Project: ARP 142

2014-2015 NASA Student Launch Maxi MAV
Critical Design Review

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Nomenclature

a = Speed of Sound
AGL = Above Ground Level
AGSE = Autonomous Ground Support Equipment
AR = Aspect Ratio
b = Fin Semi-Span
CADD = Computer Aided Design and Drafting
Cd = Coefficient of Drag
C_G = Center of Gravity
CP = Center of Pressure
COS = Control Overwatch System
C_R = Fin Root Length
CS = Control System
C_T = Fin Tip Length
C_N = Coefficient of Drag of nose cone
d = diameter
EA = Each
FOD = Foreign Object Damage/Debris
g = Acceleration Due to Gravity
G = Shear Modulus
IS = Ignition System
L = Length
L_f = Fin Length
LRS = Launch Rail System
LV = Launch Vehicle
m = Mass
M = Moment
MS = Margin of Safety
MoS = Margin of Stability
MSDS = Material Safety Datasheet
N = Number of Fins
NO. = Number
PB = Payload Bay
PCS = Payload Containment System
PPE = Personal Protective Equipment
PRS = Payload Retrieval System
S.T.E.M. = Science, Technology, Engineering, and Math
S = Fin Semi Span

t = Thickness
T = Temperature
X_n = Center of Pressure of nose cone
ρ = air density
λ = Taper Ratio

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Section 1 – Summary of CDR

1.1 Team Summary

Team

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1.2 Launch Vehicle Summary

- Length: 121.25 in
- Diameter: 5.150 in
- Projected Mass: 37.0lb_m (1.15 slugs)
- Motor: AeroTech K1050W
- Recovery System:
    - Drogue parachute will stabilize the descent. Black powder charges will split the Launch Vehicles into its independent sections. The main and payload parachutes will deploy at 1000ft AGL.
    - Drogue Parachute: 24 inch Diameter classic elliptical parachute (Cd of 1.5-1.6)
    - Main Parachute: 84 inch Diameter Iris-Ultra-parachute (Cd of 2.2)
    - Payload Parachute: 48 inch Diameter classic elliptical parachute (Cd of 1.5-1.6)
- Rail Size: 10ft of 1515 Aluminum Extrusion
- Milestone Review Flysheet: Subscale Launch completed

1.3 Autonomous Ground Support Equipment (AGSE) Summary

Upon activation the Payload Retrieval System (PRS) will move to the preprogrammed location where the payload will be located. It will then position the PRS Grasper over the payload and lower it until a micro switch in the 'palm' of the grasper is triggered. The PRS grasper will secure the payload and will deliver the payload to the Payload Bay. The Payload Bay will retract into the Launch Vehicle (LV). Once the Payload Bay is closed, the Launch Vehicle will be raised to launch position by the Launch Rail System. Then the igniter will be inserted into the motor tube. The entire AGSE will be run and monitored by a series of Arduino Nanos.

Section 2 – Changes since PDR

2.1 Changes to Launch Vehicle

- The mass of the Launch Vehicle has increased to 37.0lb_m from 29.24lb_m
- The selected motor was changed from an AeroTech K1275R to an AeroTech K1050W. This is due to the increase in the projected mass of the launch vehicle.
- The fin size is 67% bigger to increase the margin of static stability on the Launch Vehicle.

2.2 Changes to AGSE

- The Launch Rail System now uses a linear actuator bolted perpendicular to the Launch Rail; instead of a stepper motor welded to the connector rod.
- The design of the wiring harnesses for the AGSE Control System was changed to include a disconnect point, allowing the AGSE to break down into smaller parts for transport
- The dimensions have been changed on the Payload Containment System to address issues found during prototyping.
- Igniter elevator drive mechanism has been replaced by a Hirschmann AUTA 6000 series automotive power antenna that will be adapted to the application.

2.3 Changes to Project Plan

- The project budget has increased from $20,256 to $24,960, as Clark Aerospace's new design includes different materials and different components.
- The purchase orders have been moved up to accommodate a slow budget approval process.
- The full scale test flight was moved back to February 28th to make time for purchases and assembly.

2.4 PDR Action Items

PDR action items are answered directly from the PDR Feedback form.

Feedback	Actions
The launch rail needs a blast plate to protect the surrounding area.	A blast plate will be attach to the AGSE frame to help direct the motor exhaust away from the AGSE
Does the igniter have a little stopper at the end of the wire like it is depicted in the model?	The igniter design is specified in Section 4.9 Ignition System.
Please clarify /provide the structural elements of the rocket.	This is clarified in Section 3.4.4 Load Path Analysis
What construction method is used for the fins?	The Black G10 plate will be cut into shape and rounded on the leading edge. The back edge of the fin will be chamfered.
Looks like the actuator for the launch rail provides more horizontal force than it does vertical force.	The linear actuator will provide mostly vertical force to the Launch Rail as it raises the Launch Vehicle in the current design.
Could any type of wind gust tip the rocket prior to launch?	Outriggers will be placed on the AGSE frame to address this issue. Heavy car (12V) batteries will placed on the opposite side to stabilize and weigh down the AGSE frame.
Where is the payload bay located? How will the team confirm that the payload bay door is closed?	The Payload Bay is at the end of the Nosecone coupler. That is 21 inches away from the nose cone tip. A micro servo will attempt to close the payload bay door, if not it will send and error code to the AGSE. If there is no error reported the Payload Bay doors will have been closed.
By CDR, provide as much detail for the rocket's final design as possible.	This is done in Section 3 Launch Vehicle.
What size screws fit into those holes around the payload bay bulkheads?	The screws on the Payload Bay Bulkheads are .16 inch diameter. The screws being used are #12-24 screws.
The stability margin is a little low. The review team would like a margin higher than 2.	The size of the fins has been increased to increase the center of pressure and increase the margin of static stability.
The report states that the rocket will have 3 rail buttons. This is not necessary. Using 3 runs the risk of the rocket binding on the launch rail.	3 rail buttons will be used to decrease the risk factor of the Launch Vehicle; if one rail button fails, the other rail buttons will still align the vehicle on the rail.

Table 1: Action Items

Section 3 – Launch Vehicle

3.1 Mission Overview

3.1.1 Mission Statement

The mission of Clark Aerospace's Launch Vehicle team is to develop a reusable Launch Vehicle system that can load a payload from an autonomous ground support system. The launch vehicle will be launched from an autonomously raised Launch Rail. The Launch Vehicle made will be able to ascend to 3,000 feet AGL. The Launch Vehicle will break apart at the Aft Section with black powder charges. A drogue parachute will limit the Launch Vehicle to a speed of approximately 84.6 feet per second. Then at 1000 feet AGL another black powder charge will break away the Forward Section of the Launch Vehicle, deploying two parachutes that will slow the Launch Vehicle such that it will have an impact of less than 75 ft-lb_f. The Launch Vehicle should be recoverable at this impact energy.

3.1.2 Mission Requirement

Requirement	System	Verification
Target altitude shall not exceed 3,000ft AGL	AeroTech K1050W	The weight of the launch vehicle and the motor that is being used will not allow the altitude to be greater than 3,000ft AGL
Barometric altimeter for official altitude	Raven3 Altimeter	Inspection, Flight Testing
Recoverable/Reusable	Recovery	The recovery system will allow the launch vehicle to descend without damage
2 hour max flight preparation time	Pre-assemble sub systems	Assembly testing and arming tests/procedures
Remain launch-ready for one hour minimum	Avionics	New batteries will be installed before each launch, system will be inspected
No external circuitry/special ground support equipment for launch	AeroTech K1050W, avionics, payloads	Inspection and analysis
Drogue parachute deployed at apogee and main parachute and payload parachute deployed at lower altitude (1000ft AGL)	Raven3 Altimeter, recovery	The Raven3 Altimeter will be programmed to release the parachutes at different altitudes, verified through analysis and flight testing
Max kinetic energy at landing of 75ft-lbf	Recovery	The recovery system will slow the launch vehicle's descent so that the maximum kinetic energy is within the

		requirement. This will be verified through analysis, flight testing, and calculations (75≥0.5*m*v2)
Recovery system electrical circuits independent of any payload electrical circuits	Recovery, payload	Electrical systems will be designed to avoid overlap, will be verified through inspection, analysis, and ground testing
Redundant, commercially available altimeters	Raven3 Altimeters	Analysis and inspection
Dedicated arming switch for each altimeter, accessible from exterior of rocket	Arming switches	Arming switches will be designed to be accessible from the exterior of the rocket, and will be dedicated to each altimeter; will be verified through analysis and inspection
Dedicated power supply for each altimeter	Recovery electronics	There will be a dedicated lithium battery for each altimeter, as part of the Featherweight Power Perch,; this will be verified through inspection
Arming switches can be locked in the ON position	Arming switches	The arming switch system will be designed to use locking switches, and will be verified with analysis and inspection
Removable shear pins used for main and drogue parachute compartments	Recovery, rock hopper	The recovery compartments will be designed to use removable shear pins, and will be verified with analysis and inspection, as well as several calculations to ensure that the shear pins will successfully shear
Electronic tracking device in each independent section and fully functional during flight	Big Red Bee Tracker	There will be a Big Red Bee Tracker installed in the main body of the launch vehicle, which is the only independent section; it will be verified by inspection, analysis, and flight testing to ensure full functionality
Recovery system altimeters shall be located in separate	Launch vehicle (bulkheads)	There will be a physical compartment separation

compartments from other radio frequency transmitting or magnetic wave producing devices		designed into the launch vehicle to separate recovery electronics from other electronics; this will then be verified by analysis and inspection
Recovery system electronics shielded from all onboard transmitting devices, magnetic wave emitting/generating devices, and any other devices that may adversely affect operation of recovery electronics	Avionics Bay (shielding)	The avionics will be designed with shielding to prevent interference with or excitation of the recovery system; this will be verified with analysis, observation, and flight testing
Reduce weight using composite parts	Launch vehicle	The launch vehicle will be designed to use as many composite parts as possible to reduce weight; this will be verified with analysis and calculations ($m=\rho v$)

Table 2: Mission Requirements

3.1.3 LV Mission Success Criteria

The predetermined criteria is divided into three categories, wherein the specific performance relating to the criteria can be analyzed to show areas of improvement. The target criteria is the mission success criteria that Clark Aerospace will achieve. A 5% error is given to ensure safety and performance. A performance with about 5-15% error is determined to be in need of improvements. An analysis of the defficient criteria will reveal areas needed to be improved, which will then be enhanced to obtain the target goal. An error greater than 15% is considered a poor performance, which facilitates immediate response and adjusting. For each of the specific criterion below, the range of tolerance is given.

Criteria	Success	Need improvement	Poor performance
Altitude AGL	2850-3000ft	2550-2850ft	<2550ft
Impact Energy	<65ft-lb	65-75ft-lb	>75ft-lb
Main Parachute Deployment	950-1050ft	<950ft >1050ft	Pins don't shear
Payload Parachute Deployment	1000ft	<950ft >1050ft	Pins don't shear
Drogue Parachute Deployment	Apogee	After apogee	Before apogee

Table 3: LV Mission Success Criteria

Drogue Stability	Deployed at apogee, limits to 85ft/s	Deployed at apogee, >90ft/s	No stability (visibly unstable)
Drift Main (at max wind conditions)	<3000ft	3000-3450ft	>3450ft
Drift Payload (at max wind conditions)	< 2200ft	2200-2500ft	>2500ft

3.1.4 Launch Vehicle Overview

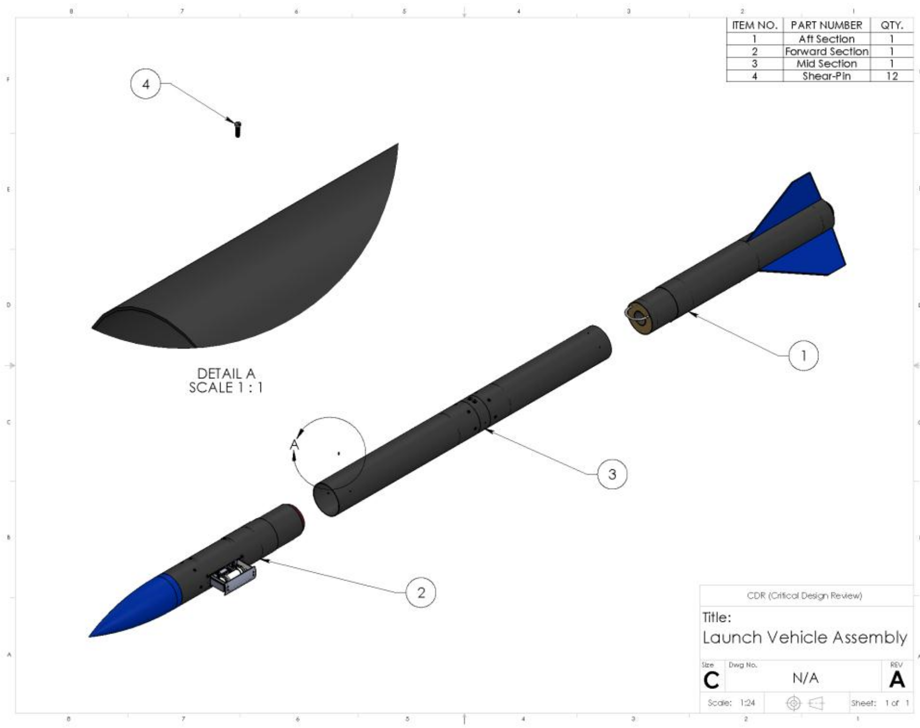


Figure 1: Launch Vehicle Exploded Assembly

The 10ft tall launch vehicle is 37lb$_m$ pre motor burn and 34.24lb$_m$ after burn and will boost the payload to an apogee of 2900ft. The body is made of 5.15 in diameter G12 fiberglass airframe and G10 fiberglass couplers. The vehicle will have three fins and three rail button guides. The launch vehicle is divided into three section; the Forward Section, the Mid Section, and the Aft Section.

Forward Section

Figure 2: Launch Vehicle Forward Section

The Forward Section will contain the Payload Bay and one Big Red Bee Transmitter. The Forward Section will consist of a 3:1 ogive fiberglass nose cone bolted onto one end of a 19in long airframe and an 8in long coupler that will be glue with aerospace grade epoxy to the other end of the airframe. Also, the Payload Bay will be placed between the nose cone and the forward bulkhead and will also be secured by 8 bolts to the airframe. The coupler will have a bulkhead cap glued to it with a U-bolt for the payload parachute. The payload parachute will be housed in the forward section coupler.

Mid Section

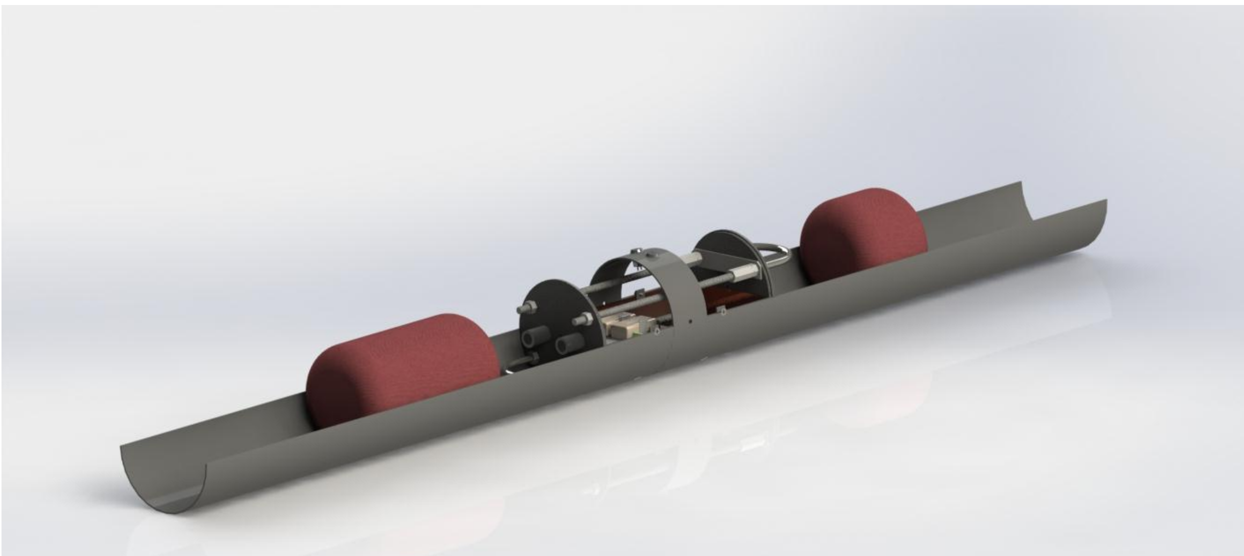


Figure 3: Launch Vehicle Mid Section

The Mid Section will comprised of two airframes bolted to the avionic bay. The avionics bay will be 10in long G10 coupler with two bulkhead caps. Two U-bolts bolted to all-thread will go through the avionic payload to seal it. The avionics bay will include six key switches, two Raven3 altimeters, two 12v batteries, and four powder wells. The forward airframe will be 28in long and contain the main parachute. The aft airframe is 24in long and will contain the drogue; and the parachutes will connect to their corresponding U-bolts.

Aft Section

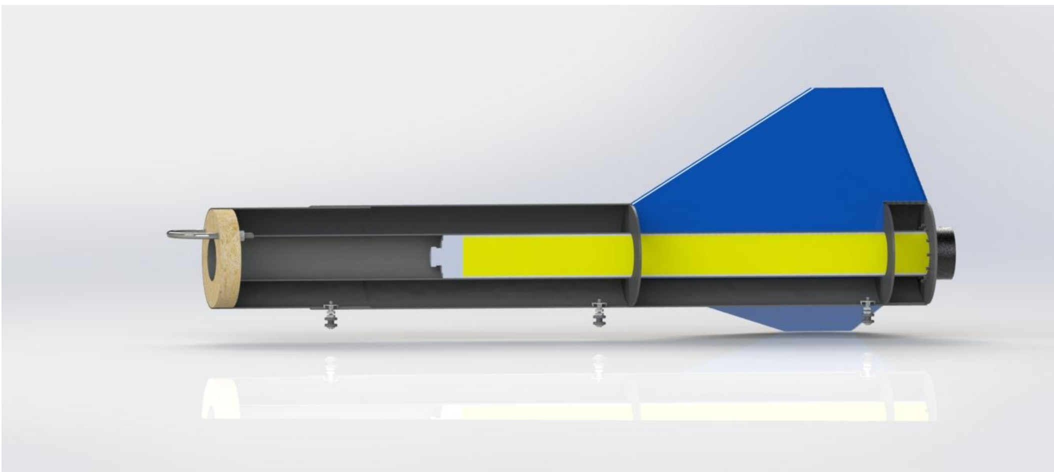


Figure 4: Launch Vehicle Aft Section

The Aft Section will comprised of a 31in airframe and an 8in coupler. The coupler will be epoxied to the airframe. There will be three fins epoxied to the airframe as well as epoxied to two centering rings and motor tube. The fins have a root length of 15in and a tip length of 3.75in. The distance from the airframe to the tip of the fin is 5.625in long. The fins will be placed so the end of each fin will be coincident with the end of airframe. At the front of the Aft Section will be a wood plug that will be held with 8 wood screws from the coupler. The wood plug will have a U-bolt bolted to it. The U-bolt will be connected to the drogue parachute through steel quick links. The Aft Section will be capped with a retainer that is bolted with 12 bolts to a centering ring. The centering ring is epoxied to a coupler spacer and the end of the airframe to help transfer energy from the motor to the airframe. There will also be three rail buttons evenly spaced out along the airframe.

Motor

Motor Name	K1050W
Manufacture	AeroTech
Single- Use/Reload/Hybrid	Reloadable
Motor Dimension	54 mm x 62.7 cm
Load Weight	2203 g

Propellant Weight	1265 g
Burnout Weight	938 g
Total Impulse	2426.4 Ns
Maximum Thrust	2172 N
Average Thrust	1132 N
Burn Time	2.1 s

Table 4: Motor Data from ThurstCurve.org

Launch Vehicle

Maturity: High
Confidence: High

- The Launch Vehicle team is confident in all calculations as the calculations were checked with RockSim9 and SolidWorks. These calculations assure the Launch Vehicle team is buying the correct components.
- The margin of static stability of the Launch Vehicle was tested successfully with a subscale model. This has confirmed the team's calculations of a stable Launch Vehicle flight.

Recovery

Maturity: High

Confidence: High

- Calculations and simulations have shown Clark Aerospace's Recovery System is robust and will dampen forces on the Launch Vehicle beyond NASA expectations.

3.1.5 Manufacturing Plan and Status

The current status of the Launch Vehicle assembly is that nothing has been ordered or assembled. Many parts of the AGSE have been 3D printed and tested at full-scale, but none of the Launch Vehicle components have been assembled.

Clark Aerospace will start ordering and subsequently assembling and manufacturing all the parts to the Launch Vehicle when funding is received from Clark College student body. All of the time critical components have been ordered out of the engineering budget. These critical components are the rocket engine and the motor hardware for full-scale testing for the FRR. All non-critical components that are readily stocked by retailers can be ordered after the budget is approved. The engineering budget spent on rocket supplies will then be transferred to the aerospace budget after the budget is approved.

The manufacturing of the Launch Vehicle will be done in stages. The first stage of manufacturing will be assessing all of the ordered parts for defects and structural issues. This will be critical for keeping the full-scale Launch risk factor low. The second stage will be fabrication all AGSE components. Starting this process second allows the AGSE team to know exactly how to dimension the components. After the

Launch Vehicle team has ordered the components and confirmed that they will all be used. This stage can be completed at Clark College, since we have access to a 3D printer. Stage three of manufacturing will be milling and drilling the necessary parts of the Launch Vehicle. All of the stage three will use drill presses and mills that are on Clark College campus. All airframe holes, AV Bay holes, bulkhead holes and modifications will be produced in stage three. Clark College offers machining classes; Clark Aerospace will be getting help from fellow colleagues in the Machining Department. This will allow experienced machinists to finish most of stage three for Clark Aerospace if necessary. Drawings of the part modifications necessary will be finished by Clark Aerospace's drafter, these drawings will help ensure the correct modifications are made. Clark Aerospace's fallback plan for milling and drilling is to finish all of the holes in the Launch Vehicle in the Clark Machining Lab. Stage three and four of manufacturing will use all of the fabrication safety techniques described in the Safety Section 5. Stage four of manufacturing is assembling all made components into full-scale assemblies. This mostly involves screwing together the airframe of the rocket. The AGSE also needs many joints fastened with screws (main example is the Launch Rail System connecting to the Launch Rail and actuator). The AGSE frame is currently being held together with studs at the joints that will provide a quick dissemble of the AGSE for shipping. Currently, Clark has the capability to manufacture the Launch Vehicle and AGSE in campus facilities.

3.1.6 Design Integrity

The Launch Vehicle will be assembled on Clark College's campus. The assembly of the launch vehicle will be done in teams of two. This will ensure that one teammate will always be on hand to call for help. The emergency contacts list will be used to contact any team member's contact in case of an accident. One safety procedure that will be followed during the assembly of the Launch Vehicle is shadowboxing. This allows for an easy check if all components are in the tool box. During the assembly of the Launch Vehicle tools will be kept out of the assembly area as needed to maintain the lowest amount of FOD. Before the Launch Vehicle is completed/sealed. The launch vehicle team will check if all the tools are in the toolbox. The launch vehicle team will also do a FOD check in the assembly area. So there is no accidental FOD left inside of the Launch Vehicle. If machining or drilling is needed to be done, a drawing will be generated to ensure the correct cuts and parts are made. Once holes are drilled the Launch Vehicle, the holes will be inspected for cracks at the site of the drill. The coupler tubes will be bolted together after all cuts and holes have been made. The bolts on the Launch Vehicle will be considered tightened when the bolts cannot be hand loosened (the bolts can only be loosened by use of a tool). The alignment of the Launch Vehicle components will be guaranteed by using prefabricated parts off of Rocketry Warehouse. The coupler tube and the airframe will be fastened together with #12-24 stainless steel screws and steel hex nuts. The alignment of the airframe tube is guaranteed by the use of coupler tubes that hold the Launch Vehicle together. The final nuts will be epoxied to the inside of the Launch Vehicle, so the Launch Vehicle can be fastened shut or opened from the external of the Launch Vehicle.

The motor retainer Clark Aerospace is using an industry standard 6061 alloy aluminum retainer flange. It has been proven to have sufficient strength in the load path analysis in Section 3.4.5. The motor retainer will be purchased from Rocketry Warehouse. The motor will be housed in a 2800 Newton-second casing. The casing is the required strength by the motor manufacturer to house this motor. All motor mounting parts are prefabricated and will be of necessary strength as designed by the manufacturer to fit with another company's product.

The material being used for the fins and bulkheads is G10 Fiberglass. It has been proven to have sufficient strength in the load path analysis in Section 3.4.5. The each fin will be custom made by Rocketry Warehouse from a 3/8in thick plate of G10 Fiberglass. All the bulkheads will be purchased from Wildman Rocketry.

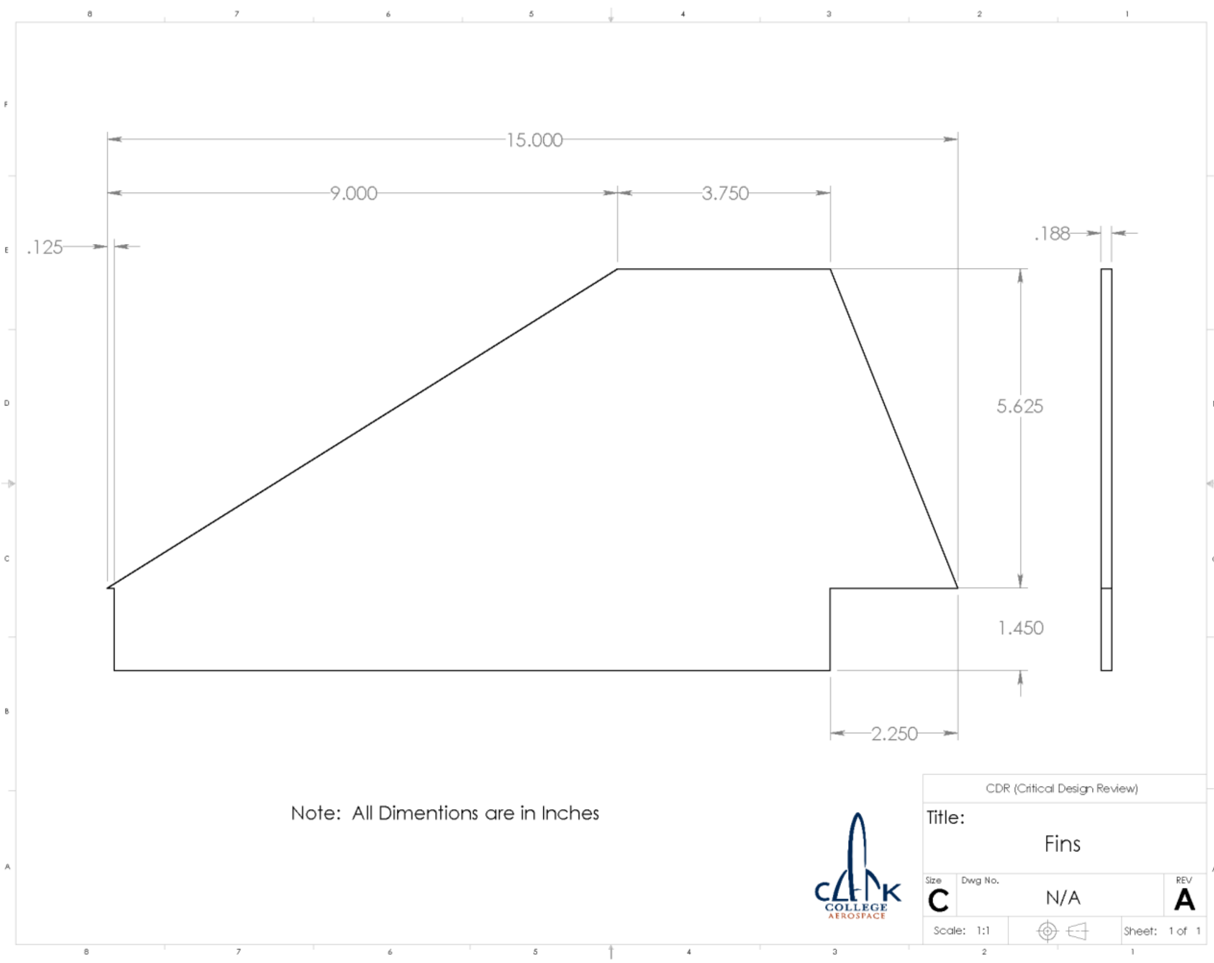


Figure 5: Dimension Fin Drawing

The Launch Vehicle has been verified through multiple methods. RockSim model of the Launch Vehicle has performed at requirement standards. The same Launch Vehicle model has been tested with calculations in MATLAB. The MATLAB calculations have shown the same results as RockSim for apogee to 20 feet of accuracy. The structural elements of the Launch Vehicle calculations have been full demonstrated in the load path analysis of the Launch Vehicle in Section 3.4.5. The Recovery System has been verified with MATLAB calculations. The parachutes used on the Launch Vehicle are also rated based on descent rate for a given weight on the manufacturer's website. The manufacturer's descent rates match with the calculations done with the MATLAB calculations. The center of mass of the Launch Vehicle is calculated with Solidorks. This prevents Clark Aerospace from inaccurately calculating the center of mass, because each part must have a correct density before it is allowed to be placed in the assembly. The center of mass calculations are roughly checked by hand using the heaviest objects in the Launch Vehicle to ensure most of the weight is accounted for in the model. These calculations have countless confirmed Solidworks accuracy of this calculation. The subscale model has also confirmed the Launch Vehicle's margin of static stability to be accurate as well. The center of pressure of the Launch Vehicle has also been checked in RockSim and MATLAB calculations. The subscale launch has also confirmed the center of pressure is approximately where it is expected (since it demonstrates stable flight).

