By:

Georgia Institute of Technology Team Autonomous Rocket Equipment System (A.R.E.S.)

Georgia Institute of Technology
North Avenue NW
Atlanta GA, 30332

Project Name: Hermes

MAXI-MAV Competition

Friday, November 6, 2015

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1 Introduction

1.1 Team Summary

Team Summary	
School Name	Georgia Institute of Technology
Mailing Address	North Avenue NW, Atlanta GA 30332
Team Name	Team Autonomous Rocket Equipment System (A.R.E.S.)
Project Title	Hermes
Launch Vehicle Name	Skyron
Project Lead	Victor R.
Safety Officer	Stephen K
Team Advisors	Dr. Eric Feron
NAR Section	Primary: Southern Area Launch vehiclery (SoAR) #571
NAR Contact, Number & Certification Level	Primary Contact: Joseph Mattingly NAR/TRA Number: 92646 Certification Level: Level 2 Secondary: Jorge Blanco

1.2 Work Breakdown Structure

Team Autonomous Rocket Erector System (ARES) is composed of twenty-one students studying varying fields of engineering. Our team is composed of less than 50% Foreign Nationals (FN) per NASA competition requirements. To work more effectively, the team is broken down into groups that focus on special tasks. Each sub-team has a general manager supported by several technical leads and subordinate members. Team memberships were selected based on each individual's area of expertise and personal interest. Figure 1 shows the work breakdown structure of Team ARES.

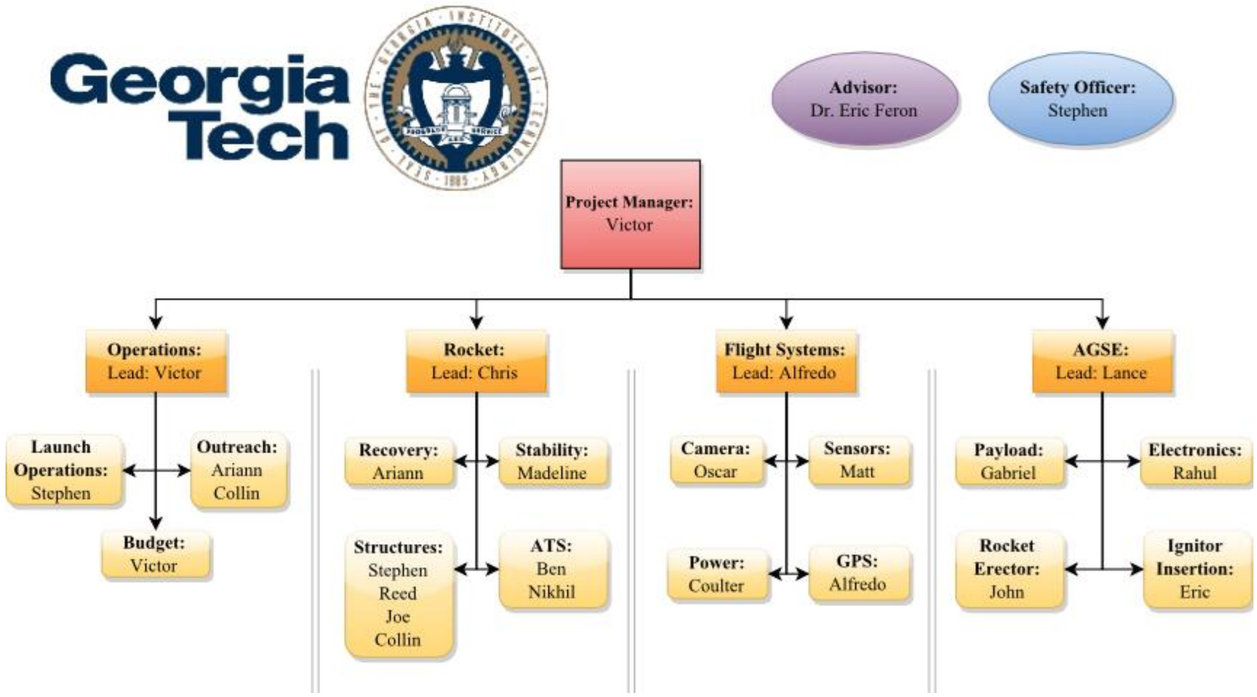


Figure 1: Team Breakdown Structure

1.3 Launch Vehicle Summary

1.3.1 Overview

The Skyron Launch Vehicle is 90.16 inches in length and projected to weigh 22.22 lb. with a 30% mass margin. Skyron is designed to accommodate a 3.5 inch PVC pipe payload in the payload bay located just before the nose cone. A Cesaroni Technology L820 reloadable rocket motor was chosen to propel the rocket to an apogee of 5280 ft. A 2.5 foot diameter drogue parachute will deploy from a compartment between the booster and avionics sections an apogee, and a 4.3 ft. diameter main parachute will be deployed below 700 ft. AGL to slow the rocket such that the kinetic energy at ground impact will be below 75 ft-lbf.

1.3.2 Changes since Proposal

- New Design of the ATS system to open tabs horizontally out from the body to an angle of 45 degrees with the rocket body instead of the previous ninety degree translation
- ATS system will be powered by four push-pull solenoids to extend the tabs
- Switch the location of the Main and Drogue Parachutes
- Motor Selection: L820 (with L990 in consideration)

1.4 AGSE Summary

1.4.1 Overview

The Autonomous Ground Support Equipment (AGSE) will have a robotic arm that can grab a payload that is off the platform and secure said payload inside the launch vehicle. The Rocket Erection System (RES) will then raise the launch vehicle from a horizontal position to a position 5 degrees from the vertical. The Motor Ignition System (MIS) will then insert an electronic match 12 inches into the motor to ignite the motor. The overall system will be largely constructed from 1010 rails and have a 10 ft. by 2 ft. base and be 1.5 ft. in height and weight approximately 60 lbs.

1.4.1 Changes since Proposal

- Switch REM from linear actuator to spool raising mechanism
- Incorporating claw design for RDPS

2 Project Hermes Overview

2.1 Mission Statement

The mission of Team ARES is:

To maintain a sustainable team dedicated to the gaining of knowledge through the designing, building, and launching of reusable launch vehicles with innovative payloads in accordance with the NASA University Student Launch Initiative Guidelines.

2.2 Mission Objectives and Mission Success Criteria

2.2.1 Launch Vehicle

Table 1: Mission Success Criteria for Skyron

Requirement	***Design feature to satisfy that requirement***	***Requirement Verification***	***Success Criteria***
Reach an altitude of 5,280 ft. as accurately as possible.	The A.T.S. will deploy during cruise flight to adjust the flight profile curve to match a real-time ideal projection of the rocket's trajectory for the designated altitude by increasing the drag coefficient of the launch vehicle.	Gathering data post-launch from the on-board altimeters.	The A.T.S. directs the launch vehicle to an accuracy in apogee of 2%.
The vehicle must be reusable.	Robust materials will be selected for the components of the launch vehicle that will be subjected to high-stress environments.	By inspecting every element of the launch vehicle to ensure no structure was compromised	No visible structural damage is visible and every component is still functional
The payload must be retained at all times during flight	A payload bay with secure payload holders will provide sufficient force to prevent detachment due to vibrations.	By inspecting the payload bay post-launch for partial or complete detachment.	The payload will remain in the same position as it was pre-launch.

2.2.2 Autonomous Ground Support Equipment

Table 2: Mission Success Criteria for AGSE

Requirement	*Design feature to satisfy that requirement*	*Requirement Verification*	*Success Criteria*
Pick up the Payload from a location at least 12" away from the launch vehicle and place the Payload inside the launch vehicle	The RDPS System is a 3-DOF arm that will automatically detect the location of the payload using IR sensors and place the payload inside the payload bay	Testing the RDPS Subsystem on the ground to ensure accurate completion of task	The RDPS has successfully placed the payload and secured the hatch; all autonomously
Raise the launch vehicle to 5 degrees off the vertical	The REM system will use an arm-spool mechanism to raise the rail the launch vehicle is sitting on effectively and safely	Testing the REM Subsystem on the ground to ensure completion of the task	Accurate measurement of the system to exactly 5 degrees off the vertical
Insert an Igniter into the launch vehicle motor	The MIS System will use a rack and pinion to system to place the igniter 12" inside the rocket motor	Testing the REM Subsystem on the ground to ensure completion of the task	The Igniter is securely placed inside the solid rocket motor

3 Launch Vehicle

3.1 Overview

The purpose of the launch vehicle Skyron is to achieve a precise altitude of 5280 ft., whiling retaining a payload and gathering flight data throughout the full length of the flight. Skyron must successfully launch, reach the altitude, deploy the recovery system at the correct altitude, and land without any structural damage. During the ascent of the vehicle, it must actively target the desired altitude using electronic guidance in order to attain the highest level of precision possible. The project also requires an extensive phase of design, manufacturing and testing that will be carried out with the highest safety standards and most efficient procedures as is reasonably possible. The main structure of the launch vehicle is illustrated below in Figure 2.

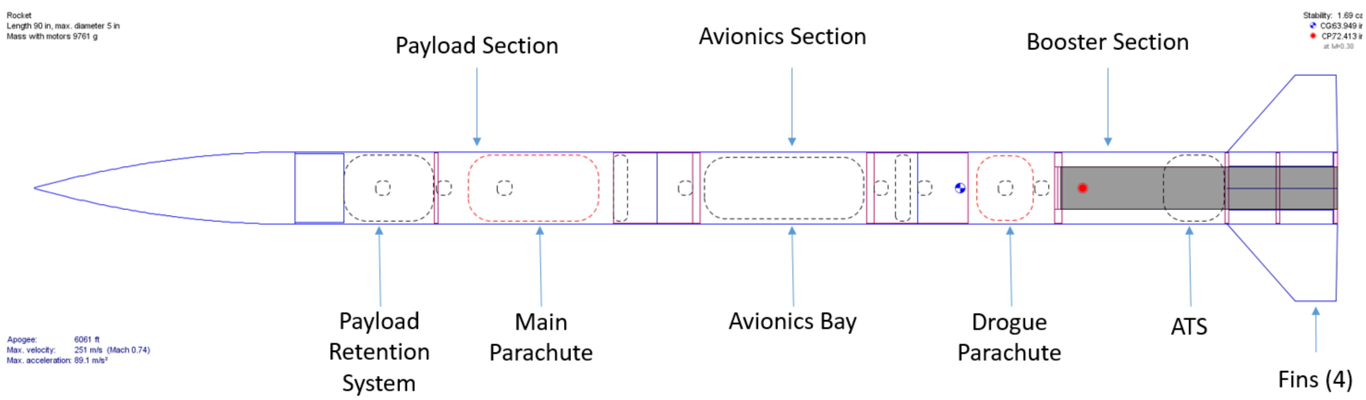


Figure 2: General Layout of Launch Vehicle

The dimensions of the launch vehicle were specifically determined in order to be able to achieve the mission requirements detailed in the previous section, and also to accommodate the various systems efficiently and effectively, while still maintaining a high stability margin to ensure the safety of the operation. The specific dimensions are as follows in Table 3.

Table 3: Length of the components of the launch vehicle

Parameter	Value
Overall Length	90 in
Booster Section	29 in
Avionics Section	18 in
Payload Section	25 in
Body Diameter	5 in
Nose Cone Length	18 in
Fin Height	5.3 in
Fin Root Chord	7.5 in
Fin tip Chord	3.1 in

The dimensions for the systems that are categorized as inner components of the launch system are detailed below in Table 4.

Table 4: Dimensions of the inner components of the launch vehicle

Parameter	Value
Payload Bay	6.2 in
Avionics Bay	11 in
ATS	4.2 in
Motor Casing	20.4 in
Couplers	7 in
Bulkheads & Centering Rings (Thickness)	0.25 in

The launch vehicle, from aft to front, consists of three detachable segments: the booster section, the avionics section, and the payload section. Skyron will utilize a dual-deployment recovery system that will minimize the drift of the launch vehicle by mitigating the effects of wind conditions. However, to still achieve the purpose of a reusable launch vehicle, a main parachute will be deployed during the descent to ensure a safe landing.

3.2 Mission Success Criteria

Table 5: Mission Success Criteria for Skyron

Requirement	*Design feature to satisfy that requirement*	*Requirement Verification*	*Success Criteria*
Reach an altitude of 5,280 ft. as accurately as possible.	The A.T.S. will deploy during cruise flight to adjust the flight profile curve to match a real-time ideal projection of the rocket's trajectory for the designated altitude by increasing the drag coefficient of the launch vehicle.	Gathering data post-launch from the on-board altimeters.	The A.T.S. directs the launch vehicle to an accuracy in apogee of 2%.
The vehicle must be reusable.	Robust materials will be selected for the components of the launch vehicle that will be subjected to high-stress environments.	By inspecting every element of the launch vehicle to ensure no structure was compromised	No visible structural damage is visible and every component is still functional
The payload must be retained at all times during flight	A payload bay with secure payload holders will provide sufficient force to prevent detachment due to vibrations.	By inspecting the payload bay post-launch for partial or complete detachment.	The payload will remain in the same position as it was pre-launch.

3.3 System Design Overview

Table 6: Launch Vehicle Requirements

Requirement	*Design Feature to Satisfy Requirement*	*Verification Method*	*Status*
Vehicle altimeter will report an apogee altitude of most nearly 5,280 feet AGL.	Low-mounted electric-controlled fins will be extended and retracted in reaction to altimeter readings to control drag and limit altitude.	Analysis	In Progress
Launch vehicle will be designed to be recoverable and reusable within the day of initial launch.	Vehicle will be constructed of fiberglass to resist fractures and ensure stability.	Design Review	In Progress
Vehicle will be prepared within 2 hours and will be able to	Compartmentalized design with standard assembly procedure.	Execution	In Progress

Requirement	*Design Feature to Satisfy Requirement*	*Verification Method*	*Status*
maintain launch-ready position for at least 1 hour.			
The launch vehicle shall have a maximum of four (4) independent sections.	Three (3) sections include: payload, avionics, and booster	Inspection	In Progress
The vehicle will be limited to a single stage, solid motor propulsion system, delivering an impulse of no more than 5,120 Newton-seconds.	Single-staged design that utilizes a single "L" impulse classification motor.	Design Review	In Progress
Team must launch and recover both a subscale and full scale model prior to each CDR and FRR respectively.	Efficient Recovery System with redundancies to ensure successful operation.	Execution	In Progress
The launch vehicle shall stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a much lower altitude.	Redundant altimeters programmed to deploy at specific altitudes.	Inspection	In Progress
At landing, the launch vehicle shall have a maximum kinetic energy of 75 ft-lbf.	Optimization of parachute sizing for the total mass of the launch vehicle	Testing	In Progress
The recovery system will contain redundant altimeters, each with their own power supply and dedicated arming switch located on the exterior of the rocket airframe	Install a master key-switch at the rear of the avionics bay to close all circuits simultaneously, and independent compartment for sensors and power supply.	Inspection	In Progress
Each detachable section of the vehicle and payload must contain an electronic tracking device and continue transmission to the ground throughout flight and landing.	Independent GPS compartment with transmission capabilities and ground station with receiving capabilities.	Inspection	In Progress

3.4 Recovery System

The main parachute will be housed above the avionics section while the drogue will be located within Skyron's booster section, as shown in Figure 3. The location of our parachutes were chosen to effectively distribute the weight through the vehicle thereby maintaining the vehicle's stability.

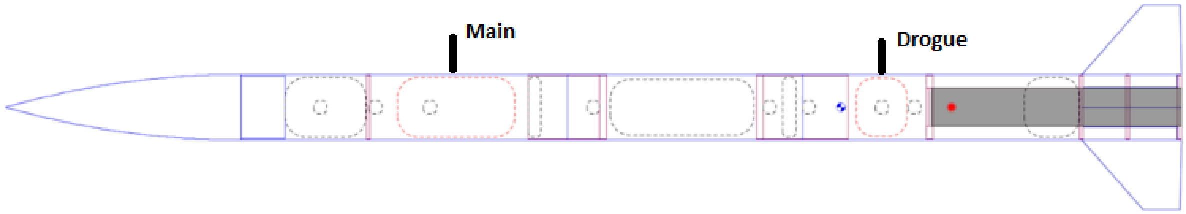


Figure 3: Parachute Locations

Parachutes made of rip-stop nylon were selected in order to ensure that both chutes support the weight of the rocket. Both parachutes will be protected by an insulated material in order to reduce the likelihood of combustion from sparks generated by the explosive charge used to separate the upper and lower section of the rocket's main body during descent. The parachutes will be secure to U-bolts located on bulkheads/centering rings insulting both the upper and lower sections from variations in pressure.

3.4.1 Parachute Requirements

Requirement Number	Requirement Definition
2.1	The launch vehicle shall stage the deployment of its recovery devices in the following order, drogue parachute, main parachute
2.2	Teams must perform a successful ground ejection test for both the drogue and main parachute
2.3	At landing, each independent section's kinetic energy shall not exceed 75 ft-lbf
2.4	The recovery system electrical circuits shall be completely independent of any payload electrical circuits
2.5	The recovery system shall contain redundant, commercially available altimeters
2.6	A arming switch shall arm each altimeter, which is accessible from the exterior of the rocket airframe
2.7	Each altimeter shall have a dedicated power supply
2.8	Each arming switch shall be capable of being locked in the ON position for launch
2.9	Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment
2.10	An electronic tracking device shall transmit the position of the rocket
2.11	The recovery system will by shielded from magnetic waves and all onboard devices, and placed in separate compartments within the vehicle

3.4.2 Parachute Dimensions

Parachutes were sized in accordance to equations highlighted in Figure 4. The equations account for the overall length and diameter of the vehicle. From the equation, it was found that a drogue chute of 24" in diameter would be a high fidelity solution. The main chute was size both to support the weight of the rocket and to minimize the impact kinetic energy of each of the rocket's independent sections. Main parachutes of diameter ranges between 72" and 85" were tested in the OpenRocket simulator and it was determined that a main parachute of 80" in diameter had both the capacity to minimize impact K.E and support the rocket's weight.

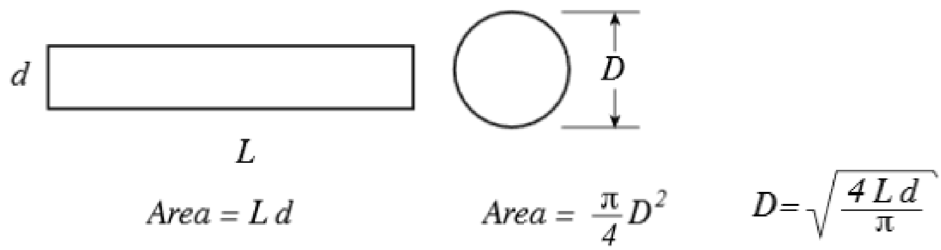


Figure 4: Calculating Area of Parachutes

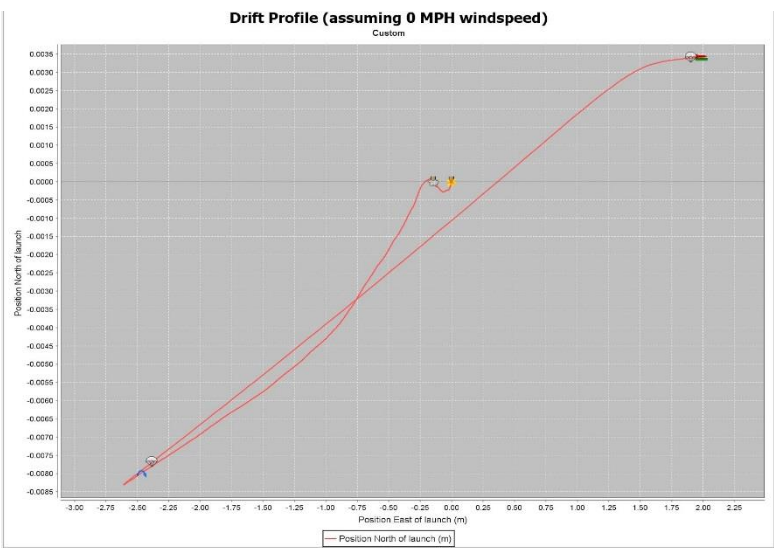
Table 7: Parachute Dimensions

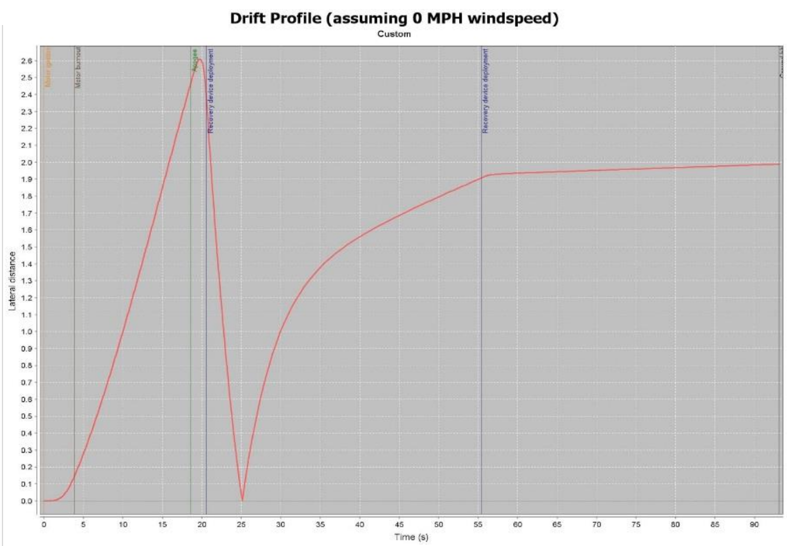
Parachute	Description	Cd	Carrying Capacity	Cost
Main	CERT-3 Large 80"	1.6	**16.2-35lb**	$27.50
Drogue	CERT-3 Drogue 24"	1.6	**2.2lb**	$145.00

3.4.3 Drift Profile Analysis

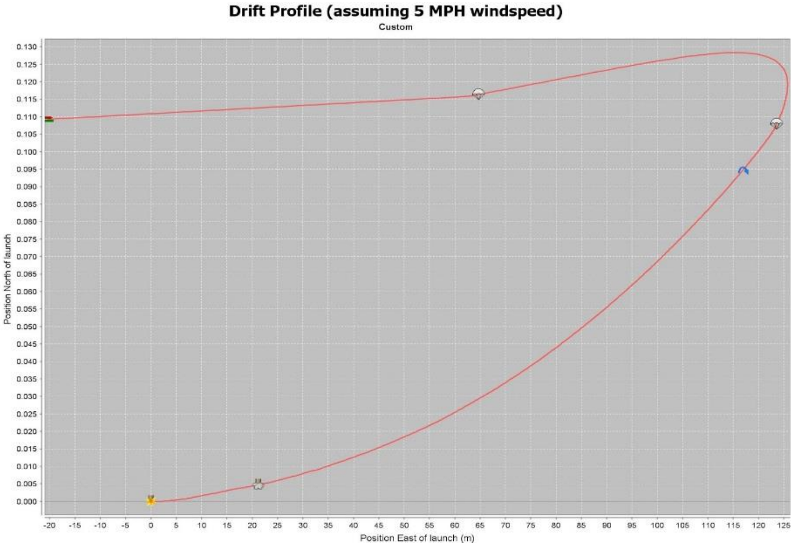
The following graphs are a simulated bird's eye view of Skyron's drift at 0,5,10, and 20 mph winds.

