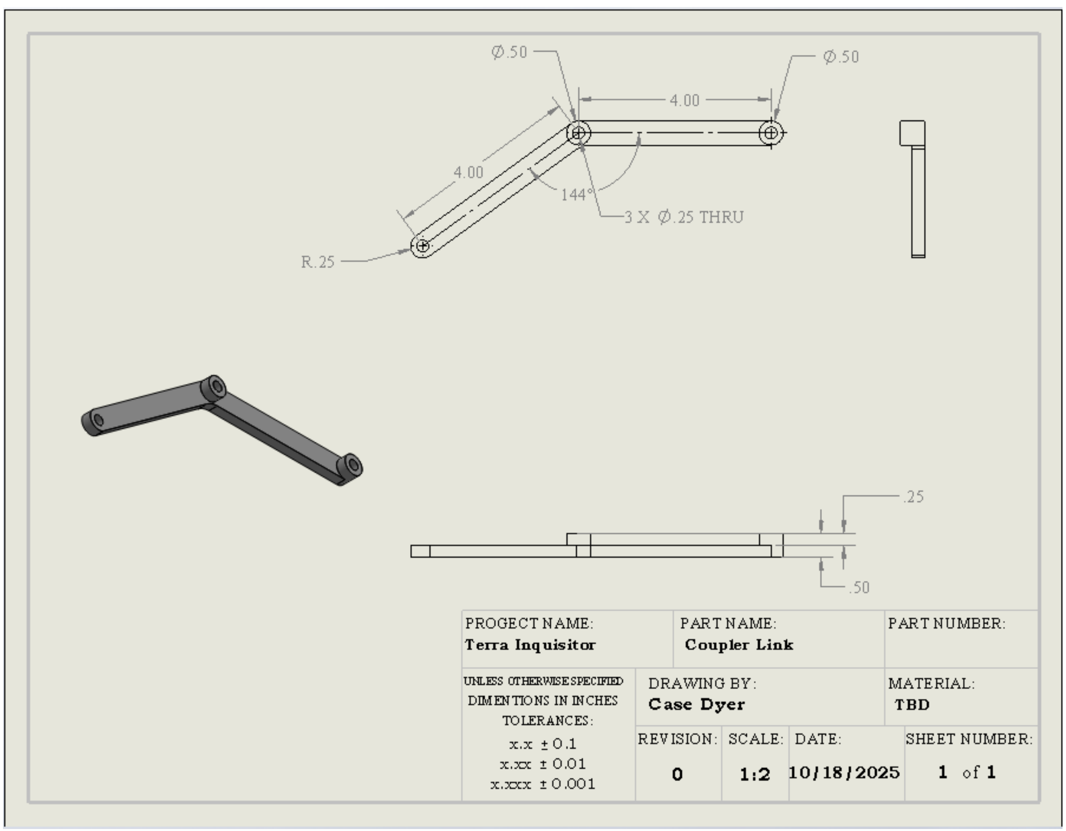


Figure 4-11 Coupler

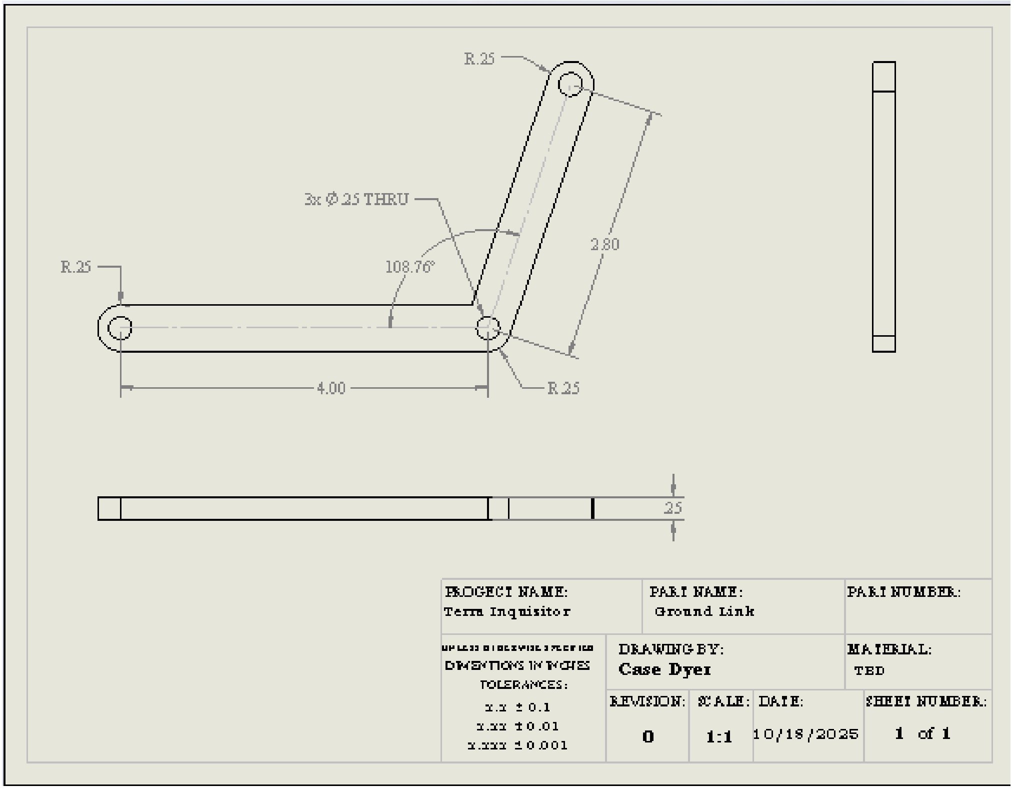


Figure 4-12 Ground

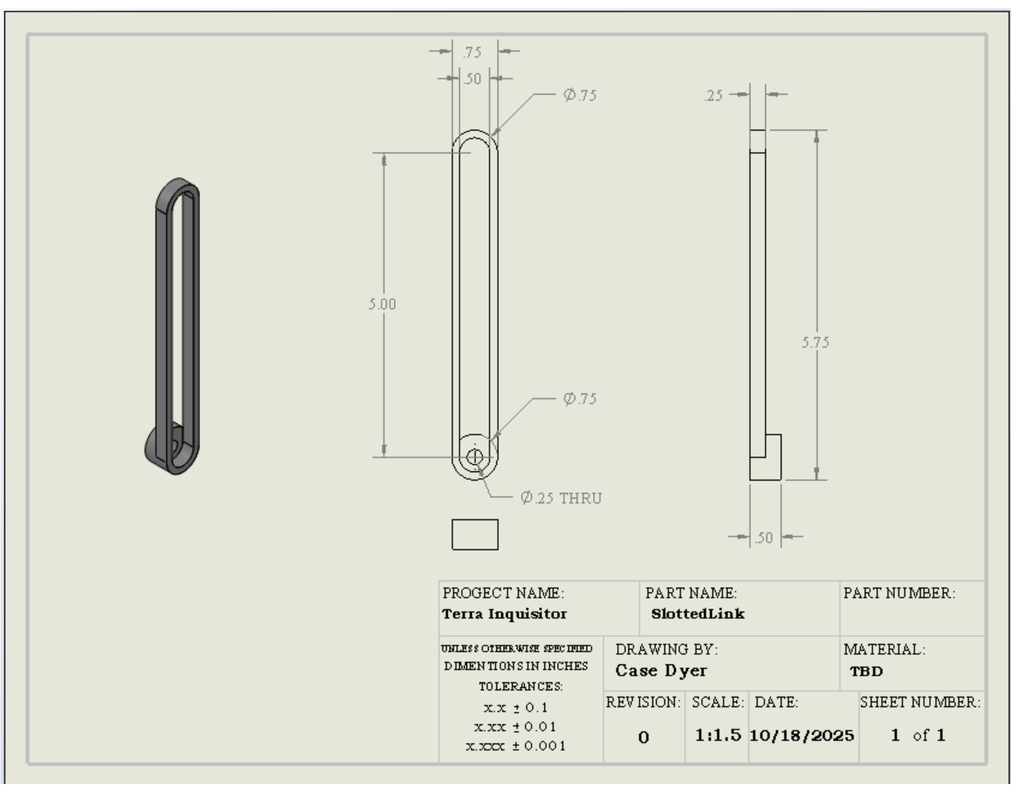


Figure 4-13 Slotted

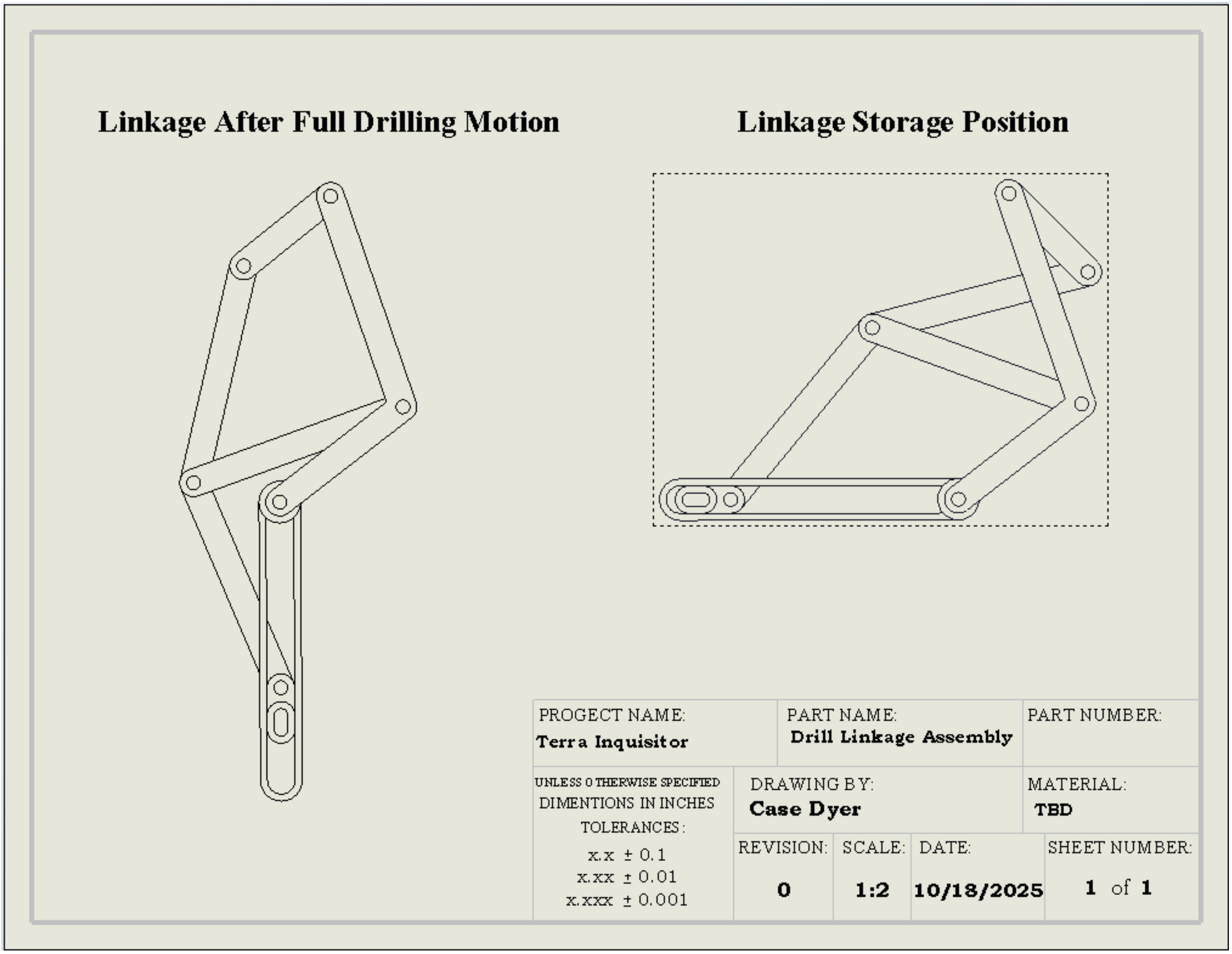


Figure 4-14 Drill Linkage Assembly

Not only can this linkage create the desired motion, storing the drill horizontally while not drilling and also rotating the linkage to its vertical position to drill, it can provide a mechanical advantage to the motion thus pushing the drill into the soil for improved soil collection. The Terra Nova team is still currently involved in the process of creating simulations to evaluated the various transition angles and velocities of each link. Thus, this design has much more to be considered, but it is a viable solution achieving all the required motion with mechanical advantage powered by one motor.

Furthermore, simulations regarding the maximum torque that would be required of a motor to power an Archimedes screw need to be completed for the comprehensive design of the drill. This torque is primarily dependent on various particular component factors that will all need to be incorporated to fully define the torque required. These factors include the driving speed of the drill, the size of the drilling head, the length of the drill, etc. This screw will be designed to collect at minimum 60ml of soil to ensure proper redundancy.

Since the assumed solution for the soil collection is drilling, one concern for the usage of a drill is the collection the soil into a containment vessel. The drill simply operated will spread the drilled dirt around the sides of the hole. To solve this issue a spring-loaded drill cover can be implemented. This will allow the drill to pull up the soil into the spring loaded cover that will then guide the soil into the chassis of the Terra Inquisitor and into the spoil containment vessel. This design also allows for the vertical motion of the drill as it is pressed deeper into the soil.

4.2.5 Electronics and Power

Power

The Terra Inquisitor requires a versatile power source. The mission of the rover, while not exceedingly long, is power intensive. The mission will require various electric motors that facilitate the movement and experimental procedure of the Terra Inquisitor.

There are a few requirements that a power source for this vehicle must meet. The overall weight of the Terra Inquisitor is very important; therefore, a lightweight power source is crucial. The power source must be able to meet the demand of the electrical components and provide the voltage level that each element requires. Lithium batteries (LiPo) are the best fit for a power source on the Terra Inquisitor. LiPo power sources are commonly used in similar applications where lightweight, yet intense power is needed, especially with electric motors. To select a LiPo power source, a decision matrix will be used to determine the best fit for the Terra Inquisitor.

Power Source			LiPo 3s			LiPo 4s		
Criteria	Weight	Parameter	Magnitude	Rating	Score	Magnitude	Rating	Score
Cost	0.15	USD	$20-$40	10	1.5	$30-$65	7	1.05
Weight	0.35	grams(g)	380	10	3.5	470	6	2.1
Capacity	0.25	mAh	5200	10	2.5	5200	10	2.5
Discharge Rate	0.25	C	80	7	1.75	120	10	2.5
Overall Score:					9.25			8.15

Table 4-4 Terra Inquisitor Power Source Decision Matrix

Cost was measured in USD. Cost was evaluated because of the need to keep the overall cost of the Terra Inquisitor's power system low. As shown above, the selection with the lowest cost received a ranking of 10. The magnitudes were selected after researching current price rates for LiPo batteries with similar specifications to the ones shown here. Cost was weighed the least as the cost of power sources does not range widely to any value that would make cost significantly important in this comparison.

Weight was measured in grams (g). Weight was evaluated because of the need to keep the overall weight of the Terra Inquisitor low. As shown above, the selection with the lowest weight received the ranking of 10. The magnitudes were selected after researching LiPo batteries with similar specifications to the ones shown here. Weight was weighed significantly higher than the rest of the criteria as it affects the outcome of not only the Terra Inquisitors mission, but also the vehicle launch and recovery as well. Saving any weight from the Terra Inquisitor, and therefore the Terra Nova, is beneficial to every system.

Capacity was measured in milliamp hours (mAh). This was evaluated because of the power requirements of the Terra Inquisitor’s electrical system. As shown above, the magnitudes are the exact same. This is because the capacity was used as a reference point so that the other criteria might be related to each other. The compared batteries were related by having the same capacity. The capacity listed in the decision matrix does not indicate the capacity required for the electrical system’s selected design. It stands only for the sake of comparison.

Discharge rate was measured in C. This was evaluated because of the need for intense power discharge to the electrical system during the mission. As shown above, the rating for the higher discharge rate received a 10.

The 3s LiPo batteries have a nominal voltage level of 11.1 volts and a fully charged voltage of 12.6 volts. The other components within the electrical system must be capable of handling any voltage swing that occurs. The motors will be able to receive power directly from the power source. The logic behind automating the Terra Inquisitor requires an input voltage between 7 and 12 volts. This means that logic can also receive power directly from the power source.