The weight of the Launch Vehicle is 37 pounds for the final design. The Payload Bay is 3D printed in PLA plastic to reduce the weight. The Aft Section weighs 15.182 lb before burn and after burn the Aft Section weighs 12.393 lb. A large portion of the Aft Section weight is in the motor. Not much else determines the weight of the Aft Section, therefore the Aft Section weight is determined by the motor needed for the Launch Vehicle. The Mid Section weighs 12.536 lb. The Mid Section includes the Avionics Bay, main parachute, and drogue parachutes. The Avionics Bay weighs 4.5 lb. This weight comes from the coupler tube, U-bolts, all thread rod, and the electronics. The majority of the weight of the Mid Section is from the G12 airframe. The Forward Section weighs 9.311 lb. The Forward Section houses the Payload Bay, Payload Bay Parachute, nose cone, big red bee transmitter, and the G12 airframe. The Payload Bay was made out of PLA to reduce the weight of the Forward Section. The G12 and G10 fiberglass weights are given by the manufacturer. So Clark Aerospace is confident in the accuracy of the weights of the fiberglass which makes up a majority of the Launch Vehicle weight. The Payload Bay weight can be adjusted with variable infill 3D printing to fit the weight estimated in the Solidworks model of the Launch Vehicle. Clark Aerospace is confident in the weight of the screws, due to Solidworks materials having the correct densities. The Launch Vehicle screws will be bought off Mcmaster-Carr, Mcmaster-Carr provides Solidworks models for every screw that sell. This allows the model of the Launch Vehicle to have an exact weight of each screw. The Avionics Bay is using known working models from last year's Launch Vehicle model. These weights were proven to be within the range of acceptable error on last year's calculations. The motor casing and the motor are taken from RockSim, which provides manufacturer data on the weight of the motor and casing. All parachute masses are provided by the Fruity Chutes (the manufacturer of the parachutes). The Mid Section provides the least accurate mass estimates. The parachute hardware was estimated based on weighing last year's hardware components that are being used this year. The maximum mass growth between the CDR design and the final product is estimated to be two pounds. The RockSim estimate of apogee with the current design is 2930.5 feet AGL. With a mass growth of two lb_m the Launch Vehicle goes to 2675.11 feet AGL. This gives a sensitivity of 127.7 feet of altitude lost per pound of mass added to the Launch Vehicle. The Launch Vehicle motor can handle up to a ten pound of mass growth without apogee dropping below 2,000 feet AGL.

3.2 Subscale Launch Vehicle

The team recently flew the subscale launch vehicle and had great results. The team use the subscale to test for static stability of Clark Aerospace's design. For the subscale of the launch vehicle, Clark Aerospace made a 1/5 scale launch vehicle. The conditions were favorable; there was only a slight breeze to the north. The subscale fallowed a stable vertical trajectory path when launched. With this test result, Clark Aerospace is confident that the full scale launch vehicle will be stable during flight.

Figure 6: Subscale Launch

Weather Conditions

Temperature: 58 °F

Wind: Relatively calm, occasionally blowing north

Flight Observations

- Stable flight, no roll
- C6-3 fired and pressurized without problems
- No weather cocking

Perform the following procedure to prepare subscale rocket for launch

Subscale Launch Procedure	Initial When Complete
Check Weather Conditions:	
Wind (Below 17 MPH)	
Visibility (Not Overcast)	
Set-up Rail System	
Attach Chosen Rocket Motor to Subscale Rocket	
Slide Launch Vehicle onto Rail System	
Clear Required Radius of all Equipment and Personal	
Attach Igniter to the Wires from Launch Switch to Rocket	
Retreat to Safe Distance	
Announce Launch in Clear Loud Voice to Ensure every is Aware of Impending Launch	

Table 1: Subscale Flight Procedure

Design Notes

- The subscale launch vehicle was 1/5 the size of that full scale launch vehicle.
- The subscale has a Center of gravity at 14.2in from the nose and a center of pressure at 18.2in from the nose.

Flight Data

Clark Aerospace did not put a computer on the subscale launch vehicle, therefore the team does not have any flight data from the subscale launch.

Impact of subscale fight on design of full-scale launch vehicle

Clark Aerospace has not changed the design of the full-scale Launch Vehicle in any way due the flight path of the subscale launch. The stable subscale launch has assured the team that they are on track for a stable, successful full size launch vehicle design.

3.3 Recovery System

3.3.1 Recovery Description

The Recovery System will consist of an Avionics Bay, a Drogue Bay and a Main Parachute Bay. The Avionics Bay will house the two Raven3 altimeters along with the power supplies, interconnecting wiring, and mounting hardware. Aft of the Avionics Bay will be the Drogue Bay. This section will house the drogue parachute, connecting hardware and powder wells. Forward of the Avionics Bay will be the

Main Parachute Bay. This section will house the main parachute, payload parachute, connecting hardware and powder wells.

The Launch Vehicle will separate at two locations. These sections will be held together with shear pins during ascent. Shear pins will be made of nylon and will provide enough strength to hold the sections together during launch. Nylon was used to ensure that the pressure difference between the air in the body tube and the atmosphere at altitude would not cause early separation. Calculations have been made to determine the amount of black powder needed to shear the pins and separate the sections.

Maintaining dual redundancy will be key in the Recovery System's success. This will be achieved by utilizing two independent recovery circuits. The primary altimeter will set off primary charges with the secondary altimeter setting off secondary charges after a short time delay. Primary charges will be filled with enough black powder to break the shear pins and push the appropriate section apart, therefore extracting the parachutes for proper inflation. Secondary charges will be filled with 20% more black powder to ensure separation of the body tube and extraction of the parachute, if the main charge fails to separate the section. Six arming switches will be placed on the outside of the Launch Vehicle. This ensures the rules of the competition are followed and risk factor is decreased while handling the Launch Vehicle.

3.3.2 Parachute Selection

Main Parachute: Iris Ultra 84" Standard Parachute
Manufacturer: Fruity Chutes
Type: Standard Nylon Toroidal (Annular)
Packing Volume: 105.1in^3
Cd of 2.2
Rating: 38lb @ 20fps
Weight: 13.4oz

Drogue Parachute: Classic 24" Elliptical Parachute
Manufacturer: Fruity Chutes
Type: Mid Power / High Power Drogue
Packing Volume: 8.0in^3
Cd between 1.5 - 1.6
Rating: 2.4lb @ 20fps
Weight: 2.2oz

Payload Parachute: Classic 48" Elliptical Parachute
Manufacturer: Fruity Chutes
Type: Mid Power / High Power Drogue
Packing Volume: 37.2in^3
Cd between 1.5 - 1.6
Rating: 7.5lb @ 20fps
Weight: 7.3 oz

The parachutes listed above were selected based on their area and packing volumes. The calculations done to determine the minimum size of the parachute was given by the drag equations. This equation applies when the drag on the parachute equals the weight force of the Launch Vehicle section. Another equation that was used to find the maximum velocity allowed at impact energy of 75ft-lb_f. The minimum area of the drogue parachute was calculated using a maximum velocity of 100 feet per second, which was a target for the drogue parachute. The graphs of the minimum diameters of each parachute was done in MATLAB.

<u>Parachute Size Equation</u>

$$Area = \frac{2 * mass * \ g}{Coefficient_{Drag} * Velocity^2 * Density_{Air}}$$

$$Velocity = \sqrt{75\ ft * lb_f\ /\ (mass * \frac{1}{2})}$$

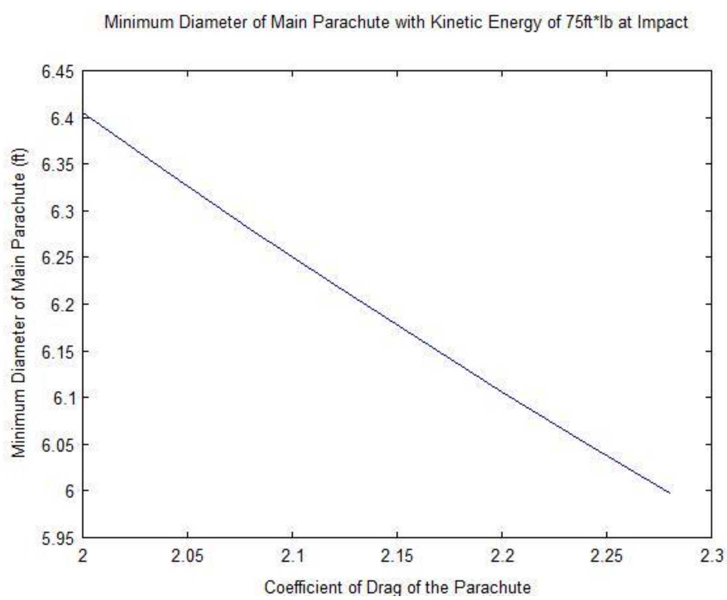


Figure 7: Minimum Size of Main Parachute Diameter

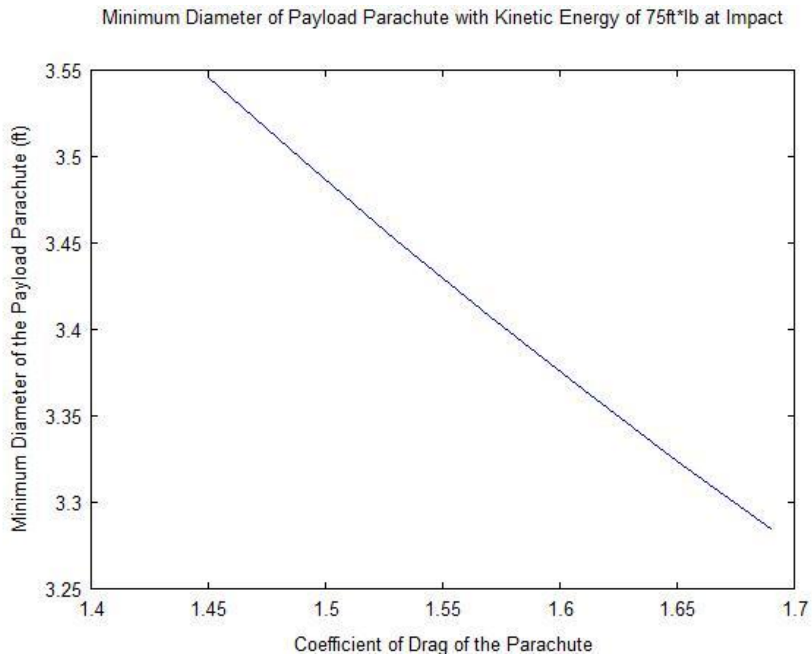


Figure 8: Minimum Size of Payload Parachute Diameter

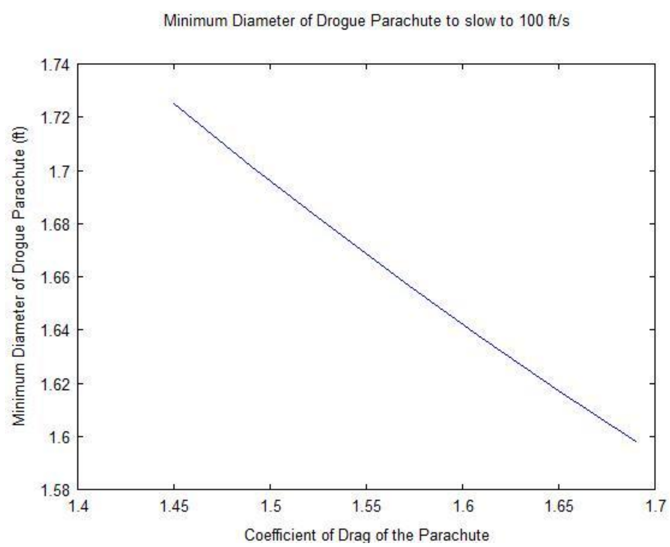


Figure 9: Minimum Drogue Parachute Diameter

Launch Vehicle Section	Parachute Used on Descent	Descent Rate	Weight of Sections	Calculated Impact Kinetic Energy
Aft Section	Main Parachute	16.4ft/s	12.393lb	51.9ft-lb_f
Mid Section	Main Parachute	16.4ft/s	12.536lb	52.5ft-lb_f
Forward Section	Payload Parachute	21.3ft/s	9.311lb	65.4ft-lb_f
Entire Launch Vehicle	Drogue Parachute	84.6ft/s	34.24lb	3,809ft-lb_f

Table 5: Calculated Kinetic Energy at Impact

3.3.3 Recovery Hardware

The drogue parachute will be attached to both the Aft Section and Mid Section through shock cords and U-bolts. The U-bolts will run longitudinally through the Avionics Bay and be secured to the opposite bulk plate with an all thread rod and coupler nuts to the U-bolts through the bulk plate. The main parachute will be attached to the Avionics Bay and be secured to the opposite bulk plate. This is shown in the Avionics Bay drawing below. The payload parachute will be attached to the Forward Section through shock cords and steel quick links on a U-bolt. On all parachutes the shock cords are connected to a steel quick link. The steel quick link will also be connected to the steel U-bolt. Steel is used on most hardware because it has known strength and is readily available. The deployment bags that are used will hold the parachutes until deployment. The deployment bags are made of Nomex, a fire-resistance fabric, so the parachutes do not get burned when the black powder charges are fired. Below is the list of recovery hardware that will be bought and used. The length of the drogue parachute shock cord is 30ft. The length of the main parachutes shock cords is 20ft. The length of the payload parachutes shock cords is 20ft. The shock cords are made of tubular nylon because it is an industry standard.

Main Parachute
1.1oz Ripstop Nylon - MIL-C-4378 Type IV
NO. 69 Nylon Thread
1” Nylon Support Tape - MIL-W-408 Type I
3/16” Type I Nylon Cord
3/4” Tubular Nylon Webbing
1/2” Square Weave Nylon Webbing
Heat Shrink Tubing Wrap
¾” 316 Stainless Steel Double Eye Swivel

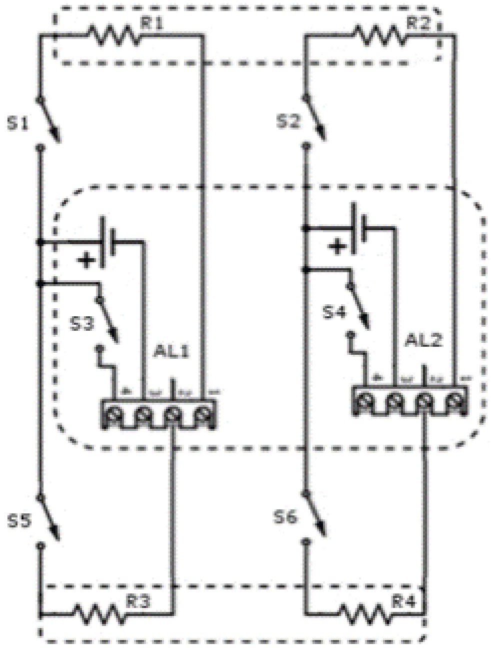
Drogue Parachute/Payload Parachute
1.1oz Ripstop Nylon - MIL-C-4378 Type IV
NO. 69 Nylon Thread
3/16” Type I Nylon Cord
3/4” Tubular Nylon Webbing
9/16” Nylon Support Tape - MIL-W-408 Type I
Heat Shrink Tubing Wrap
¾” 316 Stainless Steel Double Eye Swivel

Shock Cords
1" Mil-Spec Tubular Nylon – MIL-W-5625
Tensile Strength: 400lb
Weight per foot: 1.75 grams

Deployment Bags and Shock Cord Protectors
Nomex Fabric
Kevlar Fabric
Kevlar Thread

316L Stainless Steel Hardware
Delta Quick Links
Quick Links
U-bolts
Washers
Nuts
Bolts

3.3.4 Recovery Electronics
The recovery electronics that will be used and tested are powder charges and altimeters. The Raven3 Featherweight altimeters will be programmed to start a current at apogee and at 1000ft AGL. Six arming switches will be put on the outside of the Avionics Bay. These arming switches will be accessible from the outside of the Launch Vehicle. Two Raven3 Featherweight altimeters will be used to ensure a current will be passed to the powder charge. The current will ignite black powder charges. The altimeter will also monitor the attitude and acceleration during the flight to take flight data. The first charge will be deployed using the Raven3's pressure sensor deployment. The second charge is fired based on the specified 1000ft AGL deployment. A backup current will be set to send a half second after main deployment, if there is no change in acceleration. The secondary altimeter will also ensure that a current will be sent, in the case of altimeter failure. Two nine-volt batteries will power the altimeters. Two batteries will ensure redundancy in the Recovery System. The schematic for the altimeter and charge setup is drawn below.



Designation	Description
AL1	Primary Altimeter
AL2	Secondary Altimeter
S1	Primary Arming Switch
S2	Secondary Drogue Charge Arming Switch
S3	Primary Altimeter Arming Switch
S4	Secondary Altimeter Arming
S5	Primary Main/Payload Charge Arming Switch
S6	Secondary Main/Payload Charge Arming Switch
R1	Primary Drogue Charge
R2	Secondary Drogue Charge
R3	Primary Main/Payload Charge
R4	Secondary Main/Payload Charge

Figure 10: Recovery Electronic Schematic

The Avionics Bay will hold the altimeters and the hardware to hold the parachutes to the Launch Vehicle. The Avionics Bay will use coupler nuts and all thread rods to hold the U-bolts to each other. The arming key switches will connect to the altimeter to allow current to pass to the black powder only if the key is locked in the on state (single pole single throw switch). The arming switches will be purchased from Digi-Key. The arming switches are tubular locks with a solder lugs on the bottom to attach the wire. The arming switches will be mounted to the outside of the Launch Vehicle to the two-inch length of the G12 airframe. The rest of the Avionics Bay will be made of a ten inch G10 coupler. An aluminum bracket will be fixed to the all thread rods. An aluminum sheet will be bolted to the aluminum brackets. The altimeters and battery holders will be bolted to the aluminum sheets. The Avionics Bay lid will be made of fiberglass. Copper mesh will be epoxied on the inside of the Avionics Bay to prevent an electromagnetic interference from starting any charges or disturbing the altimeters. The Big Red Bee Transmitter will be placed in the nosecone and the copper mesh will prevent any interference from the signal getting into the Avionics Bay. Three 1/4-inch diameter relief holes will be drilled in the Avionics Bay to maintain the same pressure inside the Avionics Bay as the pressure at the current elevation of the Launch Vehicle. The calculations for the relief hole size were made using the 1/4 inch diameter relief hole for every 100 inches of cubic volume within the Avionics Bay. With this calculation the relief hole total area was divided into three holes to provide symmetry in the airframe. The programming of the altimeters will be done through a micro USB cable to the Raven3 altimeter. The Raven3 altimeters will be individually tested with lights acting as powder charges with a flight simulation of the launch. These Raven3 altimeters will also record flight data during the launch and descent; again this information will be using the Raven3 micro USB interface. All interfacing with the altimeter will take place using the manufacturers Featherweight Interface Program.

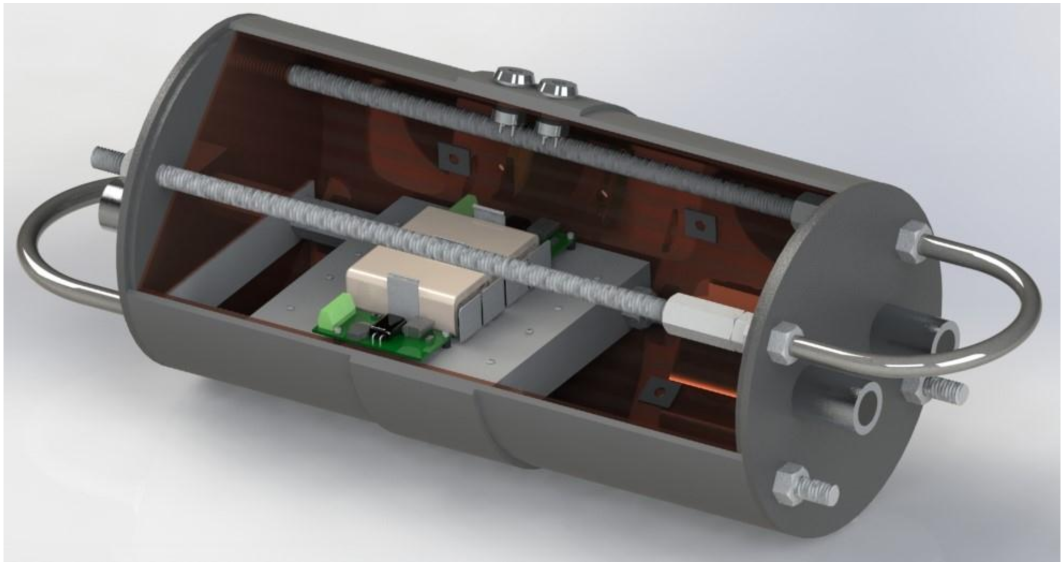


Figure 11: Avionic Bay

The amount of black powder needed to shear the nylon pins holding the sections together is calculated below. The shear screws used will be #2-56 Nylon screws (minor diameter of .0641 inches) from McMaster-Carr. The shear strength of nylon is 10,500psi. The ejection force is equal to the number of screws needed to shear times the shear force. The backup charges were given 20% more black powder to ensure the section will always separate if the first charge fails to deploy the parachutes. The length of the drogue parachute bay is 26.25 inches. The length of the Main Parachute Bay is 26.75 inches.

Shear Force Required

$$Shear\ Force = Shear\ Strength_{Nylon}(psi) * \ Cross\ Sectional\ Area$$

$$Shear\ Force = 10{,}500 * \ \pi * \left(\frac{.0641}{2}\right)^2 \ = \ 33.88\ lb$$

$$Ejection\ Force = \ Shear\ Force * Number\ of\ Screws$$

$$Ejection\ Force_{Drogue\ Charge} = 33.88 * 6 = 203.3\ lb$$

$$Ejection\ Force_{Main\ Charge} = 33.88 * 6 = 203.3\ lb$$

Black Powder Calculations

$$Gas_{Constant} = 265.92 \ lb_f * in/lb_m$$
$$Combustion\ Temperature_{Black\ Powder} = 3307\ Rankine$$

$$Weight_{Black\ Powder} = \frac{Ejection\ Force * Length}{Temperature_{Black\ Powder} * Gas_{Constant}} in\ lb$$

$$Weight_{Main\ Charge} = \frac{203.3 * 26.75}{3307 * 265.92} * \frac{454\ grams}{lb} * \frac{15.43\ grains}{gram} = 43.3\ grains$$

$$Weight_{Main\ Charge\ Backup} = 1.2 * Weight_{Main\ Charge} = 52\ grains$$

$$Weight_{Drogue\ Charge} = \frac{203.3 * 26.525}{3307 * 265.92} * \frac{454\ grams}{lb} * \frac{15.43\ grains}{gram} = 42.96\ grains$$

$$Weight_{Drogue\ Charge\ Backup} = 1.2 * Weight_{Drogue\ Charge} = 51.55\ grains$$

3.3.5 Recovery System Plan

The recovery plan will start at apogee; the Aft Section will separate from the Mid Section using black powder charges. This event will deploy the drogue parachute. The drogue will stabilize the descent of the Launch Vehicle. The current drogue parachute will slow the Launch Vehicle down to 84.6ft/s with current calculations. This gives the Launch Vehicle at this stage a maximum of 3,800ft-lb_f of impact energy, at this phase of the recovery plan. When the Launch Vehicle reaches 1000ft AGL another event will separate the Mid Section from the Forward Section (containing the Payload). The main parachute and the payload parachute will be deployed at this time. From 1000ft AGL to ground level the Mid Section and the Aft Section will descend under the main parachute. The Forward Section (containing the Payload) will descend under the payload parachute. The Forward Section under the payload parachute must make impact with less than 75ft-lb_f as a requirement of the competition. The Mid and Aft Section must also impact the ground with less than 75ft-lb_f of energy. The tables below are the impact energies of the various sections of the Launch Vehicle. The air density numbers used were interpolated from U.S Atmosphere Standard [2]. The assumption was made that Huntsville, Alabama is 600ft above sea level.

Wind Speed	**Total Drift Distance**	
	Mid and Aft Section Drift (Main)	Forward Section Drift (Payload)
5 mph	864.4ft	762.3ft
10 mph	1476ft	1271ft
15 mph	2087ft	1781ft
20 mph	2698ft	2291ft

Table 6: Launch Vehicle Drift

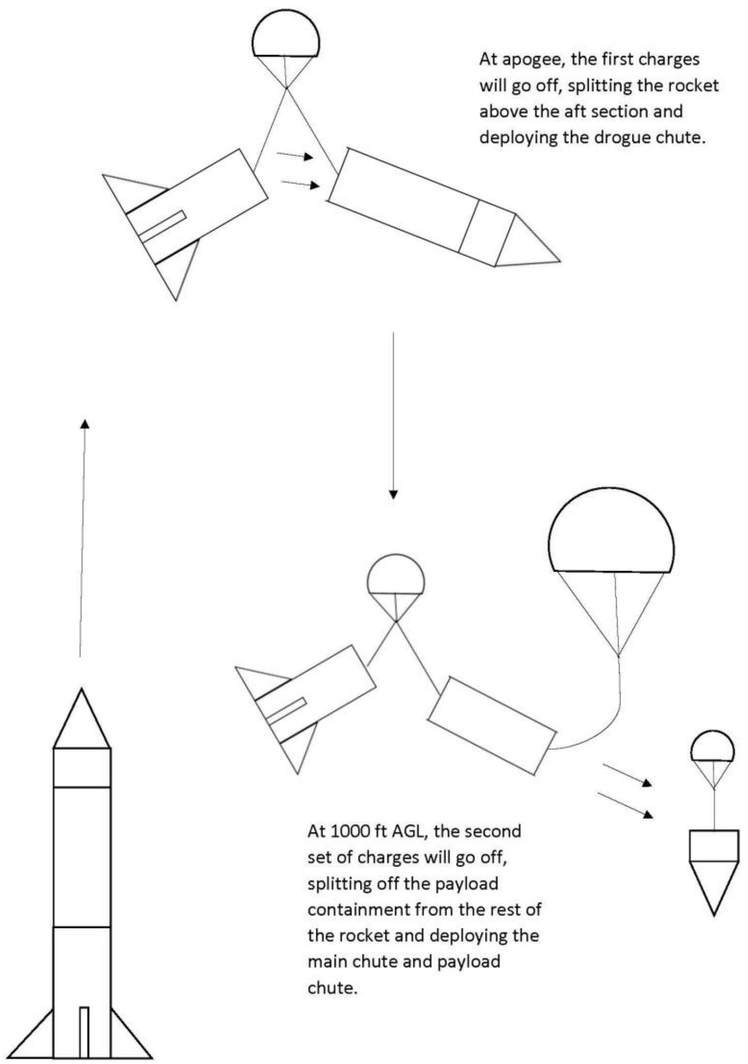


Figure 12: Recovery System Plan

3.3.6 Recovery System Tests

Clark Aerospace has not conducted any Recovery System ground tests. A subscale Recovery System was not used during subscale tests. The subscale used an engine ejection system to slow the descent of the rocket. Therefore, no recovery tests could be performed with at this time.

3.4 Mission Performance Predictions

3.4.1 Mission Performance Criteria

The performance criteria is divided into three categories, rates the performance criteria that can be analyzed to show areas of improvement. An analysis of the deficient criteria will reveal areas needed to be improved, which will then be enhanced to obtain the target goal.

Criteria	Success	Needs Improvement	Poor Performance	Calculated (MATLAB)	Calculated through Simulation (RockSim)
Altitude	2850-3000ft	2550-2850ft 3000-3450ft	<2550ft >3450ft	2865ft (dt of 0.1s) 2889ft (dt of 0.01s)	2910ft
Margin of Stability	>3.5	3.5-1.5	<1.5	3.95 (before burn) 4.59 (after burn)	3.99 (before burn)
Thrust to weight ratio	>5	5-2	<2	6.89lb_f/lb_m	NA
Velocity at end of launch rail for 5mph wind	> 44ft/s	44-35ft/s	>35ft/s	63.3ft/s	66.87ft/s

Table 7: Mission Performance Criteria

For the altitude, Margin of Stability, Thrust to weight ratio, and Velocity at end of launch rail are all in the green Success zone of the Mission Performance Criteria.

3.4.2 Flight Profile

Mission performance was predicted by using MATAB and RockSim. MATLAB was use to calculated the apogee elevation, velocity, net force, etc. of the launch vehicle until apogee. RockSim9 was used to simulate the launch vehicle from launch to landing. Clark Aerospace compared the data from RockSim9 and MATLAB for accurate prediction of what happens to the launch vehicle from launch to apogee. The team determined the center of pressure and margin of stability of the launch vehicle not only by using their own calculation, but by double-checking with RockSim9.

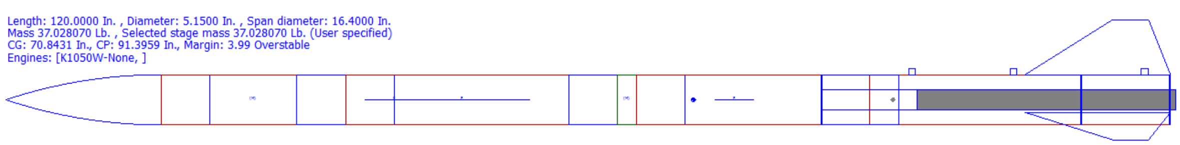


Figure 13: RockSim9 Launch Vehicle

The launch vehicle is powered by an AreoTech K1050W: a reloadable, solid-fuel APCP motor. The total impulse produced by this motor is 2426.4 N-s. The thrust curve is included below; for more information on the motor, please refer to Section 3.1.4.