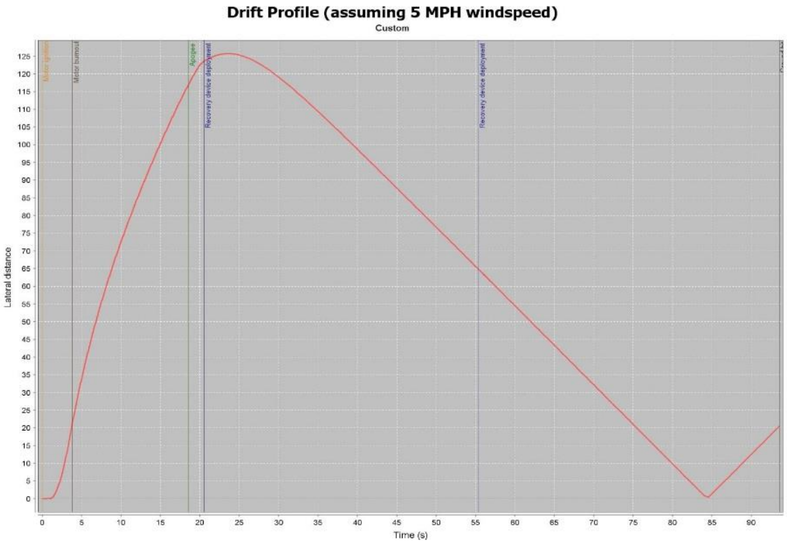
- 0mph



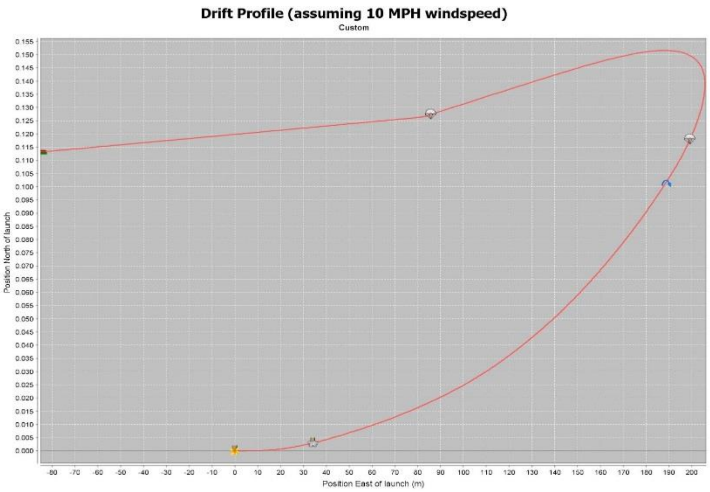


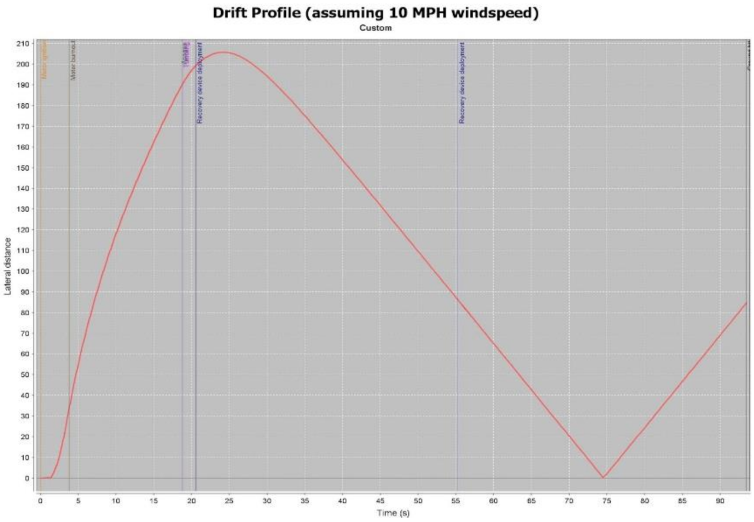
- 5mph



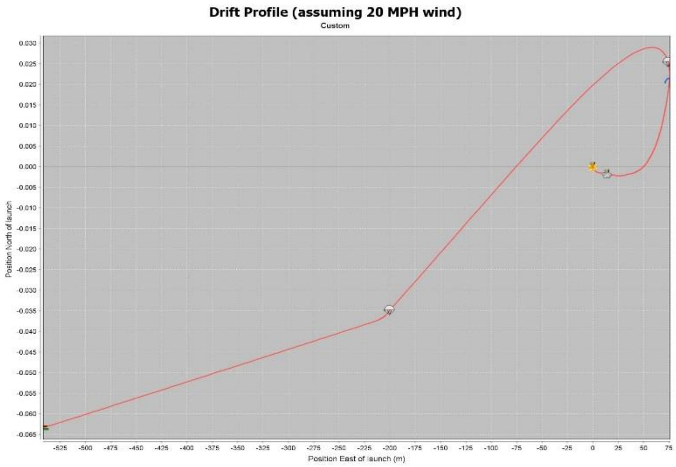


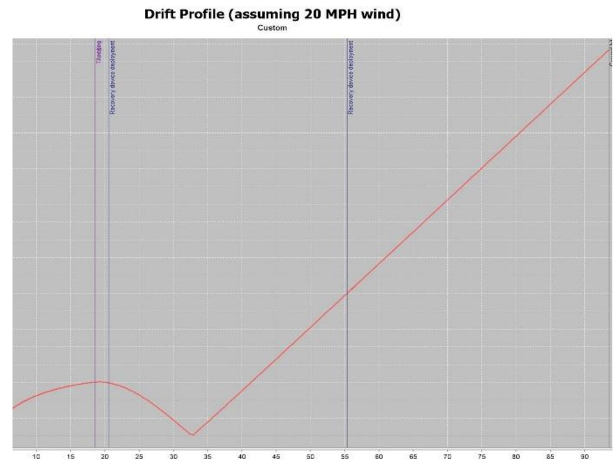
- 10-mph wind





- 20-mph wind.


Drift Profile (assuming 20 MPH wind)
Custom
Position North of launch
Position East of launch (m)


Drift Profile (assuming 20 MPH wind)
Custom
Recovery device deployment
Recovery device deployment

3.4.4 Kinetic Energy of Launch Vehicle

The impact KE was calculate for each section of the rocket body using the equation taking into account flight conditions at the launch site and allowing for margin of error.

$$KE = \frac{1}{2} mV_2$$

The impact KE of each component upon landing is show in Table 8.

Table 8:Kinetic Energy

Section	Impact KE (lbf-ft)
Booster	22.67
Avionics	12.02
Upper Coupler	16.1
Nose Cone	5.36
Total	58.72

3.4.5 Ejection Charges

To eject the parachutes, redundant black powder charges will be used. The containers housing the chutes will also be pressurized in order to ensure chute deployment. Due to the different requirements for the drogue and main chutes, two sets of calculations will be needed. The amount of black powder used in the ejections charges can be calculated through the equation below. Once the amount of black powder is determined the values can then be tested before flight. The equation relates weight of black powder to the ejection pressure, volume of the container, black powder combustion gas constant, and the black powder combustion temperature. The constants used are listed below in Table 9.

$$lb\ of\ Black\ Powder = \frac{Pressure * Volume}{R * T}$$

Table 9: Black Power Properties

Constant	Value
Combustion Gas Constant	22.16 ft lb_f / lb_m °R
Combustion Temperature	3307 °R

Using the pressurization of 10 psig and 9 psig as a structural maximum for the main and drogue chute compartments, the resulting black powder masses are calculated to be 3 grams and 1 grams for the main and drogue chutes, respectively, as illustrated below in Table 10.

Table 10: Black Powder Masses

	Main	Drogue
Total Pressurization	10 psig	9 psig
Ejection Force	446 lbf	393 lbf
Black Powder Mass	3 g	1 g

3.4.6 Testing

In order to ensure the safety and viability of the calculations made in determining the black powder masses, ground testing will be done before flying the launch vehicle. Ground testing will occur before every launch including the subscale. Skyron will be placed horizontally on the ground, on a relatively smooth surface to minimize unwanted static friction irrelevant to a flight environment. Table X1 and Table X2 illustrate the conditions for test success and failure

Table 11: Recovery System Test Success Criteria

Success Criteria
Ejection charge ignites
Shear pins break
Launch vehicle moves half the distance of shock cord

Table 12: Recovery System Test Failure Criteria

Failure Criteria
The fiberglass of the tube coupler shatters due to the charge.
The shear pins don't shear, and the launch vehicle stays intact.
The NOMEX/cloth shield fails and the parachute is burned.
The E-matches fail to ignite the black powder.

3.5 Launch Vehicle Performance Analysis

3.5.1 Fin Design

The fins will be made using G10 Fiberglass as the material of choice. Initially, the fins were attempted to be made with a smooth airfoil shape in order to improve the aerodynamics of the fin and reduce drag. Due to complications in the sanding process, it was determined that the smooth airfoil shape would be unreasonable for the fins due to the fact that G10 Fiberglass is not one solid material, but multiple layers on top of each other. During sanding, it is expected that the layers would begin to peel off one another.

The fin has a clipped delta fin shape (Figure 5) which was determined as the most viable option for a launch vehicle with four fins. With four fins, the stability of Skyron will increase as opposed to using only three fins (stability is expected increase by slightly over 50%). The fin flutter speed was calculated using the Flutter Boundary Equation published in NACA Technical Paper 4197:

$$V_f = a\sqrt{\frac{G}{\frac{1.337AR^3P(\lambda+1)}{2(AR+2)(\frac{t}{c})^3}}}$$

The corresponding variables for our fin are listed in Table 13 located below. The fin flutter speed was calculated to be 1326.109 mph. Comparing V_f to our maximum velocity V_{max} of 552.148 mph (0.72 Mach), Skyron will not experience the unstable effects of fin flutter. Exceeding the fin flutter speed will exponentially amplify the oscillations and rapidly increase the energy in the fins; causing greater induced moments and more instability.

Table 13: Fin Dimensions

Variable	*Unit*
Speed of Sound, a	1105.26 ft/s
Pressure, P	13.19 lbm/in^2
Temperature, T	48.32 Fahrenheit
Shear Modulus, G	425,000 psi
Taper Ratio,	0.3627

Variable	*Unit*
Tip Chord	7 cm or 2.75591 in
Root Chord	19.3 cm or 7.598 in
Thickness	0.318 cm or 0.1252 in
Fin Area	55.23 in^2
Span	13.4 cm or 5.275591 in
Aspect Ratio	0.50392

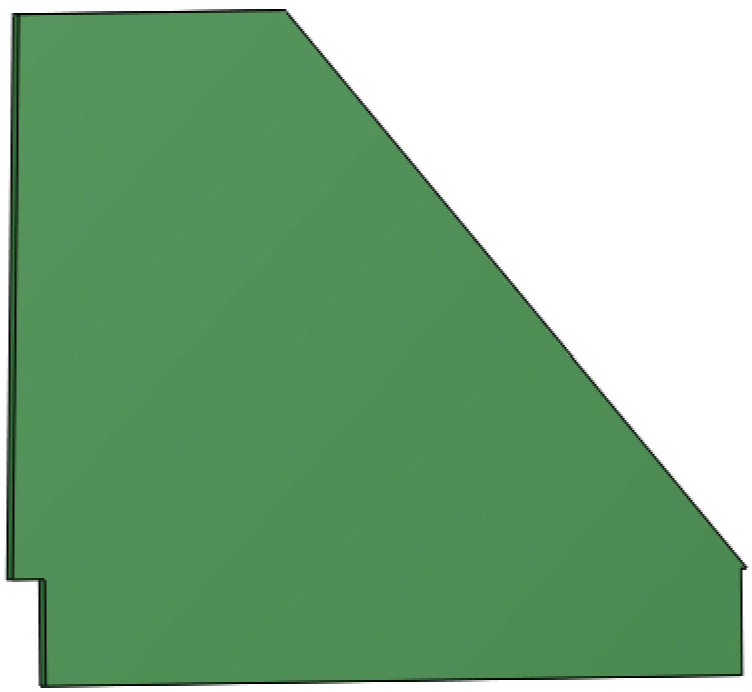


Figure 5: Solidworks Fin Model

The fin will be attached to the booster tube with a system of brackets made out of aluminum sheets that will provide a secure method of attachment as well as a simple method for a fin replacement in case there is a structural problem with one of the 4 fins. The fins will be held in place with the use of .125 in. screws to the fin braces shown in Figure 6, and this fin brace will be epoxied along all its contact surface to the booster tube. The full assembly of the booster section with fins is shown in Figure 10.

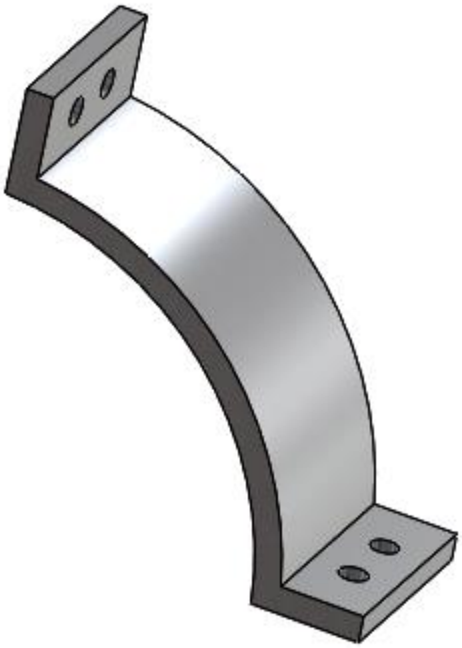


Figure 6: Fin brace

3.5.2 CP and CG

A big factor in rocket stability is the Center of Pressure (CP) and its relative location to the Center of Gravity (CG). With our OpenRocket program, multiple important equations are able to be calculated such as stability, CG, and CP as seen in Figure 7 below.

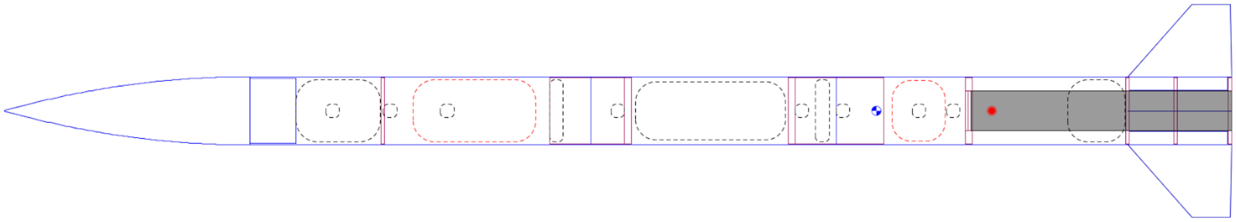
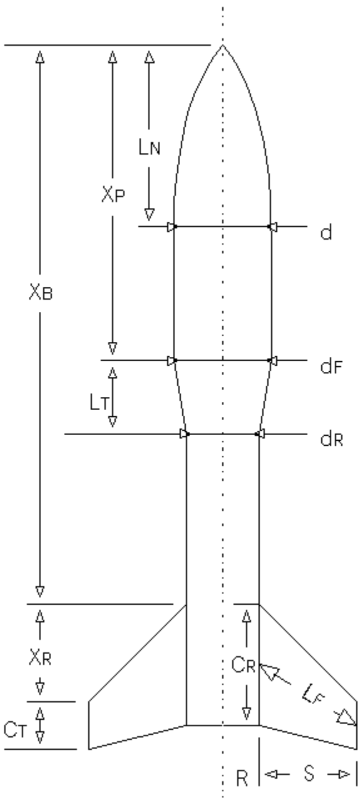


Figure 7: CP and CG locations on Skyron

To make sure that OpenRocket is correctly calculating the center of pressure accurately, the Barrowman Equations were used and compared to the calculated CP value of 184 cm from the tip of the nosecone. Diagram of the variables of the rocket and the terms that correspond to each respective length. The figure to the right describes the corresponding length. By comparing Figure

7 & Figure 8, the respective terms to be used in the equations are defined in Table 14 below. In OpenRocket, each section of our rocket can be clicked on and the respective lengths and parameters can be determined.



Terms in the equations are defined below (and in the diagram):

L_N = length of nose
d = diameter at base of nose
d_F = diameter at front of transition
d_R = diameter at rear of transition
L_T = length of transition
X_P = distance from tip of nose to front of transition
C_R = fin root chord
C_T = fin tip chord
S = fin semispan
L_F = length of fin mid-chord line
R = radius of body at aft end
X_R = distance between fin root leading edge and fin tip leading edge parallel to body
X_B = distance from nose tip to fin root chord leading edge
N = number of fins

Figure 8: General Rocket Dimensions

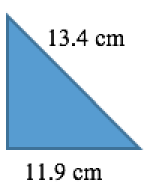
Table 14: Terms and their Respective Values

Term	Length (cm)
L_N	45.7
D	12.7
d_F	12.7
d_R	12.7
L_T	45.7
X_P	96.5
C_R	19.3
C_T	7.1
S	13.4
R	6.35
X_R	11.9
X_B	209.3
N	4 Fins

L_F, the length of fin-mid chord line, had to be calculated using the equation below. The calculations are as follows.

$$L_F = \sqrt{S^2 + \left(\frac{1}{2}C_T - \frac{1}{2}C_R + \frac{S}{tan\theta}\right)^2}$$

Using simple trigonometry rules, theta was able to be determined as follows:



$$\theta = \tan^{-1}\left(\frac{13.4}{11.9}\right) = 48.39301107°$$

Thus, L_F was calculated to be equal to 14.6013698 cm. Next, the nose cone terms need to be calculated and determined. $(C_N)_N$ is already given to be equal to 2. Since we are using a Von Karman nose cone, the closest equation we can use is for an Ogive nose cone as seen and calculated in the equation below.

$$X_N = 0.466L_N$$
$$X_N = 21.2962cm$$

Next, the conical transition terms need to be calculated. These terms were calculated using the two following equations below.

$$(C_N)_T = 2\left[\left(\frac{d_R}{d}\right)^2 - \left(\frac{d_F}{d}\right)^2\right]$$
$$(C_N)_T = 0$$

$$X_T = X_P + \frac{L_T}{3}\left[1 + \frac{1 - \frac{d_F}{d_R}}{1 - \left(\frac{d_F}{d_R}\right)^2}\right]$$
$$X_T = 11.73333cm$$

Next, the fin terms need to be calculated. These terms were calculated using the two following equations below.

$$(C_N)_F = \left[1 + \frac{R}{S + R}\right]\left[\frac{4N\left(\frac{S}{d}\right)^2}{1 + \sqrt{1 + \left(\frac{2L_F}{C_R + C_T}\right)^2}}\right]$$
$$(C_N)_F = 9.20945$$

$$X_F = X_B + \frac{X_R}{3}\frac{(C_R + 2C_T)}{(C_R + C_T)} + \frac{1}{6}\left[(C_R + C_T) - \frac{(C_R C_T)}{(C_R + C_T)}\right]$$
$$X_F = 217.8683712cm$$

Finally, the center of pressure can be calculated. First, the sum of the coefficients, $(C_N)_R$, needs to be calculated. Then, the center of pressure distance from the nose tip, $\bar{x}$, can be calculated using the terms given and solved for from above. The two equations and calculations are as follows.

$$(C_N)_R = (C_N)_N + (C_N)_T + (C_N)_F$$
$$(C_N)_R = 11.20944622$$

$$\bar{X} = \frac{(C_N)_N X_N + (C_N)_T X_T + (C_N)_F X_F}{(C_N)_R}$$
$$\bar{\boldsymbol{X}} = \mathbf{182.7957184}\boldsymbol{cm}$$

Comparing the calculation for the center of pressure from above to the value calculated from OpenRocket, 184 cm, this yields a percent error of 0.6545%. Considering that this error is nearly half of just 1%, it can be concluded that OpenRocket is a valuable and reliable tool in our rocket design and implementation process for CP and CG.