Automation

The Terra Inquisitor will be automated by an MCU on a commercial development board. Important criteria include accepting power from a 12-volt source, obtaining many pins, including pins capable of reading analog input signals, outputting pulse width modulation signals, and pins capable of I2C and SPI communication protocols. These are essential to the operation of the Terra Inquisitor in terms of movement, experimental procedures, and data logging. Preferred criteria also include having a simple software interface and large amount of community support for programming. The MCU will control any movement of the rover, the pH sensor, the temperature sensor, and the experimental data logging.

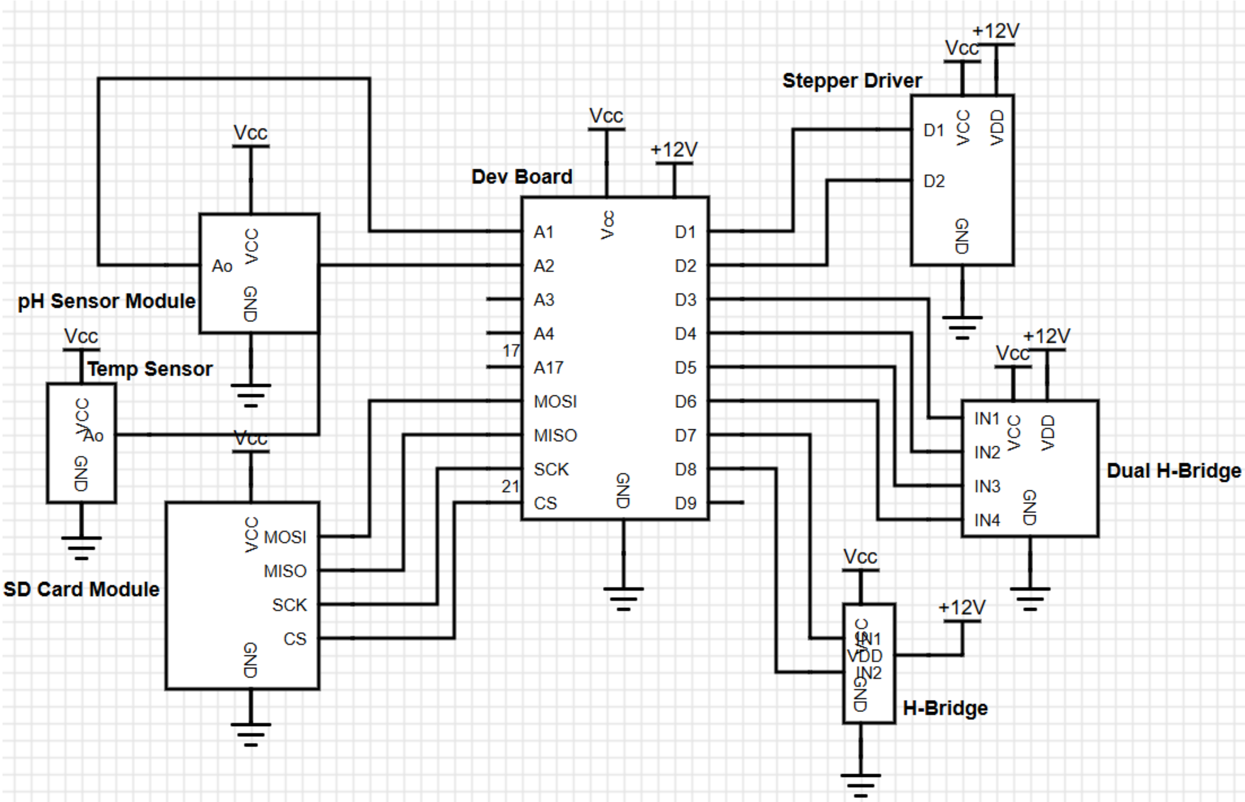


Figure 4-15 Terra Inquisitor Automation Schematic

Figure 4-15 displays the pinout requirements of the development board in control of the Terra Inquisitor. These pin requirements can be met by many commercial development boards. A development board capable of being programmed with the Arduino IDE will be selected because of the ease of implementation. The selection set for the development board consists of the Arduino Nano Every and ESP32. Both commercial development boards can be programmed using the Arduino IDE. They are the ideal prospects to control the Terra Inquisitor as they are both relatively small and lightweight. Weight is a significant criterion with every element of the design. These development boards are also ideal as the team currently has many on hand and would not need to account for these in the budget.

There will also be a commercial development board to control the mechanical separation of the launch vehicle. This board must include an ADC to read an input signal from an altimeter. This signal will initiate the mechanical separation process. In its entirety, the mechanical separation electrical system will include its own power source, development board, altimeter, and two electric motors.

Electric Motors

The payload vehicle will use electric motors to carry out many tasks. These tasks include turning the tracks that move the vehicle, turning the drill to obtain soil samples, and positioning the drill between the carrying position and drilling position. Electric motors will also be used within the mechanical separation system. These motors will carry out the task of positioning the Terra Inquisitor within the rocket so that it may exit safely. They are also included in the mechanical separation that will allow the Terra Inquisitor to exit. Depending on the task, different types of electric motors may be used. These include DC motors, stepper motors, and servo motors.

The Terra Inquisitor requires two electric motors to turn the driving tracks. These motors must be capable of producing the required output torque to move the rover and operate efficiently in terms of power consumption. The Terra Inquisitor also requires one electric motor to turn the drill. These motors must all be capable of handling the opposing torque at higher RPMs. DC motors will be used here, as per design they can handle higher torque loads at higher RPMs. The alternative electric motor for this situation, the stepper motor. As RPMs increase, stepper motors quickly lose the capability to handle high torque loads. "With micro stepping, stepper motors offer superior positional accuracy over brushless dc motors. This comes with the disadvantage of offering less torque beginning from mid-range speeds, which lead to missing steps or stalling. Steppers lack the ability to quickly accelerate, and they produce more noise than BLDCs. Overall, stepper motors are a less expensive solution, but they are limited to low-speed applications. BLDC motors are dependable, quieter solutions that offer higher efficiency and accuracy across a wide speed range." (11)

The different roles that electric motors have within the Terra Inquisitor will require both stepper motors and DC motors. The gearbox ratio that is purchased with the motors will also vary with task. For uses that require higher torque at lower speeds, higher gear ratios are optimal. The electric motors in control of the lateral movement of the Terra Inquisitor will be DC motors. These motors will be required to output torque at higher RPMs and will not be responsible for any holding torque. It is also worth noting that accurate positioning of these motors is not required. The motor responsible for mixing the soil sample with water will also be a DC motor, as similarly it will not require any precise positioning. Stepper motors will be used for the drill linkage, as with this system precise positioning and significant holding torque is required.

The mechanical separation will also require electric motors to drive movement. In the case of separation, having precise positioning of the motors in important. High RPMs are not required for this movement. Because of these reasons stepper motors will be used to drive separation.

4.2.5. Soil Testing

The soil testing experiment that will be carried out by the Terra Inquisitor will be a pH test. The soil test will be done using a pH probe that will send an analog signal to the analog digital converter on the development board containing the MCU. This requires a pH probe along with an offset/buffer module to condition the analog signal. As this is the only plausible way for a pH test to be done by the Terra Inquisitor, the system designs that are up for debate are those regarding ways to create the most accurate and consistent results, along with determining the specific components that will work best within the system.

The most restricting aspect of the experiment is that it must be carried out autonomously in the field. This restricts the experimental procedure to what the Terra Inquisitor can be built and programmed to do. This highly limits the amount of experiment error mitigation possible and plays a large role in the potential error of the soil pH test.

To obtain an accurate soil pH level using a pH probe, the soil can be mixed in a 2:1 distilled water to soil ratio. This presents a solution that the pH probe can provide consistent results with. When this process is done within a lab, multiple steps can be taken to ensure the proper mixture is obtained to minimize the error of the reading. The Terra Inquisitor is limited in the measures it can take to provide an ideal sample. A potential sample preparation system that can be implemented in the Terra Inquisitor is a mixing stage prior to the pH test. This mixing stage would be carried out by an electric motor housed within the soil sample containment vessel. 120 ml of distilled water (2:1 water to soil ratio) would be injected into the containment vessel and would then be stirred with the soil for a fixed amount of time. After this time has elapsed, the solution would then settle for a fixed amount of time to let any heavy particles sink. The pH probe would then be inserted into the upper section of the containment vessel, measuring the pH of the solution. This is a process that would only occur once per mission, so there would be no need for an in-field probe cleaning process.

Another error mitigation system that will be implemented within the Terra Inquisitor is a sample temperature reading. A temperature reading can be combined with a post-process evaluation to mitigate the sensor error. This requires a thermometer probe within the sample containment vessel that will report the temperature along with the timestamped pH value to the MCU. When the pH sensor is calibrated prior to launch, a temperature reading will be taken and recorded as the initial temperature (T_i). When the temperature reading is taken during the Terra Inquisitor's mission, the change in temperature will be calculated and used to find a $pH_{corrected}$ value. This will be done using the equation:

$$pH_{corrected} = pH_{measured} + (\Delta T * k)$$

Where $pH_{measured}$ is the pH value provided by the sensor, ΔT is the calculated change in temperature from calibration, and k is ≈ -0.03 pH/°C deviation from initial temperature.

A critical element of the soil testing system is the pH probe. A probe must be selected that meets the requirements of the Terra Inquisitor's experiment. These requirements relate to the potentially harsh conditions the rover will be subject to throughout the launch process and the nature of the experimental procedure itself. Taking these into account, a decision matrix will be implemented below to choose between two viable options for the pH probe. Probe 1 is the Atlas Scientific Spear Tip/Soil pH Sensor. This probe is designed to be used in soil and is therefore an excellent fit for this system. Probe 2 is the Gravity Lab Grade Analog pH Sensor. This sensor is a more cost-effective option that can be easily operated using Arduino.

pH Probe			Probe 1			Probe 2		
Criteria	Weight	Parameter	Magnitude	Rating	Score	Magnitude	Rating	Score
Cost	0.25	USD	$169.99	3	0.75	29.99	10	2.5
Durability	0.25	scale (1-10)	8	10	2.5	4	5	1.25
Size (Length)	0.3	millimeters	127.7	10	3	177.7	6	1.8
Accuracy	0.15	pH	0.002	10	1.5	0.1	7	1.05
Overall Score:					7.75			6.6

Table 4-5 Terra Inquisitor pH Probe Decision Matrix

Cost was measured in USD. Cost was evaluated because of the need to keep the overall cost of the Terra Inquisitor low. As shown above, the selection with the lowest cost received a ranking of 10. The magnitudes were selected based on the sale price provided by the website. Cost was weighed at 25% due to the wide price range for pH probes.

Durability was measured on a scale of 1-10, with 1 being the least durable and 10 being the most durable. These rankings were based on information presented on the website pages for each probe. This includes structural design and material.

Size was measured in millimeters. Size was evaluated because of the need to conserve space within the payload. With a limited amount of space available for the Terra Inquisitor within the launch vehicle, size was weighed the highest among the sensor criteria.

Accuracy was measured in the potential error of the returned pH value. Accuracy was evaluated because of the need to carry out a successful experiment. It was weighed the least among the criteria because of the small potential error for the less accurate selection. Both of the probes return relatively accurate readings.

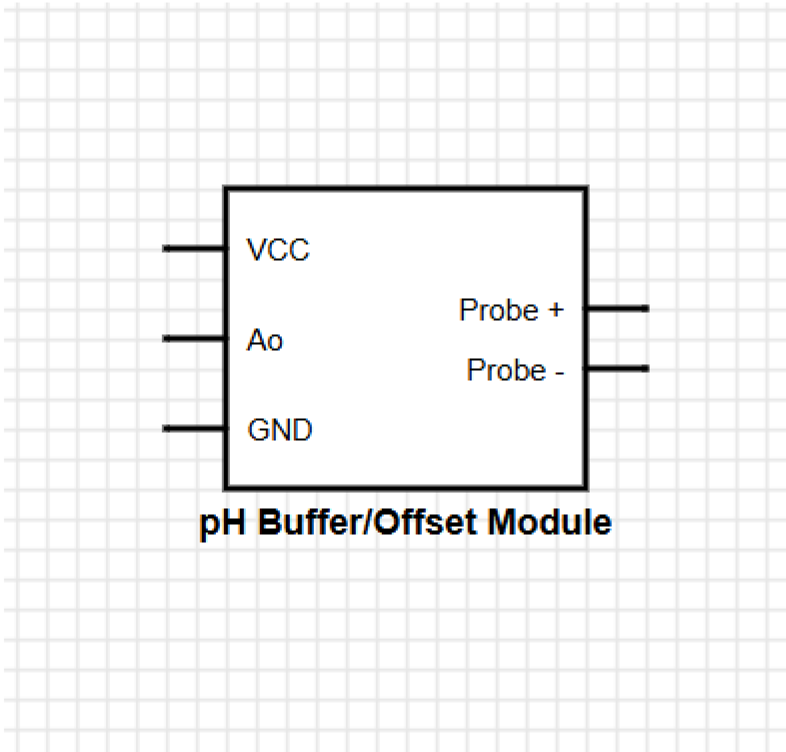


Figure 4-16 pH Sensor Module

Figure 4-16 displayed above acts as a buffer and offset for the pH sensor. The pH probe acts as a passive sensor, with a range of approximately -500mV to +500mV. The passive sensor requires an offset to be read by the ADC on the development board. The passive sensor also requires a buffer with very little input current. This requires a module designed to provide the development board with a readable voltage range. These are available commercially for a relatively low cost. The figure above explains the pinout requirements, with the pins on the left side connecting directly to the development board.

4.3. Experiment Success Criteria

The evaluation of the Terra Inquisitor's experiment is based on the successful deployment, collection, and logging of soil pH test data with proper time stamps. Successful separation is defined as the MSM autonomously separating the HAUS section after reaching ground level from apogee. Successful deployment of the Terra Inquisitor is defined as its autonomously exiting the HAUS coupler. The Terra Inquisitor's success will be based on its ability to follow its autonomous routine, and collection of at minimum 60ml of soil. The success of the soil testing will then be based on relative accuracy of the pH readings to a commercially available handheld pH reader with a known accuracy.

4.4. Payload and Launch Vehicle Interfaces

Based on the vehicle technical design detailed earlier, the Terra Inquisitor will be housed in the HAUS Section of the rocket above the transition. The payload will not be in direct contact with the airframe of the rocket but will be secured to the MSM such that after landing and separation the payload can be deployed. The MSM system will be mounted to the airframe of the rocket nose cone coupler and nose cone.

5. Safety

5.1. Safety Organization and Responsibilities

To ensure the safety of team members and all involved during the full progression of this project, a safety plan must be developed and implemented. The Safety plan will show a team-wide comprehension of the guidelines and expectations that must be upheld. As specified by the 2026 Student Launch Handbook, section 5.2, each team is required to have a safety officer. The responsibilities of the safety officers are also described in section 5.2 and give an essential understanding of expectations and requirements. The team safety officer will support the team lead in completing all tasks safely and incident-free. This will be done with adherence to all governing authorities included in 5.2 Compliance with Laws, Codes, and Regulations. During all launch procedures, NAR launch procedures and safety regulations will be used for flight design and operations. NAR/TRA team mentor and the Range Safety Officer (RSO) will oversee the launch operation and motor handling and have ultimate authority over launch readiness and viability. While facilitating and implementing the safety plan is the main responsibility of Jonathan Serbest, our safety officer, all team members acknowledge the individual requirements of understanding and compliance of the plan outlined below. This has been done through a safety briefing and provides confirmation of safety plan competency and pledge to plan adherence.

Team Safety Culture

The Terra Nova team is committed to the success and well-being of all involved. We believe that the top priority of our mission is safety, and we pledge to create an environment dedicated to the prosperity of our fellow comrades.

Safety Officer Responsibilities

General Authority and Oversight

- Serve as the primary authority for all safety-related decisions and justifications throughout the lifecycle of the project
- Hold the power to delay, suspend, or terminate any activity or launch if a safety concern exists
- Ensure compliance with AHJ requirements, campus rules, and competition policies
- Consistent risk assessments and update to any safety procedure based on the mitigation success

Training & Team Safety / Procedures

- Verify that all team members have completed required equipment training and understand PPE required

- Ensure that PPE requirements are being meet at all times.