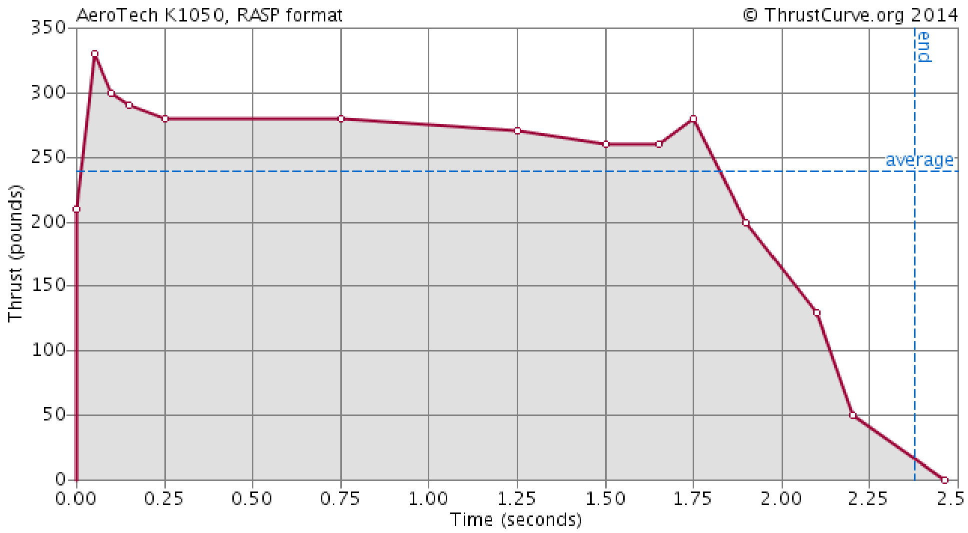


Figure 14: AeroTech K1050 Thrust Curve Graph

The fallowing carpet graph is predicting max altitude based off a range of coefficient of drag and weights of the launch vehicle. In MATLAB, the team varied the mass and the coefficient of drag to account for any changes before the launch vehicle is built. The graph was produce in MATLAB by taking in effect of the change thrust of the selected motor AeroTech K1050W using data from ThrustCurve.com [1].

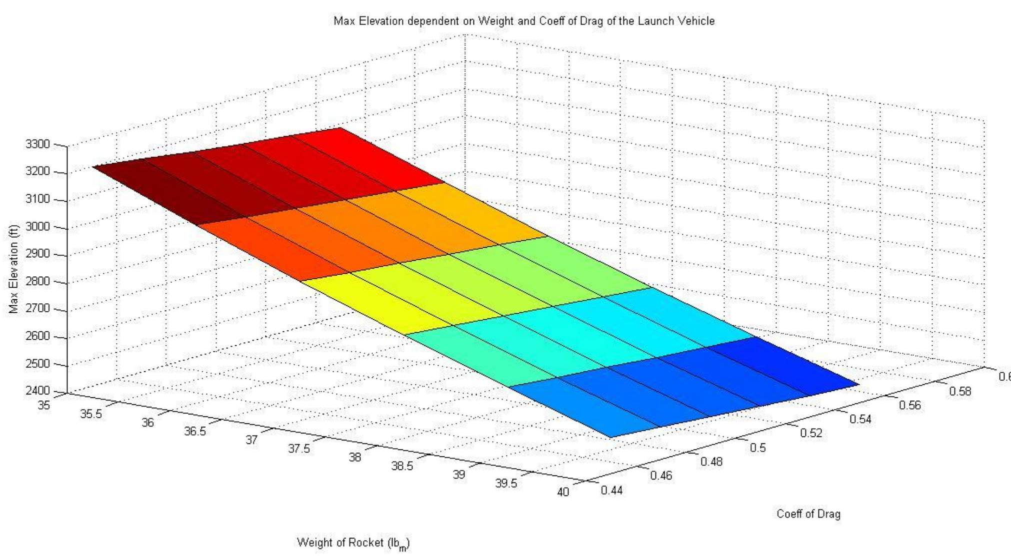


Figure 15: Max Elevation based on Cd and Weight of the Launch Vehicle

The following graphs predicting acceleration, g's, velocity, and elevation of the launch vehicle until apogee all dependent on time. Using Rocksim9 the team was able to find an average coefficient of drag, to apogee, of .47. In MATLAB, the team use several equation to calculate the net force, acceleration, drag, velocity, and elevation, see Appendix C for MATLAB equations. Again, the graphs was produce in MATLAB by taking in effect of the change thrust of the selected motor AeroTech K1050W using data from ThrustCurve.com [1].

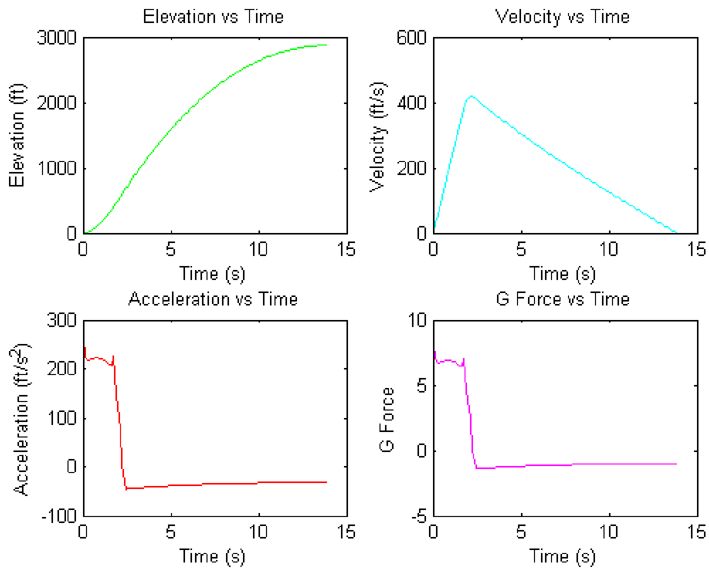


Figure 16: Prediction Graphs of Launch Vehicle to Apogee

	Calculated using MATLAB	RockSim
Apogee	2889ft	2910ft
Time to Apogee	13.38s	14.04s
Max Velocity	419.9ft/s	423.4ft/s
Max Acceleration	370.2ft/s^2	592.5ft/s^2
Max g-force	11.5	18.4

Using MATLAB, the team calculated the max apogee to be 2889ft. Alternatively, using RockSim9 the team calculated the apogee to be 2910ft. Since the difference in apogee is only 21ft the team is confident that the rocket will meet the mission requirement of an apogee range of 2850ft to 3000ft. The difference in the maximum acceleration is due to the MATLAB code using raw thrust data, which only has a small number of data points. The low amount of data points effects the resolution of the max acceleration; this is because, the maximum acceleration is located between two data points making the MATLAB calculated maximum acceleration inaccurate.

3.4.3 Margin of Static Stability

The team calculated the center of pressure of the launch vehicle by using the Barrowman Equations, shown below, and confirmed their work with the results from RockSim9.

Nose Terms

$$(C_N)_N = 2$$

$$X_N = .466 * 16in = 7.456in$$

Fins Terms

$$(C_N)_F = \left(1 + \frac{\frac{d}{2}}{S + \frac{d}{2}}\right) * \left(\frac{4 * N * \left(\frac{S}{d}\right)^2}{\left(1 + \sqrt{1 + \left(\frac{2 * L_f}{C_R + C_T}\right)}\right)^2}\right)$$

$$= \left(1 + \frac{\frac{5.15in}{2}}{5.9293in + \frac{5.15in}{2}}\right) * \left(\frac{4 * 3 * \left(\frac{5.625in}{5.15in}\right)^2}{\left(1 + \sqrt{1 + \left(\frac{2 * \ 5.9293in}{15in + 3.75in}\right)}\right)^2}\right) = 8.6163$$

$$X_F = Distance_{nose\ to\ fins} + \frac{b}{3} * \frac{C_R + 2 * C_T}{C_R + C_T} + \frac{1}{6} * \left(C_R + C_T - C_R * \frac{C_T}{C_R + C_T}\right)$$

$$105in + \frac{5.625in}{3} * \frac{15in + 2 * 3.75in}{15in + 3.75in} + \frac{1}{6} * \left(15in + 3.75in - 15in * \frac{3.75in}{15in + 3.75in}\right) = 110.63in$$

Finding the Center of Pressure

Summing up coefficients: $(C_N)_R = (C_N)_N + (C_N)_F = 2 + 8.6163 = 10.6163$

Find CoP Distance from Nose Tip:

$$\bar{X} = \frac{(C_N)_N * X_N + (C_N)_F * X_F}{(C_N)_N + (C_N)_F} = \frac{2 * 7.456in + 8.616 * 110.63in}{10.6163} = 91.189in \approx 91.2in$$

The calculated center of pressure is 91.2in and the simulated center of pressure is 91.4in. The difference of the simulated center of pressure and the calculate center of pressure is only 0.2in, therefore team is confident that we have determined the center of pressure.

Margin of Stability

Margin of Stability Before Burn

$$\frac{CoP - CoM}{d} = \frac{91.189in - 70.843in}{5.15in} = 3.95$$

Margin of Stability After Burn

$$\frac{CoP - CoM}{d} = \frac{91.189in - 67.762in}{5.15in} = 4.59$$

Clark Aerospace's launch vehicle has a center of pressure located at 91.19" in from the nose cone, and a pre-burn center of gravity at 70.84" in from the nose cone. This gives a pre-burn margin of stability of 3.95. The launch vehicle's post-burn center of gravity is located at 67.76" in from the nose cone, which gives a post-burn margin of stability of 4.59. RockSim9 calculated the pre burn stability at 3.99. Since the difference of the pre burn margin of stability was 0.04, the team is confident in the stability calculations.

3.4.5 Fin Flutter

Clark Aerospace used the fallowing equations to calculated fin flutter velocity:

$$S = \frac{(C_T \times C_R)b}{2}$$

$$AR = \frac{S^2}{b}$$

$$\lambda = \frac{C_T}{C_R}$$

$$T(°\mathrm{F}) = 59 - 0.00356(h)$$

$$\rho = \frac{2116lb}{144in} * \left(\frac{T(°\mathrm{F}) + 459.7}{518.6\ °R}\right)^{5.256}$$

$$a = \sqrt{1.4 * 1716.59 * (T(°\mathrm{F}) + 459.7)}$$

$$V_f = a\sqrt{\frac{\frac{G}{1.33 \times AR^3 \times \rho(\lambda + 1)}}{2(AR + 2)\left(\frac{t}{c}\right)^3}}$$

Calculations:

$$S = \frac{(3.75in + 15.0in)5.625in}{2} = 52.73in^2$$

$$AR = \frac{(5.625in)^2}{52.73in^2} = 0.6$$

$$\lambda = \frac{3.75in}{15in} = 0.25$$

$$T(°\mathrm{F}) = 59°F - 0.00356\frac{°F}{ft}(3000ft) = 48.32\,°F$$

$$\rho = \frac{2116lb}{144in} * \left(\frac{48.32°F + 459.7}{518.6\,°R}\right)^{5.256} = 13.19psi$$

$$a = \sqrt{1.4 * 1716.59 * (48.32\,°F + 459.7)} = 1104.9\frac{ft}{s}$$

$$V_f = 1104.9\frac{ft}{s}\sqrt{\frac{\frac{380000psi}{1.33 \times 0.6^3 \times 13.19psi(0.25+1)}}{2(0.6+2)\left(\frac{.125in}{15in}\right)^3}} = 541.7\frac{ft}{s} \cong 369mph$$

Clark Aerospace calculated the fin flutter velocity to be at 541.7ft/s. Team calculated the max velocity to be 420ft/s through MATLAB and used RockSim9 to simulate and calculate the velocity to be 438ft/s. Since the calculated max velocity is about 100ft/s less than the calculated fin flutter velocity, the team is confident that the design will not experience fin flutter that will damage the launch vehicle.

3.4.5 Load Path Analysis

The following is a load path stress analysis of the launch vehicle components during boost and recovery events. These components are those undergoing the main stress during each event and are calculated with stresses that exceed the maximum possible stresses during launch.

The materials used in the launch vehicle that beat the stress during launch and recovery events are machined aluminum 6061-T6, 316L stainless steel fasteners, and G12 filament wound fiberglass. The allowable bearing and shear stress in the following table are used to calculate the margin of safety for each component. Stress data for aluminum and steel are well established with little variance, thus ore confidence in the data for these materials is high. However, the data for filament wound fiberglass is not well established due to possible manufacturing weaknesses and Clark Aerospace's confidence in the filament wound fiberglass stress data is not high. Clark Aerospace used the following table of material properties for load path analysis.

Material	Yield Tensile Strength (PSI)	Yield Shear Strength (PSI)	Allowable Bearing Stress (PSI)	Allowable Shear Stress (PSI)
Aluminum 6061-T6	40,000	20,000	26,000	N/A
316L Stainless Steel	25,000			12,600
Filament Wound Fiberglass			33,731	
Sheet Fiberglass			19,059	

Figure 17: Launch Vehicle Material Stress Data

Load Path Analysis Formulas

$$F = W_n \times g$$
$$W_n = W_{Overall} - W_{Joint\ Below}$$
$$\sigma_{calculated} = \frac{F}{A} \qquad \tau_{calculated} = \frac{F}{A}$$
$$MS = \frac{Maximum\ Allowable\ Stress}{Calculated\ Stress} - 1$$

Determination of Maximum g Ratio

The minimum weight of the rocket is estimated to be 36.8lb. The maximum thrust of the AeroTech K1050 motor is given as 488lb ± 10%. To Account for any additional possible variation from the listed K1050 specifications, a variation of +25% will be used in place of the given ± 10%. Thus calculated maximum thrust used in the following stress analysis is

$$488\ lb \times 1.25 = 610\ lb$$

The maximum g ratio is calculated as the maximum thrust of the motor over the minimum weight of the rocket. The maximum g ratio for the rocket is then

$$g = \frac{610\ lb}{37.0\ lb} = 16.5 \approx 17$$

Launch Load Path Stress Analysis

The motor propellant is housed inside of AeroTech 54 motor casing, and secured using the 54mm Aero Pack flange mount motor retainer. The flange mount is secured to the lower motor guide using 12 steel socket head 10-24 screws. The lower centering ring makes contact against the bottom of the aft section 5" fiberglass airframe. The fin assembly is secured inside the airframe using Loctite E-120Hp epoxy.

Bearing Stress on Flange Mount Motor Retainer

The bearing area of the force being applied during flight between the motor casing and flange mount motor retainer has an area of

$$A = \pi(R^2 - r^2) = \pi(1.1175^2 - 1.0625^2) = 0.377\ in^2$$

The weight of the portion of the launch vehicle above this joint is

$$Wn = 37.0\ lb - 4.7\ lb = 32.3\ lb$$

The stress on the motor retainer flange is

$$\sigma_{Calculated} = \frac{F}{A} = \frac{Wn \times g}{\pi(R^2 - r^2)} = \frac{32.3\ lb \times 17}{0.377\ in^2} = 1{,}456\ psi$$

With a maximum allowable stress on aluminum 6061-T6 of 26,000psi, the margin of safety here is

$$MS = \frac{\sigma_{max}}{\sigma_{calculated}} - 1 = \frac{26{,}000\ psi}{1{,}456\ psi} - 1 = 16.9$$

With a well-established maximum allowable stress of aluminum and a margin of safety of 16.9, Clark Aerospace's confidence in the integrity of this pre-manufactured part is high.

Bearing stress on Lower Motor Guide

The bearing area of the force being applied during flight between the flange mount motor retainer and the lower motor guide has an area of

$$A = \pi(R^2 - r^2) = \pi(1.4875^2 - 1.0625^2) = 3.40\ in^2$$

The weight of the portion of the launch vehicle above this joint is

$$Wn = 37.0\ lb - 4.7\ lb = 32.3\ lb$$

The stress on the motor retainer flange is

$$\sigma_{Calculated} = \frac{F}{A} = \frac{Wn \times g}{\pi(R^2 - r^2)} = \frac{32.1\ lb \times 17}{3.40\ in^2} = 162\ psi$$

With a maximum allowable stress on G10 fiberglass of 19,059psi, the margin of safety is

$$MS = \frac{\sigma_{max}}{\sigma_{calculated}} - 1 = \frac{19{,}059\ psi}{161\ psi} - 1 = 117$$

In contrast to the analysis of aluminum components, the allowable stress of fiberglass has not been well established and Clark Aerospace's confidence in the analysis of fiberglass components is low. If the allowable stress on the fiberglass is overstated by a factor of 10, the margin of safety will still be 1.17; therefore, confidence in the lower motor guide strength is high.

Bearing Stress on Aft Spacer Coupler

The lower motor guide bears directly on the 5" airframe. In addition, the airframe is epoxied to the lower motor guide and the centering ring, which are connected. In reality the load will be shared between all of these connections, but the following calculations are assuming that the load is carried entirely by the bearing surface. The bearing area is

$$A = \pi(R^2 - r^2) = \pi(2.5 - 2.425) = 1.16\ in^2$$

The weight of the remaining launch vehicle is

$$Wn = 37.0\ lb - 4.7\ lb = 32.1\ lb$$

The calculated stress on the bearing area of the 5" airframe is

$$\sigma_{Calculated} = \frac{F}{A} = \frac{Wn \times g}{\pi(R^2 - r^2)} = \frac{32.1\ lb \times 17}{1.16\ in^2} = 470\ psi$$

In compressive failure tests on 3" Performance Rocketry filament wound glass airframe tubing, done by RocketMaterials.org, the maximum stress was 33,731psi. The launch vehicle's airframe is 5" Performance Rocketry G12 filament wound glass. G12 filament wound glass is a stronger fiberglass than that which was tested so for these calculations, if the stress experienced does not exceed the maximum stress of the 3" airframe, then it will not exceed the maximum stress of the 5" airframe. Using the maximum stress of the 3" airframe tests, the margin of safety when all of the stress is applied to the cross sectional area of the airframe is

$$MS = \frac{\sigma_{max}}{\sigma_{calculated}} - 1 = \frac{33{,}731\ psi}{470\ psi} - 1 = 70.8$$

In contrast to the analysis of aluminum components, the allowable stress of fiberglass has not been well established and Clark Aerospace's confidence in the analysis of fiberglass components is low. If the allowable stress on the fiberglass is overstated by a factor of 10, the margin of safety will still be 7.1, therefore confidence in the airframe strength is high.

Shear Stress from Aft Spacer Coupler to Coupler Adhesive

The adhesive between the forward section airframe and coupler experiences a maximum stress calculated as

$$W_n = 37.0\ lb - 5.90\ lb = 31.1\ lb$$

$$A = \pi * 2r * L = \pi * 2(2.5\ in) * 2\ in = 31.4\ in2$$

$$\tau_{Calculated} = \frac{F}{A} = \frac{31.1\ lb * 20}{31.4 in2} = 19.8\ psi$$

The maximum allowable stress for the adhesive is 5,000psi. The margin of safety is:

$$MS = \frac{\sigma_{max}}{\sigma_{calculated}} - 1 = \frac{5000 psi}{19.8 psi} - 1 = 252$$

Our confidence in the integrity of the adhesion inside of the airframe is high.

Shear Stress of Aft on Shear Pins

The Aft Section is attached to the launch vehicle with six 2-56 nylon shear pins. The maximum shear stress on the pins bearing the weight during launch is calculated below.

$$W_n = 37.0\ lb - 15.2\ lb = 21.8\ lb$$

$$A = \pi r^2 = \pi \times 0.86^{\,2} = 0.023\ in^2$$

$$\tau_{Calculated} = \frac{F}{A} = \frac{21.8\ lb \times 17}{6 \times 0.023\ in^2} = 2{,}686\ psi$$

The margin of safety is then,

$$MS = \frac{\tau_{max}}{\tau_{calculated}} - 1 = \frac{9{,}500\ psi}{2{,}661\ psi} - 1 = 2.54$$

Clark Aerospace confidence in the shear pins not shearing during launch is very high.

Shear Stress on Rear Avionics Bay Fasteners

The avionics bay is fastened to the upper section of the transition using 6 stainless steel flat head machine screws (12-24). The maximum shear stress on 6 fasteners is calculated as:

$$A = \pi r^2 = \pi \times 0.082^2 = 0.021\ in2$$

$$Wn = 37.0\ lb - 18.6\ lb = 17.3\ lb$$

$$\tau_{Calculated} = \frac{F}{A} = \frac{17.3\ lb \times 17}{6 \times 0.021\ in^2} = 2{,}334\ psi$$

The margin of safety is then

$$MS = \frac{\tau_{max}}{\tau_{calculated}} - 1 = \frac{12{,}600\ psi}{2{,}334\ psi} - 1 = 4.40$$

With a margin of safety of 4.40 Clark Aerospace is confident with the integration of the avionics bay.

Shear Stress from Avionics Bay Coupler to Avionics Bay Airframe

The adhesive between the avionics bay airframe and coupler experiences a maximum stress as calculated below.

$$W_n = 37.0\ lb - 21.0\ lb = 16.0\ lb$$

$$A = \pi * 2r * L = \pi * 2(2.5\ in) * 2\ in = 31.4\ in2$$

$$\tau_{Calculated} = \frac{F}{A} = \frac{16.0\ lb * 20}{31.4in2} = 10.2\ psi$$

The maximum allowable stress for the adhesive is 5,000psi. The margin of safety is

$$MS = \frac{\sigma_{max}}{\sigma_{calculated}} - 1 = \frac{5000psi}{10.2psi} - 1 = 439$$

Clark Aerospace confidence in the integrity of the adhesion inside of the airframe is high.

Shear Stress on Forward Avionics Bay Fasteners

The avionics bay is fastened to the upper section of the transition using 6 stainless steel flat head machine screws (12-24). The maximum shear stress on 6 fasteners is calculated as:

$$A = \pi r^2 = \pi \times 0.082^2 = 0.021\ in2$$

$$Wn = 37.0\ lb - 21.7\ lb = 15.3\ lb$$

$$\tau_{Calculated} = \frac{F}{A} = \frac{17.3\ lb \times 17}{6 \times 0.021\ in^2} = 2{,}064\ psi$$

The margin of safety is then,

$$MS = \frac{\tau_{max}}{\tau_{calculated}} - 1 = \frac{12{,}600\ psi}{2{,}064\ psi} - 1 = 5.10$$

with a margin of safety of 5.10 Clark Aerospace is confident with the integration of the avionics bay.

Shear Stress of Forward on Shear Pins

The Aft Section is attached to the launch vehicle with six 2-56 nylon shear pins. The maximum shear stress on the pins bearing the weight during launch is calculated below.

$$W_n = 37.0\ lb - 29.4\ lb = 7.6\ lb$$

$$A = \pi r^2 = \pi \times 0.86^{\,2} = 0.023\ in^2$$

$$\tau_{Calculated} = \frac{F}{A} = \frac{7.6\ lb \times 17}{6 \times 0.023\ in^2} = 936\ psi$$

The margin of safety is then,

$$MS = \frac{\tau_{max}}{\tau_{calculated}} - 1 = \frac{9{,}500\ psi}{psi} - 1 = 9.15$$

Clark Aerospace confidence in the shear pins not shearing during launch is very high.

Shear Stress on Rear Payload Bay Fasteners

The avionics bay is fastened to the upper section of the transition using using 4 stainless steel flat head machine screws (12-24). The maximum shear stress on 4 fasteners is calculated as:

$$A = \pi r^2 = \pi \times 0.108^2 = 0.0367\ in2$$

$$Wn = 37.0\ lb - 33.7\ lb = 3.3\ lb$$

$$\tau_{Calculated} = \frac{F}{A} = \frac{3.3\ lb \times 17}{4 \times 0.0367\ in^2} = 382\ psi$$

The margin of safety is then,

$$MS = \frac{\tau_{max}}{\tau_{calculated}} - 1 = \frac{12{,}600\ psi}{382\ psi} - 1 = 32.0$$

With a margin of safety of 32.0 Clark Aerospace is confident with the integration of the avionics bay.

Shear Stress on Forward Payload Bay Fasteners

The avionics bay is fastened to the upper section of the transition using 4 stainless steel flat head machine screws (12-24). The maximum shear stress on 4 fasteners is calculated as:

$$A = \pi r^2 = \pi \times 0.108^2 = 0.0367\ in2$$

$$Wn = 37.0\ lb - 30.6\ lb = 6.4\ lb$$

$$\tau_{Calculated} = \frac{F}{A} = \frac{6.4\ lb \times 17}{4 \times 0.0367\ in^2} = 741\ psi$$

The margin of safety is then

$$MS = \frac{\tau_{max}}{\tau_{calculated}} - 1 = \frac{12{,}600\ psi}{741\ psi} - 1 = 16.0$$

With a margin of safety of 16.0 Clark Aerospace is confident with the integration of the avionics bay.

Shear Stress on Nose Cone Bolts

The avionics bay is fastened to the upper section of the transition using 6 stainless steel flat head machine screws (12-24). The maximum shear stress on 6 fasteners is calculated as:

$$A = \pi r^2 = \pi \times 0.108^2 = 0.0367\ in2$$

$$Wn = 37.0\ lb - 34.7\ lb = 2.3\ lb$$

$$\tau_{Calculated} = \frac{F}{A} = \frac{2.3\ lb \times 17}{6 \times 0.0367\ in^2} = 178\ psi$$

The margin of safety is then

$$MS = \frac{\tau_{max}}{\tau_{calculated}} - 1 = \frac{12{,}600\ psi}{178\ psi} - 1 = 69.8$$

With a margin of safety of 69.8 Clark Aerospace is confident with the integration of the avionics bay.

3.5 Integration Approach

3.5.1 Integration Plan

The integration plan that Clark Aerospace currently uses is to standardize parts as to not miscommunicate design intent. The Launch Vehicle will interface with the AGSE in two major places the motor and the Launch Rail. The Launch Rail is a standard 1515 Aluminum Extrusion. This reduces the need for the AGSE team to make custom fasteners. There are standard fasteners available online. These fasteners can also be tested on the 1515 aluminum extrusion that is available to all Clark Aerospace members in Clark Aerospace meeting room. Therefore the standardized Launch Rail helps eliminate any error made in manufacturing of the AGSE and Launch Vehicle, since those are bought parts. Another major interface between the AGSE and Launch Vehicle is the motor, where the igniter will be inserted into the motor. Using a simple design that works with any motor solved this problem. The igniter only needs to be told when to stop based on the length of the motor. The Launch Vehicle team has standardized the motor length based on the rocket motor used in all calculations.

3.5.2 Integration Procedure

The implementation of this plan is so simple because it is done before the assembly of the Launch Vehicle. The AGSE team and the Launch Vehicle team have communicated the standardized parts that are being used. This decreases the complexity of the AGSE assembly and the Launch Vehicle assembly. This standardization plan is also confirmed in SolidWorks through a full-scale assembly of the entire Maxi-MAV project. The fallback procedure for the integration between the AGSE and the Launch Vehicle is to 3D print parts that will be a custom solution is the standardized parts do not perform as expected. This solution would not be used in critical components. 3D printing would obviously not give the necessary strength to withstand a large amount of g loading.

3.5.3 Component Compatibility

The standardization plan helps within the Launch Vehicle to ensure compatibility of components. Standardization will be ensured by purchasing most of the components prefabricated. Corresponding components will be purchased from the same retailer to ensure a compatible fit. The Payload bay was custom designed to be perfectly compatible with the airframe, ensuring the Payload Bay will always fit into the airframe tube.

3.5.4 Changes in AGSE from Subscale Test

No changes needed to be made to the AGSE after the subscale tests were done. The AGSE was designed to be flexible to the needs of the Launch Vehicle. An example of this was the Launch Rail System. The Launch Rail System was designed to be intolerant to the changing weight of the Launch Vehicle. This means that any mass growth that happens in the Launch Vehicle would not affect the materials or design of the Launch Rail. An increased mass of the Launch Vehicle would have a corresponding increase in force on the linear actuator, but it will still be well within the limits of the actuator maximum force that can be applied up to an increase of 10lb. The Payload Retrieval System was not affected by any change in the Launch Vehicle. The AGSE was designed to fit with a wide range of Launch Vehicle dimensions. The AGSE remains as mature in its design as it has through the development cycle.

3.6 Launch Operations Procedures

3.6.1 Check List

Below are launch preparation checklists.

RECOVERY PREPARATIONS	
	Initial When Completed
Program Raven3 Altimeters	
Proper wire connections:	
Raven3 Altimeters	
Batteries	
Arming switches	
Ejection charges	
New nine volt batteries	

Proper assembly of AV Bay:	
Bulk plates	
U bolts	
Check recovery for tares/holes/damage:	
Main Parachute	
Payload Parachute	
Drogue Parachute	
Harnesses	
Shock cords	
Check shock cord connections:	
Parachutes	
Launch Vehicle	
Mentor fills powder charge wells	
Properly pack parachutes and shock cords	
Arm Ravens after setup on Launch Rail	

Table 8: Recovery Preparation

MOTOR PREPARATIONS	
To be done by mentor	Initial When Complete
Inspect and clean motor case as needed	
Assemble motor following manufactures instructions	
Slide motor into rocket	
Install motor retainer	

Table 10: Motor Preparations

SETUP ON LAUNCHER	
	Initial When Complete
Rail buttons are fastened correctly	
Slide launch vehicle onto Launch Rail	
Rail is stable while rocket is on the pad	
Position rocket tilt direction if needed	
Mentor installs motor igniter	
Verify no ignition current by shorting launch clip leads	
Arm Ravens	
Verify proper toned indicating pyro continuity	
Attach launch leads to motor igniter	
Test igniter continuity	

Table 9: Launcher Setup

LAUNCH PROCEDURES	
	Initial When Complete
Check recovery preparations	
Check motor preparations	
Check igniter installation	
Check launcher setup	
Check weather conditions:	
Wind	
Visibility	
Clear launch zone of all equipment and personnel	

Table 11: Launch Procedures

POST FLIGHT INSPECTION	
	Initial When Complete
Check Launch Vehicle for damage	
Check Recovery for damage:	
Parachutes	
Harnesses	
Shock cords	
Check electronics for damage	
Check altimeter data	
Check sensor data	

Table 12: Post Flight Inspection

3.6.2 Safety and Quality Assurance

Provide detailed safety procedures for each of the categories in the Launch Operations checklist. Include the following:

- Provide data demonstrating that risks are at acceptable levels.
- Provide risk assessment for the launch operations, including proposed and completed mitigations.
- Discuss environmental concerns
- Identify individual that is responsible for maintaining safety, quality and procedures checklists

Section 4 – AGSE

4.1 Mission Overview

4.1.1 Mission Statement

The mission of Clark Aerospace's Autonomous Ground Support Equipment (AGSE) team is to develop an autonomous system to that can recover and load a payload into the Launch Vehicle which will carry it during launch and decent.