A stability caliber equal to at least 1.75 is desired right after flight. Figure 9 displays the anticipated CP and CG changes during flight in response to a 13.5 ft/s horizontal wind and mass changes based on an L820 motor and a gross lift off weight of 22.22 lbm.

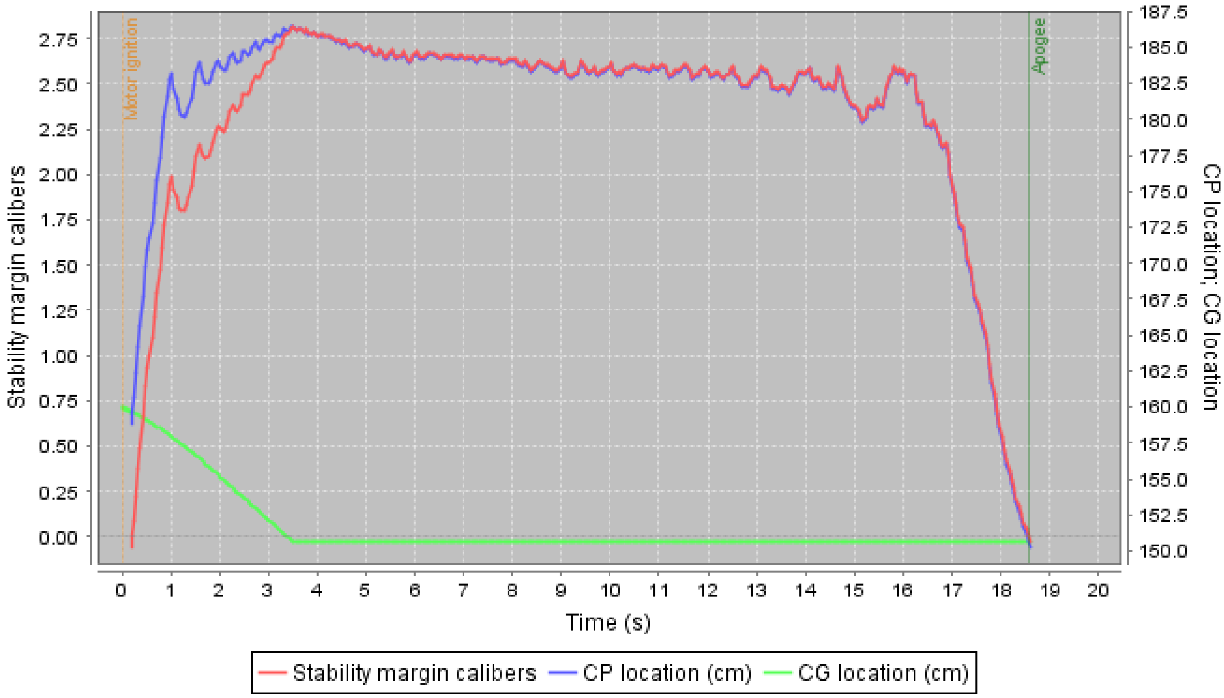


Figure 9: Stability Factors during Flight

3.5.3 Nose Cone

The nose cone style selected is a Von Karman nose cone. Von Karman nose cones are designed for a theoretical minimum drag, and described mathematically by the following equations:

$$\theta = \cos^{-1}(1 - \frac{2x}{L})$$

$$y = \frac{D/2}{\sqrt{\pi}} \sqrt{\theta - \frac{\sin(2\theta)}{2}}$$

The variables are defined below in Table 15.

Table 15: Nose Cone Symbol Definitions

Symbol	Definition
θ	Surface Turning Angle
x	Incremental Length from Nose Cone Tip
L	Overall Nose Cone Length
y	Incremental Distance from Nose Cone Centerline
D	Maximum Nose Cone Diameter

These equations yield a nose cone with a length of 18 in. and an outer diameter of 5 in.

3.5.4 Motor Selection

Currently the final motor choice for Skyron is a Cesaroni L820. However due to the space constraints between the motor tube and the inner wall of the booster section, a 54mm motor is being considered due to the more maneuverability for the ATS mechanics. The differences are outlined below in Table 16.

Table 16: Motor specifications

MOTOR NAME	Cesaroni L820	Cesaroni L990
DIAMETER	75mm	54mm
LENGTH	48.6cm	64.9cm
PROP WEIGHT	1.760kg	1.369kg
TOTAL WEIGHT	3.420kg	2.236kg
AVG THRUST	819.9N	991.0N
MAX THRUST	948.8N	1702.7N
TOTAL IMPULSE	2,945.6 N-s	2771.6
BURN TIME	3.6s	2.8s

3.5.5 Booster Section

At the head of the booster section, the motor tube is capped with a 0.25 inch thick thrust plate, secured across multiple surfaces to the motor tube as well as the body tube via epoxy and option L-bracket installation. A U-bolt runs through the thrust plate, providing a point of attachment for Recovery System components.

The entirety of the booster section is designed to slide into the main rocket body tube as a single component, including the fins and motor. Once positioned inside the body tube, the assembly may be secured via the L-bracket points. This design allows for rapid access to the booster section in the event that modification or repair is necessary.

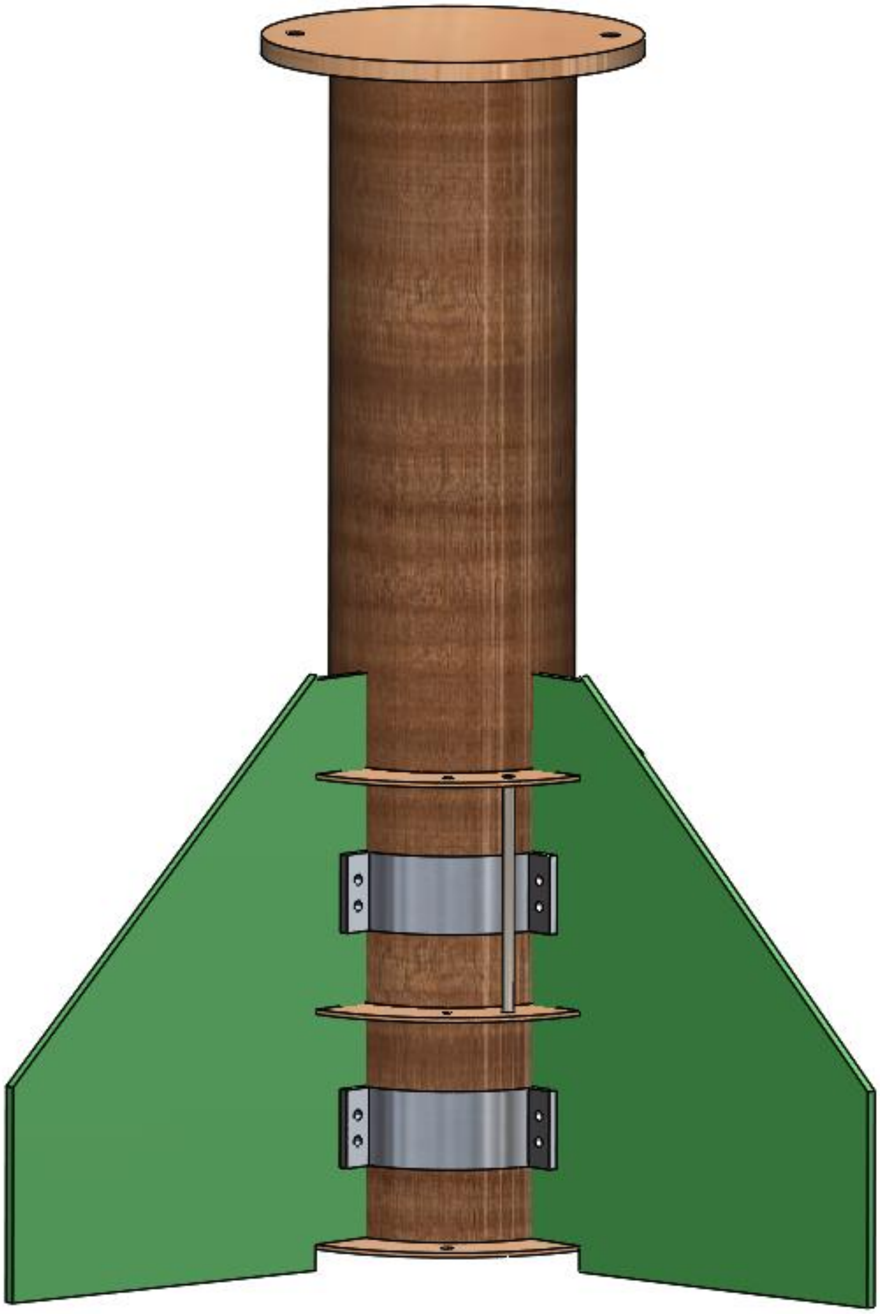


Figure 10: Booster Section Assembly

3.5.6 Altitude Predictions

Skyron will have a dry mass of 14.68 lbs. prior to the installation of the rocket motor. Currently, the selected rocket motor is rated as a L820. Based on this motor selection, the gross lift-off weight is 22.2 lbs. Flight weather conditions based on previous competitions were used as inputs for flight simulations completed in Open Rocket. Wind at launch was approximated at 13.5 ft/s with a standard atmospheric model using the elevation above sea level at Toney, Alabama. Flight simulation approximates an apogee at 5,967.848 ft. AdeGL, as shown in Figure 11.

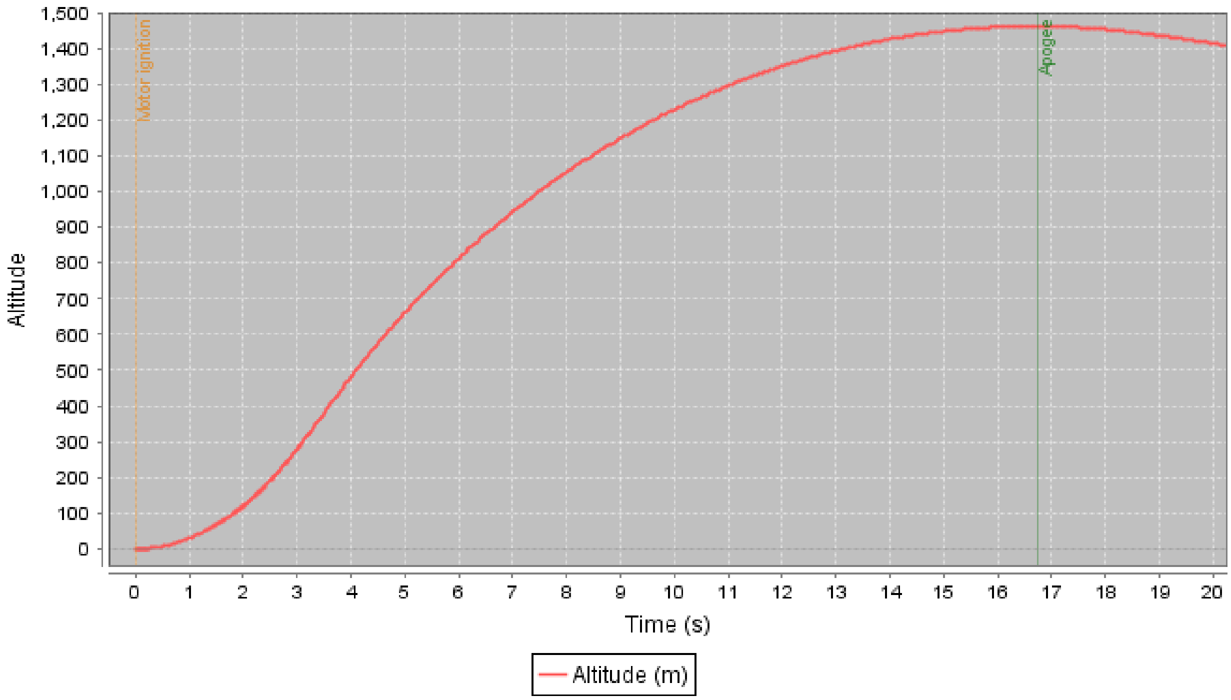


Figure 11: Altitude vs Time with a L820 Motor

3.5.7 Apogee Targeting System Analysis

Skyron will include an Apogee Targeting System (ATS) which will consist of four (4) acrylic tabs positioned between Skyron's fins, and its mechanical system will surround the inner booster section. These tabs will open laterally from the launch vehicle to an angle of 45 degrees, in an umbrella fashion. Each tab will be attached to a 90 degree hinge piece as its axis of rotation which is then attached to a hinge inside of the rocket body. The tabs will be curved to fit the 5 in diameter of the launch vehicle body in order to reduce drag when not deployed. Acrylic was chosen for the tab material because it is lightweight and easily shaped for fitting closely to the launch vehicle body. Figure 12 shows the tab design with the hinge placer attached.

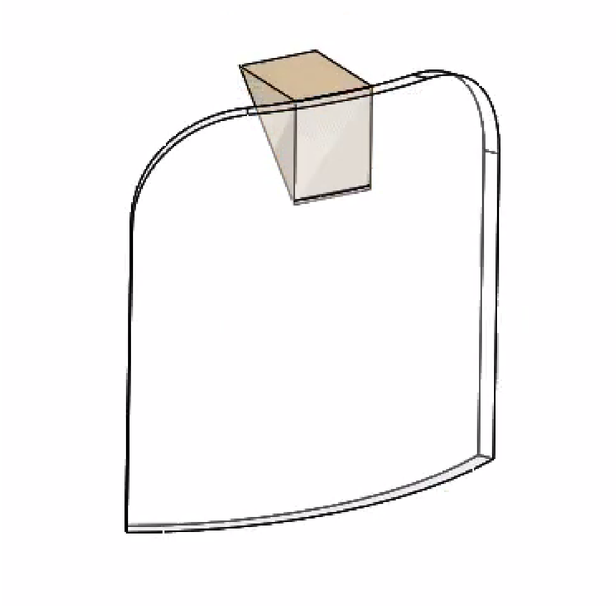


Figure 12: Apogee Targeting System Acrylic Tab

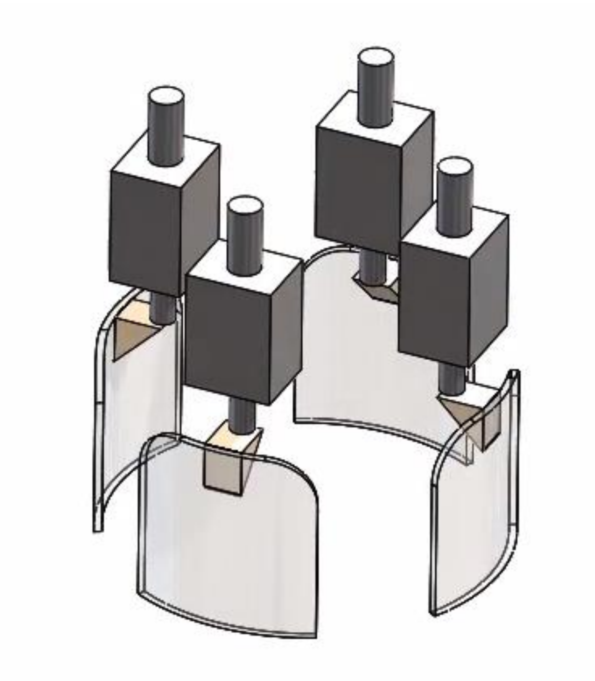


Figure 13: ATS with Solenoids

Each ATS tab will have its own large push-pull solenoid (Figure 13) with 24 DC operation and 15 Newton starting force controlling its extension. The four solenoids, mounted internally around the booster section, have a ten millimeter throw pushing down on the ninety degree hinge pieces attached to the tabs. The point of contact on the hinge will be 10 millimeters from the axis of rotation to achieve the 45 degree extension. Solenoids were chosen for the system due to their simplicity and the linear motion.

The solenoids and tabs will have two states: 0 degree extension and 45 degree full extension. The flight computer will determine the state of the system based on a need for additional drag in reaching the target apogee. The flight computer will contain pre-calculated scenarios in the onboard memory bank to be compared with the actual rocket values of velocity and apogee altitude after motor burnout. The aerodynamic effects caused by the acrylic tabs will be recorded and analyzed prior to launch. The tabs will be tested and analyzed during the subscale launch and in a wind tunnel in its two states: tabs fully deployed and tabs adjacent to the body. The wind tunnel data in combination with validated CFD results will construct the rocket guidance database for the flight computer.

The OpenRocket simulations have Skyron overshooting the targeted apogee by approximately 170 meters (560 ft.). The launch vehicle is designed with this overreach in mind. The ATS will deploy flaps to slow ascent following burnout and allow the rocket to coast to the target of 5,280 ft.

Using simulation software Ansys R16.1 and OpenRocket, we have calculated an average C_d of approximately 0.61 in normal flight. When the ATS is engaged, ANSYS Fluent shows that the C_d jumps to a value of 1.1. These resources establish a starting point for our drag calculations that we will develop into a program that will communicate precisely when to deploy and retract the ATS flaps. The program will be designed around figures gathered through the general rocket equation and energy equations. Further validation of results will be conducted in a wind tunnel and during the subscale launch.

ANSYS 16 has been used in all CFD analysis of Skyron. Previously, there was question on the placement of the ATS system on the rocket fuselage. For weight management purposes, it was hypothesized that lower in the rocket would be most suitable. The interaction between the fins and the ATS flaps was undetermined and could upset the stability of the rocket due to turbulent flow off the flaps.

The rocket was evaluated at 300 m/s well beyond the burnout velocity projected in OpenRocket of 244 m/s. To get to this assumed velocity, the rocket was evaluated using the rocket equation:

$$du = -u_e \frac{dM_v}{M_v} - \frac{D}{M_v}dt - g\cos(\theta)dt$$

Using the assumptions of zero drag, vertical launch, and using the specific impulse in place of the exit velocity we get:

$$u = g[Isp\ ln(\frac{M_{vo}}{M_v}) - t]$$

This equation evaluated at burnout, gives the max velocity of the rocket (288 m/s).