- Provide preliminary safety briefings before all hazardous tasks begin

Material & Chemical Safety

- Maintain Chemical Accounting Log

- Manage the disposal of all energetic material

- Manage magazine labels in the event of motor storage on campus.

- Assist the team mentor in transportation and handling rocket motors.

- Ensure that black powder, e-matches, and batteries are disposed of according to manufacturer guidance and regulatory codes

Equipment & Facility Safety

- Ensure equipment cleanliness and document using an inspection log

- Testing & Ground Operations

- Approve and institute test plans, hazards, and mitigations

- Monitor safe perimeter enforcement during energetics testing

- Maintain launch crew roles and distances according to code requirements

Rocket Assembly & Launch Safety

- Verify completion of:

- Recovery and Payload System Testing logs

- Confirm secure and safe installation of igniters, energetics, and deployment charges
- Enforce no spectators near pad during avionics arming
- Validate the rocket is safely integrated into the launch rail/rod
- Ensure communication with RSO/LSO and compliance with launch site protocols

Post-Launch Safety

- Lead post-flight system clean-up (removing e-matches, discharging power systems, safe transport)
- Conduct Post-Launch Checklist and evaluate new hazards discovered
- Maintain incident reporting and root-cause documentation
- Verify compliance with recovery safety during retrieval operations
- All documents are to be accounted for with Document IDs
- Track non-conformance and initiate corrective actions when safety deviations occur
- Participate in design reviews, providing safety verification inputs
- Maintain audit-ready records for all safety artifacts

5.2. Compliance with Laws, Codes, and Regulations

Due to the nature of this project, all team members understand the need for, and are compliant with, all federal, state, and local regulations. All members have read, understood, and pledge to implement the safety plan at all times. We understand that failure to comply with these requirements endangers the project and presents a potential to be acquitted from the 2025-2026 NASA USLI project.

All team members acknowledge the governing AHJ over all procedures regarding the USLI project. These include:

- NASA Student Launch Handbook (2025–2026)
- NAR/TRA Team Mentor

- NAR/TRA Safety Codes
- Range Safety Officer (RSO)
- FAA Regulations — 14 CFR Part 101, Subpart C (Amateur Rockets)
- ATF Regulations — 27 CFR Part 555
- NFPA 1125 & 1127
- University / Local Safety Policies

5.3. Motor Acquisition, Storage, Handling, and Transport

Motor Acquisition

According to the NAR High Power Rocket Safety Code and the 2025-2026 NASA USLI Handbook, all motors acquired by the team are to be commercially manufactured and certified by NAR/TRA. These motors must be purchased by the team mentor as students cannot directly obtain them. Motors purchased must be of the same level as the mentor's certification allows. Motors purchased shall be the same as prespecified to NASA.

The team will follow this acquisition process:

- All motor selections must be approved by the Project Lead and Safety Officer and pre-cleared with the team mentor prior to purchase. If the mentor indicates that a motor requires an ATF permit or exceeds allowed on-site storage limits, an alternate compliant motor will be specified.
- Motors will be purchased only from reputable, licensed vendors. When possible, the team will use on-site purchases at sanctioned launches from licensed vendors to avoid long-term storage requirements.
- If the primary or secondary motor choice becomes unavailable, the team will document the reason and submit an updated motor specification in the next deliverable for NASA review and approval.

Motor Storage

All subjects of motor storage will be under the control and supervision of the team mentor. Storage shall comply with NFPA 1127 and ATF 27 CFR regulations. Rocket motors will be kept in their original state and will not undergo any tampering or be used for any purpose other than what is defined by the manufacturer (NFPA 1127 - Note: link may not work as NFPA is proprietary and requires a user account).

Storage Location:
Using (NFPA 1127 - 2026 edition)

- Motor storage location shall be in a climate-controlled area. This will ensure that the motors will not experience any natural ailments like high humidity or temperature. These product limitations will be specified through the recommendations of the manufacturer.
- Storage will be located at a minimum of 25 ft from smoking, open flames, or any other heat source (4.19.1)
- Motor magazines shall be stored based on the net weight of rocket propellent and accordingly with the storage requirements of 27 CFR 555. (4.19.2)
- Indoor magazines shall be painted in red with the words, "EXPLOSIVES—KEEP FIRE AWAY" in white letters and to the proper dimensions specified by NFPA. (4.19.2.1)
- Indoor Magazine shall not be stored in residence (4.19.2.2)

Fire and Energetic Ignition Control:

- Detonators are not to be stored in the same magazine with other explosive materials, except during explicit circumstances. (27 CFR 555.213)
- Smoking, matches, open flames, and spark producing devices shall not permitted in or around the storage magazine. (27 CFR 555.212)

Motor Handling

Motors shall be transported and handled with mentor supervision. Team members are prohibited from loading their own motors before or on launch day. This must be done by the NAR team mentor, Elizabeth Gildersleeve. If the motor is being transported in or across states, students and personnel will show full understanding of and comply with local, state, and federal laws and regulations concerning the transportation of explosives.

Regulation of motor accessibility:

- Access to storage of all motors will always be limited to the team mentor.

Documentation:

- Motor location and movement will be documented at all times. Documented information includes the motor model number, serial number, date of storage and movement, and date of launch use.
- The Team mentor (Elizebeth Gildersleeve) and Safety Officer (Jonathan Serbest) shall write a summary of motor preparation, transport, and motor loading. This will be done at the end of launch day, documented, and dated.
- All team members will have a copy of all safety requirements during rocket handling.
- If any incident might occur during the preparation, transport, or loading of the motor, team members shall report immediately to the Safety Officer and the Team Mentor. An incident shall be implemented into the day's final report.

Motor Defect and Instability:

- In the event of a faulty motor, all team members, team mentor, and facility owners must be informed immediately.
- The motor shall not be tampered with, and proper authorities must be notified for motor disposal.

Motor Transport

Team will have no part in the process of motor transport and its storage. This will be handled by the team mentor.

5.4. Personnel Hazard Analyses (PHA)

5.4.1. Hazard Analysis Methodology

Risk identification is necessary as this will be the backbone of our safety procedure moving forward. Identifying the possible risks in and around the progression of our rocket helps all involved to suppress the chance of a major hazard happening. To begin, the criteria on how the analysis of probability is weighted is in Table 3-1 below.

Probability Levels		
Definition	Value	Probability of Occurrence
Unlikely	1	<1%
Uncommon	2	1% to 15%
Occasional	3	15% to 50%
Probable	4	50% to 80%
Likely	5	Above 80%

Table 5-1 Probability Levels

Now that the metrics for our probabilities are defined, the criteria for assessing risks and hazards will be handled through both the severity of the hazard and its likelihood. Table 3-2 below illustrates this.

Hazard Severity Criteria					
Description	**Value**	**Personnel Health**	**Equipment Health**	**Launch Vehicle**	**Mission Health**
Negligible	1	No injury	Insignificant damage	Insignificant damage/ minor reconstruction	Mission success not impacted
Moderate	2	Minor injury	Moderate damage	Moderate reconstruction	Possible mission success
Critical	3	Severe injury	Major damage	Major reconstruction required	Partial mission success
Disastrous	4	Life-threatening injuries	Complete destruction	Complete loss	Mission failure

Table 5-2 Hazard Severity Criteria

With the hazard severity visually defined, the point hierarchy from both graphs combine to give us a comprehensive understanding of the risk analysis. Defined in color and number notation, is the risk level. The risk level is found by multiplying the corresponding number rating of x-plane identifier with the intersecting y-plan identifier. This gives us the ability to score risks across our two identifiers.

Risk and Hazard Assessment Matrix					
		Severity			
		Negligible (1)	Moderate (2)	Critical (3)	Disastrous (4)
Probability	Unlikely (1)	1	2	3	4
	Uncommon (2)	2	4	6	8
	Occasional (3)	3	6	9	12
	Probable (4)	4	8	12	16
	Likely (5)	5	10	15	20

Table 5-3 Risk and Hazard Assessment Matrix

The Consolidated Hazard Assessment Matrix simplifies the numerical results of the hazard analysis by grouping the full range of values into four categories. Each category provides clear guidance on risk level, assists the team in making informed decisions per the severity of hazards, the intensity of required mitigations, and overall safety measures necessary for project activities.

Consolidated Hazard Assessment	
Definition	Value
Minimal	1-7
Tolerable	6-10
Immediate Attention	11-15
Failure	16-20

Table 5-4 Consolidated Hazard Assessment

List and meaning of hazard groups:

Minimal (1–6):

Hazards of this caliber are small and can be easily avoided by using standard safety procedures.

Tolerable (6–10):

Hazards of this caliber require the implementation of mitigation measures as the average severity for these cases is moderate. Mitigations like training, proper PPE, spatial awareness, etc. must be constantly enforced.

Immediate Attention (11–15):

Hazards of this caliber must be dealt with swift and rigorous mitigation. Before proceeding, the Safety Officer must be notified and holds the authority to stop activities if deemed necessary.

Failure (16–20):

Hazards of this caliber are unacceptable and will not be attempted. The Safety Officer must be notified, and a new technique, design, safety mitigation, etc., must be implemented to lower the risk level before proceeding.

5.4.2. Laboratory & Field Hazard and Mitigation

All locations will provide their own unique safety concerns; this requires that all team members know the correct procedure to follow depending on the surrounding environment. Below is a table providing the risk level of all locations and individual mitigation procedures.

Note: P’ & S’ (Probability & Severity respectively)

Facility Hazards					
Facilities	P’	S’	Value	Causes	Mitigations
Senior Design Lab	3	2	6	The room serves as storage: • Variety of hand and power tools • Chemicals • Variety of raw materials. • 3D printers • Soldering irons.	• Keep the room organized and clean • Label and safely store chemicals. • Provide PPE for all cases (gloves, safety glasses, face mask, or respirator). • Maintain good ventilation for soldering and 3D printing.
Machine Shop	2	3	6	Houses: • Heavy machinery • Hand and power tools • Variety of raw materials.	• Mandatory PPE in the case of machine operation, including safety glasses, hearing protection, and closed-toe shoes. • Knowledge of emergency stop locations. • Operator instructions near each machine. • Regular maintenance and inspections of equipment. • Limit occupancy in the event of machine operation.
Digital Design Studio	1	1	1	Serves as a center for: • 3D printing • Laminating • Printing	• Proper ventilation for 3D printers. • Keep materials (paper, resin, etc.) away from heat sources. • Maintain workspace.
Electrical Engineering Laboratory	1	2	2	Houses: • Wavelength generators • Hand and power tools • Electronics & soldering tools	• Provide PPE for all cases (gloves, safety glasses, face mask, or respirator). • Proper ventilation for soldering. • Review of lab safety procedures according to the Electrical Engineering Department. • Knowledge of emergency stop locations. • Fire extinguishers for electrical fires (Class C).
Materials Lab	1	3	3	Houses: • Material property testing machines • A variety of material samples • Power/Hand tools	• Provide PPE for all cases (gloves, safety glasses, face mask, or respirator). • Maintain clear zones around testing machines. • Properly label and store samples. • Knowledge of emergency stop locations for material testing machines.

					• Review lab safety procedures according to the Mechanical Engineering Department.
Thermal Fluids Lab	1	2	2	Houses: • Material property testing machines • A variety of material samples • Power/Hand tools	• Provide PPE for all cases (gloves, safety glasses, face mask, or respirator). • Use spill containment for fluids. • Ensure proper ventilation. • Knowledge of emergency stop locations. • Review lab safety procedures according to the Mechanical Engineering Department.
Mechatronics Lab	1	2	2	The room serves as storage: • Variety of hand and power tools • Variety of raw materials. • 3D printers • Soldering irons. • Electronic components	• Provide PPE for all cases (gloves, safety glasses, face mask, or respirator). • Provide fume extraction for soldering/3D printing. • Require PPE for tool use. • Emergency shutoff for robotics/electrical equipment. • Review lab safety procedures according to the Mechanical Engineering Department.
Advance Technology Center	2	3	6	Large space that holds: • Heavy Machinery • 3D printers • Laser cutters • Additive manufacturing machinery • Hand/Power tools • Variety of raw materials.	• Provide PPE for all cases (gloves, safety glasses, face mask, or respirator). • Knowledge of emergency stop locations. • Review lab safety procedures according to the Gulf Coast State College.

Table 5-5 Facility Hazards

Note: All students shall be required to receive proper training before using any high-risk equipment.

5.4.3. Laboratory & Field Safety Verification / Derived Requirements

All facilities will share the verifications due to their high similarity.

Verifications will include:

- All teammates will have physical and digital printouts of necessary PPE for all equipment in each room
- A sign in / sign off sheet will be posted in all rooms for documentation.
- The Safety Officer shall inspect and document all equipment used weekly.
- The Safety Officer shall monitor and maintain all equipment quality and cleanliness.
- AHJ shall be notified of all necessary maintenance by the safety officer.

5.4.4. Safety Data Sheets (SDS): Chemicals and Materials

Material Hazards						
Material	P'	S'	Value	Use	Effects	Mitigations
Adhesives	2	2	4	Adhesives will be used for bonding airframe parts and other structural components together.	• If handled improperly, symptoms including eye and skin irritation, and respiratory problems are possible	• Follow the safety instructions described by the manufacturer
Aluminum	1	3	3	Mainly used for bulkheads and payload components.	• Material Surface may be rough or sharp. May require machining for shaping or finishing.	• Team members shall be required to use gloves when working with any tools or materials.
Black Powder	2	4	8	Means of vehicle separation after apogee.	• Black power is prone to hazards, including fire and explosions.	• Black powder must be stored in dry, ignition-free areas. • Stored in accordance with NFPA standard. • Transported in accordance with ATF
CO2 Cartridges	1	2	2	The main means of separation after apogee.	• High-pressure gases can be volatile in extreme heat.	• Follow the safety instructions described by the manufacturer.
Epoxy	2	2	4	Bonding of internal and external vehicle components.	• Most epoxy has a two-step reaction that causes volatile gas to fill the area.	• Follow the safety instructions described by the manufacturer.
Wood	2	2	4	Material for fins	• All wood parts will be laser cut.	• Team members shall be required to use gloves when working with any tools or materials.
Fiberglass	3	2	6	Material for airframe and fin reinforcement	• Fiberglass air frame will be cut and finished with tools like band saws, Dremels,	• Team members shall be required to use gloves when working with any tools or materials.

					sanders, and hand saws. These will present hazards.	
Fiberglass Cloth	2	2	4	Material for airframe, fin reinforcement, and transition body tube shaping.	• Fiberglass cloth will need a bonding epoxy to form the cloth into a rigid shape. Epoxy will present hazards.	• Follow the safety instructions for epoxy described by the manufacturer.
Greases	1	2	2	Grease will be needed for the oiling mechanisms of the payload.	• Most commercial greases have carcinogenic hydrocarbons.	• Follow the safety instructions described by the manufacturer.
Inconel	1	3	3	It will be used in the bulkheads of the rocket	• Due to additive manufacturing, the surface finish on aluminum parts will be rough and sharp. This will require machining to obtain a finished part.	• Team members shall be required to use gloves when working with any tools or materials.
Isopropyl Alcohol	1	2	2	Used for prepping the surface of our airframe for painting.	• It can produce skin and eye irritation.	• Follow the safety instructions described by the manufacturer.
PETG	1	2	2	Various costume parts	• Can produce burns and blisters from the hot plate or material.	• Waiting ample time to allow the area to cool before
PLA	1	2	2	Various costume parts	• You can produce burns and blisters from hot plates or materials.	• Waiting ample time to allow the area to cool before
Solid Propellant motor	1	4	4	Used for rocket propulsion	• Black power is prone to hazards, including fire and explosions.	• Black powder must be stored in dry, ignition-free areas. • Stored in accordance with NFPA standard. • Transported in accordance with ATF • Train team in proper emergency plan in the event of a fire.
Spray Paints	3	2	6	Will be used in painting the sub-scale and the full-scale models.	• Product will produce toxic inhalants when used.	• Follow the safety instructions described by the manufacture.