The AGSE must be able to retrieve the payload which is set at a certain distance away from the Launch Vehicle, grasp the payload, and deliver it to the Launch Vehicle. AGSE must also be able to lift the Launch Vehicle into a 5 degree off vertical position from horizontal and insert an igniter into the Launch Vehicle's propulsion system. The Launch Vehicle must be able to safely contain the payload prior to and during launch as well as during decent.

4.1.2 AGSE Requirements

- Autonomously recover the payload and deliver it into the Launch Vehicle.
- Autonomously seal off the Launch Vehicle's Payload Bay in preparation for flight.
- Be recoverable and reusable with no modifications (Other than battery charge).
- Autonomously lift Launch Vehicle to five degrees off vertical from a horizontal position.
- Autonomously insert igniter fully into the Launch Vehicle's propulsion system.
- The AGSE must be capable of being in standby for 2 hours from FAA flight waiver approval.
- The AGSE must be capable of remaining in launch-ready configuration for a minimum of 1 hour.
- The AGSE shall be compatible with a standard 12V DC firing system.
- A maximum budget of $10,000 will be used for all components of the launch vehicle and AGSE combined as it sits on the pad.

4.1.3 AGSE Criteria

The predetermined criteria is divided into three categories, wherein the specific performance relating to the criteria can be analyzed to show areas of improvement. The target criteria is the mission success criteria that Clark Aerospace will achieve. A 5% error is given to ensure safety and performance where applicable. A performance with a 5-15% error is determined to be in need of improvements. An analysis of the defficient criteria will reveal areas needed to be improved, which will then be enhanced to obtain the target goal. An error greater than 15% is considered a poor performance, which facilitates immediate response and adjusting. For each of the specific criterion below, the range of tolerance is given so that at the time of the test, immediate categorization may be completed in order to begin analysis of the test flight.

Criteria	Success	Need improvement	Poor performance
Payload Recovery	Locate and recovery payload securely	Locate but not securely recover payload	Neither locate nor recover payload
Payload Delivery	Deliver payload securely to Launch Vehicle	Deliver payload to Launch Vehicle but not secure it	Does not deliver payload to Launch Vehicle
Payload Bay Sealing	Successfully seal and lock Payload Bay	Payload Bay seals but does not lock	Payload Bay does not seal or lock
Launch Vehicle Elevation	Properly elevates Launch Vehicle to 5 degrees off of vertical and locks support in place	Does not elevate Launch vehicle to five degrees off of vertical OR Does not lock support in place	Does not elevate Launch Vehicle to five degrees off of vertical AND does not lock support in place
Igniter Insertion	Fully inserts igniter into propulsion system	Partially inserts igniter into propulsion system	Does not insert igniter into propulsion system
Completion Time	Total elapsed time <5 minutes	Total elapsed time <8 minutes	Total elapsed time >10 minutes
Standby Time	>2 hours		<2 hours
Launch-Ready Time	>1 hour		<1 hour

Table 13: AGSE Mission Success Criteria

4.2 Overall Design

4.2.1 Design Summary

The Autonomous Ground Support Equipment (AGSE) is the launch platform for the Launch Vehicle and incorporates a number of special features into its design. These features include a set of outriggers to provide lateral stability to the AGSE and Launch Vehicle during launch, a robotic arm and grasper mechanism specially designed to retrieve a payload from the ground and deliver it to the Launch Vehicle's Payload Bay, an ignition system designed to insert a igniter into the Launch Vehicle's propulsion system, and a launch rail which will raise the Launch Vehicle into launch position.

The AGSE's Control System will be modular to allow unused systems to be shut down lowering power consumption, and will be monitored and directed by an Overwatch System. The Overwatch System will include a small LCD status display, and the entire system will be powered by two 12v car batteries.

4.2.2 Testing and Integrity of Design

The AGSE will undergo vigorous testing to ensure all systems will function as intended; each system and subsystem must be able to cycle 50 times consecutively without error before the system will being used in the field.

Payload Bay System

Maturity: High

Confidence: High

- Due to prototyping and testing of the Payload Bay, Clark Aerospace is confident in the Payload Bay's ability to interface with the Launch Vehicle; as well as interface with the Payload Retrieval System.
- Constant refinement of the Payload Bay design has improved the design of the Payload Bay improving its ability to retract and under adverse conditions.

Payload Retrieval System

Maturity: High

Confidence: High

- The reach of the robotic arm is far greater than the Launch Vehicle requires, allowing it to reach a greater number of preprogrammed locations.
- The basic design of a robotic arm is a proven design, thoroughly tested by the robotic community.
- The grasper design provides an adequate level of clearance to position the payload into the Payload Bay and retract the grasper without collision.
- 3D printing provides Clark Aerospace with rapid prototyping and opportunity to fix any future problems quickly.

Launch Rail System

Maturity: High

Confidence: High

- Thorough calculations have proven the Launch Rail System to be a robust and stable design.
- The Launch Rail System is capable of holding the Launch Vehicle at 5 degrees off vertical during liftoff due to the actuator high holding force.
- The Launch Rail itself is made to fit the launch lugs on the Launch Vehicle, therefore interfacing with the Launch Vehicle is easily done.

AGSE Frame

Maturity: High

Confidence: Medium

- The AGSE frame will use proven fabrication methods in the construction of the frame providing strength and durability.
- The AGSE frame is newly designed and has not had the advantage of being able to physically interact with the components of the model.

Control System

Maturity: High

Confidence: High

- The Control System benefits from a group of containing several experienced Arduino programmers and a hardware technician. This allows for some confidence that the programming will be thoroughly debugged before the FRR AGSE test.
- The Control System is modular, allowing for greater power control and isolating each system to prevent the propagation of programming errors. This also ensured each system has full access to the available hardware.

4.3 Integration Plan

The purpose of the integration plan is to allow the AGSE team to build ground support equipment that will to conform to the design of the Launch Vehicle. The design of the AGSE must fit with the design of the Launch Vehicle to allow the loading of the payload bay to go smoothly. The ground support equipment will have to pass a quality test to be recommended for use on launch day.

The integration strategy will be constant communication between the AGSE team and the Launch Vehicle team. The Launch Vehicle SolidWorks model will be constantly updated prior to construction. A SolidWorks assembly will link dimensions in the Launch Vehicle, Payload Bay, and Launch Rail System. This will guarantee that the dimensions of the AGSE will grow with the Launch Vehicle design. The Launch Vehicle team will also inform Clark Aerospace of any changes in the Launch Vehicle design on Fridays during the weekly team meeting. This will ensure that the AGSE design will work with the Launch Vehicle design.

The AGSE team and the Launch Vehicle team will work within the same work area, promoting communication between the two teams about design changes. SolidWorks is used to verify the interworkings of the AGSE and Launch Vehicle as changed are made. Both the AGSE team and the Launch Vehicle team maintain the assembly files of the AGSE and Launch Vehicle and regularly verify that the designs are compatible.

One example of an integrated system on the AGSE is the frame. The frame depends on the clearance the Payload Retrieval System needs to access the Payload Bay of the Launch Vehicle. This requires consistent communication on design changes. Therefore, the AGSE engineers that designed these systems must confirm any changes made in the design with the lead Launch Vehicle and chief AGSE engineer. This has promoted an AGSE design that has developed to fit the needs of the Launch Vehicle as well as its own subsystems.

The completed design of the Clark Aerospace team will be verified through simulation before being prototyped via 3D printing. A full scale version of each component of the AGSE (except for the Launch Rail System) will be produced for testing and to aid programming.

4.4 Prototyping and Testing

4.4.1 Overview

Every part of the AGSE and all of its subsystems are modeled in Solidworks and preliminary prototyping and testing is done through Solidworks simulations to ensure that all subsystems physically function together before construction begins to prevent the waste of time and materials. During the build phase each subsystem will be programmed and tested separately before being integrated into a single system. This will allow each team the freedom to develop their program based on the needs of their section without worrying about conflicting hardware requirements or code. When each subsystem has been tested and confirmed to be in operational condition independent of the others a set of Run/Stop and Status commands will be added to the code and the subsystem will be tied to the Overwatch System for final testing and development.

Due to budget constraints and lack of available sub-scale components, none of the AGSE systems will have subscale prototypes made; all testing will be done with the full-scale systems.

The Payload Retrieval System will be constructed out of PLA plastic from a rapid prototyping 3D printer, as will the Payload Grasper and Payload bay. This will allow rapid testing and minor design changes to occur with minimal downtime. The Payload Retrieval System and Payload Grasper will have to undergo a minimum of fifty (50) error free iterations of the intended operation cycle before they will be cleared as operationally ready.

As the Launch Rail system is a much simpler design that only requires a logical 1 to be sent to it for a designated amount of time, it will initially be simulated with an LED to ensure that the programmed code functions as intended. Once construction of the Launch Vehicle is completed the Launch Rail will undergo repetition testing to ensure that it can lift the Launch Vehicle to the proper launching angle a minimum of twenty (20) times before being cleared as operationally ready.

The Ignition System is utilizing a commercially available and reliable powered antenna, so prototyping of the system is not needed. It will be tested to ensure that it reaches and maintains the correct height as required and ignition of the E-Match will be simulated with an LED attached to the end of the Ignition System to ensure that it operates as intended. The Ignition System will be tested to ensure that it can perform a minimum of fifty (50) error free iterations of its intended operation cycle before being cleared as operationally ready.

The Overwatch System has no moving parts and thus requires no prototyping. It will however be tested extensively to ensure rapid and reliable operation at all stages of AGSE operation. The embedded LCD status display must work with a 100% uptime during operation, and the Begin, Halt, and Resume commands must work 100% of the time as well. To ensure this, the Overwatch system will be tested to ensure it can successfully control each of the sub-systems of the AGSE and the Halt and Resume commands will be tested a minimum of twenty (20) error free times during each phase of the AGSE's operation cycle to ensure that it can cease all operations of the AGSE at any time as required.

4.5 Launch Rail System

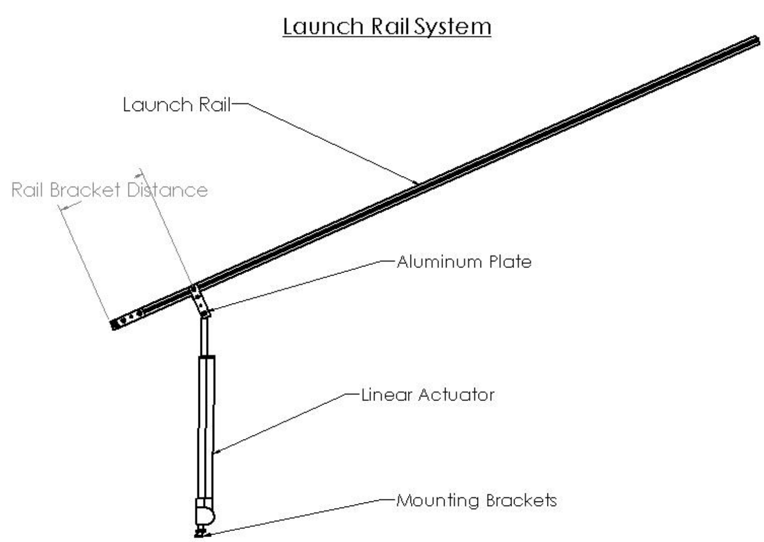


Figure 18: Launch Rail System Diagram

The Launch Rail System will rotate the Launch Vehicle from a zero degree to an 85 degree relative to the horizontal plane. The Launch Rail System will be bolted to the AGSE's frame. Steel bolts will connect the AGSE frame and Launch Rail System; these bolts will allow the AGSE to be disassembled for transport. Steel bolts were chosen since they provide large amounts of strength to the AGSE frame.

The Launch Rail will pivot on a 5/16 inch diameter steel float rod that is one foot long, which will be held to the AGSE's frame with steel footer brackets. The Launch Rail will attach to two aluminum plates with end-feed fasteners. The aluminum plate will each have a hole that will rotate on the steel threaded rod.

The Launch Rail will be rotated into position by the force of a linear actuator. The linear actuator will push on the Launch Rail through a 1/4 inch thick aluminum plate. The aluminum plate attaches to the linear actuator 9.78 inches away from the Launch Rail base (this distance is called the Rail Bracket Distance in the figure above). The aluminum plate attaches to the Launch Rail with an end-feed fastener that is made to fit within the holes of the aluminum extrusion on the Launch Rail. A Rail Bracket will be attached to the Launch Rail in between the two aluminum plates. The Rail Bracket will have a steel bolt run through both aluminum plates. So the will be two joints of the aluminum plates will be secured to the Launch Rail. The Rail Bracket will be bolted to the Launch Rail with end-feed fasteners and a steel bolt that are made to fit the 1515 aluminum extrusion Launch Rail.

The Mounting Bracket for the linear actuator will rest on a one inch square steel tube on the AGSE's frame. This Mounting Bracket will be purchased from Progressive Automation (part number BRK-02) to ensure it fits the specified linear actuator.

All bolts and rods on the Launch Rail System will be held in place by a self-locking acorn nut, which are vibration resistant.

The linear actuator will push the Launch Rail at a varying velocity. The maximum stroke length of the actuator is 16 inches. The linear actuator will be bought from Progressive Automation. The model of linear actuator will be PA-02-16-400. The speed the linear actuator pushes with is a function of the magnitude of the load being pushed. The rated speed of the linear actuator is .59 inches per second with no load. This linear actuator would reduce the time required to move the Launch Rail, since its speed is much higher than other linear actuators. This gives the other operations of the AGSE maximal time to complete their individual tasks. The linear actuator selected is capable of pushing up to a 400lb load. The length of the linear actuator is 22.89 inches. The length is given from the manufacturer on a datasheet [3]. The linear actuator has a minimum holding force of 400lb, meaning that when the power is shut off to the actuator the actuator can hold 400lb without moving. This design requires a linear actuator with a small stroke length (relative to previous designs). Therefore the time to raise the Launch Vehicle is put to a minimum.

The linear actuator will controlled by an Arduino Nano via located in the Control Bay; the Arduino Nano will trigger a relay that will allow a 12 volt battery to power the linear actuator, and a second set of relays allows the Arduino to change the polarity of the actuator to lower the launch rail. The relays switch at 5 volts and 10 milliamps; this system allows the relatively low current Arduino to control the high-draw actuator. The schematic of the Launch Rail circuit is figure below.

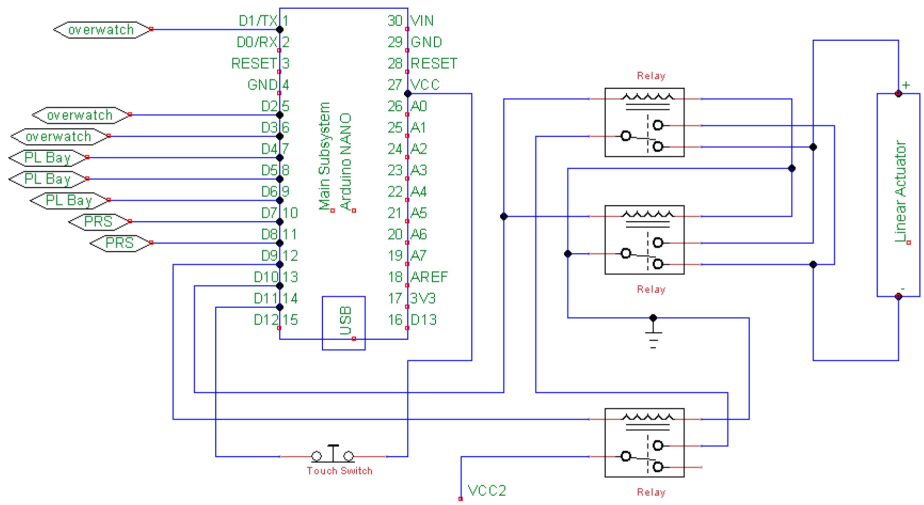


Figure 19: Launch Rail Circuit

The Arduino program will wait until the Overwatch System triggers the Launch Rail System. Once triggered, the Arduino will power the first relay powering the linear actuator to extend the actuators push rod. The Arduino program will keep powering the linear actuator for the amount of milliseconds needed to raise the Launch Rail to launch position. The number of millisecond is calculated in MATLAB code included in Appendix section B.4. A failsafe contact limit switch will be placed at 86 degrees off vertical on the AGSE frame to prevent the Launch Rail from raising an unsafe launch position.

The distance from the Rail Bracket to the base of the Launch Rail (Rail Bracket Distance in the figure below) affects the magnitude of the force required by the linear actuator. The equation used to describe the angle of the linear actuator was derived from the geometry of the figure below. β is the angle between the linear actuator and the bottom of the frame. θ is the angle of the Launch Rail, zero degrees is the horizontal position (85 degrees is the final position of the Launch Rail).

Launch Rail System Geometry

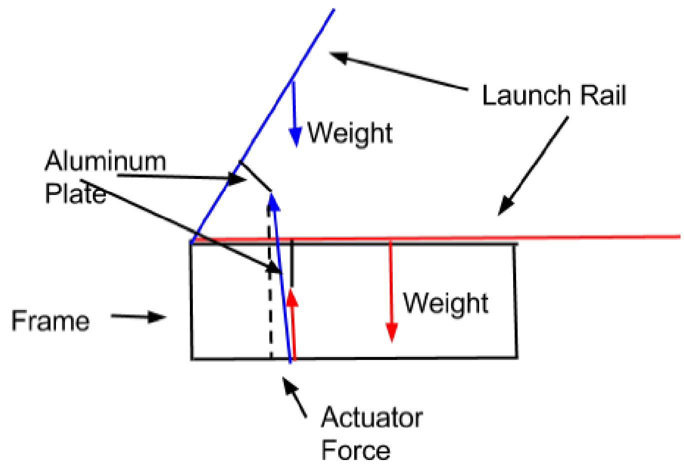


Figure 20: Launch Rail System Geometry

Moment about the Launch Rail Base

$$0 = Force_{Actuator} * Distance_{Rail\ Bracket} * \sin\big(180 - (\beta + \theta)\big) - Weight_{Rocket} * 5ft * \cos(\theta) - Coefficient_{Friciton} * Weight_{Rocket} * \sin(\theta) * Radius_{Threaded\ Rod}$$

Force on Actuator

$$Force_{Actuator} = (Weight_{Rocket} * 5ft * \cos(\theta) + Coefficient_{Friciton} * Weight_{Rocket} * \sin(\theta) * Radius_{Threaded\ Rod})/(Distance_{Rail\ Bracket} * \sin(180 - (\beta + \theta)))$$

Angle of the Actuator

$$\beta = \arctan((Frame\ Height + Distance_{Rail\ Bracket} * \sin(\theta) - Aluminum_{Plate} * \cos(\theta))/(Distance_{Mounting\ Bracket} - Distance_{Rail\ Bracket} * \cos(\theta) - Aluminum_{Plate} * \sin(\theta)))$$

Distance to Rail Bracket

$$Distance_{Rail\ Bracket} = Distance_{Mount\ Bracket} - \sqrt{\left(Actuator_{Length} - Aluminum_{Plate}\right)^2 - (Frame\ Height - Aluminum_{Plate})^2}$$

With the equation of the force on the linear actuator, it is clear that the force on the actuator varies as the angle of Launch Rail changes. The force on the actuator determines the speed of the actuator; therefore it is important to understand the magnitude of the force; the force would reveal the speed of the actuator at various points of its path. The graph below shows the relationship between the force and the angle of the Launch Rail.

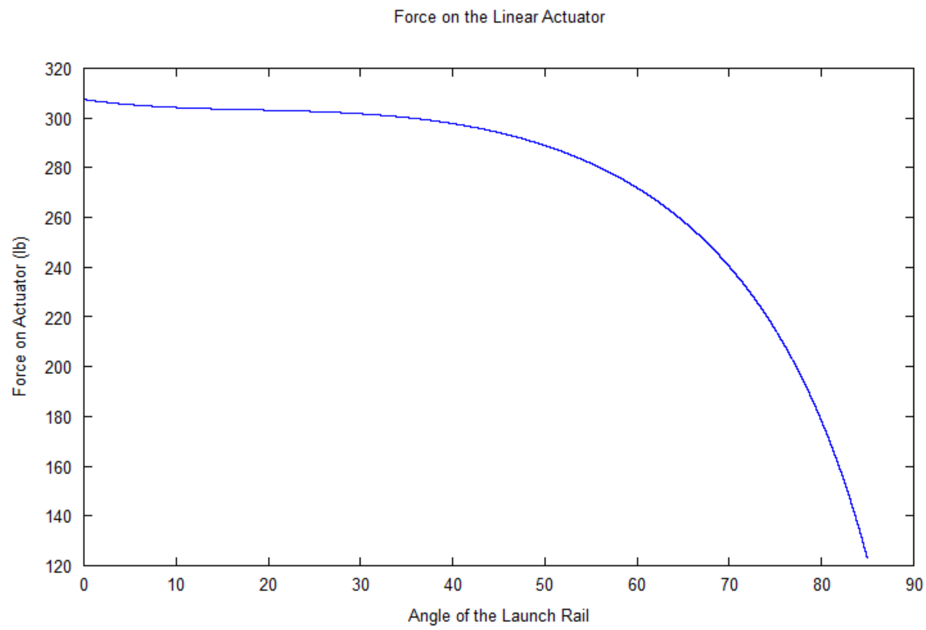


Figure 21: Force on Linear Actuator

The graph above shows that the max force on the linear actuator is about 308lb. This max force was calculated with a Rail Bracket distance of 1.0 foot. The selected linear actuator can push 400lb at max load conditions. Giving a factor of safety of 1.3. Therefore, the selected linear actuator is well within its ability to raise the rocket into position.

The linear actuator will also function as the stand during liftoff of the Launch Vehicle. The calculation has been made to make sure the linear actuator is a viable Launch Rail stand. The linear actuator has a holding force of 400 pounds. The linear actuator has a holding force when the power is turned off. This force can be used to hold the Launch Rail up during the liftoff of the Launch Vehicle. The calculations for the force of the Launch Vehicle on the Launch Rail are described below. The horizontal force on the Rail by the Launch Vehicle is from the thrust of the motor minus the weight of cosine at 85 degrees. The horizontal force the linear actuator's holding force will counteract the thrust force.

<u>Force of the Launch Vehicle Thrust</u>

$$Force\ of\ Thurst = Thurst - Weight * \cos(85) = \sin(5) * (488\ lb - (37 * \cos(85))) = \ 42.3\ lb$$

$$Linear\ Actuator\ Force = Holding\ Force * \cos(\beta) = \ 400 * (\cos(79.8)) = \ 72.1\ lb$$

$$Factor\ of\ Safety = \frac{72.1}{42.3} = 1.7$$

Another important feature of a linear actuator is its stroke length. The stroke length required to raise the Launch Vehicle is calculated from a simple equation. This equation was derived from the geometry of the Launch Rail at its 85 degree position compared to its zero degree position. The equation is given below.

Stroke Length

$$Stroke\ Length = [(Distance_{Mount} - Distance_{Rail\ Bracket} * \cos(\theta) - Aluminum_{Plate} * \sin(\theta))^2 + (Frame\ Height + Distance_{Rail\ Bracket})^2]^{\frac{1}{2}} - Length\ of\ Linear\ Actuator$$

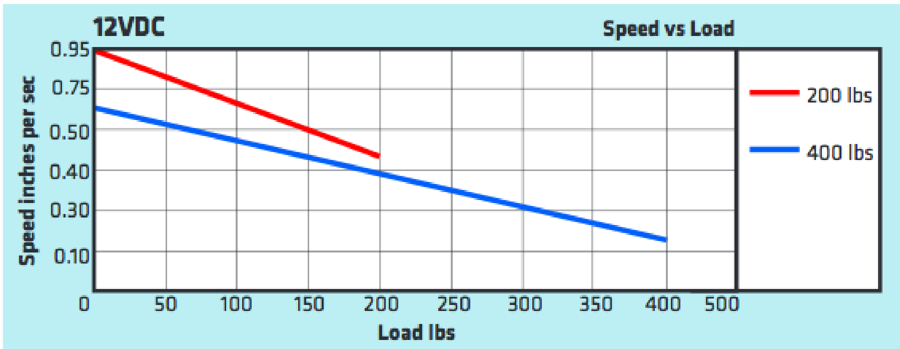


Figure 22: Speed of the Linear Actuator from Progressive Automation

With the given $\mathrm{Distance}_{\mathrm{Rail\ Bracket}}$ as 1.2 feet and the height of the AGSE frame as the length of the linear actuator selected. The stroke length is calculated to be 14.31 inches. Which is within the 16 inch stroke length of the selected linear actuator. With the stroke length calculated from the height of the frame and the Rail Brackets distance from the Base of the Launch Rail. You can get a rough estimate of the time it takes to raise the Launch Rail. Using the information given by the manufacturer of the linear actuator [3]. We can find the average speed of the linear actuator using the integral of the speed equation that is derived from the force equation.

Speed Equation

$$Speed(\theta) = .59in/s - (Force(\theta) * .0011)$$

$$Average\ Speed = \frac{1}{85-0}\int_{0}^{85} Speed(\theta)\, d\theta = \frac{1}{85}\int_{0}^{85} .59in/s - .0011 * Force(\theta)$$

$$Average\ Speed = .2945\ inches\ per\ second$$

The average speed of the linear actuator is .2945 inches per second. The average speed was calculated by MATLAB using an integral approximation. The MATLAB code is included in Appendix C.3. The error of the integral approximation was put to a small limit, such that the average speed of the linear actuator is always less than .15% different from the actual integral. So the time it takes for the linear actuator to rotate the Launch Vehicle into its final position is the stroke length divided by the average speed. With the average speed, the time to raise the Launch Rail is approximated below.

Time Taken to Lift the Launch Rail

$$Time = \frac{Stroke\ Length}{Average\ Speed} = \frac{14.3128\ in}{.2945\ in/s} = 48.6\ seconds$$

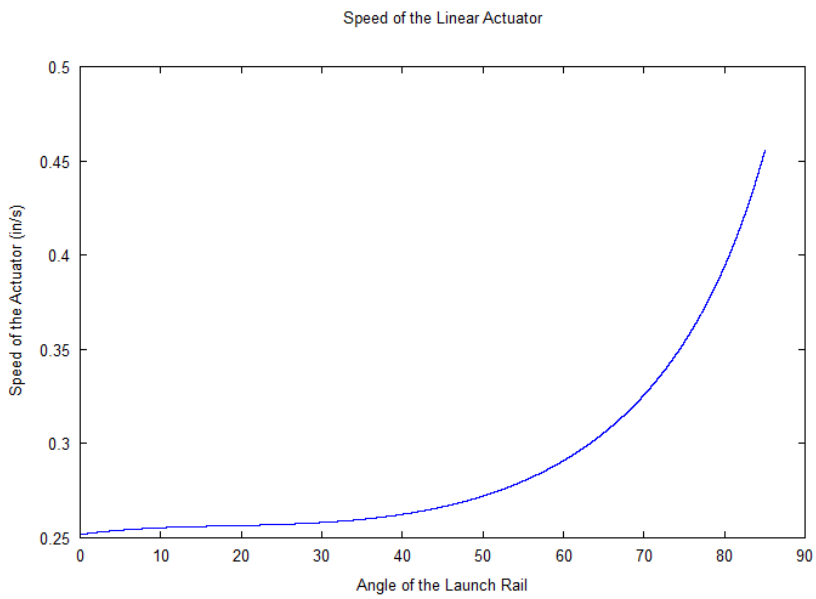


Figure 23: Speed of the Launch Rail

The time taken to raise the Launch Rail was at about 48.6 seconds. This takes up little of the competition time and leaves maximal time for the rest of the AGSE systems to complete their task. The design selected uses minimal materials, relatively small forces at a low cost. This Launch Rail System design is currently the best design in consideration of the three factors stated above. The numbers constructed above were made in to fit a real linear actuator and lift the Launch Vehicle.

The relationships were graphed as a function of the distance to the mounting bracket. The relationship of the distance to the mounting bracket to the force and actuator length were used to determine the minimum stroke length. This distance to the mounting bracket was checked against the force the linear actuator can output. The stroke length was minimized since it would be mounted vertically. The longer the stroke length needed to be (the actuator is 6.89 inches longer than the stroke length of the actuator) the taller the AGSE frame needed to be.

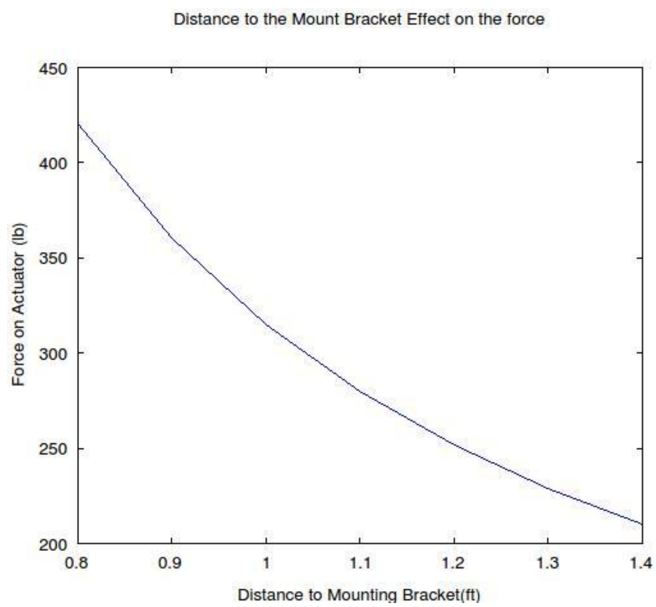


Figure 24: Force on Actuator vs. Distance to Mounting Bracket

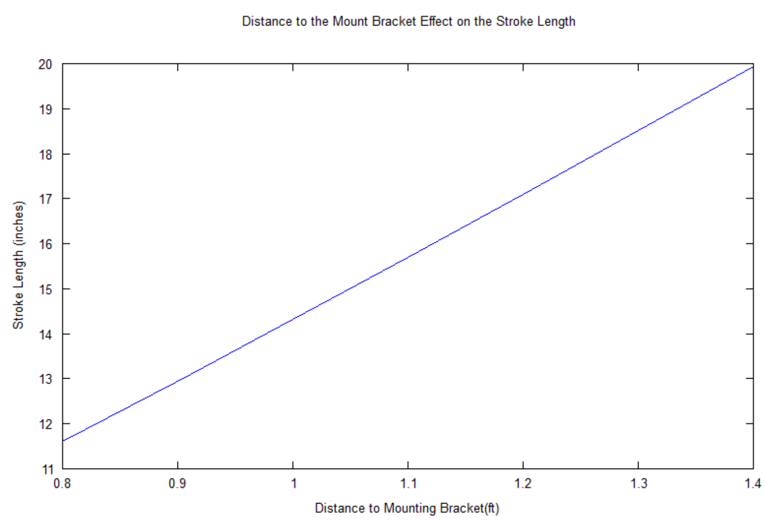


Figure 25: Stroke Length vs. Distance to Mounting Bracket

These graphs were used to understand the relationship between the distance of the mounting bracket to the Launch Rail base and actuator. The stroke length will increase proportionally as the distance to the mounting bracket increases. While inversely, the force on the actuator decreases (non-linearly) with increasing distance of the mounting Bracket from the Launch Rail base. Therefore, the distance to the Mounting Bracket was chosen as one foot. The force that is associated with the distance to the Mounting Bracket left room for mass growth of the Launch Vehicle as well as friction at the pivot.