Figure 14 shows the contour of the turbulent kinetic energy. It can be seen in the image that the flaps have little turbulent interaction with the fins. The interaction can also be seen as flow is tracked along the surface of Skyron as shown in Figure 15. These models show that extension of

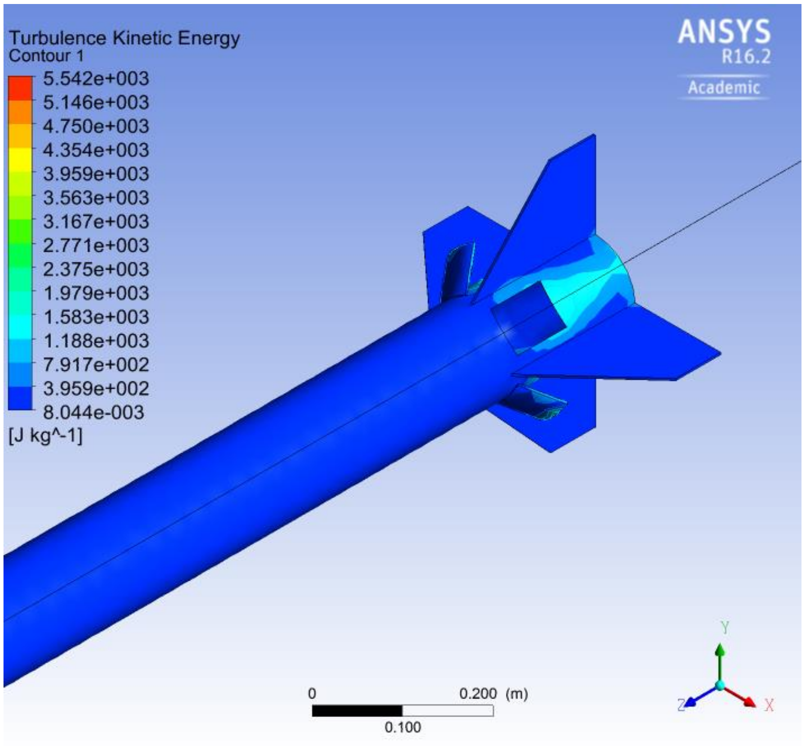


Figure 14: Contour of Turbulent KE around Skyron

the flaps should not cause the rocket to become unstable. Models show the ATS flaps 18 cm from the bottom of Skyron. Based on flow about the flaps, the ATS system could be moved up or down the fuselage with little to no change in the flow about the fins.

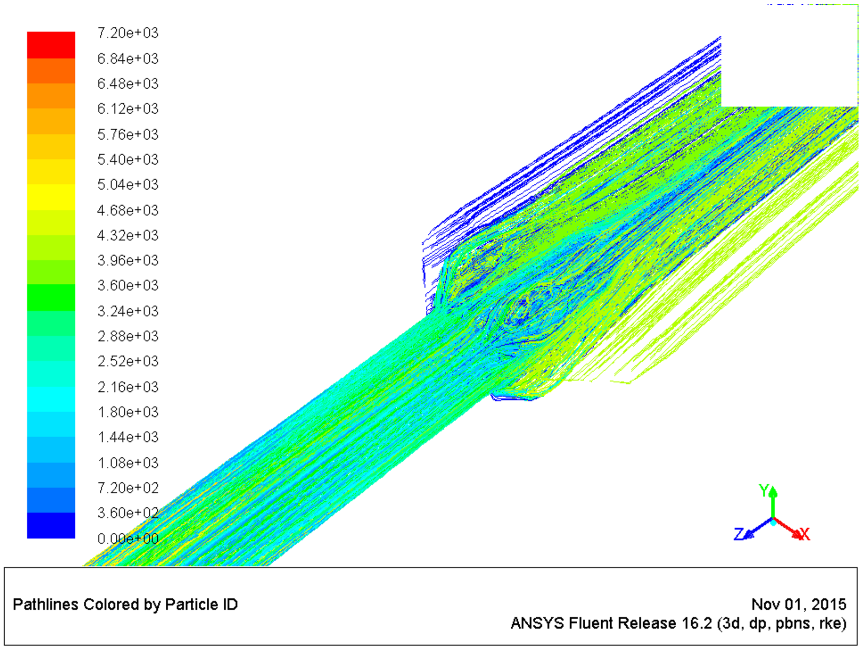


Figure 15: Track of Particles released from the rocket

Figure 16 gives us a pressure contour. The information gathered from this image will information to refine the design of the flap's control system as it pertains the extension arm and the structural integrity of the flaps.

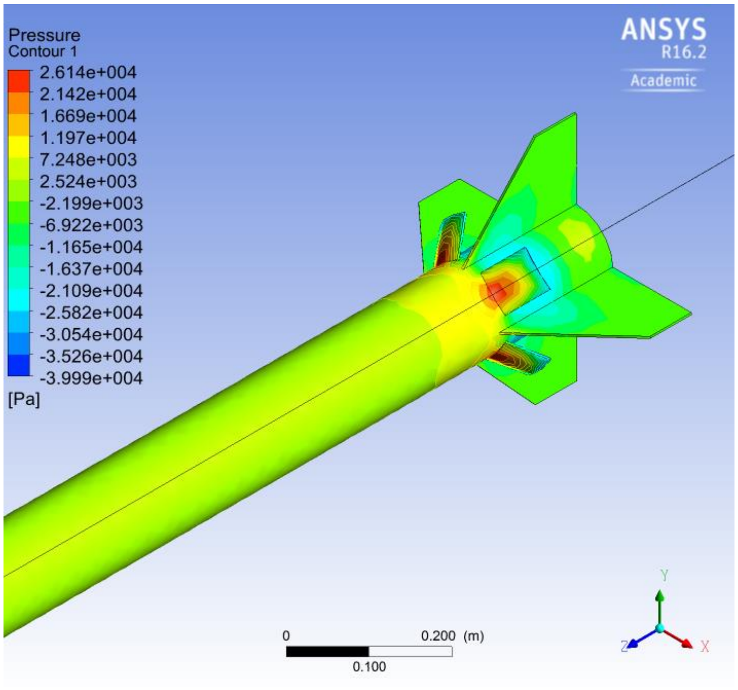


Figure 16: Pressure Contour in Pa

The simulation models are bound by the academic licensing constraints within the ANSYS programs. A finer mesh would result in a more accurate model. Further analysis will be done during the subscale launch and in the wind tunnel to validate simulation.

3.5.8 Fabrication and Materials

3.5.8.1 Fins:

This will lead to structural failure of the fins which will greatly affect the stability of the rocket. The fin will be manufactured using a water jet cutter provided by Georgia Tech. Using a water jet cutter will allow an accurate model of the fin to be made; however, because G10 Fiberglass is layered, the layers will begin to peel off due to the high pressure from the water jet cutter. To eliminate this problem, after the water jet cutting process has been completed, the fiberglass layers that have peeled off will be epoxied on and placed under weights in order to reform the original shape.

3.5.8.2 Avionics Bay:

The avionics bay consists of two different materials: G10 fiberglass and 0.125in plywood boards. These two materials require different manufacturing methods to ensure that their structural integrity isn't permanently affected. For the plywood boards, the conventional method for altering the dimensions of the board is using a high powered laser cutter for precise and safe manufacturing. As to the fiberglass tubes, What is most convenient is to use a table saw, while still taking into account the safety hazards that arise from cutting fiberglass, so the appropriate safety equipment must be used by every individual present during the time of manufacturing. As to the holes that secure the Avionics Bay in place, a conventional drill will be used while still accounting for the same safety hazards as previously discussed. These methods ensure there will be little deformation, delamination, and precise cuts for the manufacture of each component.

3.5.8.3 Booster Section

A large majority of the Booster section can be created using conventional manufacturing tools. Laser cutters will be sufficient to create the centering rings, while a waterjet cutter or CNC router would be employed in order to cut the thrust plate. Any cardboard tubing, such as the motor tube, can be cut using power tools. L-brackets would be bought rather than manufactured and subsequently attached via nuts and bolts. All components not secured via fasteners would be fixed in place by epoxy (i.e. centering rings to the motor tube).

3.5.8.4 ATS

The ATS tabs will be cut from acrylic sheets and curved to fit a five inch inner diameter by using a heat gun and five inch fiberglass tubing. The top corners will then be sanded down. The triangular hinge piece will attach to the tab by screws or bolts as well as the hinge. A small hole will be cut in the fiberglass body tube in order to fit the hinge of the ATS tab.

3.5.9 Future Testing and Analysis

The following are potential tests that are going to be performed on the launch vehicle:

1. Perform Wind Tunnel Test to obtain experimental C_d for comparison with test flight
2. Perform Wind Tunnel Test to obtain ATS C_d
3. Perform FEA Analysis on Thrust Plate
4. Use strain gauges to determine flutter and vibrations on fins
5. Perform ATS Ground Test to acquire Torque Data

3.6 Mass Breakdown

The mass of the launch vehicle is depicted in Figure 17 below. The different categories are defined by what purpose they serve in the launch vehicle's performance. Combined, all the components of

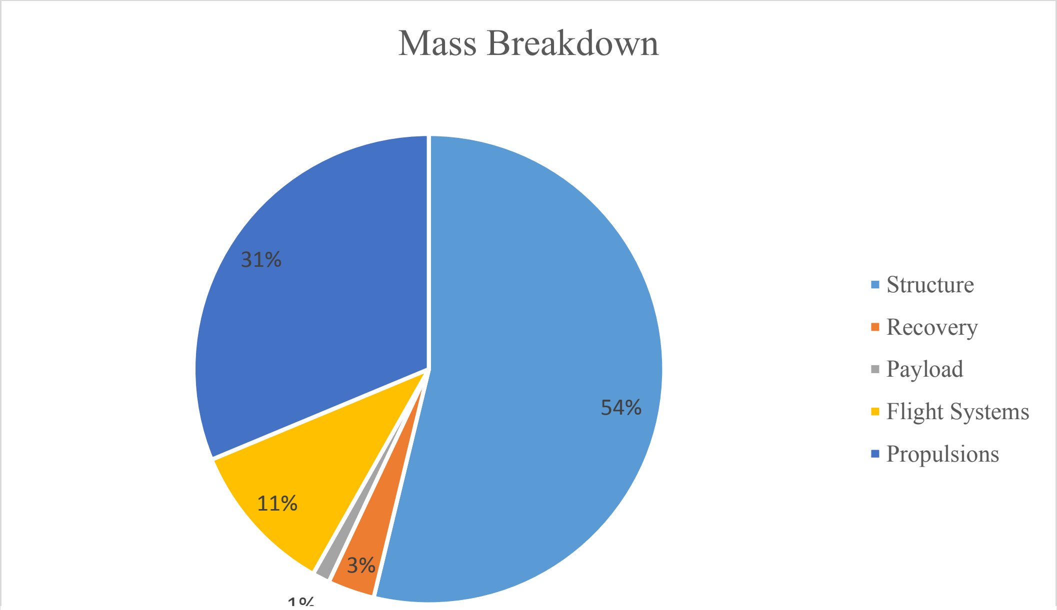


Figure 17: Mass breakdown

the vehicle have a total mass of 9749 grams. This is an educated estimation of what the total mass of the rocket will vary. Of course, this mass estimation isn't absolute, since a growth of 25-33% was accounted for since the submission of the Project Proposal.

This increase usually is due to unexpected malfunctions in some of the components, ballast, or simply the disregarding of small components such as nuts and bolts. The basis of this mass estimate is simply accounting for every known component that is required for the manufacture and completion of each subsystem, with an increment of 25% in each section of the vehicle to account for unexpected variables. Evidently, some subsystems of the launch vehicle require more thorough assembly than others, which might shift the center of gravity of the vehicle, but accounting for this is unnecessary because an increase in mass will be most likely in sections located nearer to the front of the rocket than the current center of gravity, which would mean that the separation of the center of gravity and the center of pressure can only increase. This would benefit the stability of the rocket, since the location of the center of pressure is invariant because it varies solely with respect to the outer geometry of the launch vehicle. In case the launch vehicle is lighter than expected, utilizing the same motor would be excessive and would make the vehicle overshoot the target altitude and it would also shift the center of gravity dangerously close to the center of pressure. To account for this possibility it would be required to select a lower powered motor which would still have the necessary impulse because of the reduced mass of the launch vehicle, and a lower mass property which would re-establish a safe stability margin for the vehicle.

3.7 Confidence and Maturity of Design

Designs for each subsystem have been completed and are now at the finalized design stage in accordance with the projected milestone dates. Remaining details for each design is to integrate smaller support components (i.e. L-brackets, screws, etc.) to ensure that the design is mechanically proficient.

Each subsystem performs its task under the expected dimensions and mass parameters, as well as having a relatively straightforward manufacturing process, so the overall level of confidence in the reasonably mature design is high. Of course, this level of confidence also varies slightly for each subsystem, but none falls below the safe range of expectations. Mechanically complex designs are the main concern, since the constrained volumes within the launch vehicle will require a higher level of precision at the time of assembling such systems.

The ATS is particularly concerning in this aspect due to the extreme constraints present by the diameter of the inner tube, which is a function of the diameter of the rocket motor selected. A completed Solidworks design for each subsystem validates the functionality of each system, but until their performance can be physically tested in upcoming stages of the project, the confidence in Skyron's design is at a stagnation point. Some subsystems still require slight reconfigurations as seen in the above sections; nevertheless the maturity of the design corresponds to the initial estimations.

3.8 Interfaces and Integration

Multiple subsystems will be required to cooperate for the effective operation of the entire project. Thus the interaction between these subsystems is essential and requires a heightened level of attention to detail as to the method of operation of each.

With respect to the payload bay, there must be a cooperation between the payload insertion system, and the payload bay itself. After several iterations, a consolidated design of the payload insertion system was devised, which is described in detail in a subsequent section of the report. One of the main considerations for this design was the ability to operate with the least amount degrees of freedom as possible to minimize the probability of unexpected motions in the mechanism. The insertion system has to be able to access the interior of the launch vehicle, and safely secure the payload, preferably without any complex operations. Thus, the simplest interface that the team designed involves motion along a single axis for the payload insertion. This motion demanded another simple but effective payload retention system, which would become a system (refer to the Payload Bay section above) that could be easily manufactured with additive manufacturing and relied only on the flexibility properties of the material. This design reduces significantly the possible points of failure in this specific subsystem and ensures the successful cooperation of both subsystems.

The avionics subsystem was designed specifically to involve motion solely along one axis. The design guarantees that with the insertion of the Avionics Bay into its compartment, every circuit will be closed simultaneously, with the safety measure of a master key-switch on the rear side of the airframe, ensuring the safety of this operation. This design iteration is a significant improvement from the original design which involved the separation of multiple segments of the vehicle in order to insert the Avionics Bay, and thus minimizes the probability of a mechanical failure in the design. The concept behind this design is inspired by a secure, compartmentalized system which can be easily detached from the vehicle only if the correct procedures are followed. The design has no moveable components with the exception of the Avionics Bay itself which will be secured with multiple screws to the airframe so that a permanent attachment to the vehicle during flight is guaranteed.

3.8.1 Interfaces with the Ground

Skyron will have a GPS tracking system that will deliver real-time telemetry, as well as the launch vehicle's landing location, to the ground tracking station via an Eggfinder radio transmitter. When the power system is locked to the ON position on the launch pad, the Eggfinder will begin transmitting telemetry data.

3.8.2 Interfaces with AGSE

The interaction of the launch vehicle with the AGSE is dependent on rail buttons which are secured onto the booster section, and effectively slide down the main rail of the rocket erection system. This design eliminates any degree of freedom, with the exception of the vertical motion once the launch vehicle is in its erected state at 85° above the horizontal required to launch. A further in depth description of this subsystem can be found in a subsequent section of the report.

3.9 Launch Vehicle Operations

It is the responsibility of Launch Operations to create comprehensive guides and checklists to ensure proper operation of the launch vehicle and the safety of the SLI team. Proper operation of the launch vehicle requires that certain protocols and procedures are observed by Team ARES during assembly and launch.

4 Autonomous Ground Support Equipment

4.1 Overview

The Autonomous Ground Support Equipment (AGSE) will have a robotic arm that can grab a payload that is off the platform and secure said payload inside the launch vehicle. The Rocket Erection System (RES) will then raise the launch vehicle from a horizontal position to a position 5 degrees from the vertical. The Motor Ignition System (MIS) will then insert an electronic match 12 inches into the motor to ignite the motor. The overall system will be largely constructed from 1010 rails and have a 10 ft. by 2 ft. base and be 1.5 ft. in height and weight approximately 60 lbs.

4.2 Mission Success Criteria

Requirement	*Design Feature*	*Requirement Verification*	*Success Criteria*
Grab the payload	Robotic arm with IR sensors will locate and grip the payload	Visual inspection	The payload stays in the grip of the claw
Move the payload into payload bay	Robotic arm will have 4 DOF	Visual inspection	The arm moves with speed and stability
Secure payload in payload bay	Plastic clips will snap around the payload	Visual and audio inspection (from snapping sound of plastic clips)	The payload does not fall out of the bay
Raise the launch vehicle	A cable and spool system will pull the guide rail upwards to appropriate angle	Visual inspection and sensor feedback	The launch vehicle moves from a horizontal position to 5 degrees from the vertical
Keep the launch vehicle upright	A ratchet system will ensure the launch vehicle can only move upwards	Visual inspection	The launch vehicle does not fall
Insert the igniter	A rack and pinion system will move the	Visual inspection	The igniter is inserted 1 ft.

Requirement	*Design Feature*	*Requirement Verification*	*Success Criteria*
	electronic match into the motor cavity		into the motor cavity
Safety	The electronics will have flashing LEDs and pause switches	Visual inspection	The LEDs indicate when the AGSE is on and the pause button allows for a stop in the system

4.3 System Design Overview

The AGSE will be comprised of three subsystems, the Robotic Payload Delivery System (RPDS), the Rocket Erection System (RES), and the Motor Ignition System (MIS). The RPDS will be located near the nose cone of the launch vehicle for easier access to the payload bay. The RES will be underneath the rocket's guide rail. The MIS will be attached at the end of the guide rail. The estimated time for completion is 8 minutes. A breakdown of the time can be seen in the Figure 24 below.

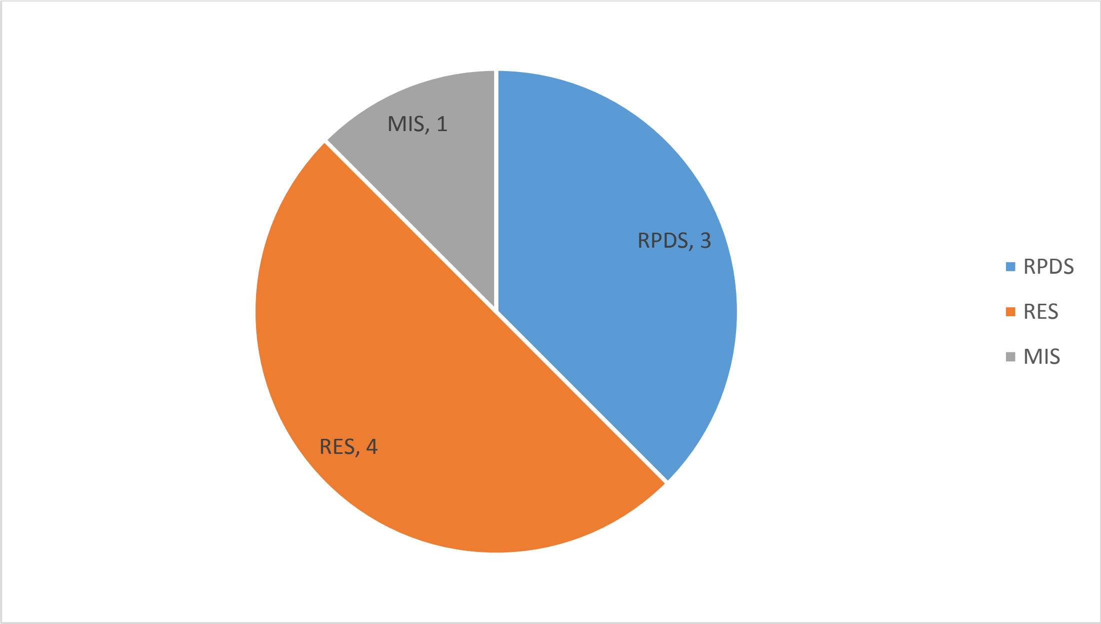


Figure 18: Estimated Time for AGSE Completion

The estimated times were estimated based on last year's competition and guesswork based on the mechanisms and systems in place.

Design Feature to Satisfy Requirement	***Requirement Verification Method***
Robotic Payload Delivery System will close the hatch securely	The security of the bay and retention system will be verified by inspection.
Low-mounted electric-controlled fins will be extended and retracted in reaction to altimeter readings to control drag and limit altitude.	Maximum altitude reading from altimeters will be recorded and verified. Later on altimeter data will be plotted and analyzed to inspect effectiveness of the ATS.
Vehicle will be constructed of fiberglass to resist fractures and ensure stability.	The launch vehicle will be inspected after ground impact for fractures and structural damage.
Simple-to-assemble Design	The vehicle will be assembled within a reasonable time interval. (2-3 hours)
Three (3) sections include: payload, avionics, and booster	Each section will be verified to remain attached to the vehicle after the launch by inspection.
Single Motor Performance	Altimeter data will be analyzed post-launch to cross reference the thrust curve to the expected curve.

Design Feature to Satisfy Requirement	*Requirement Verification Method*
Effective Recovery System	Altimeter data will be analyzed to determine accuracy and efficiency of altimeter recovery deployment.
Master key-switch at the rear of the avionics bay to close all circuits simultaneously	Functionality of all systems will be verified by collected data and auditory confirmation.
Efficient and tested GPS system	Continuous transmission of data during flight will be verified.