Steel	1	3	3	Material will be used throughout the payload.	• Material is prone to being machined or used in tandem with other hand-held/power tools.	• Handle sharp or rough material with safety equipment. • If using tools in tandem with material, safety equipment such as rugged heavy-duty gloves, eye-protective wear shall be used to prevent injury. • In the event that small metal shavings or sparks are being thrown, protective were like long sleeve wear, pants, masks, and a fire extinguisher should be easily accessible.
Thread Lock	1	2	2	Produce used in payload and airframe miscellaneous components to prevent future movement.	• If handled improperly, symptoms including eye and skin irritation, and respiratory problems are possible	• Follow the safety instructions described by the manufacturer.

Table 5-6 Material Hazards

Notice: All products will be used for their intended purpose and in their scope of material capability.

5.4.5. Safety Data Sheets (SDS): Chemicals and Materials / Derived Requirements

All chemicals and materials will share the verifications due to their high similarity.

Verifications will include:

- All teammates will have physical and digital printouts of necessary PPE for all chemicals and materials.
- The Safety Officer shall monitor and maintain all work area quality and cleanliness.
- The Safety Officer must take a monthly account of chemicals used

5.4.6. Construction Safety and Hazard Mitigation

During the construction of the rocket, team members will be exposed to a plethora of tools and machinery. It is imperative that all team members are competent of each tool's inherent risks and their hazard mitigations.

Construction Hazards							
Hazard	e.g.	P'	S'	Value	Cause	Effects	Mitigation
Compressed Air Systems	Air compressor and accessories.	1	4	4	- Faulty hose and fittings - Over-pressurization - Negligent use of tool according to provided owner's manual	- Hearing damage - Flying debris and shrapnel causing possible cuts, lacerations, and possible death.	- Make sure that equipment is well maintained and clean before using. This includes procedures like inspecting hoses and fittings. - Use ear protect when using compressor at all times. - Do not use equipment improperly. Ex. Pointing spray nozzle at others or yourself.
Construction Hand Tools	Pliers, screwdrivers, hammers, clamps, wrenches.	4	2	8	Unclean or oily hands while working, Sharp edges, blunt forces.	- Cuts - Bruises - Skin pinching - Puncture wounds	- Maintain and clean all tools after use. - Gloves are required when working with all tools. Depending on the tool, use of ear and eye protection shall be enforced in junction. - Store and procure tools safely when using.
Cutting Tools (Hand & Powered)	Knives, box cutters, scissors, hacksaws, chop saws, table saws.	3	3	9	- Unclean or oily hands while working - Negligent handling - Open wires - Dull blades - Leaving powered tools unattended	- Severe lacerations - Eye injury from debris -Electrocution - Puncture wounds	- Heavy duty gloves should be used - All wires shall be inspected before and after use. - Storage of tools safely away from heavy occupied zones and safe to hold in their stored state.

Electronics & Soldering Tools	Soldering irons, wire cutters/ strippers, crimpers.	3	2	6	- Leaving hot or powered tools unattended - Toxic fumes - Exposed wires	- Burns - Blistering - Skin pinching Cuts	- Area shall be properly ventilated - Safety glasses shall be used
Heat Tools & Adhesive Applicators	Heat guns, hot glue guns.	2	2	4	- Leaving energized tools unattended. - Hot material - Toxic fumes	- Burns - Blistering	- Heat-resistant gloves shall be required when operating. - Face mask capable of filtering chemical and partial inhalants shall be used.
Machining Tools (Heavy Equipment)	Mill and Lathe.	2	4	8	- Unclean machine - Improper maintenance - Lack of operation knowledge, - Loose material in tool grips. - Negligent use of tool according to provided owner's manual. -Exposed wires - Some Machining tools need coolant for material shaping. This coolant can be hot and contain contaminants.	- Cuts or nicks from material edges. - Metal shavings in eyes. - Limb caught in machine resulting severe wounds and even death.	- Knowledge of emergency stop locations is required. - Non-essential personal shall not be in the area while being operated. - Proper clamping of billet or part shall be confirmed Safety glasses shall be required
Power Drilling & Fastening Tools	Cordless drills/drivers, torque wrenches, tap & die sets.	2	3	6	- Unclean or oily hands while working - Negligent handling - Leaving energized tools unattended Open wires	- Cuts, lacerations, and puncher wounds from tool head. -Electrocution from open wire	- Heavy duty gloves should be used - All wires to powered tools shall be inspected before and after use. - Storage of tools safely away from heavy occupied zones and safe to hold in their stored state. - Safety glasses shall be required
Rotary & Abrasive Tools	Grinders, rotary tools (Dremel), sanders.	2	3	6	- Leaving energized tools unattended. - Negligent handling Rough, tool head. Exposed wires	-Electrocution from exposed wire - Flying debris can cause eye and skin injury. - Inhalants caused by	- Storage of tools safely away from heavy occupied zones and safe to hold in their stored state. - Face mask capable of chemical and

						sander can cause respiratory irritation.	partial inhalants shall be used. - Safety glasses shall be required

Table 5-7 Construction Hazards

Notice: All tools require that the user is well informed on the use and maintenance of any tool before use, and tools shall be used for their intended purposes. During the operation of heavy machinery or high-risk tools, only essential personnel shall be permitted in the immediate area

5.4.7. Construction Safety Verification / Derived Requirements

All construction processes and tools will share the verifications due to their high similarity.

Verifications will include:

- All teammates will have physical and digital printouts of the necessary PPE for all equipment in each room.
- All teammates must pass a competency test on all tools with a safety hazard ≤ 6 before being able to use the tool. This competency test will include proper PPE, major components of the tool, manufacturer's intended use for the tool, and proper safety procedure (may be tool-specific).
- A sign in / sign-off sheet will be posted in all rooms for documentation.
- The Safety Officer shall inspect and document all equipment used weekly.
- The Safety Officer shall monitor and maintain all equipment quality and cleanliness.
- AHJ shall be notified of all necessary maintenance by the safety officer.

5.4.8. Failure Modes and Effects Analysis (FMEA)

Failure Modes and Effects Analysis						
Facilities	P’	S’	Value	Causes	Mitigations	Verifications
Airframe	3	2	6	Hazard to fin breakage	• Airframe shall be made with a safety factor of ≥ 2 of the forces expected at ground hit velocity.	• Testing of material strength prior to launch. • Design check log shall be implemented to verify the completion of material strength.
Avionics	2	3	6	Hazard to early deployments	• The avionics bay will be equipped with multiple pitot tubes for ample	• Pre-Launch check log shall be implemented to verify completion of calibration and avionics check.

					air circulation and barometric pressure accuracy	
Recovery	1	3	3	Shock cord entangles, bulkhead bending/ breakage	• Model all bulkheads in CAD and find the stress and deformation imposed on the bulkhead. • Test the material strength of the shock cord.	• Verify shock cord strength • Design check log shall be implemented to verify the completion of material strength.
Propulsion	2	3	6	Loss of power during high-temperature cases	• Weather monitoring • Keep the motor in the shade until the time is up.	• Design check log shall be implemented to verify the completion of material strength.
Team communication	4	2	8	Misunderstanding of the team goal or the individual task.	• A collective meeting with the team at large, before team objectives are carried out.	• Communication is a curtail part of the health of the team

Table 5-8 Failure Modes and Effect Analysis

5.5. Environmental Concerns

Our team is dedicated to the safety of all personnel and the preservation of our environment. Outlined are some possible hazards we foresee during the design, building, and launch of our rocket.

Environmental Hazards						
Hazards	P'	S'	Value	Causes	Mitigations	Verification
Potential Effects and Hazards to Environment						
Material Waste	5	1	5	• PLA filament waste due to supports and shaping. • Packaging (cardboard, Styrofoam, bubble wrap) • Excess epoxy.	• Recycle as much material as possible. • Use as much as needed	• A designated recycling bin will be in the major area of waste production such as the Senior Design Lab.

Chemical Aerosol	3	2	6	Chemical reaction producing an aerosol by-product.	• Were proper PPE when using any chemical • A ventilated room or open air is required.	• Proper PPE based on chemical used and manufacturer instructions.
Energetic by-product (post launch)	5	1	5	Ash, smoke, dust, and soot.	• Do not approach the rocket launch pad or rocket until by-products have clearly dissipated.	• Post-Launch check log shall be implemented to verify completion of debris removal.
Field Debris	5	1	5	Broken fins, launch preparation disposables, snack trash, and water bottles.	• Continue to clean throughout the day. • Bring plenty of trash bags and dispose of the trash properly, with any recyclable trash being handled accordingly.	• Post-Launch check log shall be implemented to verify completion of debris removal.
Batteries	5	2	10	Improper disposal of batteries or any device using lead-acid or AGM technology.	• Dispose of batteries per the manufacture specification.	• Log of all batteries being disposed of and when.
Potential Environmental Effects and Hazards on the Rocket						
Dense Pockets of Air and Cross Wind	3	3	9	Early deployment due to avionics bay air density verification.	• The avionics bay will be equipped with multiple pitot tubes for ample air circulation and barometric pressure accuracy	• Flight computer and avionics will be calibrated to launch site elevation. • Pre-Launch check log shall be implemented to verify completion of calibration and obstruction check.
Typical Barometric Pressure Change	5	1	5	• Impacts accuracy of data collection.	• The avionics bay will be equipped with multiple pitot tubes for ample air circulation and barometric pressure accuracy	• Pre-flight check for any pitot tubes obstructions. • Flight computer and avionics will be calibrated to launch site elevation. • Pre-Launch check log shall be implemented to verify completion of calibration and obstruction check.
Terrain and Vegetation (including water landing)	3	1	3	• Harsh landing to rocket body. • Incapable of rocket recovery. • Risks to payload deployment	• Air frame shall be made with a safety factor ≥ 2 of forces expected at ground hit velocity. • Avionics bay will house a remote GPS • Payload shall be designed to traverse a multitude of terrains.	• Testing of material strength prior to launch. • Testing of Avionics Bay GPS will occur prior to launch. • Payload will be tested for its ability to operate in extreme terrains during its design and building processes. • Pre-Launch check log shall be implemented to

						verify completion of GPS calibration check.
Temperature and Humidity Extremes	4	1	4	Affect to burn time, apogee, ground hit velocity, and time to ground.	• Rocket preparation shall be done in shade for as long as possible. • Survey weather patterns thought the day.	• Ensure there are sufficient tent coverings to work under.
Solar Exposure and Thermal Gradients	4	1	4	Weakness adhesives	• Rocket preparation shall be done in shade for as long as possible. • Survey weather patterns thought the day. • Check epoxy fillets for structural rigidity.	• Check material rigidity • Pre-Launch check log shall be implemented to document confirmation of material rigidity verification.
Lightning or Severe Weather	3	2	6	Safety of mission is jeopardized as it cause severe concerns for equipment and personnel well-being.	• Do not flight until instructed at further notice by the RSO	• Verbal confirmation my mentor and RSO before resuming launch. • Pre-Launch check log shall be implemented to document confirmation of both parties.

Table 5-9 Environmental Hazards

5.6. Project-Level Risks

Project Hazards and Mitigations						
Hazards	P'	S'	Value	Causes	Mitigations	Verification
Technical Risks						
Payload capability	3	4	12	Issues with electrical and mechanical integration	• Extensive testing will be done with all sub-system components before and after integration.	• A log will record the testing of primary payload components and documented.
Recovery capability	2	4	8	Faulty sensors or premature separation	• Extensive testing will be done with all sub-system components before and after integration.	• A log will record the testing of primary recovery components and documented.

					• Multiple pitot holes will drilled into the airframe to provide ample outside air pressure conditions.	
Scaling incompatibility between subscale and full-scale models	4	2	8	Transitions makis it difficult to find nominal O.D. for the air frame making room for scaling issues.	• Scaling will be based on surface area instead of O.D.	• CAD modeling will be done to verify surface area of sub-scale.
Safety Risks						
Inadequate possession of PPE equipment	1	4	4	Error in PPE stock on hand	• Account for all PPE in stock • Lack of PPE equipment will be documented and included in the budget.	• Team members will be responsible for keeping track of personal PPE. • Specialized PPE like respirators will be logged by the safety officer. • All PPE will be stored in a secure location in the Senior Design Lab.
Team members absent in Safety meetings	2	2	4	Emergency absents or last-minute absents.	• Team members must be caught up with all safety information and processes.	• All absentees will be documented.
Safety Officer is absent during launch	1	3	3	Emergency absents or last minute absents.	• Mentor will be notified and lead the preliminary safety meeting before launch day begins.	• All absentees will be documented.
Scheduling Risks						
Motor availability	3	4	12	Selected motor is out of stock	• Motor will be purchased as soon as possible. • If motor cannot be purchased, NASA and mentor shall be notified on new motor selection.	• Weekly check of local vendors and motor availability will be track by the project manager.
Behind on schedule milestones	2	3	6	Out of stock parts preventing team from moving forward.	• Adding buffer periods in overarching timeline. This is to provide the team with ample time for catch-up, research, and refining work.	• Project manager will lead weekly team briefing including project updates and responsibility delegations.

Budget Risks						
Budget is declined	4	2	8	Budget is not accepted yet and is subject to declining due to the large expense of the rocket.	• Fun raising will be instituted. • Reaching out to local employers for sponsorship.	• Project manager will lead weekly team briefing including project updates.
Material and component price fluctuation	5	2	10	Prices listed on the budget are subject to change and have a high likely hood of fluctuation	• Budget will be continually tracked and accounted for. • If cost can be reduced for certain components or processes, project leader can save on initial budget proposal.	• Project manager will lead weekly team briefing including project updates.

Table 5-10 Project Hazards and Mitigations

5.7. Emergency Response and Incident Procedures

Motor Fire

In the event of a motor fire, team members must be trained and prepared to react in accordance with safety procedures.

Immediate action:

1. Make all team members aware of the present danger by yelling load and clear, “Fire, evacuate now”.
2. The Safety Officer must ensure that all team members are at a minimum distance of 300’. This is in accordance with NAR safety code for L class motors.
3. All team members must be accounted for by the safety officer.
4. The Safety Officer must ensure that all team members are unharmed. In the case of injury, emergency services must be called immediately, and the tending to the victim must be the top priority until emergency personnel arrive.
5. Notify the proper fire authorities and do not attempt to tame or quench the fire.

5.8. Final Assembly, Integration, and Launch Procedures / Checklists

To ensure the safety of the team and all involved, a procedure of team preparation and launch procedure shall be implemented. This procedure was derived from NAR/TRA standards and NFPA 1127 safety code.

Pre-Launch

- *Recovery and Respective Electronics Preparation*
  The recovery system is extremely important in ensuring the safe launch and landing of the rocket. All high-powered rockets require a recovery system capable or returning rocket and all components safely to the ground. This will be done while preserving the rocket's original condition and at a non-hazardous ground high velocity. Since the motor selected has an impulse over 2560 N-sec, this requires the implementation and use of an electronic actuated recovery system. Our rocket will satisfy both of these requirements in accordance with NFPA 1127 (4.10.1 & 4.10.2).

1. **Disarmed Electronics Verification** – Ensure no voltages or currents are present in avionics bay when systems are unarmed. This includes:
    a. Verifying there is no power to either flight computer.
    b. Verifying energetic circuits are open in two places (open switch and unarmed flight computer).
    c. Ensure solid soldered connections among energic circuits.
    d. Verify two fully charged power sources are present.
2. **Ensure Energetics are Disabled** – Ensure black powder/CO2 cartridges are unarmed and placed in avionics bay housing.
3. **Verify Arming Key Switch is Properly Installed** – Ensure arming system is working correctly. This is done by:
    a. Remove both power sources from the avionics bay.
    b. Connect multimeter to the terminals of the arming switch.
    c. Turn the key switch to the "armed" position.
    d. With the multimeter in the "Continuity" mode, verify the terminals are properly connected.
    e. Turn the key switch to the unarmed mode.
    f. Using the multimeter, verify the connection is open.
    g. Replace the power sources back into the avionics bay.
4. **Verify Means to Fire Energetics are Present –** Visually verify electronics matches have been secured in proper position and have secure connections to logic electrics and power.
5. **Check Bulkhead Rigidity** – Ensure all bulkhead connection points are secure
6. **Prep Chutes and Components** – Properly fold & bag drogue, pilot, and main parachutes respectively
7. **Prep Shock Cords** – Properly bundle shock cords and connect shock cord to bulkheads via quick links.