The small stroke length allows for some assembling tolerance. An example is the AGSE frame can be built, such that the actuator won't fail (be above the max force of the actuator) if the frame is too tall or too short. A small stroke length also means that a smaller linear actuator can be bought. This decreases the height of the AGSE frame and increases stability of the frame. The design of the Launch Rail System is robust and flexible. The manufacturing process tolerances have been accounted for in the design of the Launch Rail System. This leaves room for errors in manufacturing process.

4.6 Payload Retrieval System

4.6.1 Overview

The Payload Retrieval System features a six-degree-of-freedom autonomous robotic arm made almost entirely of 3D printed PLA plastic. This system utilizes a custom payload grasper driven by a mini servo to secure the payload and six standard servos working in unison to translate the arm. The Payload Retrieval System has an overall length of 35.83in from base to tip and a total working area of 55.47ft^3. The entire system is driven by an Arduino microcontroller utilizing forward kinematics to retrieve and deliver the payload.

Figure 26: Payload Retrieval System

4.6.2 Strength of Materials

The PLA plastic chosen for the Payload Retrieval System has a reported yield strength of between 8840 to 9500psi, and under the operating load of 0.25lb, the peak force exerted on the structure of the Payload Retrieval System is 1174psi, giving a margin of safety of 7.71.

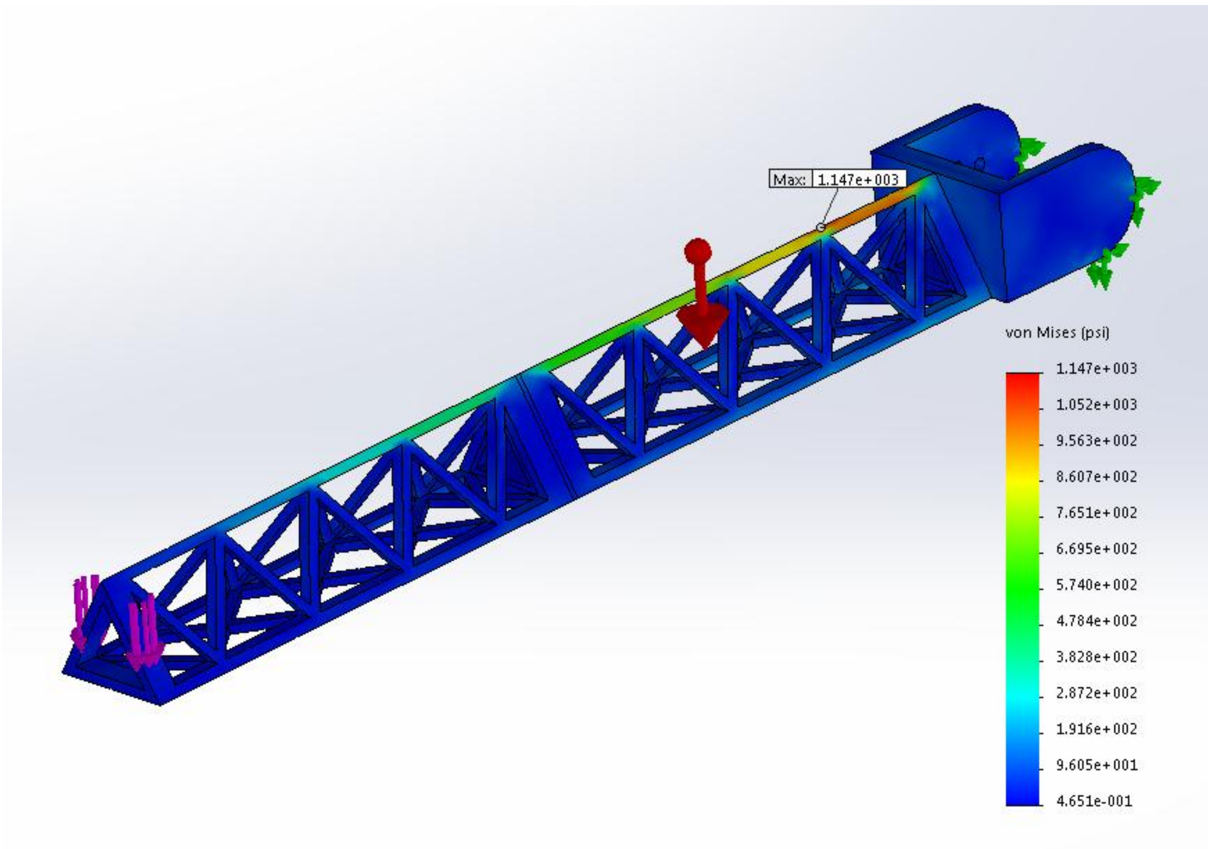


Figure 27: Payload Retrieval System Load Test

4.6.3 Margin of Safety Calculations

The servos for each articulating joint of the Payload Retrieval System were chosen specifically to have a Margin of Safety (MS) of 2.00 at a minimum to prevent sway or bounce in the structure which may cause undesirable performance of the system.

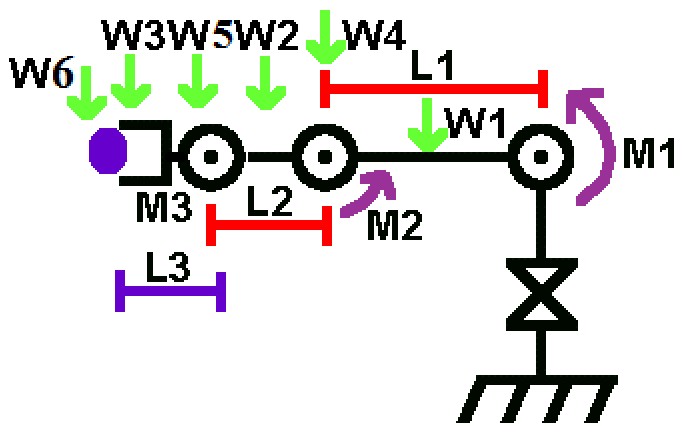


Figure 28: Free Body Diagram for Payload Retrieval System

Torque required at M3 according to the diagram above:

$$T_{M3} = (W6 * L3) + (W3 * \left(\frac{1}{3}L3\right))$$

$$T_{M3} = (.25lb * 4.95in) + (.24lb * \left(\frac{1}{3}4.95in\right) = 1.6335lb * in$$

The HK15178 servo chosen for M_3 has a reported stall torque of 4.4266lb*in

$$\frac{4.4266lb * in}{1.6335lb * in} - 1 = MS\ of\ 1.7099$$

Torque required at M2:

$$T_{M2} = [W6 * (L2 + L3)] + \left[W3 * \left(L2 * \frac{1}{3}L3\right)\right] + \left(W5 * \frac{1}{2}L2\right)$$

$$T_{M2} = [0.25lb * (10.66in + 4.95in)] + \left(0.14lb * \frac{1}{2}10.66in\right) = 4.6487lb * in$$

The BL-6168 servo chosen for M_2 has a reported stall torque of 21.6990lb*in

$$\frac{21.6990lb * in}{4.6487lb * in} - 1 = MS\ of\ 3.6678$$

Torque required at M1:

$$T_{M2} = [W6 * (L1 + L2 + L3)] + \left[W3 * \left(L1 + L2 * \frac{1}{3}L3\right)\right] + \left(W5 * \frac{1}{2}L2\right)$$

$$T_{M2} = [0.25lb * (19.36in + 10.66in + 4.95in)] + \left[0.14lb * \left(19.36in + 10.66in * \frac{1}{3}4.95in\right)\right] + \left(0.14lb * \frac{1}{2}10.66in\right) = 14.66lb * in$$

The 1270HV servo chosen for M1 has a reported stall torque of 30.3787lb*in

$$\frac{30.3787lb * in}{14.6616lb * in} - 1 = MS\ of\ 1.07199$$

4.6.4 Programming Logic

The Payload Retrieval System (PRS) will utilize pre-programmed positions to retrieve the payload and deliver it to the Launch Vehicle. This will ensure zero calculation errors that would result in mission failure. The programming for the PRS will be done in two main threads: the Main thread that contains the pre-programmed positions as well as state and position checking, and an Interrupt thread that will immediately halt all operations upon receiving a pause command from the Overwatch system.

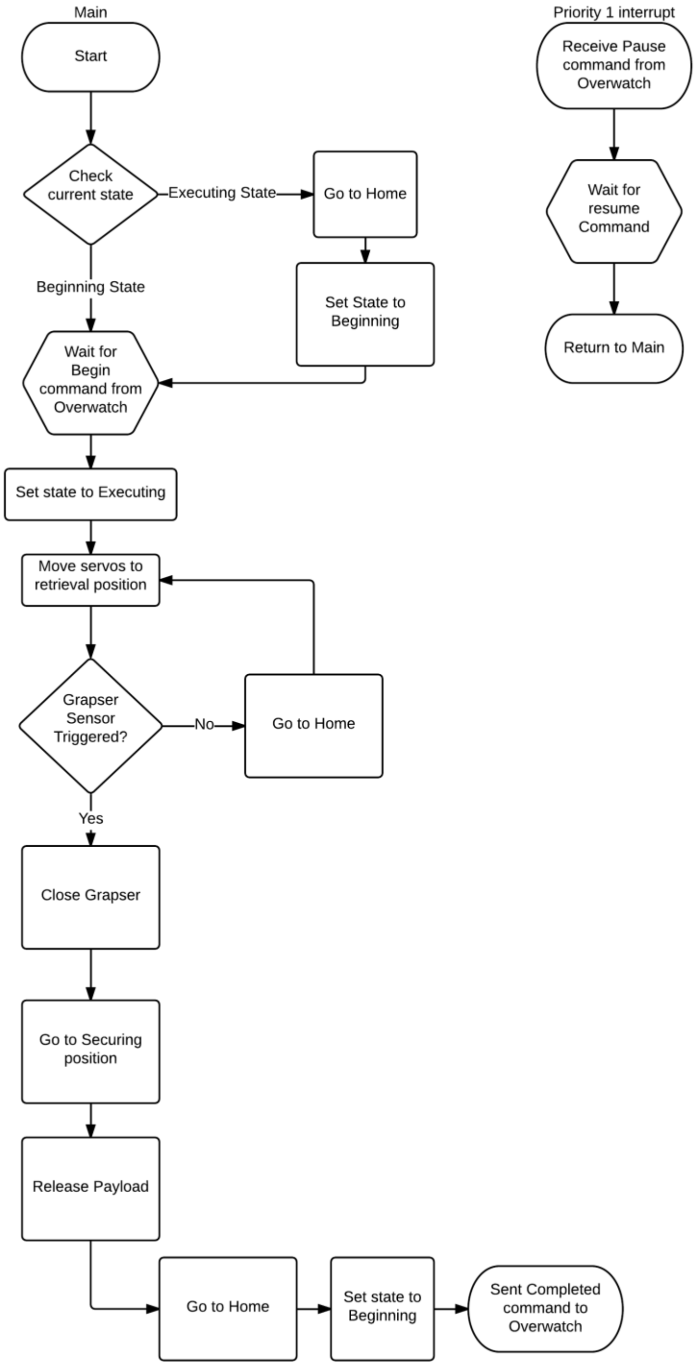


Figure 29: Payload Retrieval System Programming Flowchart

4.7 Payload Grasper

4.7.1 Overview

The payload grasper mechanism, the functional end of the PRS, will be constructed of 3D printed plastic components assembled with metal threaded fasteners and steel pivot pins. The design features four fingers in synchronized operation to contain the payload around its cylindrical profile. Movement is provided by a single HK15178 servo.

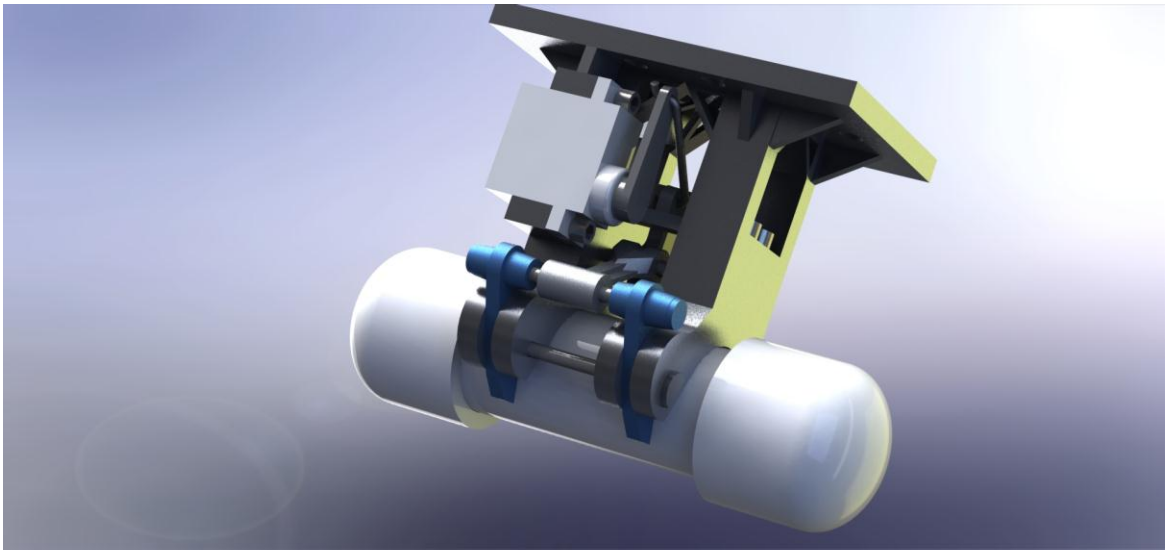


Table 14: Payload Grasper Mechanism

4.7.2 Operating Cycle

When the Payload Retrieval System has moved to the position of the payload, the Grasper will be positioned directly over and in axial alignment with the payload. The grasper will then be lowered onto the payload by the PRS arm until contact is made, which will be sensed via micro switch. Imperfect alignment off-axis is intrinsically tolerated and self-correcting due to the tapered opening provided by the Grasper's fingers when in the fully open position.

Activation of the micro switch indicates the payload is within with the Grasper's capture space, and ready to be captured. At this point, the servo will be commanded to operate through its full sweep, taking approximately 0.12 seconds. The PRS arm will then deliver the payload to the Payload Bay. After the payload is fully seated in the containment system's gripper arms the servo will be reversed, relinquishing the payload to the Payload Bay of the Launch Vehicle. The PRS arm will then return to its home position in preparation for the launch sequence.

4.8 Payload Bay

4.8.1 Overview

The Payload Bay will be powered by the AGSE via a cable that will magnetically connect to the exterior of the launch vehicle. This cable will also carry an I/O signal from the AGSE's Control System which will direct the Payload Bay's own microcontroller.

The Payload Bay will use two bulkheads to provide secure mounting points for the sliding 'tray' design we will be using. The bulkheads will be 3/8" thick, 5" in diameter, and 6.45” apart. Each bulkhead will be secured to the launch vehicle by four 1/8 inch bolts which will screw into threaded holes from outside the launch vehicle. A mounting plate located between the bulkheads which is designed to provide mounting points for all of the motors and electronics in the Payload Bay. The Payload Bay 'tray' will be able to move 3.075" out of the rocket body allowing the payload to be inserted into the containment mechanism.

All parts of the Payload Bay will be 3D Printed and will be destructively tested to ensure they meet and exceed the structural requirements needed.

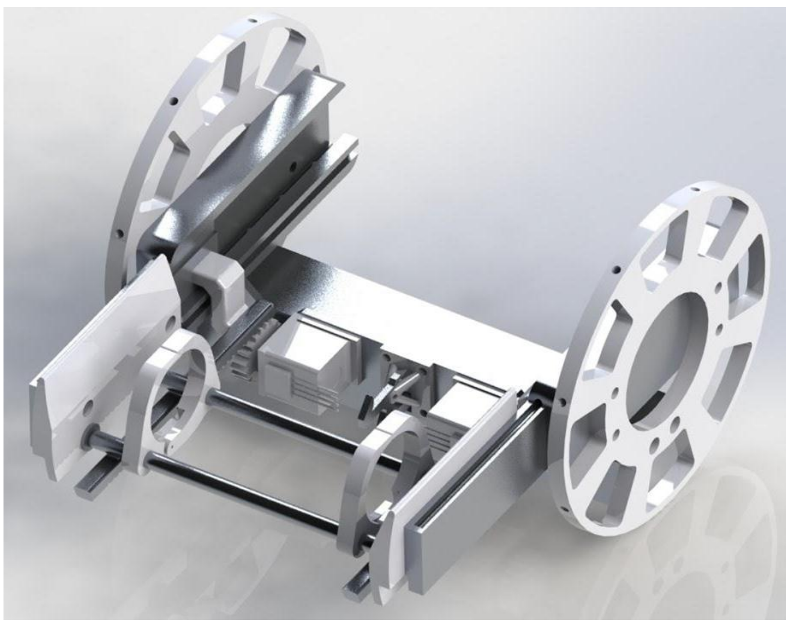


Table 15: Assembled Overview of Payload Containment System

4.8.2 Containment System

The Payload Containment system consists of two sets of small gripper 'fingers' that automatically close around the end caps of the payload when the payload is inserted into the Payload Bay; when the payload is pressed down by the Payload Retrieval system the force will rotate the fingers down and inward, locking over the payload. The gripper 'fingers' will be 3" apart and are held open by friction and a small spring. The grippers will be mounted on horizontal rails spanning the slider tray. These rails will slightly extend through the tray end caps and have cutouts on the end so that the cutouts slide into the locking slots on each side, restricting motion of the gripper arms. Each side of the tray will have a slide to help center the payload in the correct location. Once the payload has been inserted the robot arm will then release the payload and go back to home position.

4.8.3 Power Train & Locking Mechanism

Two Nema 8 stepper motors will provide the force needed to open and close the Payload 'tray'; each motor will have a gear that drives a gear rack in and out. This rack will be connected to the door and the back section of the sliding tray.

The motors will provide feedback information to the control system so it is able to sense when the tray has been fully extended or has reached the closed position. Upon doing so the payload door will be flush with the outside of the launch vehicle and the power will be cut to all motors and servos. These motors were chosen because of their small size, allowing them to fit easily inside the launch vehicle.

The primary locking mechanism for the slider tray will be the two stepper motors. Once power is cut to the Payload Bay the motors will resist any further movement, thereby locking the slider tray in place. The combined holding force of the stepper motors is 4.72 Newtons. The weight of the drawer is 0.4lb. Which provides a factor of safety of 2.53 with a total pushing force of 3.89 Newtons.

A secondary locking mechanism will be used as a backup if the stepper motors fail. This locking mechanism will consist of a small notch on the payload door; as the slider 'tray' moves into the Launch Vehicle body a receiving catch will snap into place locking the slider tray closed. A HS-35HD Nano servo motor will release the locking catch when the slider tray is ready to open. A spring will keep the catch in the locked position when the servo is not powered.

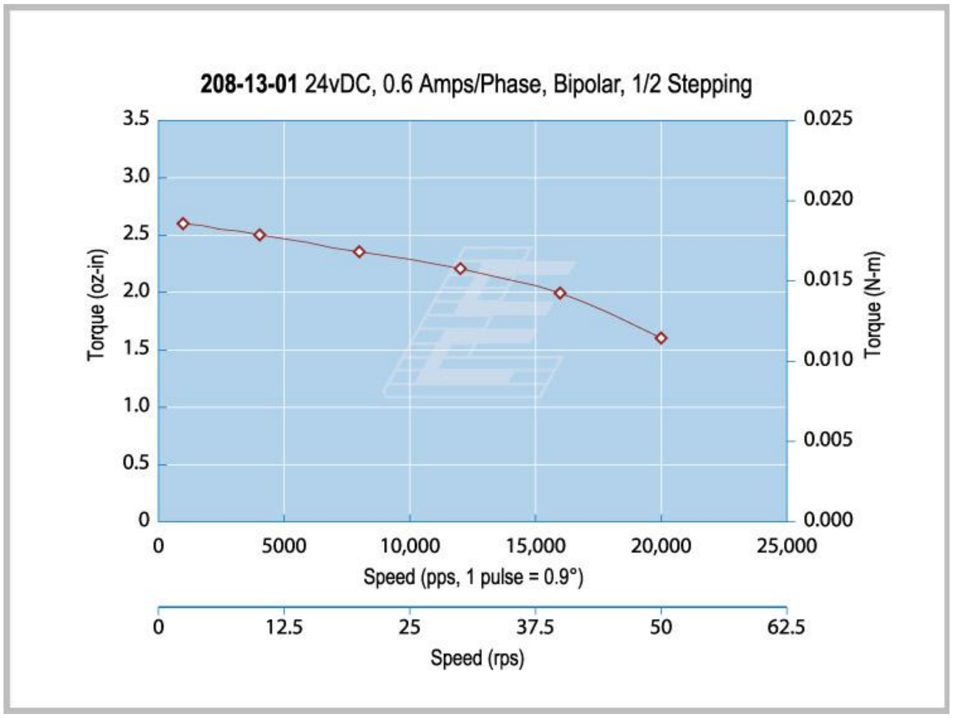


Figure 30: Holding Torque of NEMA 8 Stepper Motor

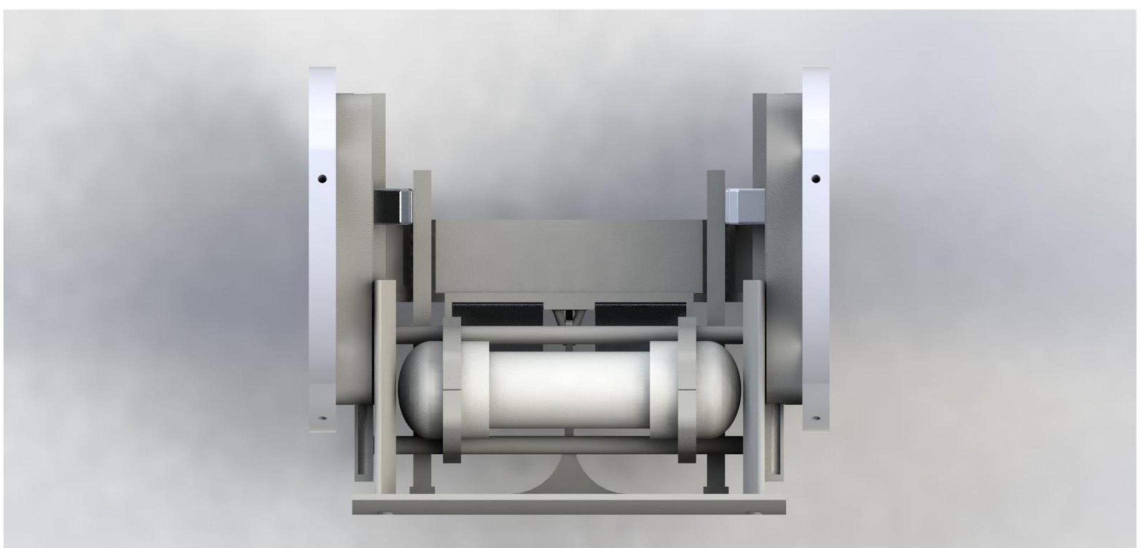


Figure 31: Payload Top View

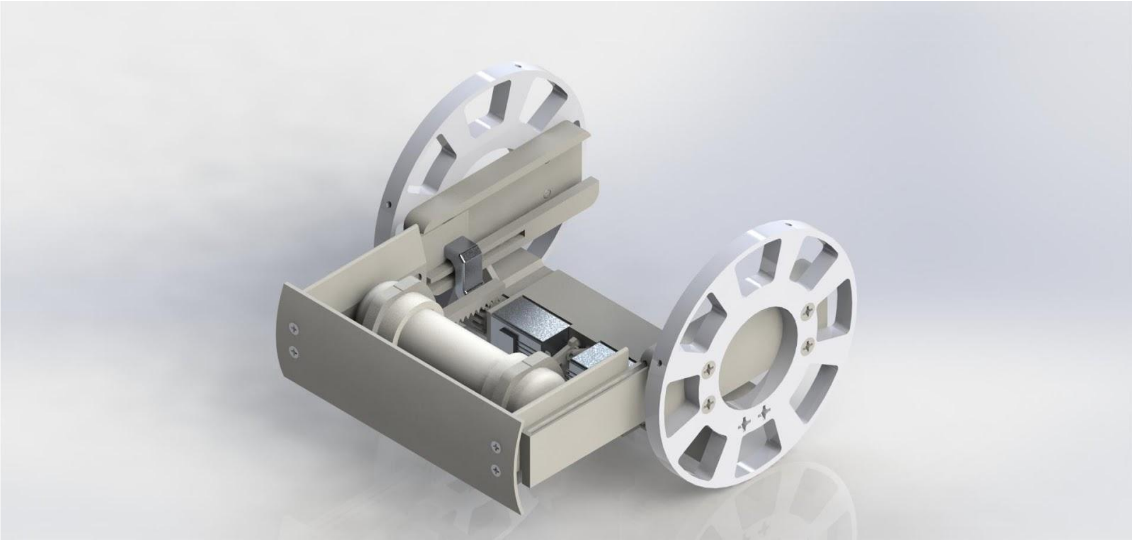


Figure 32: Payload Isometric View

Figure 33: Payload in Forward Section of Launch Vehicle

4.9 Ignition System

4.9.1 Overview

The igniter element will be inserted into the Launch Vehicle's propulsion system at the appropriate time in the launch sequence via an automated elevation system. Energizing of the igniter will be under manual control, respecting all required safety checks prior to launch.

4.9.2 Operation

To guard against accidental ignition and to satisfy design criteria, the ignition element will remain physically removed from the Launch Vehicle's propulsion system until AGSE Control System's Overwatch confirms that the Launch Vehicle is in launch position (5 degrees from vertical) and that all subsystems have completed their tasks without error.

To accomplish this, the ignition element will be attached at the end of a flexible cable, whose movement will be driven by a Hirschmann AUTA 6000 series automotive power aerial unit, adapted to suit the task.

4.10 AGSE Frame

4.10.1 Overview

The AGSE Frame was the last part of the AGSE to be designed. This design approach allowed the other components of the AGSE to be designed without structural constraints, and encouraged the design of the AGSE Frame to fit the requirements of the components without excess structure.

The AGSE Frame acts as the housing for the Payload Retrieval System, the Ignition System, the Control System and Control Bay, and provides a solid base for the Launch Rail and its lifting mechanism. The design of the AGSE frame includes several members which will be attached via bolts; these members can be disassembled allowing the AGSE to be broken down for travel.

Figure 34: Front of the AGSE Frame

The AGSE Frame has an overall length of 132in, a width of 24in, a height of 32in, and has a total mass of 224lb.

4.10.2 Material Selections

The AGSE frame will be made out of 1in diameter 1020 Mild Steel tubing. Steel was selected for its high structural strength and low production cost; this reduced cost provides a balance for the trade-off for of higher mass and increased shipping costs versus a lighter, more expensive metal such as Aluminum.

4.11 Control System

4.11.1 Overview

The actions of AGSE will directed and controlled by a modularized Control System using the ATmega328 IC installed on an Arduino Nano microcontroller. We decided to use a modularized control system to ensure any program errors are contained within their respective microcontrollers and not allowed to propagate. This approach also allows any unused subsystems to be shut down to conserve energy, allows each system full access to the hardware on which it runs, and ensures that halt commands are relayed to all systems as quickly as possible in the event of an error.

The Control System will consist of 5 microcontrollers, a LCD status display, wiring harnesses, two 12 volt power supply, and various servos and switches.

4.11.2 Location

The Control System's microcontrollers will be located on the front-side of the AGSE, installed in sockets in a shielded Control System Bay and connected to the various servos and sensors via wiring harnesses. The main wiring harness, which travels from the Control System Bay to the Payload Retrieval Subsystem and Ignition System will have a disconnect point to allow the AGSE frame to be disassembled for transport. The LCD display (indicating the current status of the Control System) will be installed within the Control System Bay and be viewable without accessing the Control System Bay.

4.11.3 Power

Power to the Control System and all related electronics (including servos, sensors, lights, etc) will be controlled by a single toggle switch located on the outer surface of the AGSE near the Control System Bay.

High draw components such as the linear actuator will be on a separate power line than the Control System and will make use of a heavier gauge wire than the rest of the Control System; high gauge power lines will be designated as VCC2 in this sections schematics. The Control System will interact with these components via relays.

When the main power switch is ON, an amber indicator light next to the switch will illuminate to provide visual confirmation that the Control System is receiving power. The indicator light will flash if the Overwatch System detects an error within the Control System.

The Overwatch System will be programmed to power down the LCD when they system goes into standby mode to conserve power.

4.11.4 Test Plan

During the build phase each subsystem will be programmed and tested separately before being integrated into a single system. This will allow each team the freedom to develop their program based on the needs of their subsystem, without worrying about conflicting hardware requirements or code. When each subsystem has been tested and confirmed to be in operational condition. A set of run/stop and status commands will be added to the code and the subsystem will be tied to the Overwatch System for further testing and development.

The Control System will be tested for errors during the development phase to develop a robust system. All systems must cycle 50 times consecutively without error before the AGSE's Control System will be used in the field.