4.4 Robotic Delivery Payload System

Requirements	*Design Features*
Locate the payload	IR Sensors
Grab the payload	Robotic Gripper Claw
Move the payload into the rocket	4 Degrees of Freedom
Secure the payload into payload bay	Payload clips

The system adopted to insert the payload consists of two independent sections. One is the robotic arm that will transport the payload from its original position into the payload bay area of the rocket. The second section is the mechanism that will secure the payload in place inside the rocket.

The design of the robotic arm is simple, yet efficient. It consists of 3 degrees of freedom enabled by three servo motors rotating in a single plane, and another smaller servo to motorize a claw mechanism to capture the payload. Because the servo motors have a maximum torque at a certain voltage input, the robotic arm was meticulously designed to prevent failure from servos. Regarding materials, most of the mechanism is composed of parts made of wood, ABS, and delrin plastic. These materials are light enough for the servos' load capability and strong enough to sustain the payload weight. Figure 21 displayed below, shows a CAD of the robotic arm assembled.

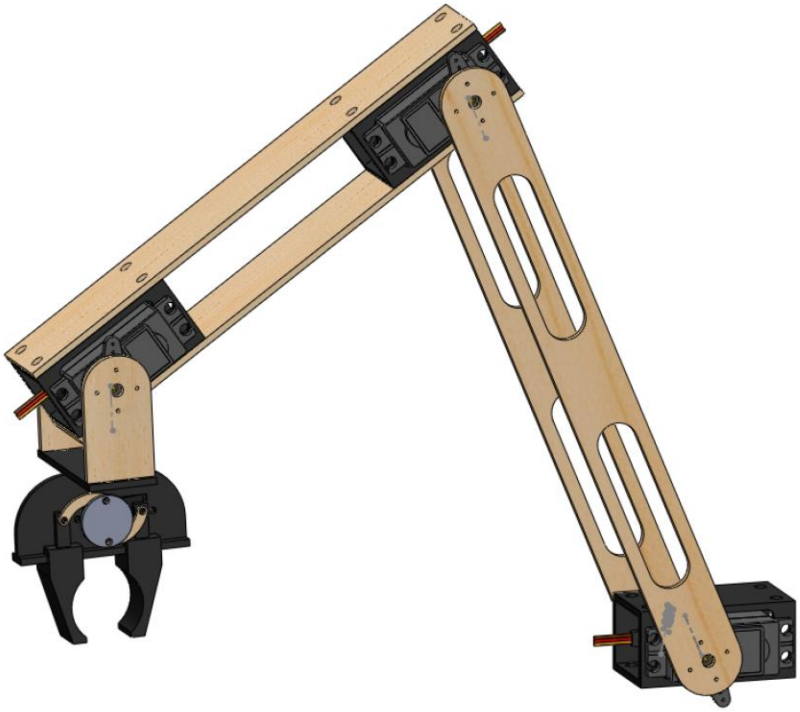


Figure 21: Robotic Arm

The mechanism in the robotic arm that grabs the payload, named "claw", was also designed to be as simple as possible. As a result, it is relatively light, it performs its tasks effectively, it is composed of relatively few parts, and it is powered by a single small servo motor. The movement of the claw is guided by a supporting rail and the mechanism that connects it to the motor allows the two claws to translate in opposite directions. The mechanism is shown below with two figures, one (left) showing the claw open and another (right) closed. Because this design is simple and practical, the parts can be made by regular FDM 3D printers and laser cut plywood.

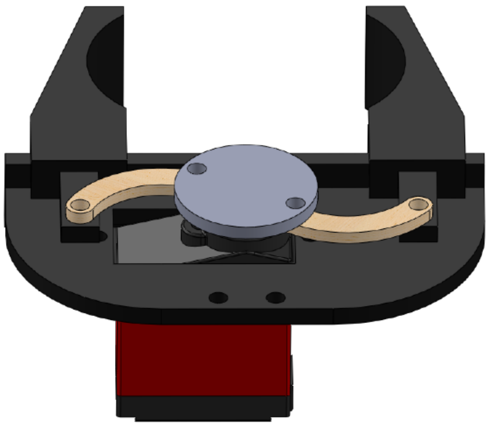


Figure 20: Open Claw

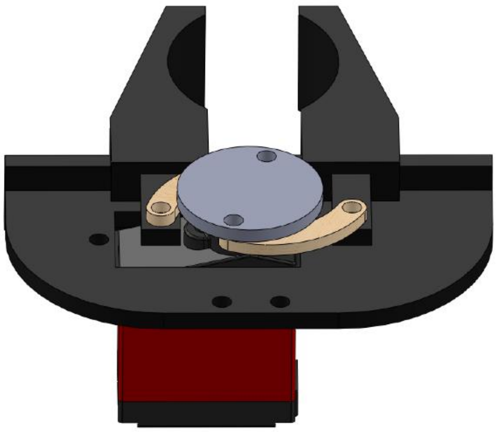


Figure 19: Closed Claw

Finally, the section that will secure the payload in the rocket is simply composed by two plastic clips that can elastically deform to encompass the payload and secure it by press fit. The figure below is a clos-eup view of the part itself.

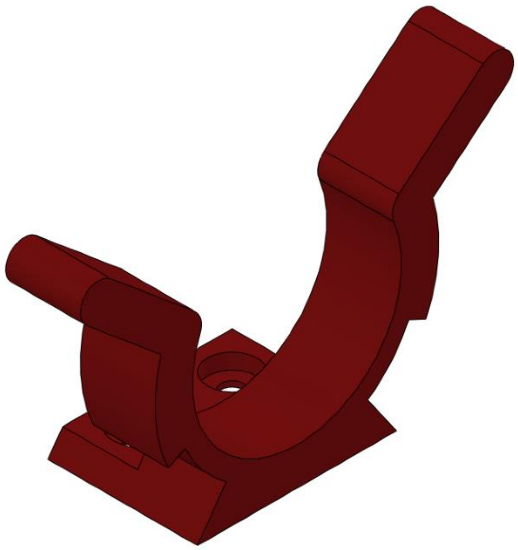
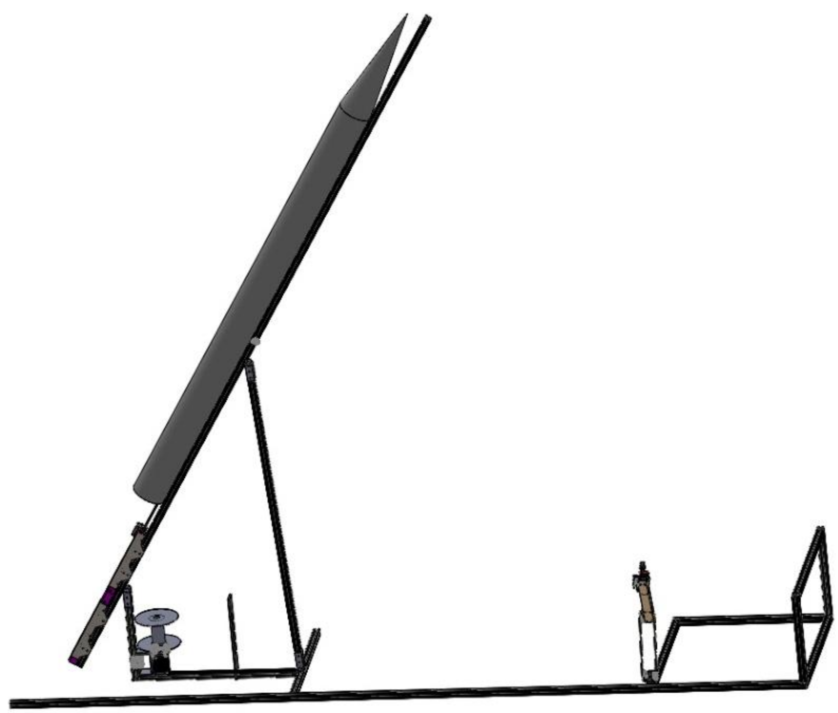


Figure 22: Payload Securing Component

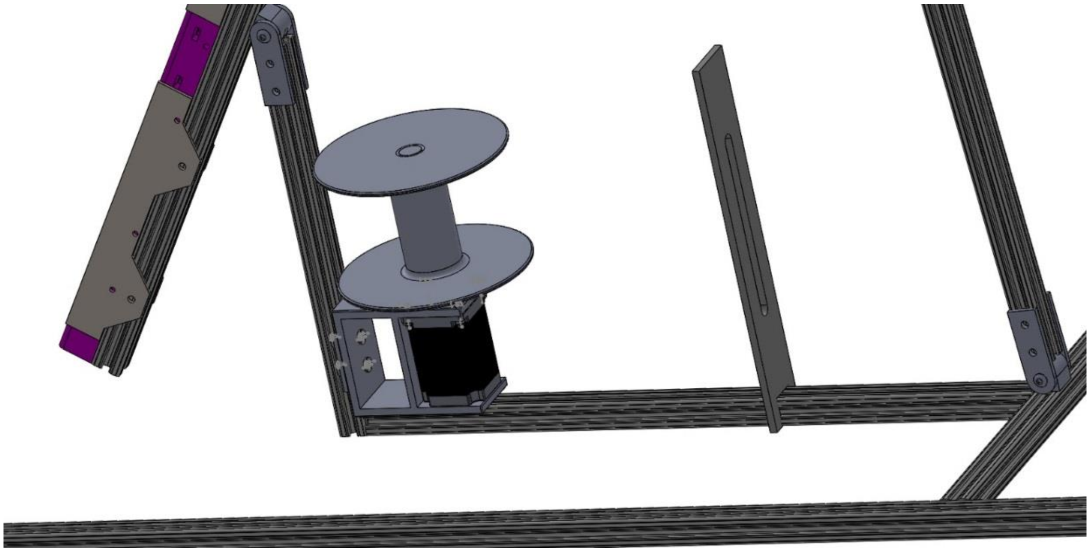
4.5 Rocket Erection System (RES)

Functional requirements of Rocket Erection System	***Design Features***
Start at horizontal position	Launch vehicle rests on railing
Raise the rocket up 85 degrees	Spool and cable system
Maintain the rocket's angle throughout ignition process	Locking system

The rocket begins in the horizontal position resting on the frame. The frame will be constructed out of aluminum t-slotted beams. The RES consists of arm, also made out of t-slotted beams, that lies angled beneath the rocket. It is connected to a pivot hinge on the frame on one end, and sliding hinge on the beam the rocket rests on on the other end. A 0.25" diameter steel cable is connected to the arm and pulled around a spool on the other end by a stepper motor. The steel cable is about 7 ft long. As the stepper motor turns the spool, the spool reels in the steel cable, which will pull the arm under the rocket. As the arm is pulled, the sliding hinge will slide down the beam the



rocket is resting on, and the rocket will raise. This simple, cheap, strong, and lightweight design relies on a steel cable to perform lifting the rocket.



4.6 Motor Ignition System (MIS)

Functional requirements of Ignition Insertion System	***Design Features***
Hold the electronic match	Fastened to rack
Move the electronic match into the motor cavity	Rack and pinion system

The Motor Ignition System (MIS), shown in Figure 23 will be a rack and pinion system powered by a DC motor. The DC motor has a gear attached to the shaft which, when spun, moves the rack up the rocket's guide rail, into the motor cavity. The rack will have an electronic match attached to the front which will ignite the rocket. Attached to the front of the MIS will be a steel blast plate. The MIS will be 1.5 ft long, allowing for the rack to move up to 18 inches into the rocket. It will be approximately 5 lbs. Attached to the front of the MIS will be a steel blast plate.

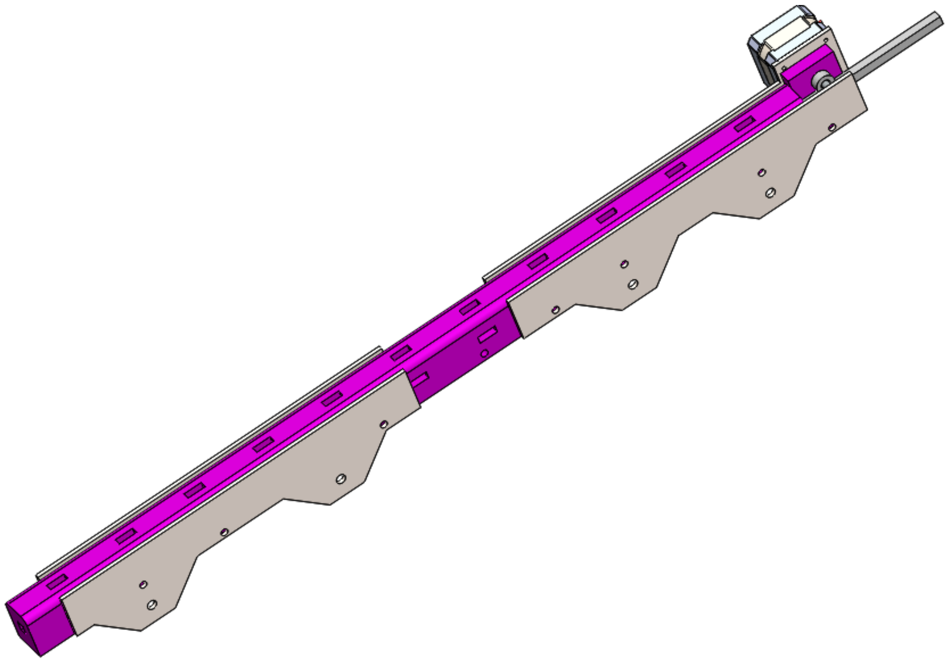


Figure 23: Motor Igniter System

4.7 Electronics

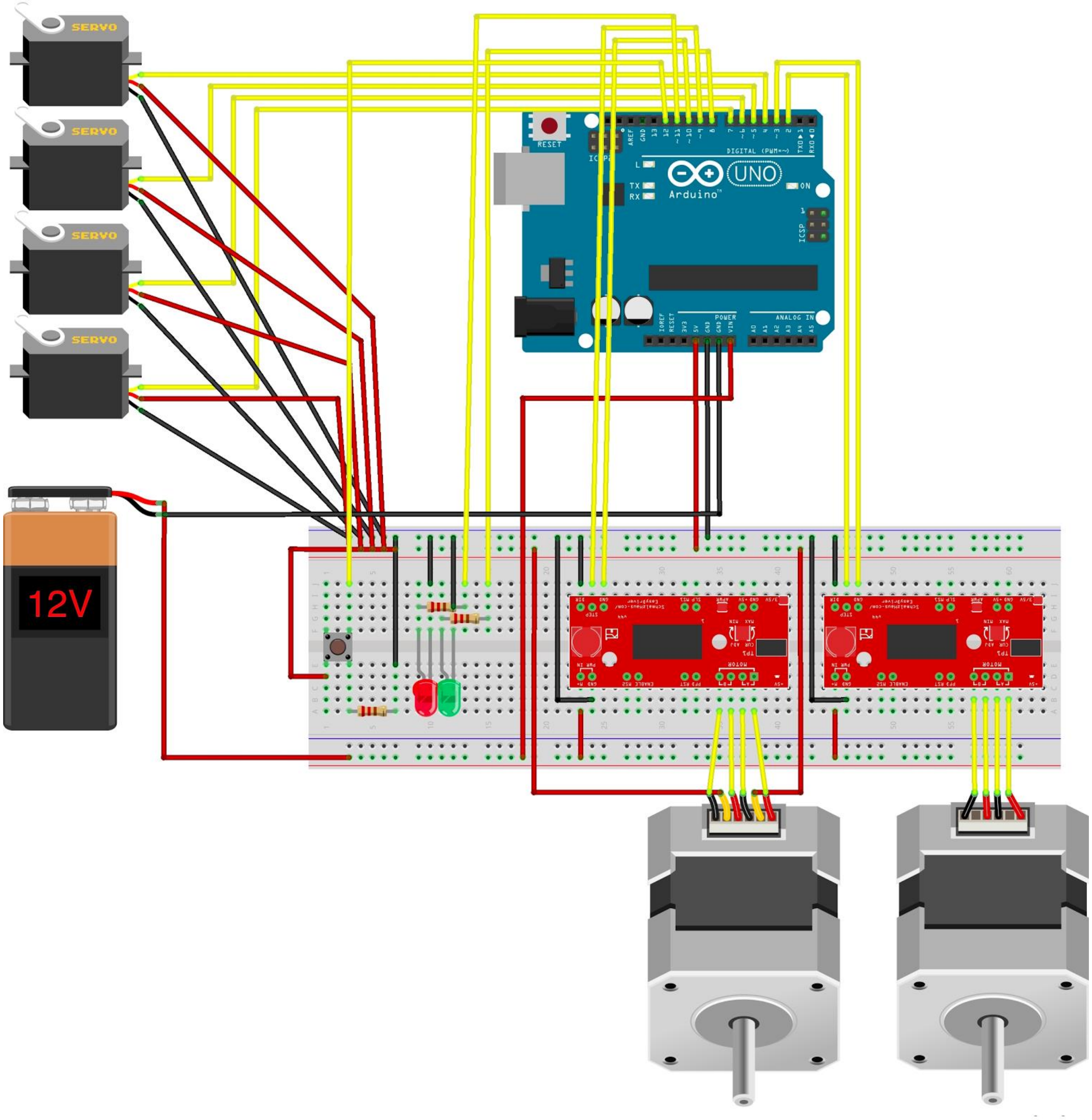
The major components of the AGSE electronics are: 4 servo motors for the payload insertion system, a unipolar stepper motor for the RES, and a bipolar stepper motor for the IIS. The minor components are 2 LEDs and a button to start and stop the program. An Arduino based system will be used to control the components because of its easy-to-use hardware and software. Specifically, an Arduino Uno-R3 will be used as the microcontroller for the AGSE. The combination of all the components of the AGSE occupy 13 digital I/O and 5 analog I/O. The Arduino Uno-R3 contains 14 digital I/O and 6 analog I/O. Also, the Uno-R3 has an operating voltage of 5V, which will work more efficiently with the motors than the 3.3V that some other Arduinos use.

4.7.1 Power

The entire system will be powered by a 12V - 10.5Ah lead acid battery. This battery has enough power to run the entire system for up to 45 minutes. Also, the Arduino Uno-R3 can run through an external voltage of up to 20V, but the recommended maximum is 12V. This makes this battery the ideal power source for the AGSE.

4.7.2 Microcontroller

The Arduino Uno-R3 will be connected as seen in the figure below. Each servo motor can directly function as input to the Arduino, but stepper motors cannot because they require a different operating voltage from the Arduino. The two drivers shown in the figure below are used to convert the operating voltage of the Arduino to the operating voltage of each specific stepper motor. All the minor components can also be connected directly to the Arduino.



Each component operates at a different current; this can be seen in the table below. The total current needed to run every system works out to be 2850 mA. Because of the 10.5 Ah from the battery, the total time the battery can power the AGSE is 2.58 hours. This was calculated using the formula:

$$Time = \frac{Battery\ Capacity}{Consumption} * .7.$$

The .7 is used to account for all the external factors that can affect the battery life. Because not every component is running at all times, this battery life should be significantly higher.

Arduino Component	***Quantity***	***Total Operating Current***
Servo Motor	4	400 mA
Unipolar Stepper Motor	1	2000 mA
Bipolar Stepper Motor	1	330 mA
LED	2	80 mA
Button	1	40 mA

Total: 2850 mA

As a safety feature, the Arduino power source will be connected through a switch. In case of any malfunction, this switch can immediately turn the Arduino off and shut down the entire system.

4.8 Component Testing

As of the PDR, the AGSE has only one scheduled test to validate the arm-spool mechanism for the RES. To test the RES, the team needs to construct a preliminary version of the frame and lifting mechanism. It will include spool, wire, and motor components, as well as the lifting arm and hinges. The first test will analyze the strength and durability of the RES by applying a 30lbs weight in place of the rocket. We will record whether or not the RES can hold the weight stationary at different angles of incline, including the final 85 degrees. The second test will analyze the speed at which the rocket is raised by timing the amount of time it takes to lift a 30lbs weight to final position. The third test determines the optimal placement for the spool in relation to the frame to yield the greatest torque on the cable to lift the rocket.

5 Flight Systems

5.1 Overview

Skyron's Flight System is responsible for ensuring we reach our target apogee through the ATS, track the location of the launch vehicle in real time, and record Skyron's flight data. The Flight Systems will incorporate a wide range of technologies to acquire the necessary data to activate the recovery system and the ATS.