8. **Insert Chutes and Components** – Carefully pack cords and parachute bags into their respective housings. Parachute bags will be flame-resistant bags since black powder is being utilized for separation. NFPA 1127 (4.10.3)

- *Payload Procedure Verification Procedure*
  1. **Assembly of Electronics and Mechanical Systems** – Ensure all electrical wires and components are properly connected and/or soldered. Verify all mechanical components are properly assembled and fastened. Ensure all there are no abnormal voltages or currents in electrical circuits when payload is inactive.
  2. **Payload Mobility Verification** – Verify mobility of the Terra Inquisitor by initiating a test routine programed to actuate the Inquisitor to move in various predetermined directions, distances, and speeds.
  3. **Payload Drilling Verification** – Verify Drilling by initiation of drilling routine to deploy the drill from its holding position when in the rocket and to begin collecting a soil sample
  4. **Payload Soil Testing Probe Verification** – Verify Terra Inquisitor's pH sensor by testing a sample of soil with a known pH. Calibrate if needed.
  5. **Payload Automation Verification** – Verify Terra Inquisitor is fully capable of completing its mission by initiating its full autonomous testing routine from the landing of rocket to sample collection and testing. After test, the Terra Inquisitor is ready by checking battery, voltage, and current levels of various components, any overheating, or excessive wear

- *Mechanical Separation Verification Procedure*
  1. **Mechanical Assembly Verification** – Verify the mechanical separation mechanism is properly assembled and all components are properly fastened and connected
  2. **Electronics Verification** – Ensure all electronical devices and wires are properly connected and/or soldered. After verification of all connections verify voltage and current levels are at the appropriate levels.
  3. **Mechanical Assembly Test Verification** – Test the mechanical assembly and electrical components are functioning and operating as designed by initiating separation procedure. Procedure of mechanical test:

     a. Ensure solenoid "unlocks".

     b. Ensure orientation stepper motor turns assembly to the correct position for payload deployment.

     c. Verify separating stepper motors rotate freely and to the designed length to deploy payload.

     d. After testing check battery, current, and voltage levels to ensure no abnormalities and/or excessive power drains. Also verify there are not points of overheating, excessive component wear, or other potential damages.

4. **Mechanical to Airframe Verification** – Verify mechanical separation assembly is properly fixed to rocket airframe for all phases of flight and payload deployment. Re-initiate separation procedure steps a-d above to ensure assembly is fully ready.

- *Motor Preparation*

  Note: Reloadable motor kit shall not be removed from manufacturer packaging until team is ready to install the motor into the reloadable motor system (RMS) and ready to launch. During the process of motor preparation and loading, the motor shall be handled by the NAR/TRA team mentor, Elizebeth Gildersleeve and accompanied by the team Safety Officer, Jonathan Serbest.

1. **RMS Inspection** – RMS must be fully capable of housing the specified motor. This means that the RMS must be clean and without any internal impedance, blocking the motor from being installed.
2. **Ensure Locational Safety** – Before continuing further, the nature of the following steps includes highly explosive material. In accordance with NAR/TRA, NFPA 1127, and ATF 27 CFR, motor preparation shall not be within "50 feet of any smoking, matches, open flames, and spark producing devices." (27 CFR 555.212)
3. **Motor Kit Inspection –** Remove motor from manufacturer sealed packaging and begin inspecting all components of the kit. The kit must pass a detailed inspection before use. Possible defects include but are not limited to indentions, incisions, tears, missing components, and leaking solid propellant.
4. **Load Motor into RMS –** During this time, the team safety officer must continue to survey the area, continuing to make sure that the area utilized is an ignition free zone.
5. **Load RMS and secure into Rocket** – Once the team mentor has successfully installed motor and additional components into the RMS, RMS will be loaded into rocket and recured.

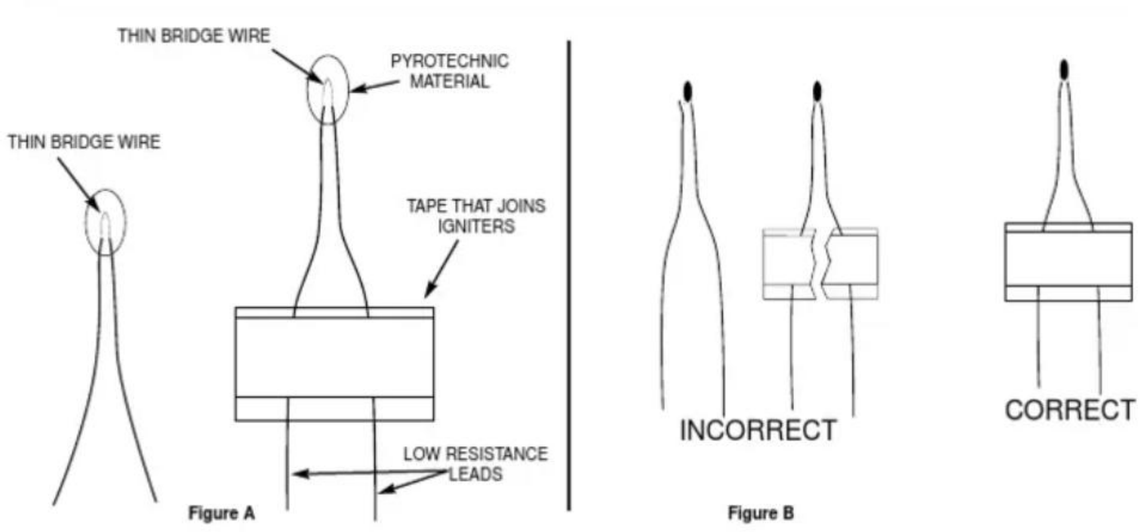
- *Rocket Preparation*
  1. **Ensure the inclusion of all main systems** –
     - Ensure recovery hardware is attached
     - Ensure reefing subsystem is in place
     - Properly fold drogue & main parachutes
     - Properly pack shock cords & folded parachutes
  2. **Insert Transition into Airframe** – Insert transition coupler into the aft opening on the HAUS section
  3. **Shear pin installation** – Insert shear pins in the 4 respective joints surrounding the connection made previous
  4. **Motor tube installation** – Insert motor tube coupler into the 5" diameter end of the Avionics section

5. **Second array of shear pin installation** – Insert shear pins in the 4 respective joints surrounding the connection made previous
6. **Locate and mark CP/CG** – Mark CP and CG on the outside of the airframe
7. **Vent port inspection** – Ensure any ventilation ports are unobstructed
8. **Airframe inspection** – Scan entire rocket body for any surface indications/defects
9. **Rocket transport** – Safely transport rocket to launch platform and place rocket on launch platform.
10. Locate the keyhole for arming the recovery system. To arm, insert and turn the key to the "on" position.

- *Setup on the launch pad*
  1. **Disarmed Electronics Verification** – look to step one of the *Recovery and Respective Electronics Preparation* for procedure information.
  2. **Ensure Electronic are disabled** - Ensure that any onboard energetics and firing circuits of any kind shall be disabled until the rocket is ready for launch. NFPA 1127 (4.13.7) This applies to:
     a. Avionics Bay
     b. Payload Vehicle
     c. Payload Mechanical Separation
  3. **Rocket Transport** – Once the rocket is prepared for launch, 3 team members, similar in shoulder height, will begin to carry the rocket to the designated launch rod.
  4. **Securing the Rocket to Launch Rod –** The rail buttons are located on the outside of the rocket air frame and will slide into the launch rod grove. This groove runs up the entirety of the rod. Once inserted, secure the rocket at rest, to the bottom of the pad.
  5. **Initiate Payload and Separation Power Systems** – Power to payload rover and mechanical separation systems must be initiated using mechanical switches. These systems then wait for activation protocol within the software to be carried out.
  6. **Arm Energetics and Firing Systems** – Using key cylinder switch, all electronic within the avionics bay must be armed. During the arming of all onboard energetics and firing circuits, there shall be no participants or spectators of any kind, near the launch pad other than authorized personnel tending to the arming and disarming operations.
  7. **Installing the Electrical Motor Igniters** – Once the rocket is in the correct orientation, install the motor igniters into the motor. Please see the "*Igniter installation*" section for information on proper installation procedure. A safety interlock is required to be wired in series, and the launch switch shall not be installed until the rocket is ready for launch.

     *****Armed systems include flight computer, altimeter, black powder/CO2 cartridges, and motor igniters.
- *Igniter installation*

Rocket Transport – The safety officer will carry the motor igniter as the rocket is being transported to the launch pad. Once the rocket is attached to the launch rod and in place, igniter installation can begin.



Igniter Installation – Insert the igniter end into the base of the rocket motor. This should be inserted until the igniter reaches the top of the motor opening.
Tape Leads – Leads must be separated from each other and taped to prevent contact. This is to prevent pre-detonation.
Tape Leads to Rocket Base – To keep the igniter pressed to the top of the motor, bend the ends of the exposed wire over the base of the rocket and tape to the air frame.
Lead Connection – Connect each lead to separate alligator clips and the alligator clip wires to the ignition system.

Launch

At launch, rocket is in place and inspection has deemed the rocket adequate for flight.

Note: All sanctioned launch areas by NAR / TRA are to have proper safety accommodation based on all AHJ.

1. **Confirmation of area safety and shutdown to launch** – Area is deemed safe when location of all participants and spectators meet the minimum distance table, provided by NAR High Power Rocket Safety Code highlighted below.

MINIMUM DISTANCE TABLE

Installed Total Impulse (Newton-Seconds)	Equivalent High Power Motor Type	Minimum Diameter of Cleared Area (ft.)	Minimum Personnel Distance (ft.)	Minimum Personnel Distance (Complex Rocket) (ft.)
0 -- 320.00	H or smaller	50	100	200
320.01 -- 640.00	I	50	100	200
640.01 -- 1,280.00	J	50	100	200
1,280.01 -- 2,560.00	K	75	200	300
2,560.01 -- 5,120.00	L	100	300	500
5,120.01 -- 10,240.00	M	125	500	1000
10,240.01 -- 20,480.00	N	125	1000	1500
20,480.01 -- 40,960.00	O	125	1500	2000

Note: A Complex rocket is one that is multi-staged or that is propelled by two or more rocket motors
Revision of August 2012

Table 5-11 Minimum Distance

After the area is deemed to be safe for launch, a five second countdown will be used before launch initiation.

2. **Verify Rocket Stability** –Verify rocket stability on the launch pad. If stability is inadequate, launch of the rocket must not proceed and must be cancelled until future notice.
3. **Watch Rocket** – it is crucial that the team and nearby spectators are always informed of the rocket's location.
4. **Stay clear of rocket until it has hit the ground** – There shall not be an attempt to catch the rocket while descending or retrieving the rocket in areas of hazard like powerlines or on top of trees. If the rocket lands on a powerline, local AHJ shall be called. NFPA 1127 (4.10.4-6).

Post-Launch

1. **Area and Vehicle Inspection** – Inspect the landing site for fire, debris, and other anomalies.
2. **Wait for Payload to Finish Task** – Payload will be deployed after rocket has landed. Rover will proceed to leave the air frame and begin completing its tasks described in payload section.
3. **Approach and retrieve rocket** – Team members have freedom to approach and procure the rocket, its payload after its deployment and job has been completed.
4. **Contact AHJ** – If needed, contact required AHJ for landing and retrieval confirmation.

5.9. Safety Training and Documentation

Training Matrix		
Role	Required Training/Certification	Method of Verification
Project Manager	• Training in the use of all equipment on campus. • An understanding of NASA sign-off procedure and documentation requirements. • Must have an understanding of safety protocol in the case of an emergency.	• Sign-off
Team Mentor	• NAR/TRA Level 2 certification	• Copy of certification
Safety Officer	• Training in the use of all equipment on campus. • Understanding of all AHJ during all steps of the project. • Certified in First Aid/CPR/AED training	• Sign-off
Payload Officer	• Training in the use of all equipment necessary for payload design. • Software debugging	• Sign-off
Recovery Officer	• Training in the use of all equipment necessary for recovery design. • Software debugging • Packing parachutes	• Sign-off
Electronics Officer	• Training in the use of all equipment necessary for recovery and payload design. • Software debugging • FCC compliance awareness	• Sign-off

Table 5-12 Training Matrix

Note – (sign-off) is a method of verification in which a person signs an agreement stating competency in their required training/certification.

ID Nomenclature	
Abbreviation	**Meaning**
Class	
SAFE	Safety
OPS	Operations
TEST	Testing
REC	Recovery
ELC	Electronic
PAY	Payload
Purpose	
SIO	Sign-in/out
CKL	Check log
ATND	Attendance
TEST	Testing
CNTS	Count of stock
Time	
PREL	Pre-launch
PSTL	Post-launch
Frequency	
PER	Every Launch
YR	Yearly
MNTH	Monthly
AN	Annual

Table 5-13 ID Nomenclature

Project Document Identification					
Doc. Name	**Doc. ID**	**Rev.**	**Date of Revision**	**Owner**	**Auditor/Approver**
Room Sign-in/out	SAFE-SIO-ALL-MNTH-R0	R0	N/A	Krieg Conrad	Jonathan Serbest
Pre-launch Rocket Preparation Check List	OPS-CKL-PREL-PER-R0	R0	N/A	Krieg Conrad	Jonathan Serbest
Launch Day Material, Component, and Equipment Check List	OPS-CKL-PREL-PER-R0	R0	N/A	Krieg Conrad	Jonathan Serbest
Post-Launch Check List	OPS-CKL-PSTL-PER-R0	R0	N/A	Krieg Conrad	Jonathan Serbest
Attendance Log	SAFE-ATND-ALL-MNTH-R0	R0	N/A	Krieg Conrad	Jonathan Serbest

Chemical Accounting	SAFE-CNTS-ALL-MNTH-R0	R0	N/A	Jonathan Serbest	Krieg Conrad
Equipment Quality and Cleanliness Control	OPS-CKL-ALL-MNTH-R0	R0	N/A	Jonathan Serbest	Team
Material Property Testing	TEST-TEST-DEV-AN-R0	R0	N/A	Case Dyer, Matthew Wilson	Krieg Conrad, Jonathan Serbest
Payload Component Testing and System Competition	PAY-TEST-DEV-PER-R0	R0	N/A	Case Dyer, Matthew Wilson	Krieg Conrad
Recovery Component Testing and System Competition	REC-TEST-DEV-PER-R0	R0	N/A	Austin Zaal, Matthew Wilson	Krieg Conrad

Table 5-14 Project Document Identification

Note: All documents listed above are live and subject to change. Document owners will be held responsible for all revisions and date of revisions and Auditors must approve of all revisions beforehand. Document ID uses the template (Class-Purpose-Time-frequency-Revision).

6. Project Plan

6.1. Requirements Verification

The special performance and design limitations of the Terra Nova launch vehicle and Terra Inquisitor payload are outlined in the following team-derived requirements.
These specifications, which go above and above the NASA USLI 2026 Handbook's minimal standards, were put in place to save costs, increase dependability, and guarantee that the launch vehicle and payload can accomplish mission accomplishment in a safe and repeatable manner.
Every need may be measured, supported by evidence, and confirmed by examination, testing, or analysis.

6.1.1 Derived Vehicle Requirements

Requirement V-1:
The launch vehicle shall use a motor that fits a 75/5120 RMS casing.
Justification:
This is due to the RMS currently being in the possession of the Terra Nova team. The usage of this RMS will reduce the cost of the overall rocket by $758.00 and help ensure the team stays within the outlined budget.
Verification:
Make sure the motor is made for the specified RMS as you go through the purchasing procedure.

Requirement V-2:
All coupler lengths shall be at least 2.125 times the ID for separating sections and 1.625 times the ID for non-separation sections.
Justification:
This requirement is to ensure the Terra Nova team allows for redundancy over those specified per Handbook Req 2.5.
Verification:
Dimensional inspection of manufactured couplers and structural test fit during integration.

Requirement V-3:
The weight of the HAUS Section and all its components shall not exceed 250 oz.
Justification:
This requirement is to ensure the impact energy of the section is below our set maximum energy of 65 ft-lb and the targeted range of 60 ft-lb. The 250 oz was calculated using the average velocity at ground impact for the current design (15.7 fps) and the set target of 60 ft-lb.
Verification:
Estimating weight of assembly before fabrication and then weighing after assembly to verify.