4.11.5 Schematics - Overview

The Control System will feature the following systems and subsystems:

- The Overwatch System
- The Main Subsystem
- The Payload Bay Subsystem
- The Payload Retrieval Subsystem
- The Ignition Subsystem

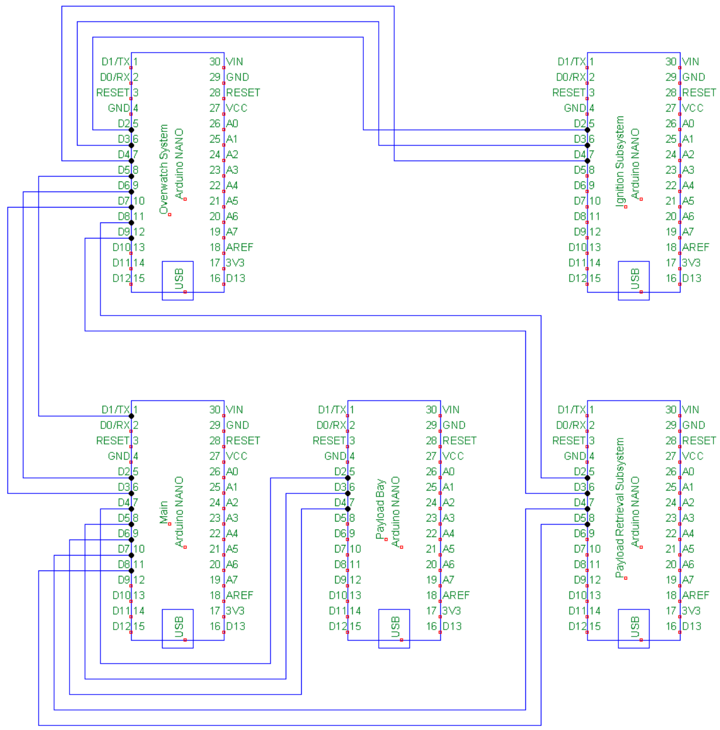


Figure 35: Control System Diagram (Microcontroller I/O)

4.11.6 Overwatch System

The Overwatch System is the only system that the operators directly interact with. It will control when the other subsystems are turned on or off, when they run, and relay halt commands. This system will also drive the LCD display showing the current status of the Control System.

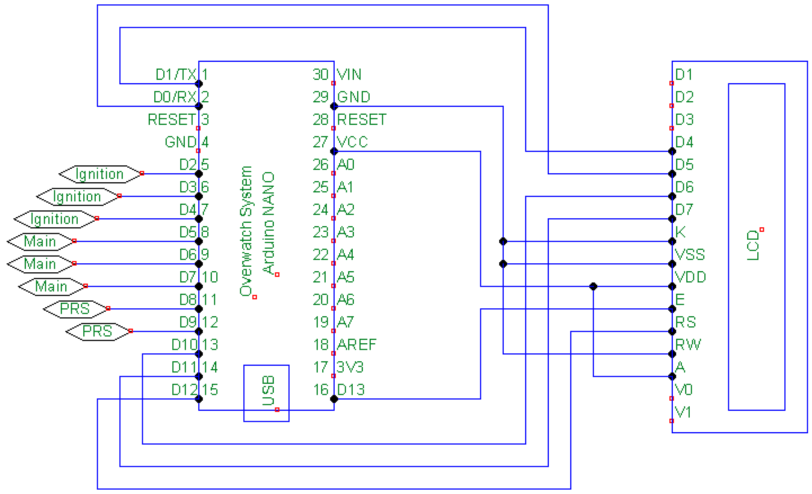


Figure 36: Overwatch System Diagram

4.11.7 Main Subsystem

The Main Subsystem controls the raising and lowering of the launch rail and communicates with the Payload Retrieval System and Payload Bay subsystems to coordinate actions such as opening the Payload Bay for the Payload Retrieval Subsystem.

This system makes use of high draw components; the control system will interact with these via relays.

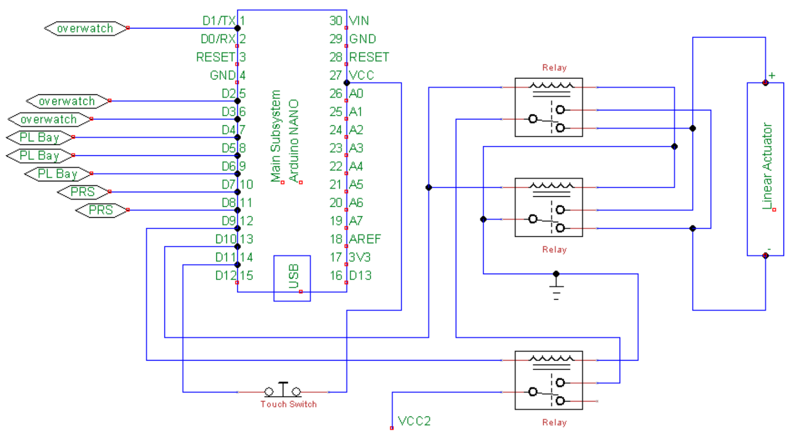


Figure 37: Main Subsystem Diagram

4.11.8 Payload Bay System

The Payload Bay Subsystem controls the opening, closing, and locking of the Payload Bay. This subsystem is installed within the Launch Vehicle and is connected to the Main Subsystem by a 5 pin cord which carries both I/O and VCC/VDD. This cord will externally plug into the Launch Vehicle near the

Payload Bay and be held in place with magnetic couplers until the Launch Vehicle is raised; it will be disconnected by the action of the Launch Vehicle raising.

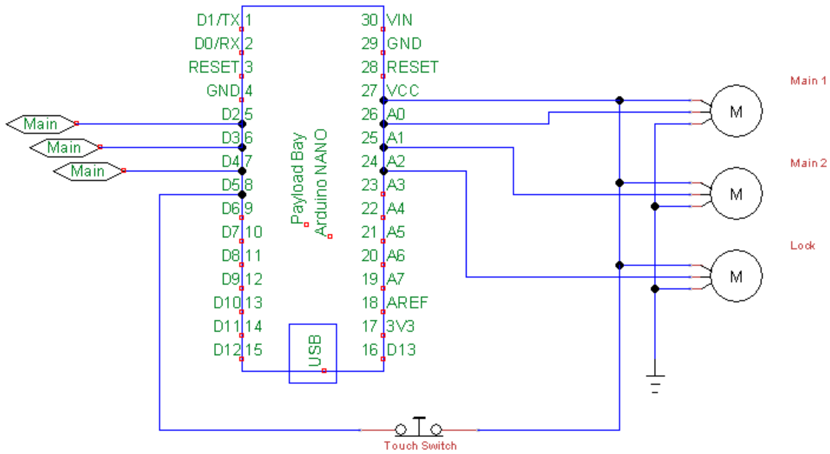


Figure 38: Payload Bay System Diagram

4.11.9 Payload Retrieval Subsystem

The Payload Retrieval Subsystem controls all servos and sensors associated with the articulation of the arm and grasper to facilitate the retrieval and delivery of the payload to the Payload Bay. It makes use of a contact sensor installed in the grasper mechanism to indicate when the payload is within the grasper.

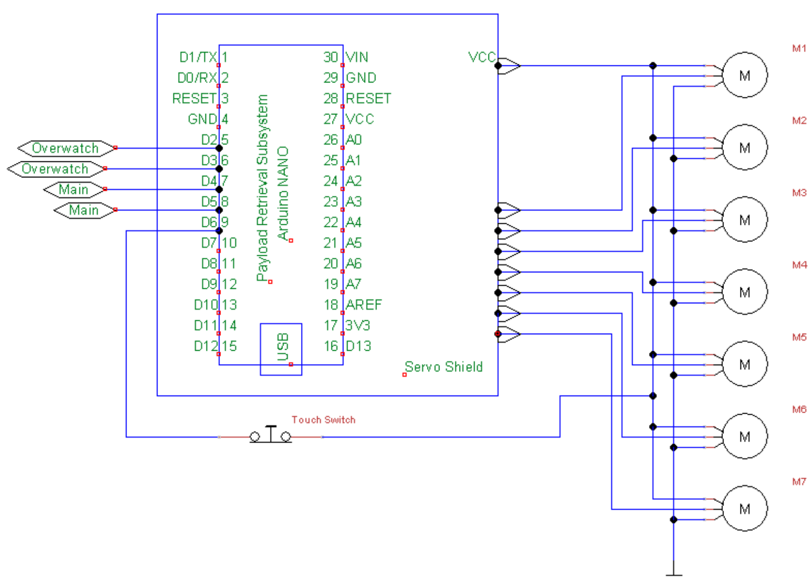


Figure 39: Payload Retrieval Subsystem Diagram

4.11.10 Ignition Subsystem

The Ignition Subsystem controls the delivery of the ignition match into the Launch Vehicle's motor. It relies on the limited reach of its mechanism and a timed run-time to insert the match into the Launch Vehicle accurately.

This system makes use of high draw components; the control system will interact with these via relays.

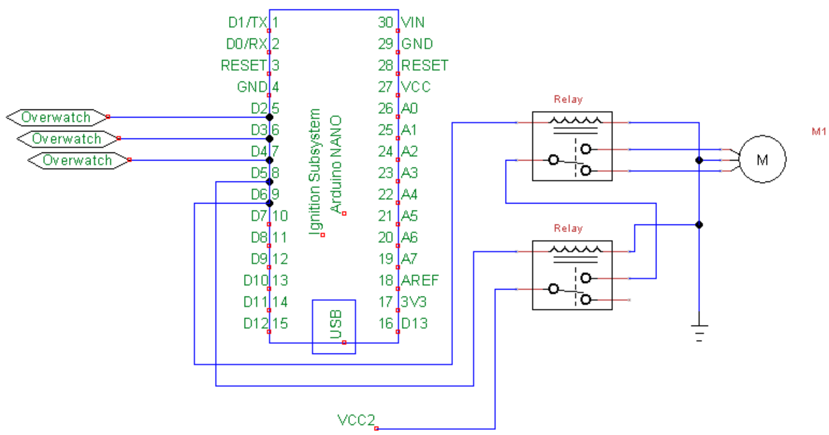


Figure 40: Ignition Subsystem Diagram

4.12 AGSE Concepts and Features

4.12.1 Creativity of the Design

The design of the AGSE was split up into smaller manageable systems with an individual assigned to each section. Individualizing operations led to innovations in each system with different individuals specializing in each operation of the AGSE. The Launch Rail System is flexible with the weight of the Launch Vehicle it can raise. The linear actuator calculations show the Launch Rail System can handle up to a fifty-pound Launch Vehicle. The Payload Retrieval System is flexible in the length of the robotic arms extension. The robotic arm has a maximum reach of 35.83 inches; this allows for variations in the position of the payload as well as the height of the AGSE frame.

The robustness of the AGSE design is due to the creativity of each AGSE system designers. The 3D printing of most of the AGSE will allow the manufacturing of the components to fast and responsive to any testing that is done on the AGSE. This all increases the flexibility of the design by allowing the AGSE systems to be manufactured with the press of a button. All of these design options show forethought and top down design. They have larger application with the spirit of the competition as well.

4.12.2 Significance of the Design

The significance of the design is that the AGSE is 3D printed and robust. Therefore, if any of the parts are broken on Mars, as per the spirit of the competition, they can be reprinted and assembled easily on site.

The Launch Rail System is also significant because the design can hold many different weights. This will allow the Launch Rail System to be used to launch a variety of different weighted payload samples or Launch Vehicles from a standardized Launch Rail. This allows the AGSE to be reusable in different Launch Vehicle situations.

The reach of the Payload Retrieval System is 35.83 inches at maximum. The reach extends in 3D space, so design could be extend to reach many different payloads off a rover-loaded shelf. This would meet the spirit of the competition. This setup design would use a position driven Payload Retrieval System, instead of the visually driven detection system used in the current design. The robustness of the design leads to multiple configurations and design flexibility to real world conditions.

4.12.3 Suitable Level of Challenge

The AGSE has been designed with mechanical engineering calculations using statics and material strength calculations. These were parts of common engineering classes that are available at Clark College. Launch Vehicle calculations and all of the Launch Rail System calculations were done in MATLAB.

An uncommon problem that needed to be solved was an integral approximation to find the average speed of the linear actuator: This was solved with the expertise of students that had taken from the numerical methods class from Clark College.

4.13 Experimental Logic

4.13.1 Approach

The approach we will take to testing all AGSE subsystems will be to cycle each system individually 20 times prior to assembly to test for errors, and the entire system a minimum of 50 times once it has been assembled. If an error is found during the testing phase they will be isolated and addressed before any further testing will take place. The AGSE Control System will send statuses to each Arduino Nano that monitors a subsystem. Each Arduino Nano will send an error code or a working status back to the Control System.

4.13.2 Method of Investigation

The Method of Investigation which will be employed will be observation and analysis of collected data. The collected data will consist of time it takes for a system to complete its cycle and any observed variance from previous cycles, wear, etc.

Section 5 - Safety

5.1 Safety Overview

While Clark Aerospace has a safety officer, **safety is the responsibility of each and every team member.** All team members have the ability and responsibility to call a halt to any activities that risk damage to the launch vehicle or have the potential to harm any crew member, onlooker, or bystander. A delayed launch will fly eventually. An obliterated rocket will never fly again.

3.1.1 Safety Officer

- Michael M. is the team Safety Officer
- The Safety Officer's primary responsibility is to minimize hazards to the launch vehicle and ensure safe working conditions for the crew through a set of detailed procedures.
- Specific responsibilities include:
    - Assembly documentation review
    - MSDS maintenance
    - Pre-Launch briefings
    - Emergency checklists
    - Safety Over watch
    - Monitoring and ending Safety Halts.

Material Safety Datasheets (MSDS)

- The safety officer will maintain the material safety datasheets, contained in Appendix D.
- The safety officer is responsible for training the assembly and launch team on proper use of the MSDS, including how to identify the proper response to spills or exposure, proper handling of chemicals and equipment, and proper use of PPE when dealing with hazardous materials.
- Finally, the safety officer must ensure all MSDS are readily available and in the area the hazardous chemicals reside.

Emergency Contacts

- The safety officer shall develop and maintain a list of emergency contacts for each team member on staff.

5.1 Safety Checklists

5.1.1 Final Assembly Checklist and Considerations

Foreign Object Debris/Foreign Object Damage

- FOD is any object alien to the Launch Vehicle/AGSE.
- FOD control is a serious consideration for all aerospace applications.
- Due to limitations in facilities, Clark Aerospace does not have access to a secure work area. This fact undermines the team's ability to completely eliminate FOD.
- To manage this risk Clark Aerospace, under guidance of the Safety Officer, will institute a strict FOD inspection policy.

FOD Inspection Policy:

During final assembly of the Launch Vehicle, there will be a five foot "Keep-Out" zone around the assembly area. This zone will be called the "FOD Critical Area"

- Only equipment and personnel vital to the final assembly of the Launch Vehicle will be allowed to enter the FOD Critical Area.
- Non-vital equipment (includes food, drinks, cellphones, and documentation) not vital to assembly will not be allowed to enter the FOD Critical Area.
- All tools and equipment taken into the FOD Critical Area must be accounted for either by "shadowboxing" a tool box, or through a sign in/out system.
- Every section of the launch vehicle (to be assembled) must be visually inspected for FOD by both the Safety Officer and the Launch Vehicle Team Lead.
- Any component within a section that cannot be visibly inspected (such as a sub-component that has been sealed earlier in the assembly process) must have been previous inspected for FOD by both the Safety Officer and Launch Vehicle Team Lead.
- All components that were previous inspected will be marked and identified on the sealed section "FOD Free".
- Before final assembly is considered complete, all tools and equipment must be accounted for and logged back in.

Final Assembly Safety Checklist	Safety Officer Initials	Mission Director Initials
FOD control policy enforced during sub-component assembly		
FOD control policy enforced during integration into Launch Vehicle		
All tools accounted for		
All code up to date with most current version		

Table 16: Final Assembly Checklist

5.1.2 Launch Checklists

Recovery Preparation		
	Safety Officer Initials	**Mentor Initials**
Program Raven3 Altimeters		
Proper Wire Connections:		
Raven3 Altimeters		
Batteries		
Arming Switches		
Ejection Charges		
Big Red Bee Transmitters		
New Batteries		
Proper Assembly of AV Bay:		
Bulk Plates		
U Bolts		
Check Recovery System for Tears/Holes/Damage		
Main Parachute		
Drogue Parachute		
Payload Parachute		
Harnesses		
Shock Cords		
Check Shock Cord Connections		
Parachutes		
Launch Vehicle		
Properly Pack Parachutes and Shock Cords		
Mentor Fills Charge Wells		

Table 17: Recovery Preparation Checklist

Motor Preparation		
To Be Done By Mentor:	**Safety Officer Initials**	**Mentor Initials**
Inspect and clean motor case as needed		
Assemble motor following manufactures instructions		
Insert motor into Launch Vehicle		
Install motor retainer		
Inspect E-match for damage		

Table 18: Motor Preparation Checklist

AGSE Preparation		
	Safety Officer Initials	**Mentor Initials**
Ensure All Bolts are Tightened		
Ensure Ground Screws are Fully Deployed		

Ensure Tension Cables are tight		
Ensure AGSE is Level		
Ensure Ignition System is Fully Retracted		
Ensure MagSafe Connection is Secure		
Check Battery Connections		
Check Overwatch Status		
Check Payload Retrieval System Status		
Check Launch Rail Status		
Check Igniter Status		
Check Payload Bay Connection		
Check Payload Bay Status		
Verify Correct Placement of Payload		

Table 19: AGSE Preparation Checklist

Final Setup		
	Safety Officer Initials	**Mentor Initials**
Rail Buttons Are Fastened Securely		
Slide Launch Vehicle onto Launch Rail		
Ensure Launch Vehicle Slides Freely on Launch Rail		
AGSE is Stable on the Pad		
Verify no ignition current by shorting launch lead clips		
Arm Raven3 Altimeters		
Attach Launch Leads to Motor Igniter		
Ensure System Correctly Responds to Halt Command		
Ensure System Correctly Responds to Reset Command		

Table 20: Final Setup Checklist

Launch Checklist		
	Safety Officer Initials	**Mentor Initials**
Verify Recovery Preparations Checklist is Complete		
Verify Motor Preparations Checklist is Complete		
Verify AGSE Preparations Checklist is Complete		
Verify Final Setup Preparations Checklist is Complete		
Verify Power LED Steady On		
Arm Raven3 Altimeters		
Attach Launch Leads to Motor Igniter		

Check Weather Conditions:		
Wind (Less than 17 MPH)		
Visibility (Not Overcast)		
Clear Launch Area of Equipment, Personnel, and FOD		
Final Check of Status LCD		

Table 21: Launch Checklist

Post-Flight Inspection		
	Safety Officer Initials	Mission Director Initials
Check Launch Area for Environmental Damage		
Check Launch Vehicle for Damage		
Check AGSE for Damage		
Check Payload for Damage		
Check Recovery for Damage:		
Parachutes		
Harnesses		
Shock Cords		
Check Electronics for Damage		
Check Altimeter Data		
Log Altimeter Data		

Table 22: Post-Flight Inspection Checklist

5.2 Hazard Analysis

5.2.1 Personal Safety

Safety Halt

As previously stated, Clark Aerospace members are required to call a "safety halt" to any activity in progress if they believe the activity presents an unnecessary/unsafe risk to personnel or equipment. If a halt occurs prior to rocket ignition all electronics will be immediately reverted to a safe state. Only after all activity is halted will the issue be discussed. **Safety halts will last a minimum of two minutes.** If the issue is resolved quickly, all team members are expected to use the remainder of the two minutes to evaluate other safety hazards. Only the crew member that has called the safety halt, the safety officer, or the Mission Director can end the safety halt.

PPE - Personal Protective Equipment

The safety officer shall ensure the proper maintenance of PPE. PPE will include, but is not limited to, hardhats, gloves, safety glasses, and dust masks. The safety officer shall define which PPE is required for each task to ensure the safety of crew members. It is also the responsibility of the Safety Officer to ensure proper maintenance of PPE.

5.2.3 Risk Mitigation

Probability	Severity			
	1 Catastrophic	2 Critical	3 Marginal	4 Negligible
A – Frequent	1A	2A	3A	4A
B – Probable	1B	2B	3B	4B
C – Occasional	1C	2C	3C	4C
D – Remote	1D	2D	3D	4D
E – Improbable	1E	2E	3E	4E

Table 23: Severity Reference Table

Management Risk and Approval Authorization	
Level of Risk	**Approving Authority**
High Risk	**Highly Undesirable**. Documented approval from the Safety Officer and Mission Director required to continue.
Moderate Risk	**Undesirable**. Documented approval from the Safety Officer is recommended to continue. Before proceeding, reference checklists and procedures.
Low Risk	**Acceptable**. Documented approval from Safety Officer suggested before continuing. Keep in mind established procedures and reference checklists before proceeding.
Minimal Risk	**Acceptable**. Documented approval not required, but an informal review by the Safety Officer/Mission Director is recommended. Keep in mind established procedures and follow checklists.

Table 24: Management Risk and Approval Authorization

Probability Definitions	
Description	**Qualitative Definition**
A – Frequent	High likelihood of occurring or predicted to occur repeatedly.
B – Probable	Likely to occur or predicted as a common occurrence within the operational timeframe.
C – Occasional	Predicted to occur occasionally or intermittently within the operational timeframe.
D – Remote	Unlikely to occur but can be anticipated to happen with time.
E – Improbable	Very unlikely to occur and is not predicted to be experienced with time.

Table 25: Risk Probability Definitions

Severity Definitions			
Description	**Risk to Personnel Safety**	**Risk to Facility/Equipment**	**Environmental**
1 – Catastrophic	Loss of life or permanent severe injury	Loss of facility, systems, or any associated hardware	Irreversible severe environmental damage that violated law and/or regulation
2 – Critical	Severe injury or occupational-related illness	Major damage to facilities, systems, or equipment	Reversible environmental damage causing a violation of law and/or regulation
3 – Marginal	Moderate injury or occupational-related illness	Minor damage to facilities, systems, or equipment	Reversible environmental damage without violation of law or regulation where restoration activities can be accomplished
4 – Negligible	Minor injury or occupational-related illness	Minimal damage to facilities, systems, or equipment	Minimal environmental damage not violating law or regulation

Table 26: Severity Definitions

Personal Hazards					
Possible Hazard	**Possible Cause**	**Impact**	**Pre-Mitigation Category**	**Proposed Mitigation**	**Post-Mitigation Category**
Injury/Death	Systems malfunction/testing mishap	Injury/Death of team personnel	D1	Follow pre-determined procedures and checklists	D1

Table 27: Personal Hazards

Exposure to hazardous materials	Manufacturing process	Possible respiratory and skin irritation	B3	Wear Proper attire and safety equipment. Follow proper handling and use instructions in MSDS	B3
Machine shop injuries	Not following proper procedure Not being aware of surroundings	Personal injury	C3	Proper PPE Follow pre-determined procedures	C3

Launch Vehicle Hazards					
Possible Hazard	**Possible Cause**	**Impact**	**Pre-Mitigation Category**	**Proposed Mitigation**	**Post-Mitigation Category**
Hardware Failure	Improper construction of vehicle body	Catastrophic structural failure	D1	Follow construction procedures Proper testing and verification of schematics	E1
Software Systems Failure	Programming errors Improper Wiring	Recovery System Failure/Loss of Vehicle	E1	Proper Testing of language and processes prior to flight	E1
Mechanical Failure	Improper amount of black powder	Improper separation of airframe Poor/no deployment of Recovery System	D1	Proper Design and construction of airframe. Correct black powder amount	D1
Recovery System Failure	Early Deployment No Deployment Avionics Failure	Extreme Damage/Loss of vehicle	D1	Proper Design Correct packing procedures Correct shear pins	D1
Launch Vehicle Damaged in Transport	Improper packaging/handling	Failure to meet launch ready status	E1	Properly package everything Explicit handling instructions on shipping containers	E1

Loss of fin(s)	Improper fin flutter calculations Improper construction	Unstable flight Catastrophic airframe failure (Shredding)	D1	Verify calculations Follow construction plan	D1
Unstable Flight	Improper calculations	Loss of launch Vehicle	D1	Verify CoP and CoG calculations Subscale Flight	E1

Table 28: Launch Vehicle Hazards

5.2.4 Environmental Hazards

There is no mitigation plan for winds, rain, or weather (in general). Aerospace activities are simply at the mercy of the elements. It is important, therefore, to define specific requirements for environmental limits. By stating strict limits for wind, rain, and temperature the team can eliminate any launch risks. In the end, the team has no control over the environment's impact on the mission. The team does, however, have some control over the mission's impact on the environment. It is a fact of rocketry that chemicals are burned and pollution is produced. At Clark Aerospace the plan is to do the best the team can to mitigate these factors by being conscientious about the uses of electricity and consumables during assembly and testing of the system. For instance, by simply eliminating post-it notes, this not only reduces the chance of FOD, but saves the consumption of paper and petroleum based adhesives. The largest possible negative impact the team can sustain outside of severe injury/death is a loss of vehicle event. An explosion or uncontrolled descent can spread fiberglass and chemicals over a wide area. Knowing proper cleanup and containment techniques for these contaminates will allow the team to react quickly and limit the damage or impact to the environment. Finally, all rocket launches pose a risk of fire. For that reason a properly rated fire extinguisher will always accompany a loaded motor as well as any potential flammable materials.

Environmental Hazards					
Possible Hazard	Possible Cause	Impact	Pre-Mitigation Category	Proposed Mitigation	Post-Mitigation Category
Chemical Spill	Incorrect handling of chemicals	Irreversible environmental damage	D1	Follow all laws/regulations as well as MSDS procedures	E1
Fire	Lack of blast shield	Burned environment	D4	Ensure blast shield is in place	E1

				before all launches and have a fire extinguisher accompany all loaded rocket motors	
Rocket Debris	Catastrophic failure of rocket during launch or flight	Potentially harmful debris spread across a large area	D3	Ensure all flight calculations are completed before launch	D3

Section 6 - Project Plan

6.1 Budget

Sub Scale Launch Vehicle

Part	Quantity	Unit	Unit Cost	Total Cost
Balsa Wood 1/32x3x36 (2 pcs)	EA	1	$2.49	$2.49
Tammie's Hobbies Body Tube Pack	EA	1	$19.95	$19.95
Estes C6-3 Rocket Engine (3-pack)	EA	1	$17.49	$17.49
Subtotal:				$39.93
Total cost of sub-scale Launch Vehicle components: (with tax)				$43.3041

Table 29: Subscale Launch Vehicle Budget

Full Scale Launch Vehicle

Part	Unit	Quantity	Unit Cost	Total Cost
5 inch Nose cone	EA	1	$75.00	$75.00
12 inch length 5" Airframe G12 Fiberglass	EA	1	$38.00	$38.00
24 inch length 5" Airframe G12 Fiberglass	EA	2	$76.00	$152.00
36 inch length 5" Airframe G12 Fiberglass	EA	2	$114.00	$228.00
75mm G12 Fiberglass motor tube (3 foot)	EA	1	$82.04	$82.04
54mm to 75mm adapter	EA	2	$37.00	$74.00
5 inch G12 Coupler	EA	3	$51.00	$153.00
G10 AV-bay lid	EA	3	$3.99	$11.97
75mm to 5Inch G10 Centering ring	EA	3	$8.00	$24.00
75mm Flange retainer	EA	1	$52.00	$52.00
Rail button guides (2 pack)	EA	2	$4.00	$8.00
Epoxy Loctite E-120HP	EA	7	$13.38	$93.66
3/16 Black G10 plate 12" x 24"	EA	3	$64.00	$192.00
10-24 Steel tee nut (10 pack)	EA	1	$5.74	$5.74
10-24 Steel slotted machine screws (50 pack)	EA	1	$8.50	$8.50
10-24 Steel socket head screw (50 pack)	EA	1	$8.34	$8.34
10-24 Stainless steel hex nut (100 pack)	EA	1	$9.00	$9.00
12-24 Steel airframe screws (100 pack)	EA	1	$7.50	$7.50
5 inch G10 coupler bulk plate	EA	3	$7.00	$21.00
Stainless steel number 14 wood screw (25 pack)	EA	1	$11.60	$11.60
5 Inch G10 Airframe bulk plate	EA	4	$7.00	$28.00
AeroTech K1050W Rocket motor	EA	3	$157.49	$472.47
Super Lube grease	EA	1	$5.99	$5.99
BRB900 Transmitter	EA	2	$199.0	$398.00
BRB900 Receiver	EA	1	$99.00	$99.00
Wildman club membership	EA	1	$30.00	$30.00

Aft closure	EA	1	$37.76	$37.76
Forward plugged closure	EA	1	$39.95	$39.95
Forward seal disc	EA	1	$13.49	$13.49
RMS-54 2800 N-sec motor casing	EA	1	$127.52	$127.52
Subtotal:				$2,507.53
Total price of full-scale Launch Vehicle Components (with tax):				$2,719.42

Table 30: Full Scale Launch Vehicle Budget

Recovery System

Part	Unit	Quantity	Unit Cost	Total Cost
Main parachute 84 inches	EA	1	$256.00	$256.00
Payload parachute 48 inches	EA	1	$106.00	$106.00
Drogue parachute 24 Inches	EA	1	$58.00	$58.00
11/16” Large shock cords	Per Yard	7	$1.50	$10.50
11/16” Large shock cords	Per yard	7	$1.50	$10.50
11/16” Large shock cords	Per yard	10	$1.50	$15.00
5/16” Steel quick links	EA	8	$5.50	$44.00
Deployment bag 4” x 12”	EA	1	$39.00	$39.00
Deployment bag 3” x 9”	EA	2	$33.00	$66.00
Steel 3 inch U-bolt (5 pack)	EA	1	$7.24	$7.24
5/16”-18 Aluminum hex nuts (100 pack)	EA	1	$9.74	$9.74
Raven Altimeters	EA	2	$155.00	$310.00
9 volt batteries 10 pack	EA	1	$6.95	$6.95
9 volt Battery Holder	EA	2	$2.58	$5.16
Arming Key Switches	EA	6	$5.75	$34.50
Coupling Nuts	EA	4	$4.73	$18.92
Nylon Unthreaded Spacers 1/8” OD (25 pack)	EA	1	$7.54	$7.54
Nylon #2-56 Shear screw (100 pack)	EA	1	$5.11	$5.11
Copper Mesh	EA	1	$56.92	$56.92
Aluminum angle brackets	EA	2	$1.19	$2.38
Steel #0-80 socket head cap screw	EA	1	$7.76	$7.76
Nylon unthreaded #0-80 spacer	EA	1	$7.54	$7.54
Steel Allthread 5/16”-18	EA	4	$3.88	$15.52
6061 Aluminum Sheet .05” 4”x24”	EA	1	$11.38	$11.38
#0-80 Stainless steel pan head screws	EA	1	$7.29	$7.29
Steel #0-80 Hex nut	EA	1	$5.02	$5.02
Subtotal:				$1,123.97
Total price of Recovery Systems (with tax):				$1,224.38