5.2 Success Criteria

Table 17: Mission Success Criteria for Flight Systems

Requirement	*Design Feature to Satisfy Requirement*	*Requirement Verification*	*Success Criteria*
The vehicle shall not exceed an apogee of 5,280 ft.	Drag from the ATS system	Subscale flight test	Apogee within 1% of target
The vehicle will be tracked in real- time for location and ground recovery	GPS module will be used in the vehicle and base station	Subscale flight test	The vehicle will be located on a map after it lands for recovery
The data of the vehicle's flight will be recorded	Sensors will save data into a memory card	Subscale flight test	The data will be recovered and readable after flight

5.3 Flight Systems Avionics Bay

The Avionics bay will house the components in charge with the recovery system, ATS system, and data collection system. Skyron's Avionics Bay (AB) is where all the board readings, measurements and information is processed. To house all of the necessary avionics components located in Table 18, the AB will be placed on a 11" x ⅛" vertical plywood board attached perpendicularly to a G10 Fiberglass 5in Diameter hatch (Figure 25). This slot-vertical board hatch assembly will then be screwed in place, using standard issue screws with ⅛" diameter, to an inner body tube. The goal of the new dual slot feature with screws is to improve overall hatch security during flight (Figure 24).

Table 18: Avionics Components

Part	*Function*
Stratologger SL100	Altimeter - used to receive and record altitude
MMA8452Q	Accelerometer - used to receive and record acceleration
mbed LPC 1768	Microcontroller - used to receive sensor data to compute and control the ATS system
Eggfinder TX/RX Module	GPS module - used to track the rocket in real time
9V Alkaline Batteries	Used to power all Avionics components
3.7V Lithium-Polymer Batteries	High discharge batteries used for the solenoids

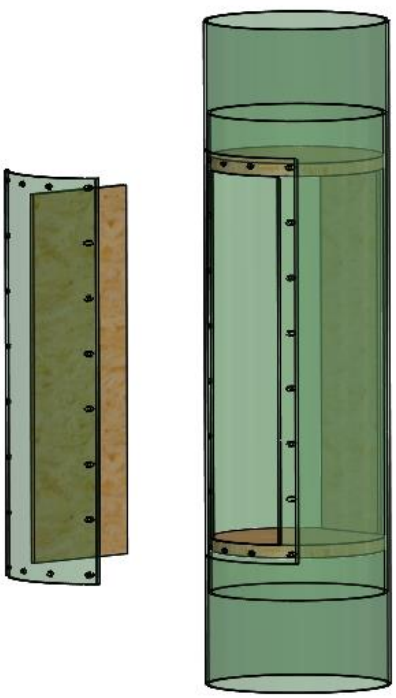


Figure 25: Avionics Bay in an Open Configuration

Figure 24: Avionics Bay in a Closed Configuration

5.4 Altimeters

We will be using two StratologgerCF altimeters that record data at a rate of 20 samples per second and store it for later use. They also include a Data I/O connector which allows real-time altimeter data to be sent to the onboard flight computer. Table 19 lists the different ports of StratologgerCF and briefly describes the functionality of each.

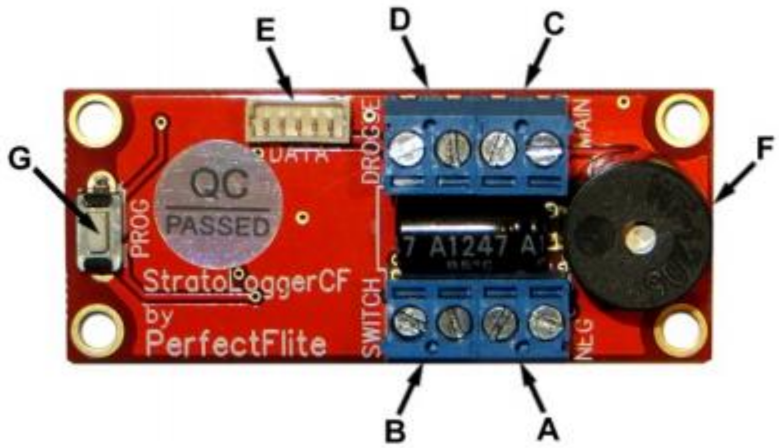


Figure 26: StratologgerCF

Table 19: Stratologger Port Details

Port	*Name*	*Description*
A	Battery	Connect a 9V battery here
B	Power Switch	Connect a power switch here
C	Main Ejection Output	Connect to match for deployment
D	Drogue Ejection Output	Connect to match for deployment
E	Data I/O Connector	Connect to flight computer for real-time data transfer
F	Beeper	Audibly reports setting via a series of beeps
G	Preset Program Button	Not used

These altimeters are functional up to 100,000 feet and deploy both main and drogue chutes. Figure 27: Electrical Schematic of Altimeter System represents the electrical process by which both the main and drogue parachutes are deployed.

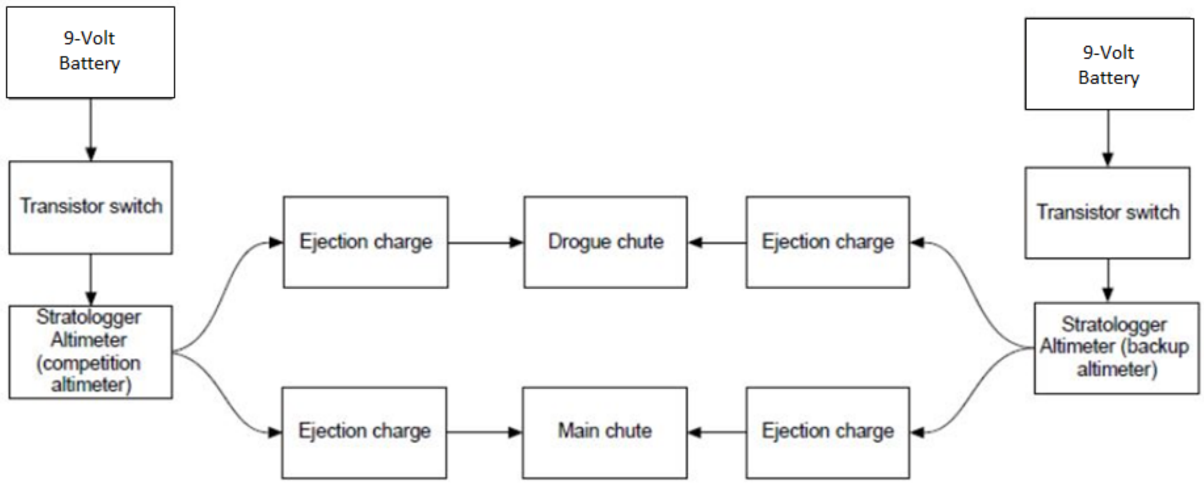


Figure 27: Electrical Schematic of Altimeter System

5.5 Apogee Targeting System Electronics

Two altimeters and one accelerometer will be the only sensors used to feed information to the controller in order to store the information, and use it to ensure it will reach apogee. The heart of the avionics will be the microcontroller. We will use the MBED NXP LPC1768. The altimeters will send data serially to the MBED while the accelerometers will send data through I2C ports. The MBED will run computations to store correct values and use those values to make flight

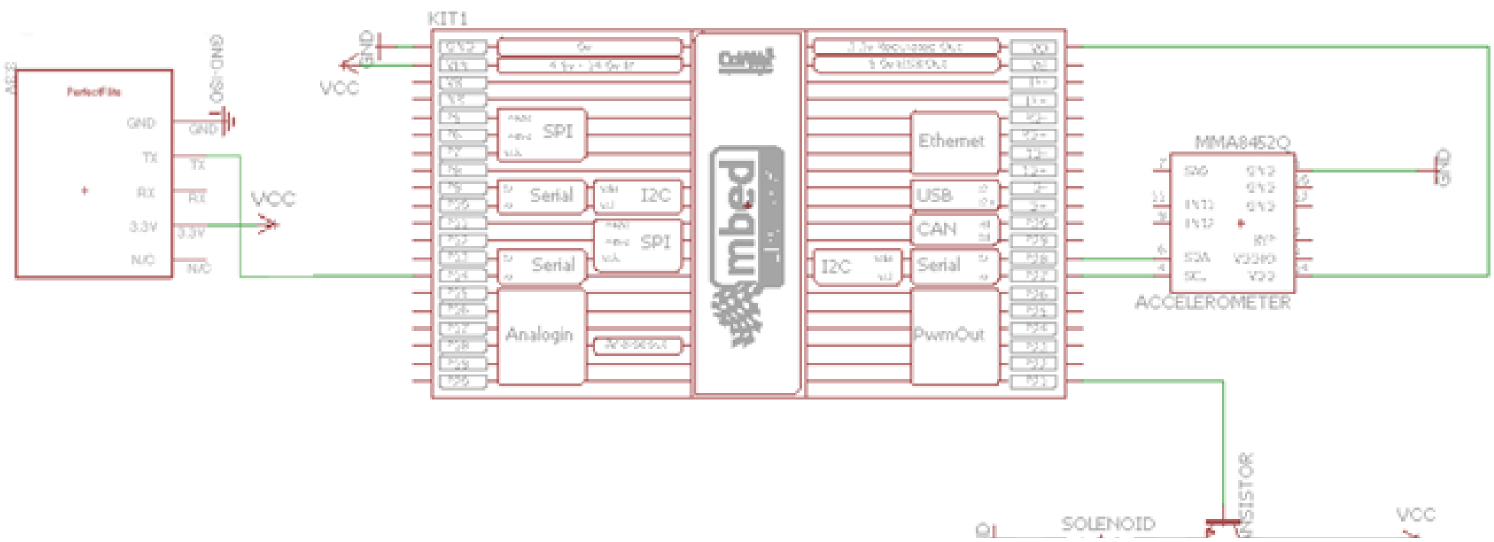


Figure 28: EagleCAD of main components

adjustments. The connections of the avionics section, along with the separate GPS tracker, are shown in the simplified diagram of Figure 28. Finally, the schematic with the main components are shown in Figure 29.

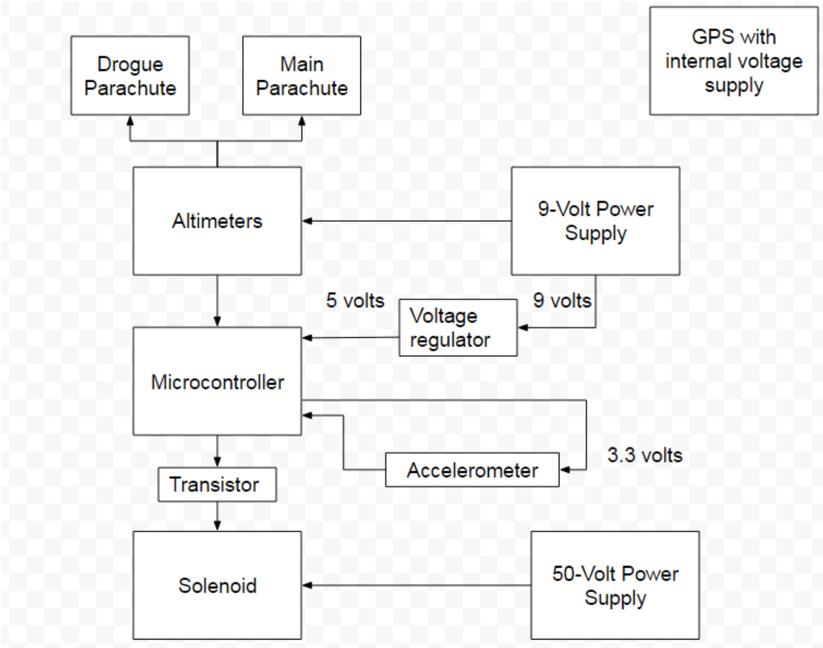
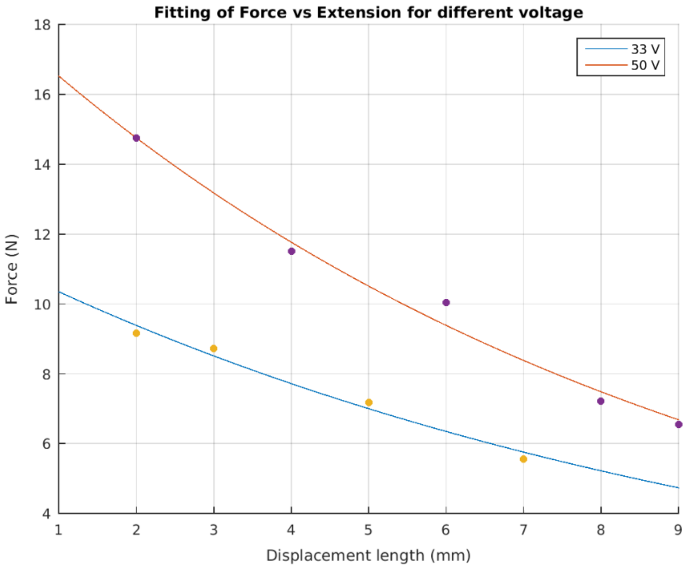


Figure 29: Overall Schematic of Flight Systems

5.6 Component Testing

To test the solenoids used in the Apogee Targeting System, we designed a simple force test to see how much force the solenoid could generate. The solenoid was tested with how much weight (a container with a fixed amount of water) it could pull/push in a vertical position. The force was measured by finding the maximum amount of water that the solenoid could lift at each displacement value The following graph illustrates the result of the test.



This graph shows the results of an experiment to test an individual solenoid's force rating when powered by a 50V source and a 33V source. The x-axis represents the displacement of the starting position of the solenoid and the y-axis measures the resulting force. The general of the graph is that the lifting power of the solenoid increases exponentially as the starting displacement increases.

5.7 GPS

The GPS will be the telemetry system's most important sensor. We will use an Eggfinder GPS tracker to send NMEA data to stream the rocket's position as it launches and lands. The module transmits data in the 900 MHz license-free ISM band at 100mW. The module sends packets in 9600 baud, 8 bits, and no parity. The module will be in a separate compartment within the avionics bay. It will be shielded by placing aluminum sheet between the GPS tracker and the rest of the compartments.

5.8 Power

The rocket's avionics bay will be powered by 9V batteries for the microcontroller, Stratologgers, and GPS each having their own 9V source. The solenoid ATS be powered separately by a 50V source comprised of either 9V or high power Li-Po batteries. Here are some considerations for each battery type:

Table 20: Different Battery Configurations

Battery	*Total Voltage*	*Number*	*Weight*	*Max discharge*	*Volume*	*Pros*

9V	56	6	320g	500 mA	117.17 cm^3	Easy Assembly
Li-Po (3.7V)	51.8	14	252g	10 A	167.09 cm^3	Rechargeable, Customizable Design

6 Safety

6.1 Overview

Team A.R.E.S. is dedicated to maintaining safe operating conditions for all team members and anyone involved in competition activities. Under the tutelage of the Safety Officer, Stephen Kim, Team A.R.E.S. will undergo rigorous safety briefings to ensure the integrity and safety of the entire team and equipment is unchanged. During manufacturing, fabrication, and testing of rocket vehicle and AGSE components, it is important to identify the hazards of your environment, and how following safety procedures and protocols can prevent accident and injury to oneself or damage to competition hardware. When working with construction equipment, Team A.R.E.S. members are instructed to work in minimum team sizes of two. This ensures that one team member would be available to provide immediate assistance or quickly get help should an incident occur while using the equipment. The Invention Studio, where team members use the necessary equipment for manufacturing and fabrication, is equipped with first aid kits, fire extinguishers, safety glasses, and expert supervision for the use of all equipment. During physical testing of the rocket structure, and during ejection charge testing, team members will wear safety glasses, have a first aid kit and fire extinguisher on hand, and have licensed safety officials present. In order to use the machines, all team members have been briefed on the proper protocols and procedures of using the lab machines. Risk identification and mitigation techniques are used to assess the dangers of tools and activities to personnel, and how they may create safe operating conditions. To that end, Table XX lists the procedure to identify what hazards and risks may exist and how to minimize the chances of occurrence.

Step Name	***Step Definition***
1. Hazard Identification	Team will collectively brainstorm to identify any possible hazards that the team may encounter.
2. Risk and Hazard Assessment	Team will determine the severity and probability of consequences in case the hazard were to be encountered. How to approach each hazard will also be reviewed.

3. Risk Control and Elimination	After the hazard has been identified and assessed, a plan will be put in place to ensure the hazard will not occur.
4. Reviewing Assessments	The entire process will be repeated for any new hazards or existing hazard that needs to be updated.

Table XX lists the hazards, risks, and mitigations that may be experienced by the team.

Hazard	*Severity*	*Likelihood*	*Mitigation & Control*
Batteries Explode	Burns, skin and eye irritation	Low	Wear safety glasses and gloves when handling. Make sure no shorts exist in circuits using batteries. If battery gets too hot, stop its use and disconnect it from any circuits.
Black Powder	Explosions, burns, skin and eye irritation	Medium	Wear safety glasses, gloves when handling black powder. Be careful when pouring black powder. Operate in a static-free environment
Dremel	Cuts and scrapes	Medium	Only operate tools with supervision of teammates. Use tools in appropriate manner. Wear safety glasses to prevent debris from getting into eyes.
Power Tools	Cuts, punctures, and scrapes	Medium	Only operate power tools with supervision of teammates. Use tools in appropriate manner. Wear safety glasses to prevent debris from getting into eyes.
Epoxy/Glue	Toxic fumes, skin and eye irritation	High	Wear gloves, nitrile for epoxy, face masks, and safety glasses. Work in well ventilated area.
Exacto/Craft Knives	Cuts, serious/fatal injury	Medium	Only use knives with teammate supervision. Only use tools in appropriate manner. Do not cut in the direction towards oneself.

Fire	Burns, serious/fatal injury	Low	Keep a fire extinguisher nearby. If an object becomes too hot, or does start a fire, remove power (if applicable) and be prepared to use the fire extinguisher.
Hammers	Bruises, serious/fatal injury	Medium	Be aware of where you are swinging the hammer, so that it does not hit yourself, others, or could bounce and hit someone.
Hand Saws	Cuts, serious/fatal injury	Medium	Only use saws with teammate supervision. Only use tools in appropriate manner. Wear safety glasses to prevent debris from getting in eyes.
Waterjet Cutter	Cuts, serious/fatal injury, flying debris	Low	Only operate under supervision of Undergraduate/Graduate Learning Instructors, and with other teammates. Follow proper operating procedures, wear safety glasses.
Improper dress during construction	Cuts, serious/fatal injury	High	Wear closed toed shoes, tie back long hair, do not wear baggy clothing.
Power Supply	Electrocution, serious/fatal injury	Medium	Only operate power supply with teammate supervision. Turn off power supply when working with circuitry.

6.2 Launch Vehicle Safety

Table XX lists the possible failure modes and respective failure prevention procedures that the Launch Vehicle may encounter during testing.

Potential Failure	***Effects of Failure***	***Failure Prevention***
Apogee Targeting System (ATS)	Vehicle will not reach target altitude	Test ATS using subscale launch vehicles

Body structure buckling on takeoff	Launch failure, damage to launch vehicle, unable to be reused, flying shrapnel towards personnel/crown	Test structure to withstand expected forces at launch with a factor of safety. Have proper sized couplers connecting sections.
Drogue separation	Main parachute will deploy at high speed and may rip or disconnect from vehicle, launch vehicle may become ballistic	Perform ground test and flight test.
Fins	Fins could fall off, causing unstable flight. Fins break or disconnect from launch vehicle, unable to be classified as reusable	Test fin at attachment points using expected forces to ensure strength of attachment method. Do not have fins with sharp pointed edges, ensure parachute is large enough to minimize impact kinetic energy, test fin at attachment points using expected forces to ensure strength of attachment.
Ignition failure	Failure to launch	Follow proper procedures when attaching igniter to AGSE.
Launch buttons	Launch vehicle will separate from rail, causing an unstable flight	Ensure launch rail is of proper size to accommodate the buttons, ensure buttons slide easily into rail.
Main parachute separation	High impact velocity may damage vehicle and make it unrecoverable, vehicle may become ballistic causing serious injury or death	Perform ground test and flight test to ensure veracity of deployment method.
Motor failure	Motor explodes, damaging launch vehicle/AGSE beyond repair	Follow NAR regulations and manufacturer's instructions when assembling motor. Assemble motor under supervision.
Motor retention	Motor casing falls out, lost motor case, could damage persons/property	Test reliability of motor retention system

Payload separation	Main parachute may not deploy correctly, higher impact velocity may damage launch vehicle, or cause personal/property damage	Perform ground and flight test to ensure veracity of deployment method
Thrust plate failure	Motor goes through vehicle, damage to vehicle, causing it to be not reusable	Test plate and attachment method to withstand expected launch forces with a factor of safety

6.3 AGSE Safety

Potential Failure	***Effects of Failure***	***Failure Prevention***
Payload is not secured in bay	Payload will bounce inside payload bay, disrupting flight	Test various plastic clip dimensions to find best fit
RES is not stable while raising	Rocket will not be raised, and potentially the motors will be broken	Test subsystem, add counterweights to reduce necessary force from motor, and add more framing to increase stability
RES does not stay upright	Launch vehicle will fall unpredictably	Perfect ratchet system, ensure tension in steel cable
Electronics short circuit or are overloaded	System will lose control	Fuses will protect electronics, subscale testing will prevent short circuits and overloads

6.4 Environmental Concerns

As already mentioned in Section 6.1, the same methodology to identify and assess risks for vehicle and payload safety will be used to identify hazards for constructing various flight and testing components. A Material Safety Data Sheet (MSDS) is on hand for all materials used in the construction of components, and team members have been briefed on best practices for creating a safe workplace.