6.1.2 Derived Recovery Requirements

Requirement R-1:
The total time from apogee to ground shall not exceed 80 seconds.
Justification:
This performance goal drives the custom recovery system design: a small drogue at apogee and a reefed-main deployment that minimizes descent time while keeping impact energy within safe limits.
Verification:
Review of flight data from altimeter records verifying that the interval between apogee and touchdown was less than 80 seconds.

Requirement R-2:
Another requirement set by this team is to hit the ground with impact energy less than 65 ft-lb.
Justification:
The targeted goal of the team is to hit the ground with less than 60 ft-lb, thus allowing for a 7% margin of error from the specified requirement of 65 ft-lb. Achieving both this and the time to ground goal simultaneously will be difficult, but it can be done with proper management of the recovery system. Rearranging the mass to be more evenly distributed throughout the three separating portions of the rocket make the problem far more approachable, and simulation data from OpenRocket predict a mean ground hit velocity of 15.7 ft/s ground hit velocity. Current predictions of impact energies are all below the targeted goal of 60 ft-lb.
Verification:
Measured descent rates from flight data are compared to expected values; impact energy is calculated using measured mass and recorded final velocity.

6.1.3. Derived Payload Requirements

Requirement P-1:
The minimum separation force that will be provided by the Terra Nova MSM is 35 lb.
Justification:
This requirement was more fully derived in 4.2.1. Mechanical Separation. This requirement was derived based on simulation data of the worst possible landing orientation. To ensure the MSM is capable of separating for the deployment of the Terra Inquisitor, the worst-case force has been defined as the minimum force that must be provided. This ensures proper redundancy for various unpredictable obstacles.
Verification:
Bench test of MSM assembly to confirm output force ≥ 35 lb.

Requirement P-2:
The minimum force that must be provided by the payload propulsion system is 6.5 lb.
Justification:
This requirement was more fully derived in 4.2.3. Propulsion System based on simulations for the worst possible case. To ensure the Terra Inquisitor propulsion system is designed with sufficient redundancy, the worst-case driving force is the minimum force that must be provided by the system. This ensures the system is able to handle a variety of obstacles that cannot be effectively simulated.
Verification:
To confirm ≥ 6.5 lb driving force under load, motor torque and traction tests will be conducted on the built payload chassis.

6.2. Budgeting and Funding

6.2.1. Budget

The budget shown below provides a comprehensive, line-item breakdown of all components required for the project. Items not listed are materials, tools, or components already available to the team through existing university or lab resources. Some costs are estimated or flexible due to available inventory and shared resources, but all major procurements and critical hardware are fully accounted for.

Terra Nova Project Budget

Item	Description	Quantity	Estimate Shipping & Handling	Price ea.	Total	Link	Status
Full Scale Airframe and Motor							
Nose Cone	Fiberglass Nosecone FNC-6.0	1	$40.00	$190.98	$230.98	(Click Here)	Not Ordered
6in ID Body Tube	6" fiberglass airframe 60in	1	$55.00	$279.81	$334.81	(Click Here)	Not Ordered
5in ID Body Tube	5" fiberglass air-frame 30in	2	$40.00	$129.67	$299.34	(Click Here)	Not Ordered
6" coupler	G12CT-6.0 12" lengths	1	$15.00	$71.00	$86.00	(Click Here)	Not Ordered
5" coupler	G12CT-5.0 12" lengths	3	$20.00	$62.57	$207.71	(Click Here)	Not Ordered
Motor Tube	BT-3.00	1	$10.00	$14.16	$24.16	(Click Here)	Not Ordered
Motor Retainer	RA75L - 75MM MOTOR RETAINER ASSEMBLY FOR LOC TUBES	1	$10.00	$57.00	$67.00	(Click Here)	Not Ordered
Fiberglass Sheet	1/4 INCH G10 FIBERGLASS SHEET 1 SQUARE FOOT for fins	4	$25.00	$46.00	$209.00	(Click Here)	Not Ordered
Rail guides	Large Airfoiled Rail Buttons (fits 1.5" Rail - 1515)	1	$10.00	$11.73	$21.73	(Click Here)	Not Ordered
Standoffs for the rail buttons	5/16" Rail Button Standoff	2	$10.00	$3.74	$17.48	(Click Here)	Not Ordered
Rocket Motor	RMS-75/5120 Reload Kit (1 Pack) - 12142P - Hazmat FedEx surcharge	3	$85.00	$376.99	$1,215.97	(Click Here)	Not Ordered
Adhesives	Epoxy fillers	1	$0.00	$100.00	$100.00	(Estimates)	Not Ordered
Paint / finishing supplies	Used for both rocket airframes	1	$0.00	$150.00	$150.00	(Estimates)	Not Ordered
Fasteners & hardware(bolts, screws, ect.)	Used for both rocket airframes	1	$0.00	$75.00	$75.00	(Estimates)	Not Ordered
3D printer Filiment	nter Filament, Excellent Toughness High Precision, Odorless Non-Tox	1	$0.00	$79.99	$79.99	(Click Here)	Not Ordered
Fiberglass Cloth	**#120-38 Standard E-Glass Fiberglass Cloth 38**	6	$15.00	$9.90	$74.40	(Click Here)	Not Ordered
						Total:	$3,193.57
Sub-Scale Airframe and Motor							
Large Diamter Body Tube	Phenolic Airframe Tubing - 3.900" ID	1	$5.00	$28.04	$33.04	(Click here)	Not Ordered
Small Diamter Body Tube	Phenolic Airframe Tubing - 3.002" ID	2	$5.00	$25.79	$56.58	(Click here)	Not Ordered
Large Coupler Tube	PML Phenolic Coupler Tube - 3.78" x 36"	1	$5.00	$33.65	$38.65	(Click here)	Not Ordered
Small Coupler Tube	PML Phenolic Coupler Tube - 2.88" x 36"	1	$5.00	$29.16	$34.16	(Click here)	Not Ordered
Fiberglass Sheet	1/8 INCH G10 FIBERGLASS SHEET 1 SQUARE FOOT	2	$15.00	$19.80	$54.60	(Click Here)	Not Ordered
Motor Retainer	Screw On Retainers for 54mm Tubes	1	$10.00	$44.08	$54.08	(Click Here)	Not Ordered
RMS	54/1280 Complete Motor Hardware Set (w/ Forward Seal Disc) - 5412M	1	$10.00	$232.99	$242.99	(Click here)	Not Ordered
MOTOR	RMS-54/1280 Reload Kit (1 Pack) - 108014 - - Hazmat FedEx surcharge	1	$65.00	$135.99	$200.99	(Click here)	Not Ordered
Rail Buttons	Standard Rail Button (fits 1" Rail - 1010)	1	$5.00	$5.58	$10.58	(Click here)	Not Ordered
Nose Cone	Plastic Nosecone PNC-3.9	1	$15.00	$24.95	$39.95	(Click here)	Not Ordered
Main Chute	48" Elliptical Parachute - 8.6lb at 20fps	1	$20.00	$161.21	$181.21	(Click here)	Not Ordered
Droge Chute	12" Elliptical Parachute - 0.5lb at 20fps	1	$20.00	$77.51	$97.51	(Click here)	Not Ordered
						Total:	$1,044.34
Recovery Systems							
Shock Cord	Paramax Shock Cord - 100 ft	1	$10.00	$35.00	$45.00	(Click Here)	Not Ordered
All-thread rods + washers + nuts	Connect bulkheads internally for payload & motor retention structure.	1	$0.00	$40.00	$40.00	(Estimates)	Not Ordered
Black Powder / E-matches	E-matches (80 pieces and 3ft)	1	$75.00	$66.40	$141.40	(Click Here)	Not Ordered
C02 Canisters		2	$25.00	$25.00	$75.00	(Estimates)	Not Ordered
Flight Compuer	Eggtimer Proton	2	$20.00	$80.00	$180.00	(Click Here)	Not Ordered
Sub Scale Apogee Drouge	12" Elliptical Parachute - 0.5lb at 20fps	1	$20.00	$77.51	$97.51	(Click Here)	Not Ordered
Sub Scale Main Chute	48" Elliptical Parachute - 8.6lb at 20fps	1	$20.00	$161.21	$181.21	(Click Here)	Not Ordered
Full Scale Apogee Drouge	15" Compact Elliptical Parachute - 0.8lb at 20fps	1	$25.00	$88.20	$113.20	(Click Here)	Not Ordered
Full Scale Main Chute	Iris Ultra 120" Compact Parachute - 79lb @ 20fps; 44lb @ 15fps	1	$25.00	$685.59	$710.59	(Click Here)	Not Ordered
Shear Pins	Small Nylon Shear Pins - 20 pack	2	$5.00	$4.63	$14.26	(Click Here)	Not Ordered
Full Scale CO2 Ejection System	The "Double Eagle" Kit	1	$35.00	$279.00	$314.00	(Click Here)	
Subscale CO2 Ejection System	Peregrine CO2 Ejection Device (8g, 12g)	1	$35.00	$239.99	$274.99	(Click Here)	Not Ordered
Battery packs		3	$5.00	$25.00	$80.00	(Estimates)	Not Ordered
Wiring, connectors, switches & small electronic	Electronic Sytems for Both Subscale and Full	1	$15.00	$75.00	$90.00	(Estimates)	Not Ordered
						Total:	$2,357.16
Payload System							
Micro SD	Micro SD Storage Device	2	$0.00	$10.98	$21.96	(Click Here)	
PCB Building		1	$15.00	$175.00	$190.00	(Estimates)	Not Ordered
Microcontrollers & electronic components	Anything extra we don't have in lab	1	$0.00	$100.00	$100.00	(Estimates)	Not Ordered
Prototyping parts	Anything extra we don't have in lab	1	$0.00	$40.00	$40.00	(Estimates)	Not Ordered
Soil Sampling Kit	PH Probe	1	$35.00	$170.00	$205.00	(Click Here)	Not Ordered
						Total:	$556.96
Saftey							
Hand Protection	SAS Safety Raven 7 mil Nitrile Gloves (Alt)	2	$0.00	$10.98	$21.96	(Click Here)	Not Ordered
Ear Protection	3M Folding Earmuffs Model 90563H1-DC	3	$0.00	$10.65	$31.95	(Click Here)	Not Ordered
Lung Protection	spirator (20-Pack): N95 particulate respirator from 3M fits your respirat	2	$0.00	$17.31	$34.62	(Click Here)	Not Ordered
Eye Protection	ewear SF200P1-DC: Premium eyewear with anti-fog lens and flexible f	4	$0.00	$6.98	$27.92	(Click Here)	Not Ordered
Eye Protection (Over-the-glasses)	3M Over-the-Glass Safety Eyewear (47110-WV24)	2	$0.00	$1.22	$2.44	(Click Here)	Not Ordered
						Total:	$118.89
Transportation, Lodging, Community Outreach, & Misc.							
Campus Veihcle	Provided by Florida State University - Panama City	1	Not aplicable	$0.00	$0.00	Not Applicable	-----
Gas	Estamite For all Travel both community events and launches	1	Not aplicable	$400.00	$400.00	(Estimate)	-----
Lodging	Air B&B	1	Not aplicable	$2,000.00	$2,000.00	(Click Here)	-----
Shirts	Custom designs incorporationg University branding, team logo, and team sponsers	8	30	$38.00	$304.00	(Click Here)	Not Ordered
Food	Food for students for occasians like launch days and the Hudson Trip	1	Not aplicable	$600.00	$600.00	(Estimates)	-----
Miscellaneous Supplies	Anything outside of the currently stated budget	1	Not aplicable	$200.00	$200.00	(Estimates)	-----
3D printer Filiment	Creality PETG Filament 1.75 Black 4 kg	1	$0.00	$79.99	$79.99	(Click Here)	
						Total:	$3,583.99

Fundraised

Company	Description	Given Funds	Contact
Floirda State Universtiy Panama City	Seed funding through the Deans Office to participate in the NASA USLI Competition	$2,500.00	
		$0.00	
		$0.00	
		$0.00	
		$0.00	
		$0.00	

NOTE: The variance is set to add 10% to help mitigate any unexpected price changes throughout the year.

Subtotal:	$9,775.97
Variance:	$977.60
Total:	$10,753.57
Amount Spent:	$0.00
Fundraised:	$2,500.00
Remaining Funds:	$2,500.00

Table 6-1 Line-Item Budget

6.2.2 Funding Plan

The Terra Nova Team has a comprehensive finance plan to support participation in the 2026 NASA University Student Launch Initiative.

The strategy utilizes institutional support, industry partnerships, and community engagement to secure funding for all project phases: design, fabrication, testing, competition participation, and STEM outreach.

The projected total budget is $10,753.57, as outlined in Table 6-1.

6.2.3 Funding Sources

6.2.3.1 University Support

- Florida State University – Panama City (FSU-PC):
  The Dean's Office has committed $2,000–$3,000 in seed funding to establish the project foundation.

- INSPIRE Program and their Industrial Partners:
  The FSU Inspire Program, in collaboration with Astro America and Maritech Machining Inc., has offered in-kind manufacturing support including 3D-printed metal parts and heat treating at no cost to the team.

6.2.3.1 Industry Partnerships

The team is establishing sponsorships with local and regional STEM-oriented organizations through FSU-PC's Office of Advancement.
A tiered recognition system encourages partner engagement.

Sponsorship Tiers:

Tier	**Contribution**	**Recognition**
Garnet Sponsor	$500	Logo on team apparel; social media & event recognition
Gold Sponsor	$1,500+	Prominent logo placement; full recognition at events; company name on rocket internals

Target Partners:

- Tech Farms (STEM incubation hub)
- Booz Allen Hamilton (aerospace & defense)
- Maritech Machining Inc. (precision manufacturing)
- VSC Fire & Security (systems integration)
- Bay County Chamber of Commerce (community and business outreach)

6.2.4 Outreach and Fundraising Strategy

Phase Approach:

Phase	**Status**	**Description**
Phase 1 University Funding	Complete	Secured seed funding from Dean’s Office.
Phase 2 Industry Engagement	In Progress	Contacting STEM partners via FSU-PC connections.
Phase 3 Community Outreach	Not Begun	Broaden outreach to local businesses emphasizing STEM education impact.

Community & STEM Engagement

- **Chamber of Commerce Networking:** Attend First Friday events and Business-After-Hours sessions for sponsor outreach.
- **Public Engagement:** Conduct community STEM launches, school presentations, and local science fairs to increase visibility and attract sponsors.

6.2.5 Contingency Planning and Risk Mitigation

6.2.5.1 Contingency Reserve

A 10% contingency reserve of $977.60 is allocated for unexpected expenses, including design modifications, supply delays, or cost fluctuations.

6.2.5.2 Risk Mitigation Tiers

Tier	Strategy	Purpose
Tier 1	Request additional university resources (departments, Student Government Council).	Immediate backup funding
Tier 2	Expand regional/industry sponsorship outreach.	Sustain project growth.
Tier 3	Conduct emergency fundraising or community events.	Cover shortfalls.
Tier 4	Leverage in-kind support (Maritech, Astro America).	Reduce direct costs.

6.2.6 In-Kind Contributions

The team receives substantial non-monetary support through:

- Astro America – 3D metal printing and prototype support.
- Maritech Machining – Fabrication and heat-treating services.

These contributions significantly reduce the team's direct expenditure and fabrication lead times.

6.2.7 Financial Oversight and Accountability

- Project Lead (Krieg Conrad) maintains primary financial oversight.
- Weekly budget reviews occur at team meetings, with monthly financial summaries documented in team minutes.
- Procurement Process:
  - All purchases follow FSU-PC purchasing policies.
  - Each expenditure requires approval by Project Lead and relevant subsystem lead.
  - Receipts and transaction records are maintained in the team's shared financial log.

6.2.8 Summary

The Terra Nova Team has developed a diversified and sustainable financial strategy that combines university support, industry partnerships, and community outreach.
With multiple funding tiers, in-kind contributions, and a 10% contingency reserve, the team is financially positioned for full mission execution — from subscale testing to launch week in Huntsville.

The Terra Nova Team is confident that this plan will meet the $10,753.57 project requirement and ensure successful participation in the NASA USLI 2026 competition.