Table 31: Recovery System Budget

Payload Containment System

Part	Unit	Quantity	Unit Cost	Total Cost
Sugatsune ESR-3313-8 Drawer	EA	1	$10.88	$10.88
Nema 8 Newegg Stepper Motor	EA	2	$27.00	$54.00
Hs-35HD Ultra nano Servo	EA	1	$24.99	$24.99
#10-24 flat head bolts (100 pack)	EA	1	$10.95	$10.95
¼"-20 steel flat head bolts (50 pack)	EA	1	$12.22	$12.22
#5-40 flat head bolts (100 pack)	EA	1	$5.67	$5.67
Subtotal:				$118.71
Total price of Payload Containment System (with tax):				$136.9073

Table 32: Payload Containment System Budget

Travel

Travel Expense	Unit	Quantity		Unit Cost	Total Cost
Flight to Huntsville	Per Person	11		$475	$5225.00
Rental Van	Per Person/seats	2		$750	$1500.00
Meals	Per person	11		$350	$3850.00
Lodging	3 Rooms for 6 nights/7 days	3	6	$106	$1908.00
Subtotal:					$12,483.00
Total price of Travel (with tax):					$13,537.81

Table 33: Travel Expenses

AGSE

Part	Unit	Quantity	Unit Cost	Total Cost
HK15178 Hobbyking Analog Servo	EA	1	$2.29	$2.29
Aerostar ASI-621MG Servo	EA	1	$23.75	$23.75
Corona DS339HV Hobbyking Servo	EA	1	$10.25	$10.25
Corona BL-6168 Hobbyking Servo	EA	2	$43.16	$86.32
TGY-1270HV Hobbyking Servo	EA	1	$32.50	$32.50
EverStart 12 volt volt Battery (in Huntsville)	EA	2	$110.00	$220.00
Rocket igniter	EA	3	$20.00	$60.00
1 Kilogram of PLA plastic filament	EA	1	$48.00	$48.00
Steel turntable	EA	1	$10.30	$10.30
Welding material fees	EA	1	$200.00	$200.00
Grinding disks	EA	3	$25.00	$75.00
1" diameter 1020 steel tube	Per 20 Foot	8	$35.00	$280.00
6061 Aluminum to be machined	EA	2	$65.70	$131.40
Steel 1 foot smooth rods	EA	1	$7.78	$7.78
M5 Socket Head Cap Screws (100 pack)	EA	1	$8.63	$8.63
Steel Hex Nuts M5 threading (100 pack)	EA	1	$1.73	$1.73
10-24 Steel flat head screws 3/8" length (25 pack)	EA	1	$4.24	$4.24

10-24 Steel hex nuts	EA	1	$1.72	$1.72
5/16 Inch self-locking Acorn Nut (10 Pack)	EA	1	$13.73	$13.73
5/16 Steel Square Head Bolt	EA	1	$6.07	$6.07
3/8 Inch Nylon Flat Washers (5 pack)	EA	2	$2.05	$4.10
Steel End-Feed Fastener (4-Pack)	EA	2	$2.71	$5.42
Aluminum Plate 1/4 inch thick	EA	4	$6.35	$25.40
12 Volt Relay (SPDT sealed)	EA	5	$1.95	$9.75
24 pin SMD connector	EA	3	$1.50	$4.50
24 pin power Extension Cable	EA	5	$6.99	$34.95
Arduino Nano	EA	8	$10.00	$80.00
Sparkfun micro switch (2 terminal)	EA	2	$1.50	$3.00
Servo shield	EA	1	$17.50	$17.50
20 Gauge electrical wiring	Per Foot	20	$1.20	$24.00
Arduino LCD display 16X2	EA	1	$13.92	$13.92
Automotive antenna extender	EA	1	$137.56	$137.56
1515 Aluminum extrusion	Per Foot	10	$8.29	$82.90
Linear Actuator PA-02-16-400	EA	1	$135.99	$135.99
Mounting Bracket BRK-02	EA	2	$8.50	$17.00
External Limit Switch	EA	1	$7.99	$7.99
Prototyping board	EA	10	$3.6	$36.00
ABS Plastic sheet 24x24x1/8	EA	5	$9.9	$49.50
Magsafe plug	EA	1	$9.99	$9.99
15 Pin female headers	EA	20	$0.62	$12.40
6 volt regulator	EA	20	$1.00	$20.00
6 inch Black zip ties (100 bag)	EA	1	$12.75	$12.75
25 ft 20 Gauge wire	EA	2	$3.36	$6.72
Spool of solder	EA	1	$31.99	$31.99
Cable sleeving	Per foot	50	$1.03	$51.50
Subtotal:				$2,058.54
Total price of AGSE (with tax):				$2,538.23

Table 34: AGSE Budget

Total Launch Vehicle and AGSE Expenses

Totals	Total Cost
Total AGSE expenses	$2,539
Total Payload Containment system expenses	$137
Total Recovery systems expenses	$1,224
Total Sub-scale Launch Vehicle expenses	$43
Total Full-scale Launch Vehicle expenses	$2,719
Total Projected Expenses of the Launch Vehicle and AGSE:	$6,662.00

Table 35: Total Expenses

6.2 Funding/Fundraising

The current cost of the AGSE and Launch Vehicle materials is $6,662. Clark Aerospace may need to switch to the Mini MAV competition, if the AGSE has non-resolvable problems. The cost of the Launch Vehicle and AGSE were not taken into consideration, while the being designed. Therefore the design of the Launch Vehicle and AGSE are not compromised by the low cost of the materials.

The projected funds needed to supply this year's Clark Aerospace activities are $24,960 with shipping and travel. To help fund the project, a request will be sent first to the Clark College Foundation in order to obtain an initial working budget. This will happen with the approval of the project by the Dean of S.T.E.M. and the President of Clark College. Plans will be submitted to the said persons and reviewed in order to make a comprehensive and obtainable financial goal. The request sent to the Clark College Foundation will be $24,960 (accounting for shipping and unforeseen expenses). This funding will be used for the fundamental purpose of building the Launch Vehicle and AGSE, and will ensure that the Launch Vehicle and AGSE are built and prepared for NASA's Student Launch this April. Leftover funds from this grant will be used for transportation and lodging of the team members at the competition.

Additional fundraising will provide the team with means to travel and lodge during the competition, and to ensure that the project is carried out to its greatest potential. Funding will be sought for from local businesses and major corporations. Clark Aerospace will submit requests to known sponsorship programs of various businesses, and if necessary will provide a presentation outlining the project and specifying the needs for that business's support. The team will additionally seek venues where a booth or representative may participate. At these events, Clark Aerospace hopes to find funding from public and private entities, but will also seek to educate the public on the team's project.

The following list of entities that Clark Aerospace will seek financial support from is not exhaustive: Boeing, Washington Space Grant Consortium, Riverview Community Bank, and iQ Credit Union. Initial research into each company's guidelines for sponsorship will be sought before sending in a request. If no such guidelines are found, Clark Aerospace will do its best to contact the company for funding, within reasonable means.

Clark Aerospace hopes to provide sponsors with the opportunity to have a brand logo placed on the rocket before and during the competition. This is part incentive and part reward to businesses that provided monetary or other means for the team to operate. Another reward might include having on hand at the competition a brochure.

Clark Aerospace will seek the funds as early in the school year as possible, in order to adjust the budget as needs be. If the funding received is inadequate for the team's current expenses, proper budget cuts will be enacted, but not at the expense of compromising the rockets ability or design. If there are any overages in the purchasing of the Launch Vehicle and AGSE expenses, then budget cuts will be made to the travel budget. A small budget buffer will be put in the budget request, so any budget shortfalls can be covered. If the travel budget is too big, students will be asked to pay for fractions of their travel costs.

6.3 Community Support

Clark Aerospace plans on working with the Clark College newspaper, The Independent, to help publicize its efforts to the student body. Additionally, Clark Aerospace plans to work with local newspaper The Columbian and The Oregonian, as well as the Vancouver Business Journal to publicize its effort to individuals and local businesses. Clark Aerospace will also seek expertise from advisors and other members of Clark College about specialized subjects in aerospace engineering. This will help support Clark Aerospace's ability to design and test a Launch Vehicle and AGSE.

Clark Aerospace has already begun fundraising by contacting the following local aerospace-related companies and organizations, and will continue seeking donations as the year progresses.

- INSITU
- Composites One
- Boeing
- SSA
- AACO Avionics
- Aerocenter
- Washington NASA Space Grant Consortium
- Washington State

6.4 Major Programmatic Challenges and Solutions

Challenge	Solution
Failure to meet team specific critical deadlines	Establish checkpoint deadlines to allow verification of progress
Team Member leaves team	Team management pro-actively coordinated reassignment of duties
Failure to achieve testing and verification due to project complications	Schedule testing and verifications dates that allow secondary dates if needed
Loss of data	Establish multiple backup systems including Google drive, personal storage devices and hard drive files

Table 36: Challenges and Solutions

6.5 Timeline

6.5.1 Critical Milestones

Deadline Date	Critical Milestones	Date Completed
October 6,2014	Proposal Deadline	October 6,2014
October 11,2014	Team selection announcement	October 11,2014
October 31,2014	Team web presence established	October 31,2014
November 5,2014	PDR reports, presentation, and flysheet posted on website	November 7,2014
November 19,2014	PDR video teleconference	November 19,2014
January 16,2015	CDR report, presentation, and flysheet posted on website	January 16,2014
January 21-Febuary 4,2015	CDR video teleconference	
March 16,2015	FRR report, presentation, and flysheet posted to website	
March 18-27,2015	FRR video teleconference	
April 10,2015	Mini/Maxi Launch day	

Table 37: Critical Milestones

6.5.2 Events

Date	Events	Date Completed
September 11, 2014	Proposal requested by NASA	September 23,2014
September 23, 2014	Team meeting and schedule for proposal	September 23,2014
September 24, 2014	Group brainstorm and reading of rules	September 24,2014
September 25, 2014	AGSE design & payload containment system session	September 25,2014
September 26, 2014	AGSE design session	September 26,2014
September 29, 2014	Finalizing AGSE design	September 29,2014
September 30, 2014	Launch vehicle design session	September 30,2014
October 1, 2014	Proposal documentation meeting	October 1,2014
October 2, 2014	Launch design finalization meeting	October 2,2014
October 14-20, 2014	Updating design and dimensioning AGSE components	October 20,2014
October 21, 2014	Fully dimensioned rocket due. Rocket calculations finished and prepared to be checked.	October 21,2014
October 31, 2014	Web presence established	October 31,2014
November 3, 2014	Finalize PDR designs including launch rail, robotic arm, and ignition system.	November 3,2014
November 5, 2014	PDR reports, presentation, and flysheet posted on website	November 5,2014
November 19, 2014	PDR video teleconference	November 19,2014
November 28, 2014	Purchase Prototyping materials	November 28,2014

December 20, 2014	Subscale Launch	December 20,2014
December 1-30, 2014	AGSE prototyping and testing	January 1,2015
January 16, 2015	CDR report, presentation, and flysheet posted on website	January 16,2015
January 16, 2015	Submit final budget to the ASCC	
January 16, 2015	Start assembling 3D printed AGSE components	
January 21-Feburary 4, 2015	CDR video teleconference	
January 23, 2015	Receive ASCC funding	
January 26, 2015	Submit itemized product orders	
February 23, 2015	Start assembling Launch Vehicle components from ordered components	
February 23-27,2015	Start assembling AGSE ordered components	
February 27, 2015	Final safety checks before sealing the Launch Vehicle	
February 28, 2015	Full scale launch Vehicle test launch	
March 10, 2015	Recommend Mini/Maxi MAV based on AGSE tests	
March 16, 2015	FRR reports, presentation, flysheet posted on website	
March 18-27, 2015	FRR video teleconference	
April 7, 2015	Team travels to Huntsville, AL	
April 7, 2015	Launch Readiness Reviews (LRR)	
April 8, 2015	LRR's and safety briefing	
April 9, 2015	Rocket fair and tours of MSFC	
April 10, 2015	Mini/Maxi MAV Launch day, Banquet	
April 11, 2015	Middle/High school launch day	
April 12, 2015	Backup Launch day	
April 29, 2015	Post-Launch Assessment Review posted on website	
May 11, 2015	Winning team announced	

Table 38: Events

6.5.3 AGSE Team Deadlines

Date	AGSE Team Deadlines	Date Completed
October 31, 2014	Finalized Launch rail, Robotic arm, and ignition Solidworks designs	October 31,2014
November 3, 2014	Rough draft due for sub sections of AGSE designs	November 3,2014
November 4, 2014	Compile final AGSE Assembly in Solidworks	November 4,2014
November 6-20, 2014	Begin prototyping AGSE components for design testing, includes 3D printing AGSE components	November 21,2014
December 15, 2014	Begin rough drafts of CDR sub sections	December 15,2014
December 20, 2014	Start programming the Arduinos for subsystems	December 20,2014
December 25, 2014	Test Arduino code for errors and printed components	December 25,2014

December 27, 2014	Final test of 3D printed components	December 27,2014
January 5, 2015	Launch Vehicle team looks at AGSE prototypes will fit with the Launch Vehicle specifications	January 5,2014
January 7, 2015	Revise all AGSE systems to Launch Vehicle team criteria	
January 10, 2015	Document deadlines for overall design review	
February 10-March 6, 2015	Start final Assembly of AGSE	
March 6, 2015	Full-Scale Test of AGSE	
March 8, 2015	Test all AGSE subsystems for FRR performance review	
March 16-20, 2015	Disassemble AGSE for shipping	
March 31, 2015	Ship AGSE	
April 7, 2015	Prepare and modify AGSE to working condition	
April 8, 2015	Present AGSE	
April 10, 2015	Competition Day	

Table 39: AGSE Team Deadlines

6.5.4 Launch Vehicle Team Deadlines

Date	Launch Vehicle Team Deadlines	Date Completed
October 24, 2014	Find dimensions for LV main components	October 31,2014
October 31, 2014	Finalized calculations (center of mass, masses, and dimensions)	October 31,2014
November 3, 2014	Finish integrated component calculations (parachutes, payload bay, etc.)	November 3,2014
November 2, 2014	Finalize dimensions for LV	November 4,2014
November 4, 2014	Begin checking calculations	November 4,2014
November 6-20, 2014	Start strength calculations	November 11,2014
November 10-14, 2014	Start designing Sub-scale launch vehicle	November 14,2014
December 13, 2014	Purchase Sub-scale materials	December 14,2014
December 15-19, 2014	Assemble Sub-scale launch vehicle	December 16,2014
December 20, 2014	Sub-scale launch	December 20,2014
December 25, 2014	Review sub-scale Launch data	December 25,2014
January 1, 2015	All calculations for Full-scale launch vehicle are finalize	January 1,2015
January 12, 2015	Send in budget request to ASCC	January 12, 2015
January 26, 2015	Purchase Full-scale materials	
February 10-15, 2015	Assemble Full-scale launch vehicle	
February 15-20, 2015	Analysis and testing launch vehicle components	
February 28, 2015	Launch vehicle full-scale preliminary launch	
March 10, 2015	Compare Launch data with calculated data	
March 11-16, 2015	Make emergency changes to full scale	
March 14, 2015	Secondary Full-scale launch (as needed)	
March 16-20, 2015	Disassemble rocket for shipping	
March 31, 2015	Ship Launch Vehicle	
April 10, 2015	Launch Rocket at Huntsville	

Table 40: Launch Vehicle Team Deadlines

6.6 Educational Engagement

The team will be various S.T.E.M events in Vancouver, WA that include;

- Elementary Science Olympiad on November 8th, 2014.
- MESA day on March 21st, 2015

Clark Aerospace will also visit various Schools and organizations in the Greater Vancouver and Portland area to include;

- The Girls Scouts of America every other Thursday from November 6th, 2014 to December 4th, 2014
- Rise and Star Community Center every other Thursday from November 13th, 2014 to December 11th, 2014
- Clark College Olivia Learning Center every other Tuesday from January 6th, 2015 to March 3rd, 2015.
- Harney Elementary every other Thursday from January 8th, 2015 to March 12th, 2015
- Boys and Girls club every other Tuesday from January 13th, 2015 to March 10th, 2015

While attending these events, schools and Originations the Clark Aerospace team will be interacting with children from the ages of 5-16 years old mentoring them in the S.T.E.M. fields by;

- Helping with Science and Math homework
- Conducting a design and Engineering project for an accurate recyclable rocket
- Conducting a design and Engineering project for a durable and safe package container that will be stressed tested through a multitude of assessments.
- Interactive Displays of Engineering and Science past feats

The number of students currently reached with S.T.E.M activities is 500 students to date.

Section 7 - Conclusion

- The design of the Launch Vehicle has been fully defined and simulated with several types of software. Clark Aerospace is confident in the design of the Launch Vehicle with the subscale launch confirming the design of the Launch Vehicle as stable.

- The design of the AGSE has been refined since the PDR. The AGSE team has addressed the problems that were raised during the PDR teleconference. Many parts of the AGSE have been prototyped and 3D printed. Therefore having a physical model to interact with in person ironed out many issues.

- Clark Aerospace is confident it has the ability and knowledge to fabricate the Launch Vehicle described in this paper. The AGSE is already in manufacturing process and the rest of the AGSE can be manufactured entirely at Clark College.

Appendix A – Sources

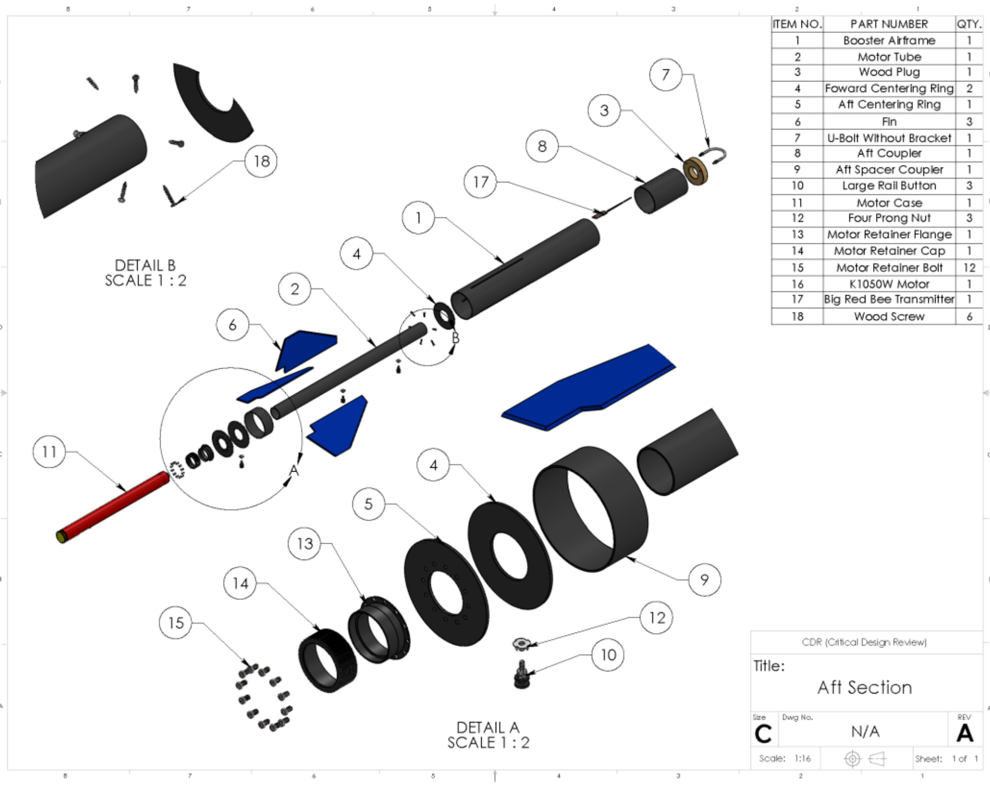
[1] John Coker, (April 2, 2009). *Simulator Data*. ThrustCurve.org [Online] Available at: http://www.thrustcurve.org/simfilesearch.jsp?id=1380

[2] Engineering ToolBox. *U.S Standard Atmosphere*. Engineering ToolBox [Online] Available at: http://www.engineeringtoolbox.com/standard-atmosphere-d_604.html

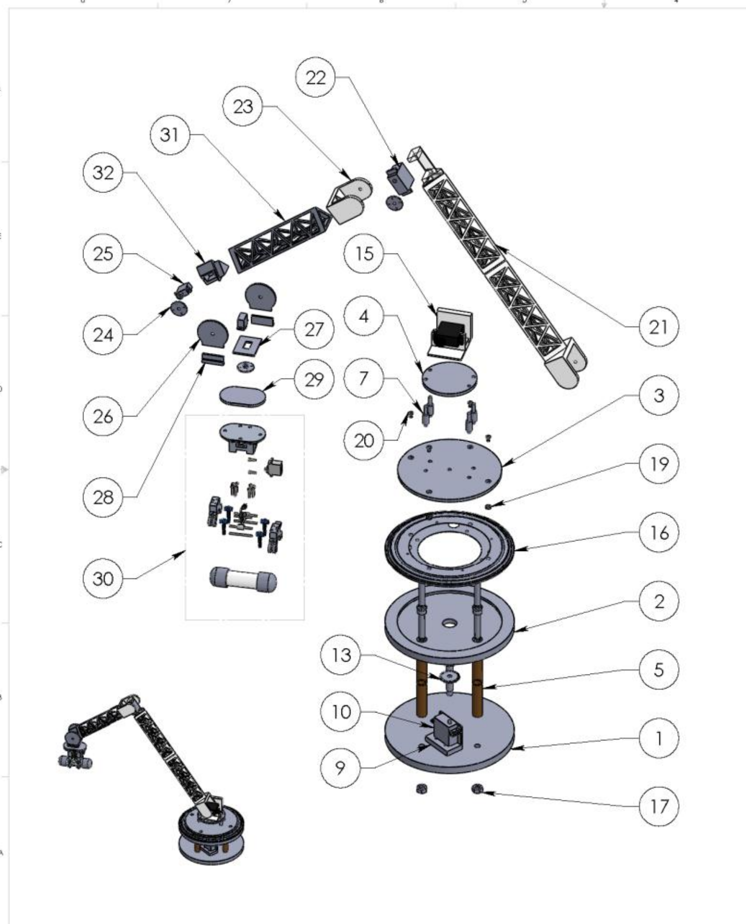
[3] Progressive Automations. *PA-02 Linear Actuator*. Progressive Automation [Online] Available at: http://www.progressiveautomations.com/images/pdf/Linear_Actuator_PA-02.pdf

[4] Huang Xianke. (December 9, 2009). *Zhejiang Dongya Electronic CO., LTD.* [Online] Available at: https://www.sparkfun.com/datasheets/Components/General/JZC-11F-05VDC-1Z%20EN.pdf

Appendix B – SolidWorks Drawings



ITEM NO.	PART NUMBER	QTY.
1	Booster Airframe	1
2	Motor Tube	1
3	Wood Plug	1
4	Foward Centering Ring	2
5	Aft Centering Ring	1
6	Fin	3
7	U-Bolt Without Bracket	1
8	Aft Coupler	1
9	Aft Spacer Coupler	1
10	Large Rail Button	3
11	Motor Case	1
12	Four Prong Nut	3
13	Motor Retainer Flange	1
14	Motor Retainer Cap	1
15	Motor Retainer Bolt	12
16	K1050W Motor	1
17	Big Red Bee Transmitter	1
18	Wood Screw	6



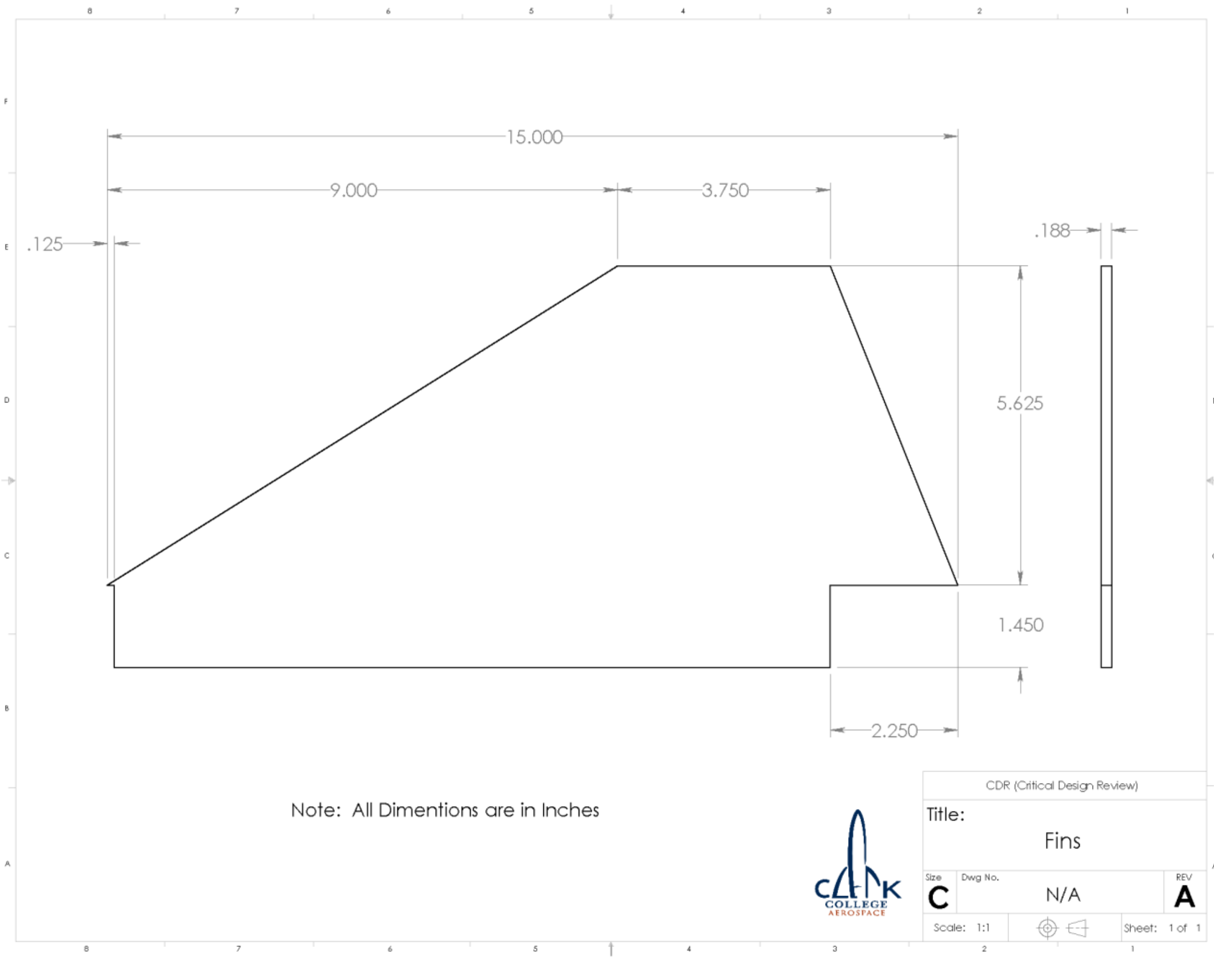
ITEM NO.	PART NUMBER	QTY.
1	Base Plate 1^AGSE Robotics	1
2	Base Plate 2^AGSE Robotics	1
3	Base Plate 3^AGSE Robotics	1
4	Base Plate 4^AGSE Robotics	1
5	Base Spacer^AGSE Robotics	4
6	Main Shaft^AGSE Robotics	1
7	Spacer Plate 4-5^AGSE Robotics	4
9	Mounting 1^AGSE Robotics	1
10	Servo Motor 16^AGSE Robotics	1
11	WRIST ASSEMBLE^AGSE Robotics	1
12	Shaft Gear^AGSE Robotics	1
13	Base Gear^AGSE Robotics	1
14	Motor Head^AGSE Robotics	1
15	Shoulder-Humerus fitment^AGSE Robotics	1
16	1544T200^AGSE Robotics	1
17	90592A024	4
18	91292A222	4
19	90480A011	4
20	91500A240	4
21	Humerus Printable 2^AGSE Robotics	1
22	Elbow Motor (ASI621MG)^AGSE Robotics	1
23	Humerus Printable^AGSE Robotics	1
24	Servo Arm (Disc)^AGSE Robotics	3
25	Servo Motor 6^AGSE Robotics	2
26	Wrist rotate^AGSE Robotics	2
27	Wrist plate^AGSE Robotics	1
28	Wrist Support^AGSE Robotics	2
29	Grasper to servo arm attachment^AGSE Robotics	1
30	GRASPER^AGSE Robotics	1
31	Truss 8in^AGSE Robotics	1
32	Wrist servo attach^AGSE Robotics	1