7 Project Plan

7.1 Project Schedule

Team ARES's project is driven by the design milestone's set forth by the NASA SLI Program Office. These milestones – and their dates – are listed in Table XX. Additionally, a preliminary Gantt chart is provided in Appendix 1. It is important to note that due to the complexities of both the launch vehicle and AGSE designs, the Gantt chart will contain only high-level activities. In order to visualize the major tasks/steps in our design, the Team will utilize a PERT Chart/Network Diagram. This will allow for the identification of the critical path(s), and any alternative paths.

Table XX Design Milestones set by SLI Program Office

Deadline	***Date***
Proposal	11 SEPT
Web Presence Established	23 OCT
PDR Documentation	6 NOV
PDR Teleconference	9-20 NOV
CDR Documentation	15 JAN
CDR Teleconference	19-29 JAN
FRR Documentation	14 MAR
FRR Teleconference	17-30 MAR
Competition	13-16 APR
PLAR Documentation	29 APR

7.2 Schedule Risk

7.2.1 High Risk Tasks

Two items have been identified as "High Risk Items." These are:

- Launch Vehicle ATS Design – failure will lead to overshooting the intended target
- Recovery System Design – failure will result in potential disaster for launch vehicle

Table XX identifies the mitigations for these two items:

High-Risk Task	*Potential Impact on Project Hermes*	*Mitigation*
Launch Vehicle ATS Design, Fabrication, and Testing	1) Schedule Impact 2) Budgetary Impact 3) Not qualifying for Competition Launch	1) Ensure personnel have direct and free access to experienced personnel on and off the team 2) Ensure personnel have the necessary knowledge to effectively utilize simulation and analysis tools 3) Ensure personnel are familiar with relevant fabrication techniques
Recovery System Design, Fabrication & testing	1) Excessive Kinetic Energy during landing resulting in damage to the launch vehicle 2) Failure to deploy drogue and/or main parachute resulting in a high energy impact with the ground destroying the launch vehicle	1) Ensure recovery system lead has direct and free access to experienced personnel on and off the team 2) Provide real time feedback of the design decision to ensure all recovery-related requirements and meet with at least a 5% margin wherever possible 3) Ensure proper manufacturing techniques are utilized during the fabrication of the recovery system

7.2.2 Low-to-Moderate Risks Tasks

The “low-to-moderate risk tasks” are considered to be those risks that pose a risk to either the project schedule and/or project budget but little to no risk of not meeting the Mission Success Criteria in Table XYZ. The risks and mitigations are provided in Table XX.

Risk Task	*Potential Impact on Project Hermes*	*Mitigation*
Fabrication of Launch Vehicle Sections	1) Schedule Impact 2) Budgetary Impact 3) Not qualifying for Competition Launch	1) Ensure personnel have direct and free access to experienced personnel on and off the team 2) Ensure personnel have the necessary knowledge to effectively utilize simulation and analysis tools 3) Ensure personnel are familiar with relevant fabrication techniques
Full-Scale Launch Vehicle Test Flight	1) Schedule Impact 2) Budgetary Impact 3) Not qualifying for Competition Launch	1) Ensure Launch Procedures are established practiced prior to any launch opportunity. 2) Have a sufficient number of launch opportunities that are in different geographical areas as to minimize the effects of weather on the number of launch opportunities.
Flight Computer Fabrication/ Calibration	1) Budgetary Impact 2) Not able to collect in-flight data	1) Ensure proper manufacturing techniques are observed during fabrication. 2) Ensure Manufacturing and Fabrication Orders (MFO's) are sufficiently detailed for the task.

7.3 Critical Path

The critical path for the next section of the NASA SLI Program involves cooperation across all four major fronts: Launch Vehicle, AGSE, Flight Systems, and Project Plan

8 Project Budget

8.1 Funding Plan

In order to fund the 2015-2016 competition cycle, Team ARES have sought sponsorships from academic and industry sources. The current sponsors of Team ARES and their predicted contributions can be found in Table XX. Additionally, the Team has also received a dedicated room in which the Team can construct and store their launch vehicle, payload, and other non-explosive components. All explosive components (i.e. black power) are properly stored in Fire Lockers in either the Ben T. Zinn Combustion Laboratory or the Ramblin' Rocket Club Flammable Safety Cabinet. Furthermore, the Georgia Tech Invention Studio will support all fabrication needs of the Team.

Sponsor	***Contribution***	***Date***
2014-2015 Unused Funds	$1,200	--
Georgia Space Grant Consortium	$1,000	Nov 2015
Georgia Tech School of Aerospace Engineering	(est.) $1,000	Dec 2015
Georgia Tech Student Gov't Association	(est.) $1,000	Dec 2015
Corporate Donations	(est.) $2,000	Jan 2016
Orbital ATK Travel Stipend	(est.) $400	Apr 2016
Total	$6,600	

8.2 Current Sponsors

Table XX lists the current sponsors of Team ARES and their contributions

Sponsor	***Contribution***
Georgia Space Grant Consortium	Financial Contribution for general project expenses
Advanced Circuits	Manufacturing of Flight Systems throughout design process

8.3 Projected Project Costs

The projected project budget is approximately $5.872.38 – below the projected fundraising goal by just over 11%. This cost was derived using the actual project costs from the 2015-2016 NASA SLI competition cycle and a 15% margin was added to the Launch Vehicle and Flight Systems costs during the previous project cycle. The project budget breakdown is listed numerically in Table 21: Budget Summary and graphically in Figure 30.

Table 21: Budget Summary

Section	***Cost***
Avionics	$700.00
AGSE	$808.60
Launch Vehicle	$963.78
Testing	$900.00
Motor	$1,000.00
Operations	$1,000.00
Outreach	$500.00
Total Budget	$5,872.38

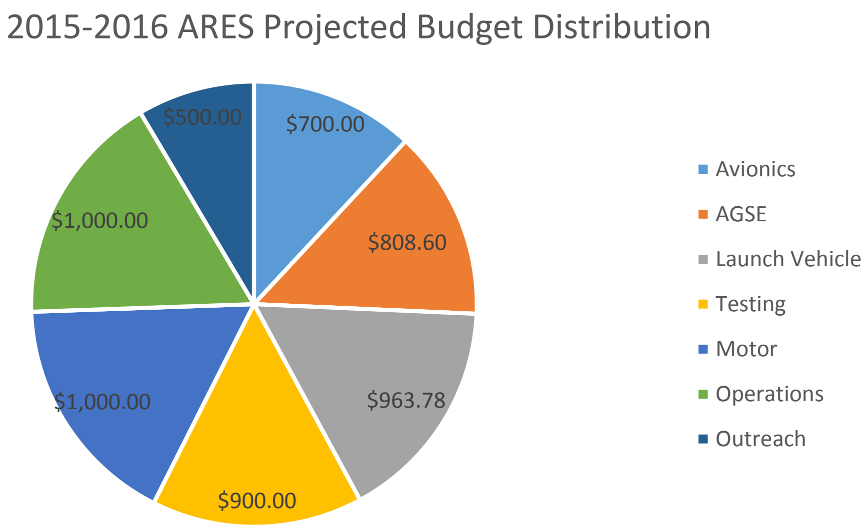


Figure 30: Budget Summary

8.4 Budget Summary

Table 22 lists the expenses as of the PDR Milestone. The summary is broken down into five (5) main categories: Launch Vehicle, AGSE, Flight Systems, Operations, and Testing. The Launch Vehicle and Flight Systems categories are further broken down into two (2) subcategories: Flight Hardware and Testing. Operational expenses include: non-system specific test equipment, Team supplies, non-system specific fabrication supplies, as well as any travel and outreach expenses. Any system-specific equipment bought for testing is charged against that specific system.

Table 22: Expenses as of PDR

Subsystem	***Amount***
Launch Vehicle	$0
Flight Systems	$14.53
AGSE	$92.69
Operations	$20.00
Testing	$2.50
Total	$129.72

As of PDR, no purchases have been made for the Launch Vehicle, however with the Subscale launch in two weeks, purchases will be made sooner rather than later.

9 Education Engagement Plan and Status

9.1 Overview

The goal of Georgia Tech's outreach program is to promote interest in the Science, Technology, Engineering, and Mathematics (STEM) fields. Team A.R.E.S. intends to conduct various outreach programs targeting middle school Students and Educators. Team A.R.E.S. will have an outreach request form on their webpage for Educators to request presentations or hands-on activities for their classroom. The team plans to particularly encourage requests from schools in disadvantaged areas of Atlanta, with the goal of encouraging students there to seek careers in STEM fields.

9.2 Atlanta Maker's Faire

Team ARES had a booth at the Atlanta Makers Fair, a fair in which various craftsman from the community and Georgia Tech assemble to show off their accomplishments. The intent of this program is to give clubs, organizations, and other hobbyists the opportunity to show others their unique creations and skills. The event is open to the entire Atlanta community and had a large attendance this year. The Team ARES booth had a display of our various rockets, as well as a station for children to use stomp rockets. Our booth had 45-60 middle school aged children attend and participate in the stomp rocket activity across the two days.

9.3 FIRST Lego League

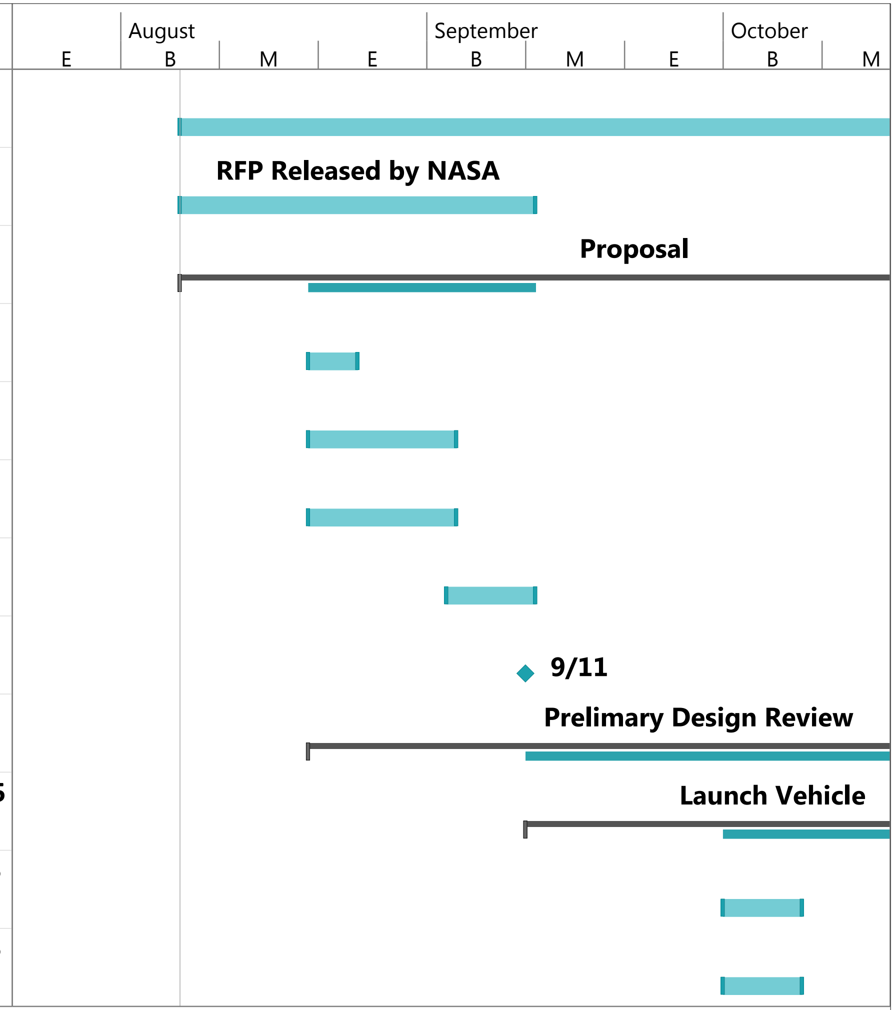
FIRST Lego League is an engineering competition designed for middle school children in which they build and compete with an autonomous MINDSTORMS robot. Annual competitions are held centered on a theme exploring a real-world problem. Team A.R.E.S. plans to have a booth at the Georgia Tech FIRST Lego League Tournament, with the goal of illustrating how the skills and ideas utilized in the competition translate to real world applications; in particular, a rocket with autonomous capabilities. The team also plans to help judge the tournament.

9.4 CEISMC GT

The Center for Education Integrating Science, Mathematics, and Computing (CEISMC) is a partnership uniting the Georgia Institute of Technology with educational groups, schools, corporations, and opinion leaders throughout the state of Georgia. Team ARES is dedicated to the enhancement of STEM education and will look forward to partnering with CEISMC and their events in the near future.

10 Appendix I

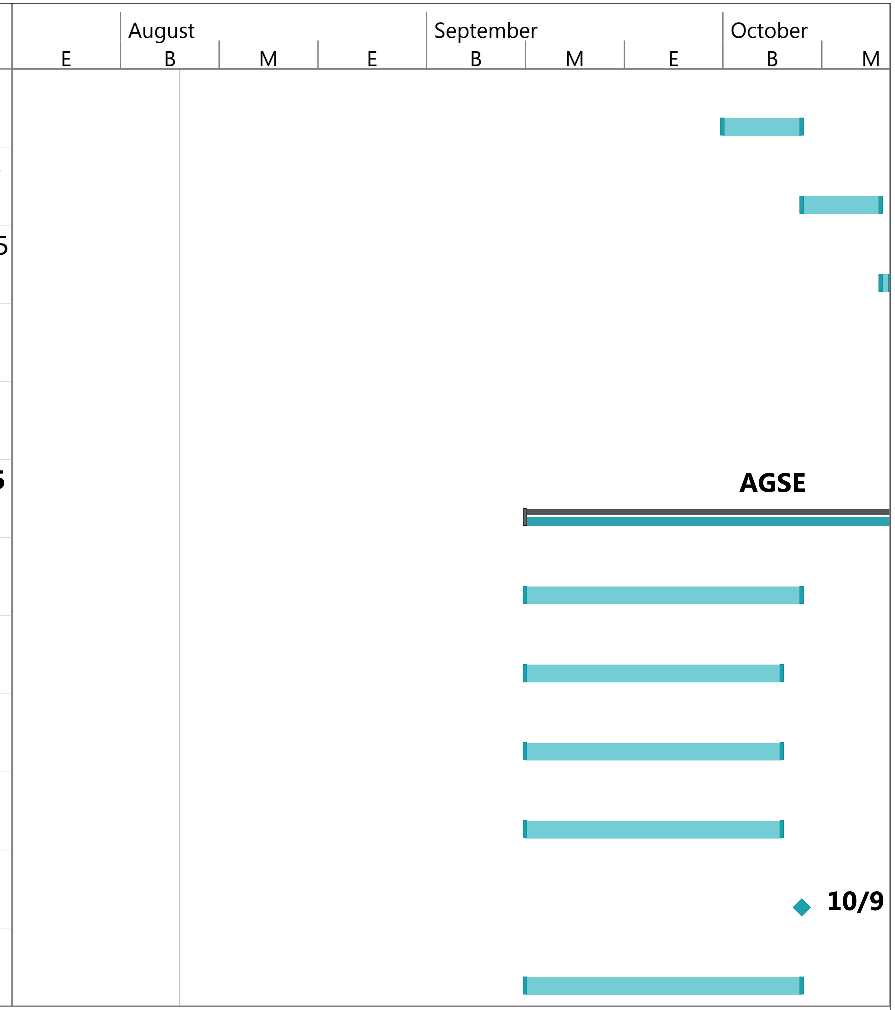
ID		Task Mode	Task Name	Start	Finish
1			NASA SL Competition	Fri 8/7/15	Mon 4/18/16
2			RFP Released by NASA	Fri 8/7/15	Fri 9/11/15
3			**Proposal**	**Fri 8/7/15**	**Fri 11/6/15**
4			Team Formation	Thu 8/20/15	Mon 8/24/15
5			Initial Rocket Design	Thu 8/20/15	Thu 9/3/15
6			Initial AGSE Design	Thu 8/20/15	Thu 9/3/15
7			Internal Proposal Review	Thu 9/3/15	Fri 9/11/15
8			Proposal Submitted	Fri 9/11/15	Fri 9/11/15
9			**Prelimary Design Review**	**Thu 8/20/15**	**Fri 11/6/15**
10			**Launch Vehicle**	**Fri 9/11/15**	**Fri 10/30/15**
11			Avionics Bay Final Design	Thu 10/1/15	Thu 10/8/15
12			ATS Final Design	Thu 10/1/15	Thu 10/8/15



Project: GC 15 MK 1
Date: Fri 11/6/15

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

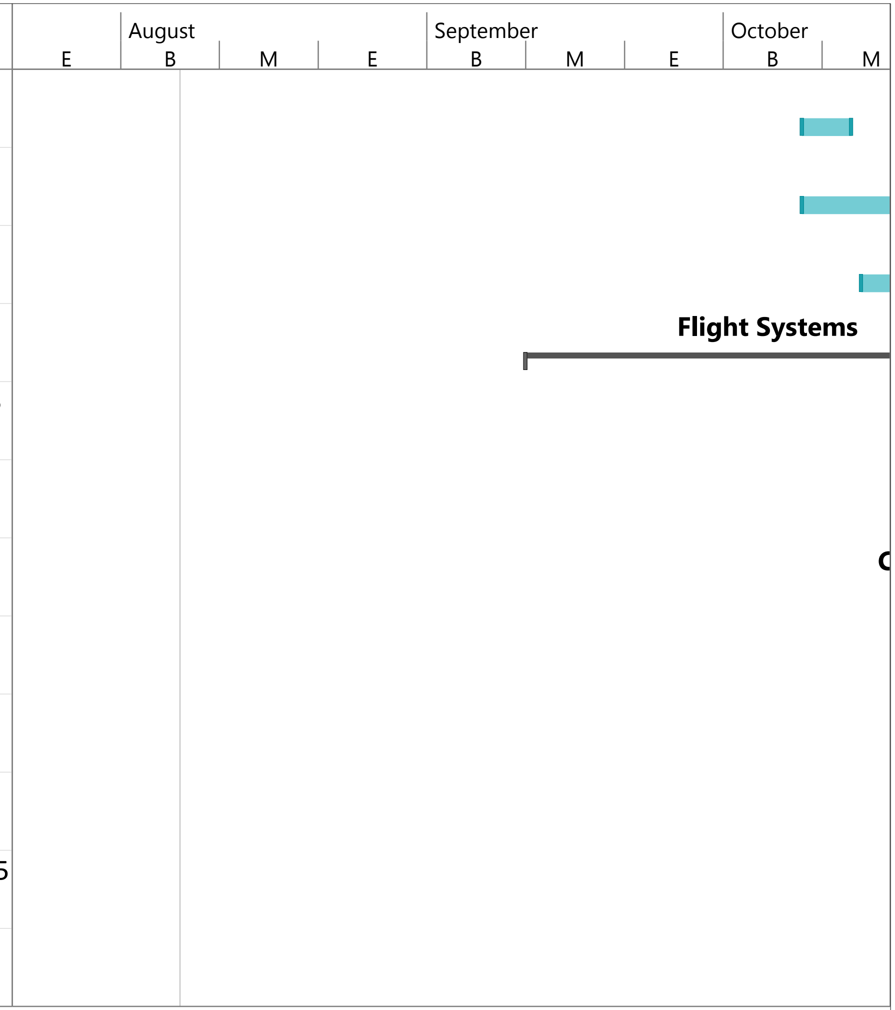
ID		Task Mode	Task Name	Start	Finish
13			Individual CAD Components	Thu 10/1/15	Thu 10/8/15
14			Complete Materials List for Full Scale	Fri 10/9/15	Fri 10/16/15
15			FullScale Design Complete	Sat 10/17/15	Sat 10/17/15
16			Complete Materials List for Sub Scale	Mon 10/19/15	Thu 10/22/15
17			Sub Scale Material Purchase	Thu 10/22/15	Thu 10/22/15
18			**AGSE**	**Fri 9/11/15**	**Fri 10/30/15**
19			Finalize Overall Design	Fri 9/11/15	Thu 10/8/15
20			PLIS Overall Design	Fri 9/11/15	Tue 10/6/15
21			REM Overall Design	Fri 9/11/15	Tue 10/6/15
22			MIS Overall Design	Fri 9/11/15	Tue 10/6/15
23			AGSE Internal Design Review	Fri 10/9/15	Fri 10/9/15
24			Electronic Schematics	Fri 9/11/15	Thu 10/8/15