6.3 Project Timeline

Our timeline is shown here, along with a Gantt chart that breaks it down into weekly objectives. In addition to working on the documentation deliverables, several system officers and their teams will focus on certain tasks. Depending on the availability of the local schools, we will continue our community participation on Fridays and weekends with the goal of visiting K–12 institutions at least once a month. We'll also go to university events like Tech Days and Discovery Days. To guarantee timeline compliance, the leadership team will convene once a week. Due to changes in our class schedules, the present scheduled meeting time of Tuesdays at 9:30 am is subject to change in the upcoming semester. The Terra Nova Project's timetable and Gantt chart are shown below, starting after the submission of the Proposal. By using both, we are able to get a visual depiction of our project status as well as a work list.

Week	Dates	Documentation & Analysis	Build, Fabrication & Testing	Outreach & Administrative
Week 1	Sep 22 – 28 2025	Draft PDR outline and deliverables (Report, Slides, Flysheet). Transfer Proposal content (facilities, team org, safety, engagement). Initialize payload design via Pugh chart.	Receive Inconel 718 tensile specimens; define labeling & test process.	Schedule preliminary STEM visits; confirm mentor meetings.

Week 2	Sep 29 – Oct 5	Add morphological charts & design iterations; enter payload design; begin hazard & FMEA drafts; document recovery subsystem calculations & wiring.	—	Continue outreach scheduling; update safety roster.
Week 3	Oct 6 – 12	Draft "Changes Since Proposal"; complete mission performance predictions.	—	NASA Kickoff & PDR Q&A (Oct 9); funding outreach begins.
Week 4	Oct 13 – 19	Transfer draft report into slides; peer-review formatting; integrate subsystems.	—	Coordinate community availability; mentor check-in.
Week 5	Oct 20 – 26	Finalize PDR outline; integrate subsystem sections; peer review hazard/FMEA; Decision **Gate #1 – confirm content owners.**	Verify inventory; draft test templates; prep SharePoint test log.	Schedule ≥1 STEM outreach; confirm PDR rehearsal mentor; update file system.
Decision Gate #1	**Confirm all subsystem sections, FMEA, and safety documentation are peer-reviewed and compliant before PDR submission.**			
Week 6	Oct 27 – Nov 2	Final review of PDR Report/Slides/Flysheet; integrate final CAD & simulations; mentor mock presentation.	Manufacturability review; confirm materials & labeling process.	Verify budget; test NASA upload; update outreach tracking.
Week 7 — PDR Due	Nov 3 – 9	**Submit PDR (Nov 3)**; record lessons learned; outline CDR structure; documentation carry-forward.	Begin payload/avionics mock-ups; create build logs; verify recovery fit.	Publish outreach summary; update travel roster.
Week 8	Nov 10 – 16	Expand CDR skeleton; draft "Changes Since PDR"; electronics layout narrative; risk matrix update.	Bench prototyping (payload & avionics); drogue deployment mock-up.	Conduct first school event; plan spring outreach.
Week 9	Nov 17 – 23	Insert CADs into CDR draft; add recovery diagrams & narrative.	Continue payload prototyping; iterate avionics bench tests.	Log outreach data; mentor updates.
Week 10 Gateway Due	Nov 24 – 30	Proofread CDR draft; refine subsystem text; compliance check for Gateway.	Inventory received parts; continue prototyping.	**Submit Gateway Registration (Nov 28)**; light outreach.

Week 11 CDR Q&A	Dec 1 – 7	Light workload (finals); attend **CDR Q&A (Dec 3)**; integrate NASA feedback.	—	Maintain outreach log; record Q&A minutes.
Week 12 Subscale Launch	Dec 8 – 14	Add placeholders for Subscale Results in CDR; prep data templates.	Finalize subscale build; integrate avionics; **Subscale Launch Dec 13**; log & backup data.	Document launch outreach; capture media.
Week 13	Dec 15 – 21	Draft Subscale Results, payload lessons, recovery updates; compile near-final CDR. Compare subscale flight vs. simulation. **Decision Gate #2 – Post Subscale**	Begin full-scale prep; redesign payload via subscale data; update PCB.	File outreach photos; coordinate travel funding.
Decision Gate #2	**Evaluate subscale flight data vs. simulation (±10 % apogee tolerance) to authorize full-scale fabrication.**			
Week 14 (Holiday)	Dec 22 – 28	Add "Changes Since PDR"; polish subsystem sections.	Finalize payload technical design.	Maintain sponsor contact; light outreach.
Week 15	Dec 29 – Jan 4 2026	Integrate subsystem text; proofread & format.	Send bulkhead & boat-tail designs; confirm heat-treat & finishing specs.	Year-end budget & outreach update.
Week 16 CDR Due	Jan 5 – 11	**Submit CDR (Jan 7)**; internal debrief; outline FRR structure.	Airframe: motor mount/fin can assembly; payload flight-version fabrication.	Post-CDR sponsor updates; outreach planning.
Week 17	Jan 12 – 18	Draft FRR skeleton; subsystem integration descriptions; payload verification plan.	Finish fin can; recovery wiring; payload bench test.	Logistics prep for test launches.
Week 18	Jan 19 – 25	Draft "Changes Since CDR"; update CAD with as-built; document ground-test procedures.	Airframe couplers & payload bay; **1st ejection test**; avionics ICT.	Confirm spring outreach calendar.
Week 19	Jan 26 – Feb 1	Integrate subsystem updates into FRR draft; redundancy plan; payload data methodology. **Risk Review & Mitigation Update.**	Payload vibration testing; **2nd ejection test**; airframe finish work.	Sponsor engagement; plan Huntsville travel.

Week 20	Feb 2 – 8	Update hazard analysis w/ test data; finalize structural verification; draft launch procedures. **Decision Gate #3 – Flight Readiness Approval.**	Complete final integration; parachute packing; continuity checks.	Submit mid-year outreach summary; mentor review.
Decision Gate #3	**Verify integration, dual ejection tests, and safety sign-offs before proceeding to full-scale launch and FRR submission.**			
Week 21 FRR Q&A	Feb 9 – 15	Team photos (Feb 9); attend **FRR Q&A (Feb 11)**; integrate clarifications.	Final readiness checks; buffer.	Plan community flight-test event.
Week 22 Full-Scale Flight Test	Feb 16 – 22	Draft Full-Scale Results templates ahead of test.	**Full-Scale Launch Feb 21**; flight execution & inspection.	Host outreach at launch; capture media.
Week 23 Backup Flight	Feb 23 – Mar 1	Insert Full-Scale Results (if flown Feb 21); finalize FRR draft.	**Backup Launch Feb 28** (if needed); disassembly & inspection.	Outreach/media for backup launch.
Week 24	Mar 2 – 8	Proofread FRR; mentor safety review; compliance check.	Repack parachutes; inspect harness; analyze flight logs.	Prepare FRR outreach materials.
Week 25 FRR Due	Mar 9 – 15	**Submit FRR (Mar 9)**; debrief; prep Addendum placeholders.	Rebuild/reintegrate per NASA feedback; continue payload testing.	Finalize travel accommodations.
Week 26 Spring Break	Mar 16 – 22	Prepare FRR Addendum templates; update STEM documentation.	Touch-ups, paint, pack spares.	Light outreach; travel logistics.
Week 27	Mar 23 – 29	Draft Launch-Week logistics & outreach report updates.	Final rocket prep; test ejection/payload.	Confirm travel roles; safety docs.
Week 28	Mar 30 – Apr 5	Finalize Launch-Week docs; print checklists; plan PLAR structure.	Final bench & power-cycle tests.	Pre-travel outreach posts; community reminders.
Week 29 Addendum (if req.)	Apr 6 – 12	Submit FRR Addendum (if requested); final proofing.	Final maintenance & packing for transport.	Confirm lodging & transport.
Week 30 Launch Week Q&A	Apr 13 – 19	Attend **Launch Week Q&A (Apr 15)**; finalize checklists; compliance verification.	Final readiness & continuity tests; crate packing.	Final travel docs; emergency contacts.

Week 31 Competition Launch Week (Huntsville)	Apr 20 – 26	**Apr 20–26 Detailed Ops:** **Mon:** Checklist print & travel prep. Tue: Transport arrival & inventory. **Wed:** RSO inspection & manifest upload. **Thu:** Full assembly & RSO approval. **Fri:** Internal rehearsal & final checks. **Sat Apr 25: Competition Launch Day** (Flight & retrieval). Sun: Post-flight data backup & teardown.	Field operations, launch execution, and post-flight inspection.	On-site outreach & sponsor engagement; attend closing ceremonies.
Week 32	Apr 27 – May 3	Draft PLAR; insert flight & payload analysis; lessons learned.	Post-flight teardown; anomaly analysis.	Publish outreach report; send sponsor thanks.
Week 33 — PLAR Due	May 4 – 10	**Submit PLAR (May 10)**; archive documentation & raw data.	—	Final outreach report; budget closeout; mentor debrief.

Table 6-2 Project Timeline

The Terra Nova Project - Gantt Chart

Week Highlight: 7 | Plan Duration | Actual Start | % Complete | Actual (beyond plan) | % Complete (beyond plan)

Category	ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
PDR Development						
	Draft PDR Outline & Assign Content Owners:	1	1	1	1	100%
	Write Subsystem Sections:	2	2	2	2	100%
	Draft Hazard Analysis & FMEA:	2	2	2	2	100%
	Mission Performance Sims	3	1	3	1	100%
	Format & Peer Review PDR:	4	2	4	2	100%
	PDR Mock Presentation	6	1	6	1	100%
	Submit PDR Deliverables:	7	1	7	1	100%
Material Testing						
	Prepare Inconel Specimens:	9	1	9	1	50%
	Conduct Material Tests:	10	4	10	4	0%
Subscale Build & Test						
	Subscale Design Finalization:	1	2	1	2	0%
	Subscale Fabrication:	8	5	8	5	0%
	Subscale Launch:	12	0	12	0	0%
	Analyze Subscale Flight Data:	13	1	13	1	0%
CDR Development						
	Draft:	8	2	8	2	0%
	Integrate Subscale Lessons:	13	2	13	2	0%
	Finalize CDR Report & Slides:	15	2	15	2	0%
	Submit CDR Deliverables:	16	0	16	0	0%
Full-Scale Build & Test						
	Begin Full-Scale Fabrication:	16	3	16	3	0%
	Ground Ejection Tests:	18	2	18	2	0%
	Payload Vibration Tests:	19	2	19	2	0%
	Final Integration & Assembly:	20	2	20	2	0%
	Full-Scale Launch (VDF):	22	0	22	0	0%
FRR Development						
	Draft FRR Report & Slides:	22	3	22	3	0%
	Submit FRR Deliverables:	25	0	25	0	0%
Launch Week						
	Prepare Logistics & Travel:	26	2	26	2	0%
	Competition Launch:	31	0	31	0	0%
Post Launch						
	Draft PLAR & Lessons Learned:	32	2	32	2	0%
	Submit PLAR:	33	0	33	0	0%
Ongoing Activities						
	STEM Outreach Visits:	1	30	1	30	25%
	Sponsor & Budget Mgmt:	1	33	1	33	22%
	Safety & Risk Updates:	2	30	2	30	22%

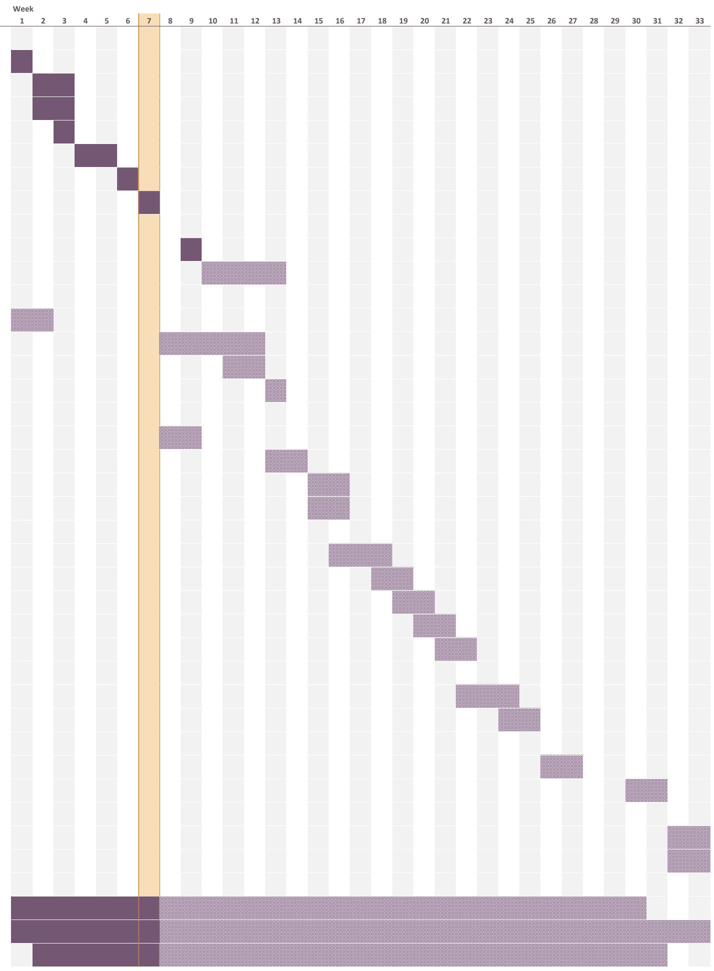


Table 6-3 Gantt Chart

Appendices

Appendix A: Facilities

A.1 On-Campus Facilities

A.1.1 Senior Design Lab

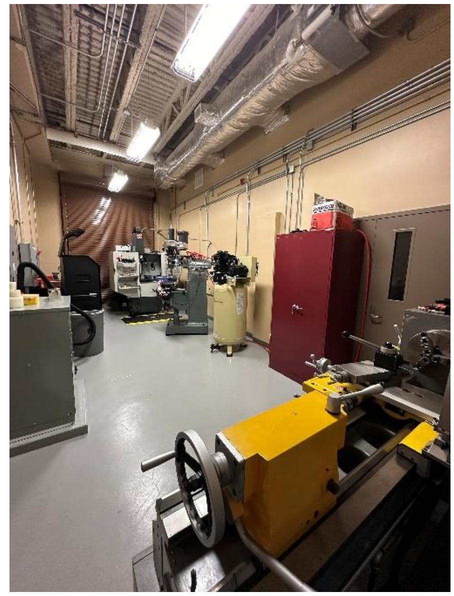
The Senior Design Lab is a room designated for the senior design projects of mechanical engineering students at FSU PC. There are many tools, components, mechanisms, and past projects. This abundance of tools and parts will be helpful in the construction of the sub-scale and full-scale rockets as well as the HAUS payload and Excursion Habitat for the STEMnauts. This room will also be used for the storage of all our nonvolatile materials following the required safety procedures.

Personnel Required: No special personnel required
Access: Swipe Card Access
Hours: 24/7
Equipment:

- *Siglent 4-channel oscilloscopes* (3 stations)
- *Siglent Arbitrary Waveform Generators* (3 stations)
- *Agilent and Siglent Power Supplies* (3 stations)
- Agilent Benchtop Multimeters (3 stations)
- Whiteboards
- Computers
- Hand tools
- Mounted vice grips

A.1.2 Machine Shop

The machine shop at FSU PC contains a lathe, CNC machine, and milling machine. Due to the limited equipment and available time of required personnel, we are in communication with a local machine shop for the manufacturing of any parts that our project requires to be outsourced, prioritizing cost and time effectiveness. The partnering with our local machining industry will be outlined later in this section.



Personnel Required: Instructor James Keith
Access: Swipe Card Access
Hours: Monday – Thursday 5pm – 7pm
Equipment:

- *Enco Model 328-1312* – Lathe
- *Ingersoll Rand Model 2475* – Milling Machine
- *Ingersoll Rand 2475N5 Grainger* – Air Compressor
- *HAAS Model SMINIMILL* – CNC Machine

A.1.3 Digital Design Studio

The DDS is located in the Robins Center for Academic Excellence and Innovation. It is open to all FSU PC students and is used for studying, working on school projects, or hanging out. The DDS equipment includes printers, many Dremel 3D printers, poster board printer, and a laser cutter engraver.

Personnel Required: DDS Employee
Access: N/A
Hours: 9:00am – 10:00pm
Equipment:

- *Dremel Digilab 3D Printers* (8 available)
- *Epson SureColor P9570* – Poster Board Printer
- Cricket machine & Hot Press – Shirt Maker
- Industrial embroidery machine
- Sewing machines (12 available)

A.1.4 Electrical and Computer Engineering (ECE) Laboratory Capabilities

Access to the Electronics Lab at FSUPC provides students with the means to design, prototype, and test a wide range of electrical systems. The lab is well equipped for analog system analysis, and equally capable with digital communication systems.

Personnel Required: No special personnel required
Access: Swipe Card Access
Hours: 24/7
Equipment:

- *Siglent 4-channel oscilloscopes* (30 stations)
- *Siglent Logic Analyzers* (6 stations)
- *Siglent Arbitrary Waveform Generators* (30 stations)
- *Agilent and Siglent Power Supplies* (30 stations)
- *Agilent Benchtop Multimeters* (30 stations)
- Electrical components for prototyping i.e. resistors, transistors, capacitors, inductors, diodes, operational amplifiers, etc.

A.1.5 Materials Lab

The Materials Lab is under the supervision of Dr. Yvonne Traynham. The lab has a variety of equipment sufficient to thoroughly test the mechanical properties of any material we select for this project. This equipment includes but is not limited to tensile, torsion, hardness, Charpy, and Izod testers. We plan on this lab playing a major role in the designs of our project and the testing of the new additive manufacturing, 3D metal printing. Through our agreement with our local machining industry, we are allowed to design many components of our rocket using 3D printed metals. Due to this methodology of manufacturing being so new, we considered it necessary to thoroughly test our materials to ensure there are no anomalies in their mechanical properties. This will ensure our 3D printed metal is able to withstand the forces and conditions under which it will be subjected. Two members of our group, Safety Officer Jonathan Serbest and Payload System Officer Case Dyer, are involved in a special project particularly involving the testing of the mechanical properties of the 3D printed metals we desire to use. The usage of this lab will also be important in the final selection of other materials for the project.

Personnel Required: Dr. Yvonne Traynham
Access: Swipe Card Access
Hours: 8:00am – 4:00pm
Equipment:

- *MTS Criterion 43 (Model C43-504)* - Universal Electromechanical Testing Machine
- *Tinnius Olsen Torsion Tester*
- *Mark 10 Tester with EM303* Test Stand and *M3-500 Series 3* Force Gauge
- *Qualitest (Model QPI-IC-12J)* - Izod Impact Tester
- *Wilson (Model VH1102)* - Vickers Microhardness Tester
- *Laxco XD30M* - Metallurgical Microscope
- *Laxco SeBaCam5 external digital camera* – Micrograph Images
- *Buehler Simplmet 4000* – Metallurgical Mounting Equipment
- *Buehler Ecomet 30* - Polishing Equipment
- *Laxco Stereo Zoom Head Microscope*
- *Tinnius Olsen HTK5* – Tension, Compression, or Cycling Tester (2 available)
- *Wilson Charpy Impact Tester*

A.1.6 Thermal Fluids Lab

The Thermal Fluids Lab is under Dr Mauricio Chagas. This lab contains equipment for the testing of fluid and heat transfer systems. The equipment that especially pertains to this project is the Open Wind Tunnel which can be used for the testing of various airframe components.

Personnel Required: Dr. Mauricio Chagas
Access: Swipe Card Access
Hours: 8:00am – 4:00pm
Equipment:

- *Gunt ET 405* – Heat pump for cooling and heating operation
- *Gunt WL 430* – Heat conduction and convection
- *Gunt WL 202* – Fundamentals of temperature measurement
- *Gunt HM 283* – Experiments with a centrifugal pump
- *Gunt HM 150.11* - Losses in a pipe system
- *Gunt HM 170* – Open wind tunnel
- *Gunt WL 203* – Fundamentals of Pressure measurement
- *Turbine Technologies Rankine Cycler*
- *Gunt HM 150.13* Methods of flow measurement

A.1.7 Mechatronics Lab

The Mechatronics Lab is a classroom for the Mechanical Engineering department, housing the majority of the small electronics and tools for mechatronic projects. This lab will particularly be used for 3D printing polymer-based parts because it has two of our best 3D printers, Bamboo Carbon X1s. It also houses many oscilloscopes, arbitrary waveform generators, and other components for mechatronics systems.

Personnel Required: No personnel required
Access: Swipe Card Access
Hours: 24/7
Equipment:

- *X-1 Carbon Bambu Lab 3D printers* (2 available)
- *Dremal Digilab 3D printers* (4 available)
- *Siglent 4-channel oscilloscopes* (6 available)
- *Siglent Arbitrary Waveform Generators* (6 stations)
- *Agilent and Siglent Power Supples* (6 stations)
- *Agilent Benchtop Multimeters* (6 stations)
- Mechatronic Components for prototyping i.e. sensors, microcontrollers, etc.

A.2 Off-Campus Facilities

A.2.1 Maritech Machine Inc

Maritech Machining Inc. is a 21,000 square foot, Panama City based, precision machining facility. It is a key external partner in FSU-PC's InSPIRE (Innovation, Sustainability, and Preeminent Research & Education) Program. InSPIRE is working to foster collaborative innovation by connecting students with industry-grade advanced manufacturing and aerospace testing facilities and resources. Maritech houses new metal additive manufacturing systems including a GE Concept Laser PBF (powder bed fusion) and a GE ARCAM EBM Q10Plus, enabling high-precision metal 3D printing and materials testing. These capabilities alongside multi-axis CNC, heat treating, and waterjet cutting. This equips our team to fabricate complex flight components and evaluate mechanical properties efficiently.

Personnel Required: Maritech Employee
Access: With Employee
Hours: Monday – Friday 7:30am – 4:00pm
Equipment:

- *DMG Mori CNC NLX2500/700 – Y-Axis* live tooling lathe with milling and sub spindle
- *DMG Mori CNC NLX2500/1250* - Y-Axis live tooling lathe with milling
- *DMG Mori CNC NLX1500/500 – Y-Axis* live tooling lathe with milling and sub spindle

- *Flow Mach 500 5-Axis CNC waterjet*
- *Femco CNC Turning Center 24" x 49" capacity*
- *Brideport EZPathII CNC lathe 20" x 40" capacity*
- *Doosan CNC Turning Center 12" x 20" capacity*
- *Doosan CNC Turning Center 10" x 20" capacity*
- *Monarch Engine Lathe 40" dia. x 22' between centers*
- *Okuma Genos M560-V 4-Axis CNC Milling Center 20" x 40" capacity*
- *Haas VF5 CNC Milling Center 50" x 26" capacity*
- *Doosan CNC Vertical Milling Center 40" x 20" capacity*
- *Brideport EZ Track CNC Milling Center 9" x 49" capacity*
- *WMW Heckert 450 x 1800 Horizontal Vertical Mill* 3500 lb Table capacity, travels: X 52", Y 34", Z 24.75"
- Assorted Manual Vertical and Horizontal Knee Mills, Engine Lathes, Keyseaters, Shapers, and Surface Grinders
- 5 Ton overhead crane
- *CNC Plasma Cutter FabMaster-II Plate Pro*
- *Miller 600 AC/DC Welder:* Mig, Flux core
- *Miller 300 AC/DC Welder*: Mig, Flux core, Stick
- *Miller Syncrowave 250 DX*: Tig, Stick
- *Miller Millermatic 250 DX*: Mig, Flux core
- *Hypertherm 1250 Plasma Cutter*
- *Schindler Electric Furnace*: Temperature Range +2000°, capacity: 18" x 12" x 18" programmable Honeywell DCP 100
- *Starrett Hardness Tester 3814*: Basic Rockwell comparisons on the A,B, anc C scale
- *Keyence Laser MDX-2*
- *Mitutoyo Crysta-Plus M7106 Coordinate Mearsuring Machine, Measuring* volume: 27.56" x 39.27 x 23.62" with 1,762 lb table capacity
- *Mitutoyo Crysta-Apex CNC CMM 9108*, Measuring volume: 34.4" x 39.37" x 31.49" Table capacity 2,600 lbs
- *Keyence WM-3500 Wide Area CMM*, Measuring volume: 25 feet radius, ability to transport to customer site
- *GE Concept Laser PBF* (powder bed fusion)
- *GE ARCAM EBM Q10Plus*

A.2.2 Gulf Coast State College – Advanced Technology Center (ATC)

The GCSC ATC serves as a partner facility for FSU students through cross campus collaboration. The 93,000 sq. ft engineering and manufacturing center provides professional grade machining, fabrication, and additive manufacturing equipment.

Personnel Required: Faculty/staff supervision for CNC, welding, and heavy equipment; student operation permitted for basic fabrication and 3D printing.
Access: Swipe Card Access
Hours: 8:00am - 5:00pm weekdays; extended access possible with arrangement.

Equipment:

Fabrication Capabilities

- CNC Machining
  - *Haas VF-2 CNC Mill* – high-precision milling with multi-axis capabilities for airframe and bulkhead components.
  - *Haas ST-10 CNC Lathe* – precision turning for custom aluminum and steel parts.
  - *Lucifer RD7-KHE24 Furnace* – enables post-machining heat treatment for strengthening critical load-bearing components.
- Conventional Machining
  - *Vertical/horizontal band saws, drill press, manual mills, and bench lathes* – support for custom fittings, couplers, and small-batch parts.
  - *Surface grinders and buffers* – ensure proper tolerances and smooth finishes on recovery and payload hardware.
- Welding & Cutting
  - *Lincoln MIG/TIG welders* – assembly of steel support rigs, test fixtures, and recovery hardware.
  - *Thermal Dynamics Econopak50 Plasma Cutter* – precision cutting for sheet-metal components.
  - *Avani Welding Booths* – controlled environment for safe welding operations.
- Heavy Handling
  - 5-ton overhead crane – allows safe lifting of heavy fabricated assemblies and test rigs.
  - 4-column vehicle lift – used for ground support and transport test systems.

Additive Manufacturing & Prototyping

- Polymer Printing

    - *Stratasys Dimension Elite* – high-resolution ABS parts for avionics mounts and payload housings.
    - *Objet Connex260* – multi-material polymer printing, useful for complex payload geometries.
    - *MakerBot Replicators (multiple units)* – rapid iteration of small-scale components for subscale testing.
- Powder & Specialty Printing
    - *ZCorp 310 Plus* – powder-based prototyping for lightweight mockups and wind tunnel test models.

Support & Safety

- *Snap-On tool carts and cabinets* – fully stocked for fabrication support.
- *Captair Flex fume hood* – ensures safe handling of volatile materials.
- *PhysiciansCARE First-Aid station* – for compliance with OSHA lab safety requirements.
- *Portable generator* – supports field-testing avionics and recovery subsystems in off-grid conditions.

Appendix B: Safety

Required PPE for Identified Hazardous Tools [1]

Tool / Task	**Required PPE (Checklist Format)**	**OSHA Reference**
Hand tools	• Safety goggles • Work gloves	per OSHA 29 CFR 1910.242 & 1910.138
Power tools (drills, saws, grinders)	• Safety goggles or face shield • Hearing protection • Gloves (non-slip)	per OSHA 1910.243, 1910.95, 1910.133
Cutting / grinding	• Face shield • Safety goggles (ANSI Z87.1) • Gloves (cut-resistant)	per OSHA 1910.133 & 1910.138
Painting / epoxy use	• Nitrile gloves • Safety goggles • Respirator (if ventilation poor)	per OSHA 1910.132 & 1910.134
Lifting or handling heavy materials	• Steel-toe boots • Leather gloves • Hard hat	per OSHA 1910.136 & 1910.135
Working at height	• Hard hat • Harness / fall arrest system	per OSHA 1910.140
Electrical work	• Safety glasses	per OSHA 1910.137 & 1910.333
Mixing propellant (black powder, ejection charge)	• Face shield • Antistatic gloves • Safety goggles	per OSHA 1910.252 & 1910.120

Tool / Task	Required PPE (Checklist Format)	OSHA Reference
	• Cotton lab coat (no synthetics)	
General lab or rocket assembly	• Safety glasses • Nitrile gloves • Closed-toe shoes	per OSHA 1910.132

Appendix C: Additional Documentation

Rev 1 Submitted Oct. 6, 2025: Notes: Clarified shear properties as torsional; Included Data Acquisition software

Inconel 718 Tension and Torsion Testing Proposal

EML 4542 ~ Material Selection on Design

Proposed by Case Dyer and Jonathan Serbest

Project Scope

There are many factors that affect the mechanical, thermal, and electrical properties of a material, including chemistry, microstructure, bonding, temperature, and even manufacturing process. There has been recent innovation in additive manufacturing technology enabling the 3-D printing of metals. Because this manufacturing process is just now becoming available, there is little known about the effects of this process on the properties of materials. We propose the testing of the mechanical properties of 3-D printed Inconel 718. This testing involves both tensile and torsional tests. Tension testing to determine the mechanical properties of modulus of elasticity, ultimate tensile strength, yield strength, modulus of resilience, ductility, and %reduction in area. Torsional testing to determine application-based properties of torsional yield, shear modulus, and maximum shear stress. Combining the results of both these tests will be used to determine Poisson's ratio.

Proposed 2025-2026 Project Schedule

PROPOSED PROJECT SCHEDULE				September		October		November		December	
All	Task Name	Planned Start	Planned Completion	1–15	16–end	1–15	16–end	1–15	16–end	1–15	16–end
1	**Ideation**	9/15/2025	10/2/2025	X	X	X					
2	Concept Generation	9/15/2025	9/30/2025	X	X						
3	Proposal	9/29/2025	10/2/2025		X	X					
4	**Implementation**	10/2/2025	10/22/2025			X	X	X	X		
5	Varify sample dimensions nesessary	10/2/2025	10/3/2025			X					
6	Coordination with Maritech	10/3/2025	10/7/2025			X					
7	Obtain Test Samples	10/7/2025	10/20/2025			X	X				
8	Tension Testing	10/21/2025	10/21/2025				X				
9	Torsion Testing	10/22/2025	10/22/2025				X				
10	**Documetation**	10/22/2025	12/1/2025				X	X	X	X	
11	Data Exportation	10/22/2025	10/22/2025				X				
12	Data Analyzation	10/23/2025	11/1/2025				X	X			
13	Project Report	11/3/2025	11/30/2025					X	X		
14	Report Submission	12/1/2025	12/1/2025							X	
15	**Presentation**	12/3/2025	12/4/2025							X	
16	Class Presentation	12/3/2025	12/4/2025							X	
17	Research Symposium	APRIL OF 2026				TBD					

Project Implementation

- Inconel 718 samples will be prepared according to ASTM E8/E8M Specimen 3 for tension tests to ensure equipment does not exceed 75% of full-scale capacity.
- Sample size for torsion testing is TBD based on available equipment.
- The samples will be procured from a local machining company, Maritech Machining Inc.
- Project sample acquisition funded by FSU InSPIRE program.
- Samples tested using MTS Criterion 43 Universal Electromechanical testing machine and Tinnius Olsen Torsion Tester available in FSU PC's Materials Lab.
- Data will be acquired by TWE Elite and Navigator.
- Data will be analyzed using Microsoft Office 365 software.

Bungee Rockets

Austin Zaal

10/08/2025

Revision 2

Description:

This project proposes testing several different elastic line materials for the purpose of designing the recovery system for our rocket. When deploying parachutes after the apogee event, shock cords are used to hold the separated components & parachutes together during recovery. This year we intend to pursue a goal that requires our rocket to land from apogee very quickly, which means we will face forces during deployment that are higher than usual. To combat this, I proposed the idea of using a Kevlar-elastic hybrid shock cord to both dissipate these forces while also holding strong. It is my goal within this project to identify material properties for different types of cord, such as tensile properties and spring & damping constants, in order to model how this cord concept will act before we commit to flying with it.

Resources Needed

- Several types of Elastic Cord
- Small Tension Testing Machine in Materials Lab
- MATLAB
- Excel

Schedule

1. Acquire Materials (10/31/25)
2. Model the cord deployment event in Open Rocket to define peak loads (10/31/25)
3. Test in tension with elastic properties (11/07/25)
4. Determine how each type of cord will react under deployment loads (11/10/25)
5. Identify most applicable material for the elastic portion of shock cord (11/14/25)
6. Provide a prototype for the Terra Nova Kevlar-elastic shock cord (12/1/25)

Deliverables

10/02/25 – Submit Proposal

10/23/25 – Submit Revision 2

11/03/25 – NASA Preliminary Design Review (PDR) Due

12/01/25 – Project Due

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