Project: GC 15 MK 1
Date: Fri 11/6/15

Task
Split
Milestone
Summary
Project Summary
Inactive Task
Inactive Milestone
Inactive Summary
Manual Task
Duration-only
Manual Summary Rollup
Manual Summary
Start-only
Finish-only
External Tasks
External Milestone
Deadline
Progress
Manual Progress

ID		Task Mode	Task Name	Start	Finish
25			Complete Materials List	Fri 10/9/15	Tue 10/13/15
26			SubSystem Testing Planning	Fri 10/9/15	Thu 10/29/15
27			Prelimaniry PLIS Construction	Thu 10/15/15	Thu 10/29/15
28			**Flight Systems**	**Fri 9/11/15**	**Thu 10/29/15**
34			PDR Review	Thu 10/29/15	Thu 11/5/15
35			PDR Submitted	Fri 11/6/15	Fri 11/6/15
36			**Critical Design Review**	**Mon 11/9/15**	**Fri 1/15/16**
37			Flight Systems	Mon 11/9/15	Mon 11/9/15
38			Full Design Implementation	Mon 11/9/15	Mon 11/23/15
39			Full Component Testing	Mon 11/23/15	Mon 11/30/15
40			Recovery System Test	Sat 11/28/15	Sat 11/28/15
41			**Launch Vehicle**	**Mon 11/9/15**	**Fri 1/15/16**



Project: GC 15 MK 1
Date: Fri 11/6/15

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

ID		Task Mode	Task Name	Start	Finish
42			Final Design of Launch Vehicle	Mon 11/9/15	Sat 12/12/15
43			ATS Static Ground Testing	Mon 11/9/15	Fri 11/13/15
44			ATS Wind Tunnel Testing	Sun 11/22/15	Sat 12/12/15
45			Structural Testing	Mon 11/30/15	Sat 12/12/15
46			Full Scale Material Purchase	Mon 11/23/15	Mon 11/30/15
47			Full Scale Material Purchase	Mon 11/16/15	Fri 11/20/15
48			Beginning of Full Scale Construction	Mon 1/11/16	Fri 1/15/16
49			**Flight Readiness Review**	**Thu 1/14/16**	**Mon 3/14/16**
51			Avionics Bay Refinement	Sat 1/16/16	Thu 3/3/16
52			Control System for ATS Refinement	Sat 1/16/16	Thu 3/3/16
53			**Launch Vehicle**	**Mon 1/18/16**	**Thu 3/3/16**
54			Final Launch Vehicle Construction	Mon 1/18/16	Fri 2/19/16

August: E B M E; September: B M E; October: B M

Project: GC 15 MK 1
Date: Fri 11/6/15

Task	Inactive Summary	External Tasks
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Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

ID		Task Mode	Task Name	Start	Finish
55			Full Scale Recovery System Launch	Sat 2/13/16	Sat 2/13/16
56			Full Scale Test Launch	Sat 2/20/16	Sat 2/20/16
57			**AGSE**	**Mon 1/18/16**	**Thu 3/3/16**
58			Finalize Construction of Entire AGSE		

August — E B M; September — E B M; October — E B M

Project: GC 15 MK 1
Date: Fri 11/6/15

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
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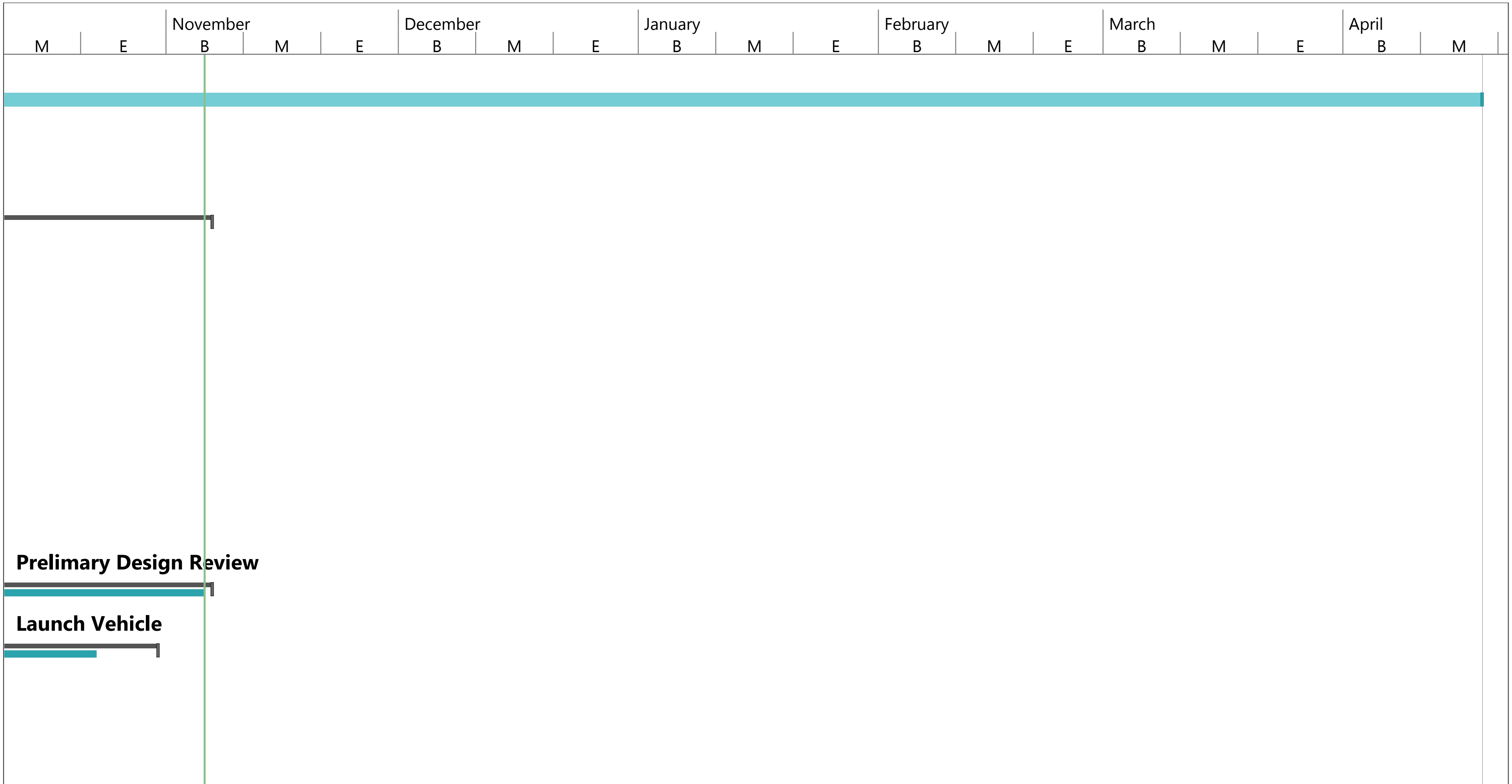

Project: GC 15 MK 1
Date: Fri 11/6/15

Task	Inactive Summary	External Tasks
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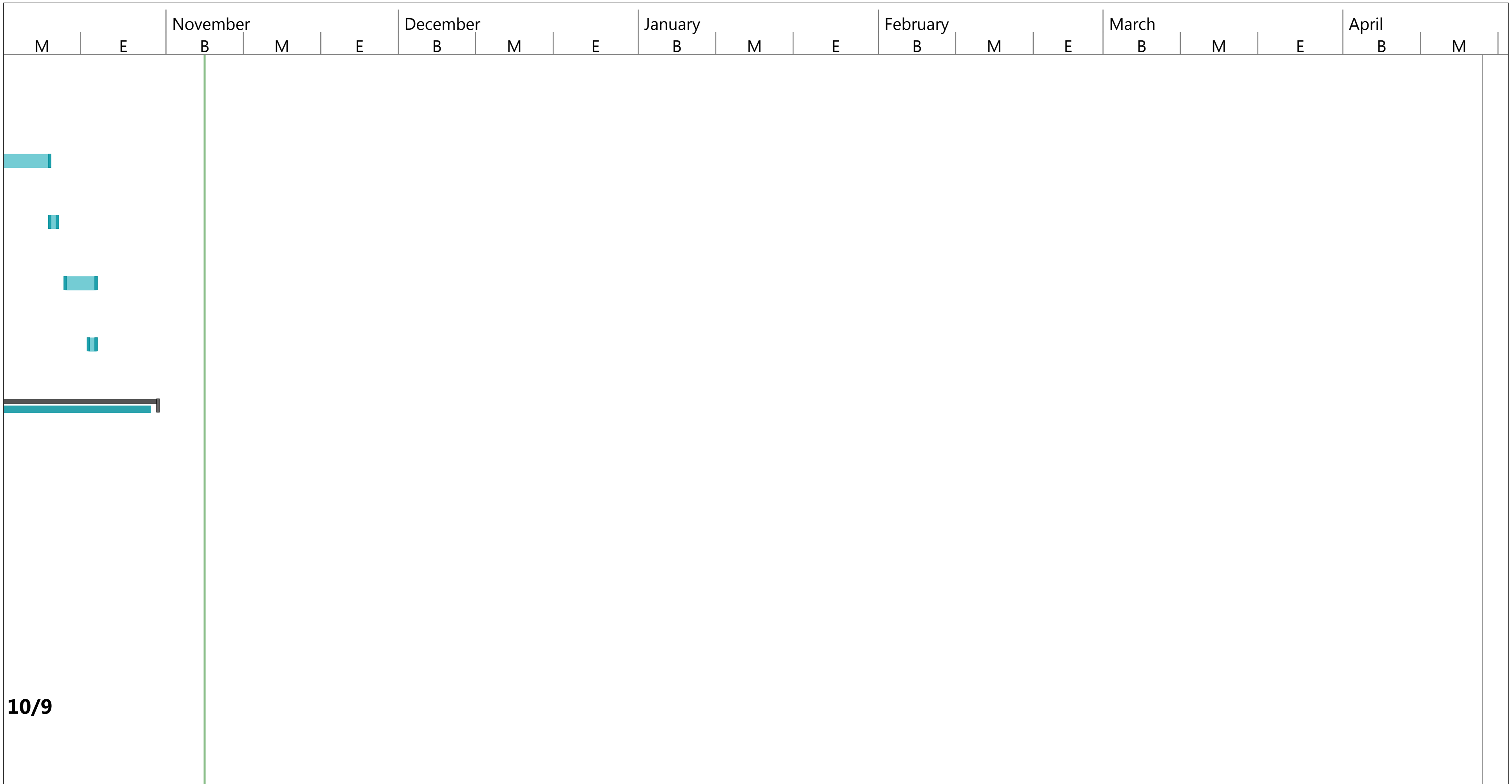

Project: GC 15 MK 1
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Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
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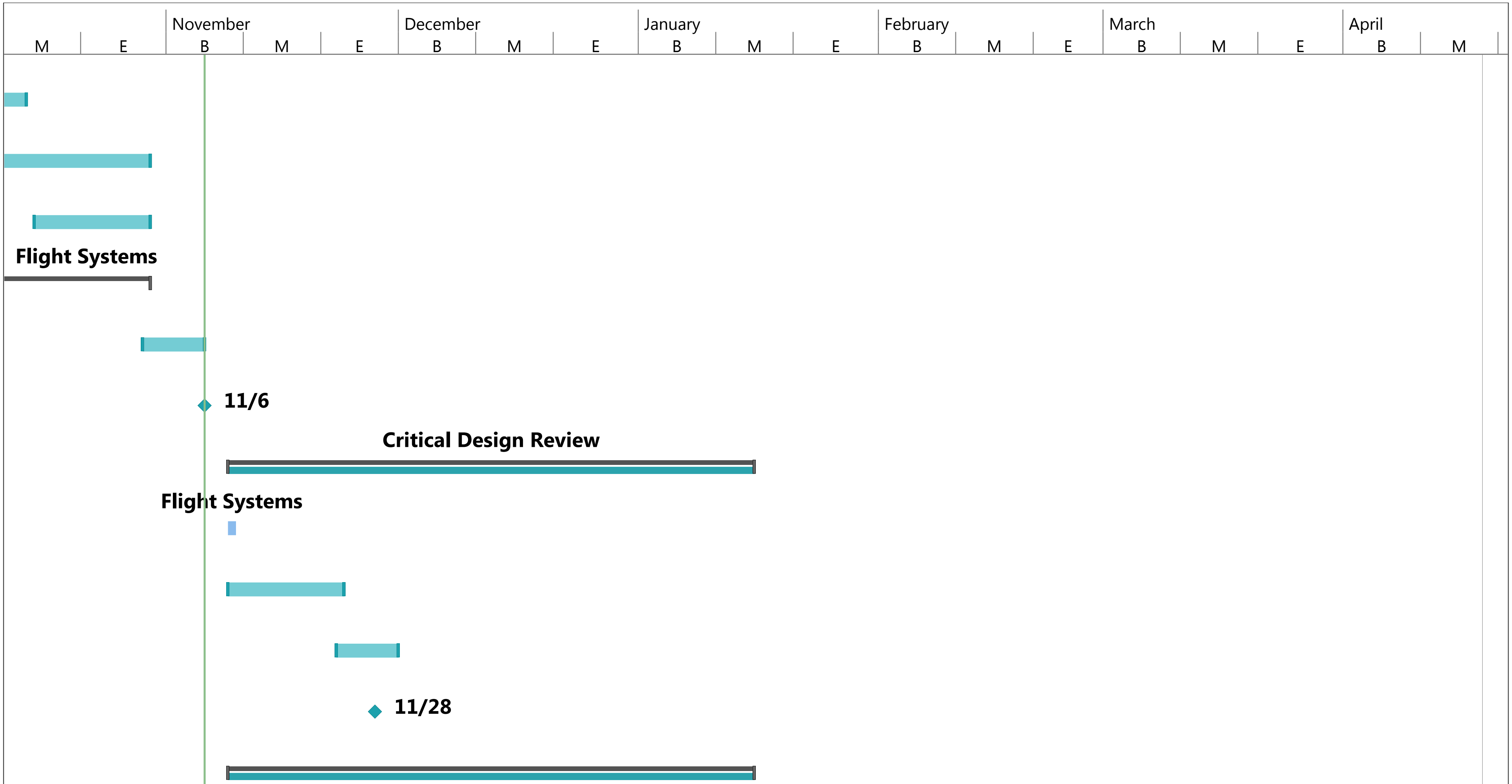

Project: GC 15 MK 1
Date: Fri 11/6/15

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Project Summary
Inactive Task
Inactive Milestone
Inactive Summary
Manual Task
Duration-only
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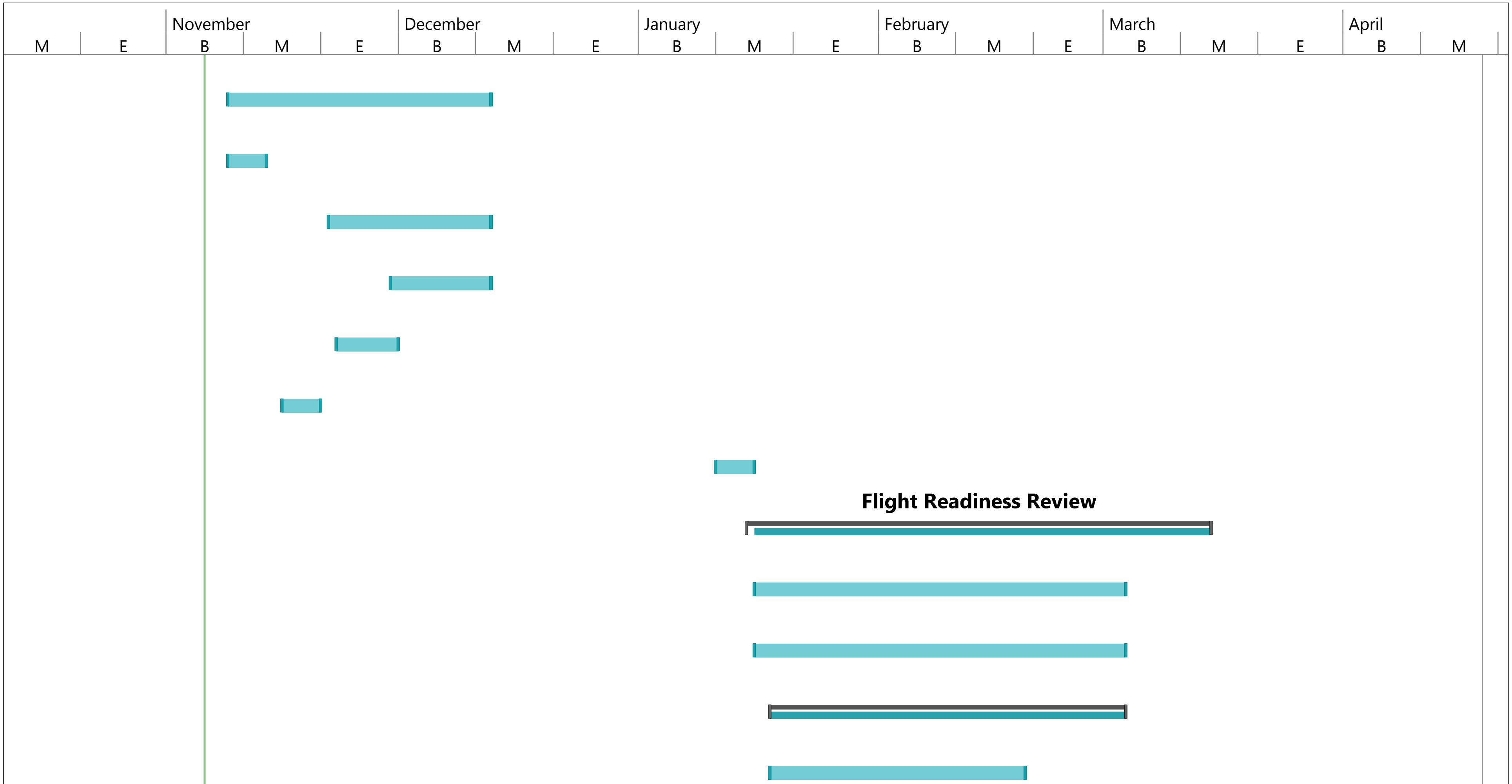
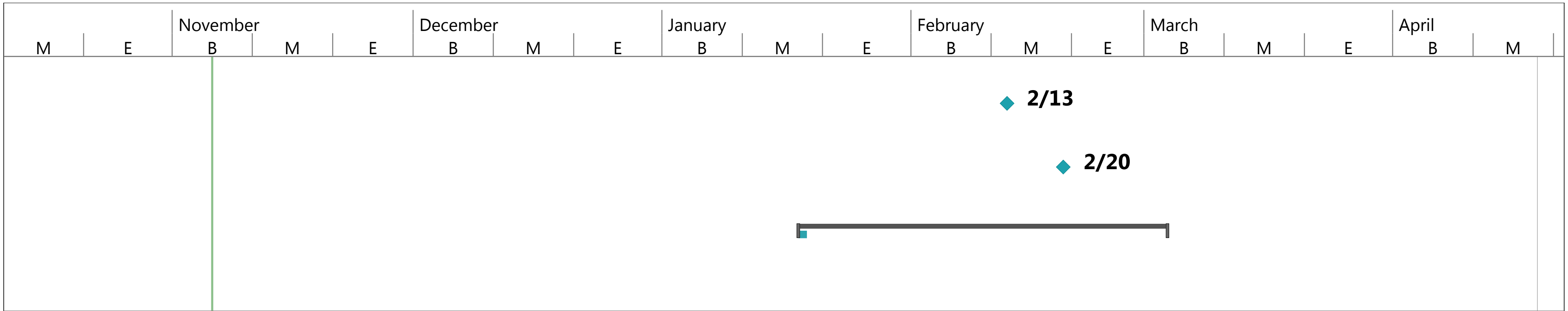
External Milestone
Deadline
Progress
Manual Progress



Project: GC 15 MK 1
Date: Fri 11/6/15

Task		Inactive Summary		External Tasks	
Split		Manual Task		External Milestone	
Milestone		Duration-only		Deadline	
Summary		Manual Summary Rollup		Progress	
Project Summary		Manual Summary		Manual Progress	
Inactive Task		Start-only			
Inactive Milestone		Finish-only			



Project: GC 15 MK 1
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External Milestone
Deadline
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Manual Progress