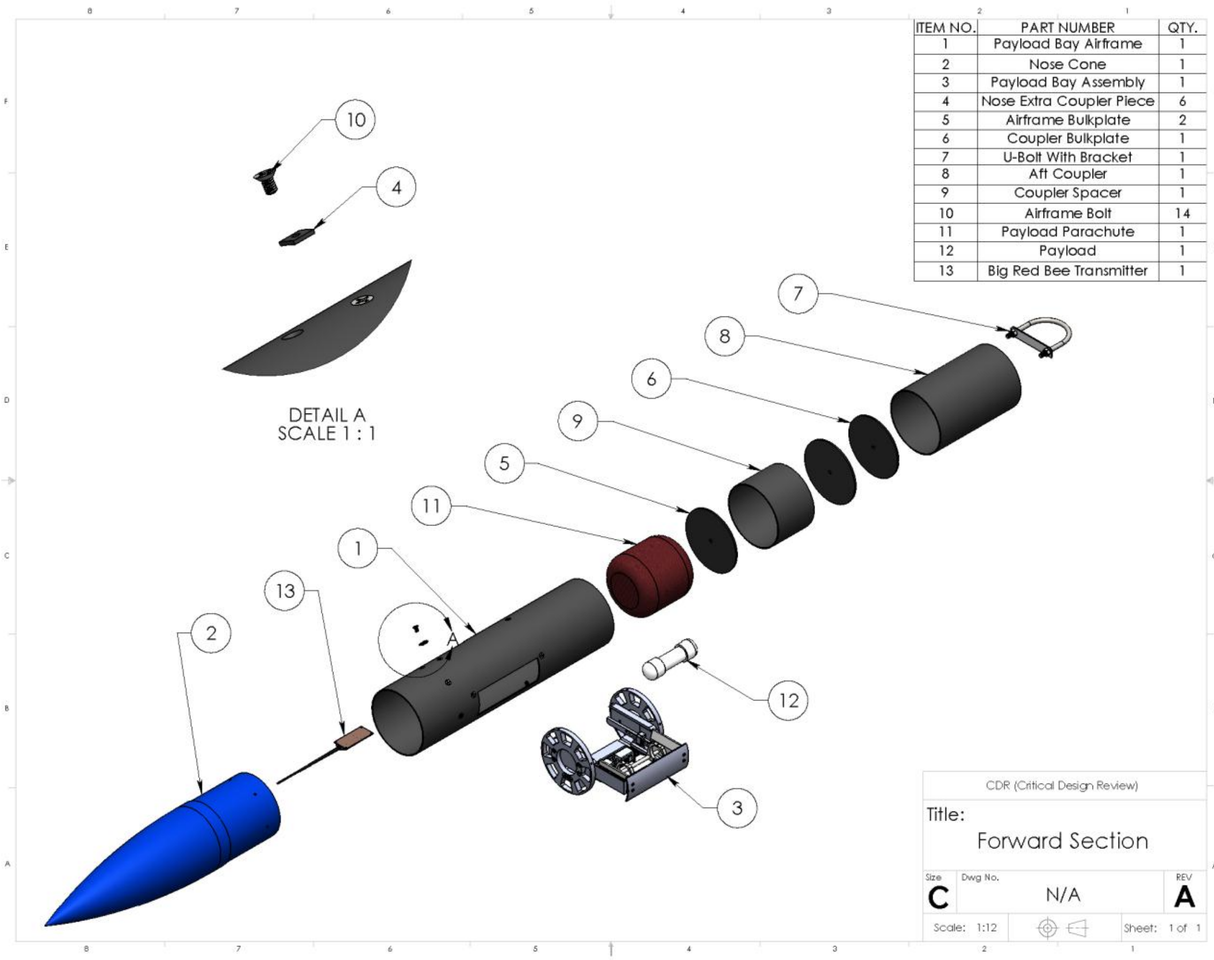
CDR (Critical Design Review)

Title: AGSE Robotics

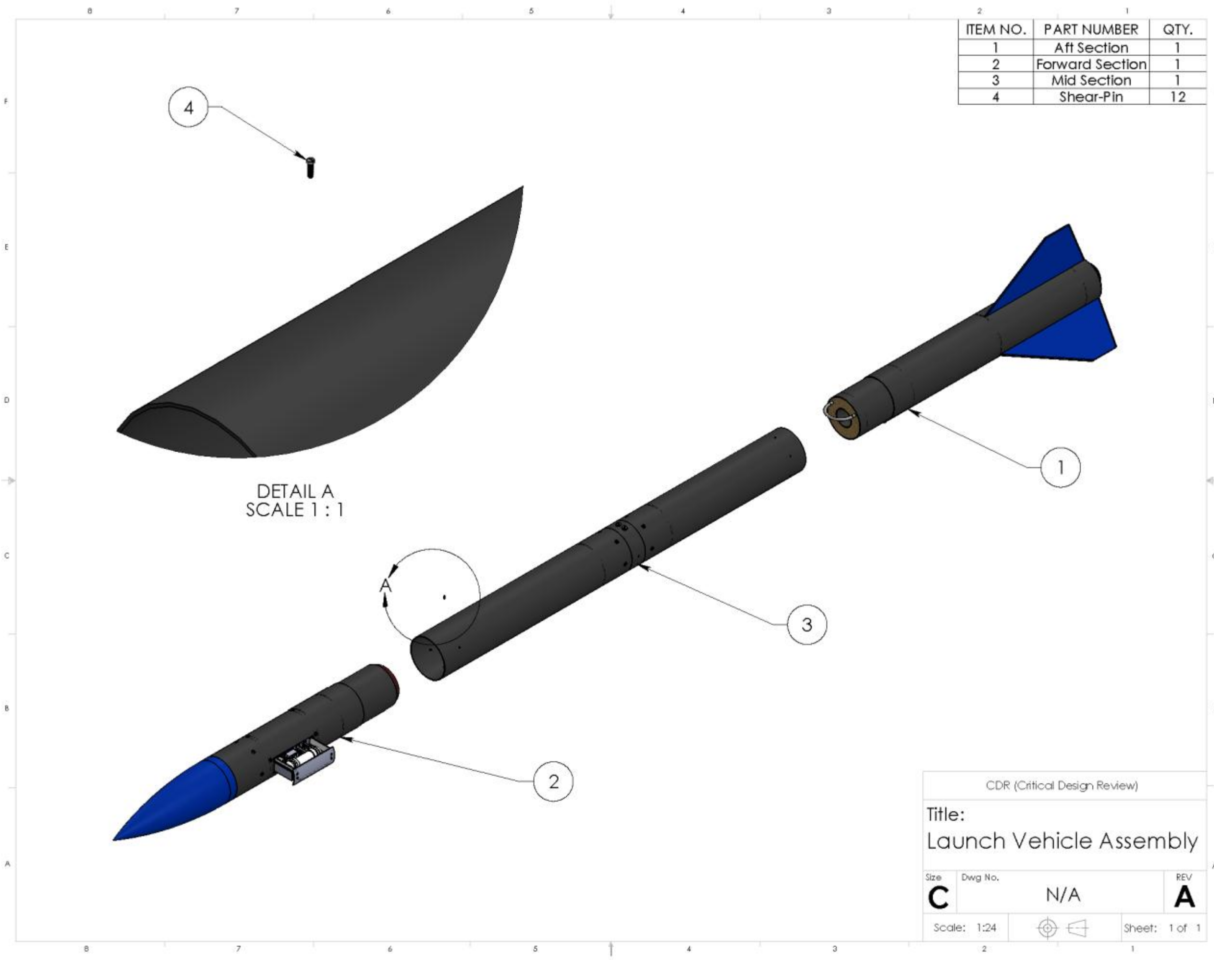
Size: C | Dwg No.: N/A | REV: A

Scale: 1:8 | Sheet: 1 of 1

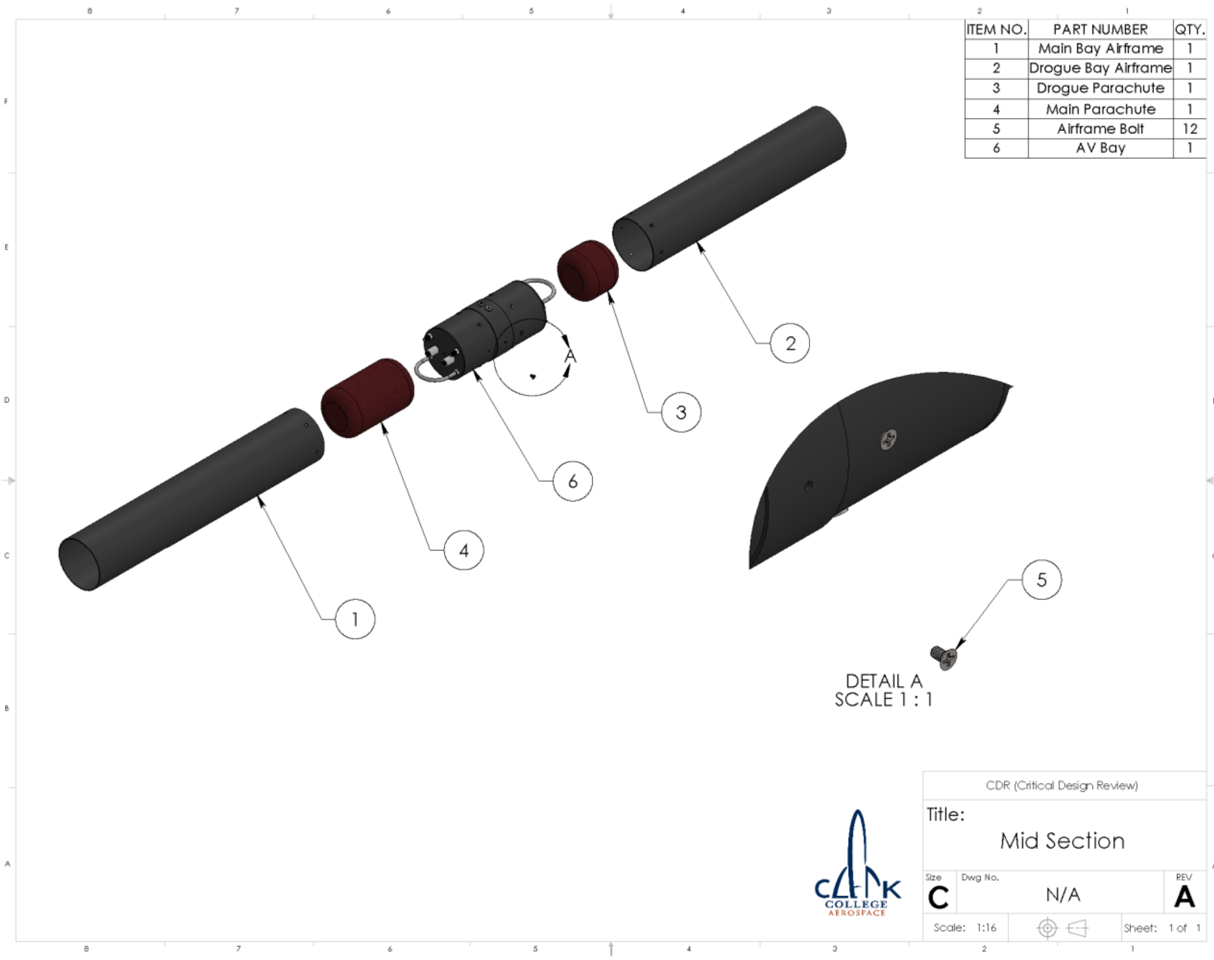

15.000
9.000
3.750
.125
.188
5.625
1.450
2.250
Note: All Dimentions are in Inches
CDR (Critical Design Review)
Title:
Fins
Size
C
Dwg No.
N/A
REV
A
Scale: 1:1
Sheet: 1 of 1



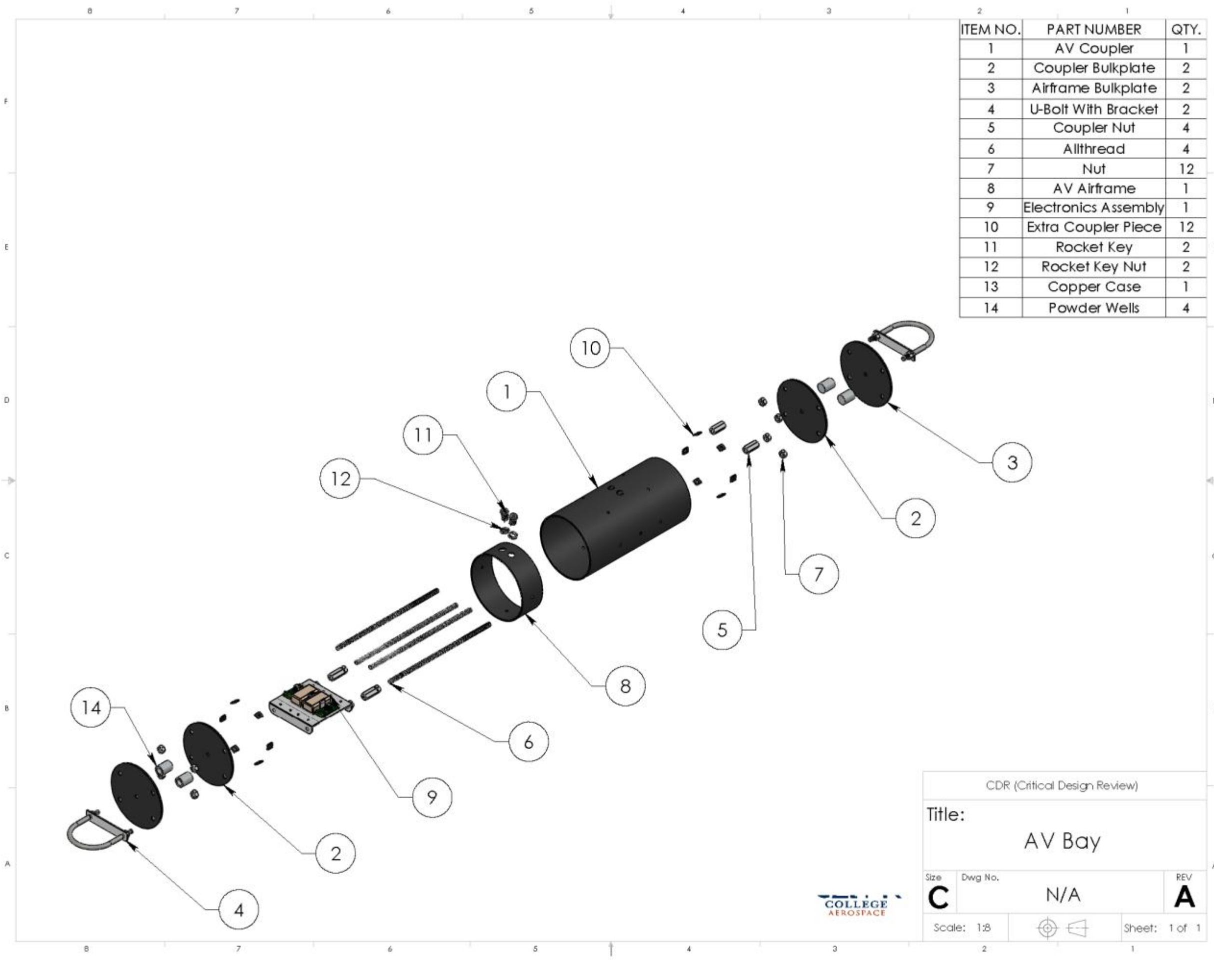
ITEM NO.
PART NUMBER
QTY.
1 Payload Bay Airframe 1
2 Nose Cone 1
3 Payload Bay Assembly 1
4 Nose Extra Coupler Piece 6
5 Airframe Bulkplate 2
6 Coupler Bulkplate 1
7 U-Bolt With Bracket 1
8 Aft Coupler 1
9 Coupler Spacer 1
10 Airframe Bolt 14
11 Payload Parachute 1
12 Payload 1
13 Big Red Bee Transmitter 1
DETAIL A
SCALE 1 : 1
CDR (Critical Design Review)
Title:
Forward Section
Size C
Dwg No. N/A
REV A
Scale: 1:12
Sheet: 1 of 1



ITEM NO. | PART NUMBER | QTY.
1 | Aft Section | 1
2 | Forward Section | 1
3 | Mid Section | 1
4 | Shear-Pin | 12
DETAIL A
SCALE 1 : 1
A
1
2
3
4
CDR (Critical Design Review)
Title:
Launch Vehicle Assembly
Size C
Dwg No. N/A
REV A
Scale: 1:24
Sheet: 1 of 1



ITEM NO. | PART NUMBER | QTY.
1 | Main Bay Airframe | 1
2 | Drogue Bay Airframe | 1
3 | Drogue Parachute | 1
4 | Main Parachute | 1
5 | Airframe Bolt | 12
6 | AV Bay | 1
A
DETAIL A
SCALE 1 : 1
CDR (Critical Design Review)
Title:
Mid Section
Size C
Dwg No. N/A
REV A
Scale: 1:16
Sheet: 1 of 1
CLARK COLLEGE AEROSPACE



ITEM NO.	PART NUMBER	QTY.
1	AV Coupler	1
2	Coupler Bulkplate	2
3	Airframe Bulkplate	2
4	U-Bolt With Bracket	2
5	Coupler Nut	4
6	Allthread	4
7	Nut	12
8	AV Airframe	1
9	Electronics Assembly	1
10	Extra Coupler Piece	12
11	Rocket Key	2
12	Rocket Key Nut	2
13	Copper Case	1
14	Powder Wells	4

Appendix C – MATLAB Code

C.1 Launch Vehicle Calculations

To save space, the team decided to switch the change in time (dt) in the flight data code to 0.1 seconds from 0.01 second they use for calculation. Therefor the some of the calculated number will be slightly off from the rest of the paper.

```
clear, clc
format shortg
```

Input Values

```
%Motor Stuff
wM=4.8568; %Weight of Rocket Motor
wRPro=2.7888; %Weight of Propellent in Motor

%Rocket Weight/Center of Mass
CoM1=70.843; %in from Nose, Center of Mass Before Burn
wR1=37.029; %lb, Rocket Weight Before Burn
CoM2=67.762; %in from Nose, Center of Mass After Burn
wR2=34.240; %lb, Rocket Weight After Burn
wRd=32.173; %Weight of Rocket without Motor
wRF=9.311; %lb, Weight of rockets Foward Section
wRM=12.536; %lb, Weight of rockets Mid Section
wRA=12.393; %lb, Weight of rockets Aft Section (After Burn)

%Rocket Dimensions/Values
d=5.15; %in, diameter of rocket
L=120; %in, length of rocket
Cd=.47; %coefficient of drag of rocket
LoNC=16; %in, Length of Nose Cone

%Fin Stuff
FTC=3.75; %Fin Tip Chord
NoF=3; %Number of Fins
FT=.125; %in, Fin Thickness
ShearM=380000; %psi, Shear Modulus

%Stuff from AGSE/Launch Rail
AGSEh=0; %ft, Distance to Base of Rocket form the Ground (AGSE Height)
theta=5; %degrees, Angle of Launch Rail Off of Vertical

%Launch Conditions
E0=600; %ft, Altitude of Launch site
    %Huntsville, AL Altitude: 600ft
```

```
    %Bend, OR Altitude: 3600ft

%Goals
targetAlt=3000; %ft, Target Altitude
AltMdEp=2000; %ft, Altitude of Main/Payload Parachute Deployment

%Constant(s)
g=32.174; %ft/s^2, gravity
```

Load Data

```
load TimeThrust.txt
    %[Time (s), Thrust of Motor (N)]
    %from ThrustCurve website
load TimeWeight.txt
    %[Time (s), Weight of Rocket (lb)]
    %from RockSim
load AirData.txt
    %[Altitude(above Sea Level)(ft), Temperature(F), Gravity(ft/s^2),
Pressure(lb/in^2), Density(slugs/ft^3), Viscosity(lb/ft^2)]
    %from The US Standard Atmosphere 1976
```

Calculations with No Home :(

```
TimeThrust2=[TimeThrust(:,1) TimeThrust(:,2)/ 4.4482];

    %converts Thrust from N into lb

Size=length(TimeThrust(:,1)); %Finds size of input data
```

Fin Size (Trapezoidal)

```
FRC=FTC*4; %Fin Root Chord
FSS=1.5*FTC; %in, Fin Semi-Span
Hf=2*FTC; %in, fin root to airframe distance
MCL=sqrt((.5*FRC-(.5*FTC+Hf))^2+FSS^2); %in, Lenght of fin mid-chord line
```

Center of Pressure/Margin of Stability

```
Cnn=2;

Xn=.466*LoNC;

NtoF=L-FRC %in, distance from nose tip to fin root leading edge
Cnf=(1+(d/2)/(FSS+d/2))*(4*NoF*(FSS/d)^2/(1+sqrt(1+(2*MCL/(FRC+FTC))^2)));
```

```
Xf=NtoF+(Hf/3)*(FRC+2*FTC)/(FRC+FTC)+1/6*(FRC+FTC-FRC*FTC/(FRC+FTC));
CoP=(Cnn*Xn+Cnf*Xf)/(Cnn+Cnf); %in, Center of Pressure
MoS1=(CoP-CoM1)/d; %Margin of Stability Before Burn
MoS2=(CoP-CoM2)/d; %Margin of Stability After Burn
```

Fin Flutter

```
FwRA=.5*(FRC+FTC)*FSS; %Fin wRing Area
AR=FSS.^2/FwRA; %Aspect Ratio
Gamma=FTC/FRC;
Temp=59-(0.00356*targetAlt); % Degrees F
P=2116/144*((Temp+459.7)/518.6)^5.256; %lb/ft^2, Pressure
a=sqrt(1.4*1716.59*(Temp+460)); %Speed of Sound
VFF=a*sqrt(ShearM/((1.337*AR^3*P*(Gamma+1))/(2*(AR+2)*(FT/FRC)^3))); %ft/s
    %Velocity of Fin Flutter
```

Flight Data

```
CSA=pi*(d/2/12)^2; %ft^2
tRange=[0 (TimeThrust2(:,1))' 2.5:.1:20]; %time for loop

dE=0; %Starts loop
s=1; told=0; %intial values
while dE>=0
    t=tRange(1,s);
    if t==0 %intial values
        wR=wR1;
        Th=0; dt=0; Vel=0; EoR1=0; EoR2=0; nf=0; Acc=0; drag=0;
    elseif t>=min(TimeThrust2(:,1)) && t<=max(TimeThrust2(:,1));
        [i]=find(TimeThrust2(:,1)==t); %find min location
        Th=TimeThrust2(i,2); %thrust of rocket
        wR=wRd+TimeWeight(i,2); %weight of rocket
        dt=t-told; %change in time
        nf=Th-(drag+wR); %net force of rocket
        Acc=nf/(wR/g); %acceration of rocket
        Vel=Vel+Acc*dt; %velocity of rocket
        AD=Interp(4,EoR1+E0,[AirData(:,1),AirData(:,5)]); %density of air at elevation
        drag=Cd*(.5*AD*Vel.^2*CSA); %drag of rocket
        EoR2=Vel*dt+EoR1; %elevation of rocket
    else
         Th=0; %Thrust of Rocket
        wR=wR2; %weight of rocket
        dt=t-told; %change in time
        nf=Th-(drag+wR); %net force of rocket
        Acc=nf/(wR/g); %acceration of rocket
        Vel=Vel+Acc*dt; %velocity of rocket
```

```
        AD=Interp(4,EoR1+E0,[AirData(:,1),AirData(:,5)]); %density of air at elevation
        drag=Cd*(.5*AD*Vel.^2*CSA); %drag of rocket
        EoR2=Vel*dt+EoR1; %elevation of rocket
    end
    dE=EoR2-EoR1; %change in elevation
    stuff=[t wR Th nf drag Vel Acc EoR2*cosd(theta)];

    EoR1=EoR2;
    told=t;
    if dE>=0 %remove last data point if it has a negative dE
        D(s,:)=stuff;
    end
    s=s+1;
end
```

Flight Data II

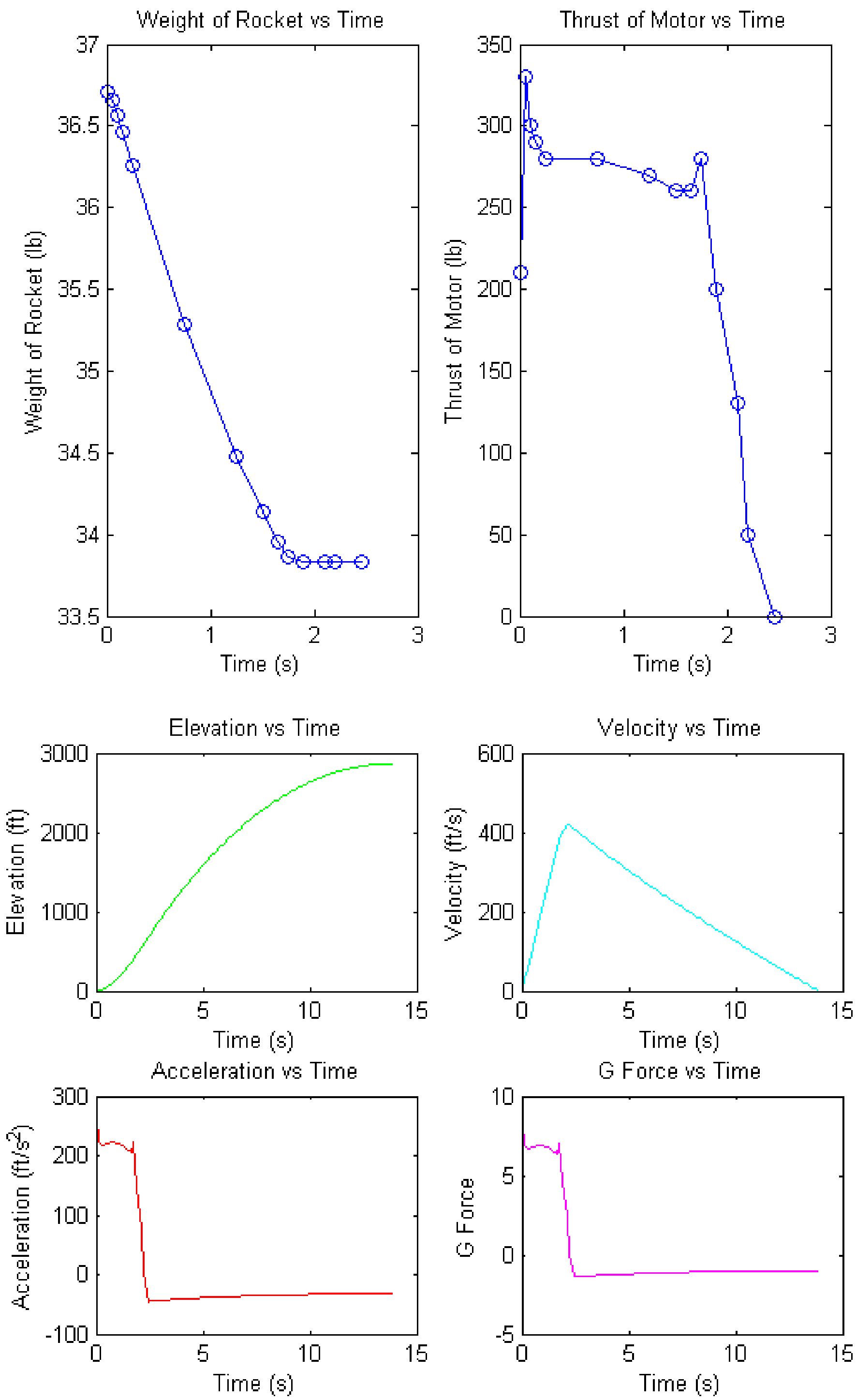
```
n=0;

x=5;

JJ=0;

II=0;

tRange=[0 (TimeThrust2(:,1))' 2.5:.01:20]; %time for loop
S2=(40-35)/x;
S1=(.55-.45)/x;
for wR3=35:S2:40;
    JJ=JJ+1;
    II=0;
    E=0;
    for Cd=.45:S1:.55;
        II=II+1;
        dE=0; %Starts loop
        s=1; told=0; %intial values
        E=0;
        while dE>=0
            t=tRange(1,s);
            if t==0 %intial values
                wR=wR3;
                Th=0; dt=0; Vel=0; EoR1=0; EoR2=0; nf=0; Acc=0; drag=0;
            elseif t>=min(TimeThrust2(:,1)) && t<=max(TimeThrust2(:,1));
                [i]=find(TimeThrust2(:,1)==t); %find min location
                Th=TimeThrust2(i,2); %thrust of rocket
                wR=wR3-wM+TimeWeight(i,2); %weight of rocket
```

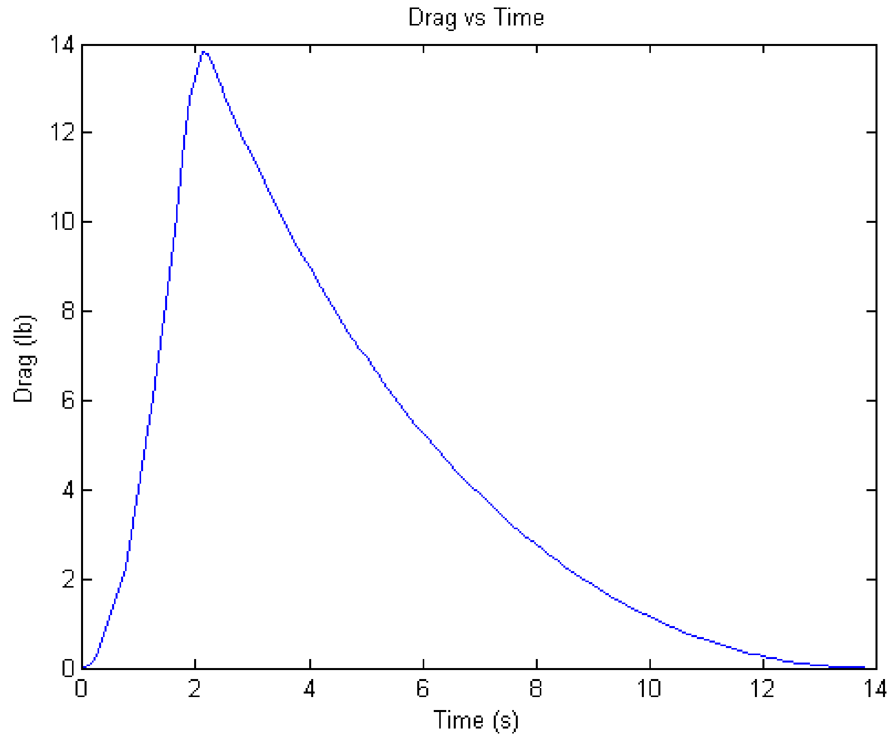
```
                dt=t-told; %change in time
                nf=Th-(drag+wR); %net force of rocket
                Acc=nf/(wR/g); %acceration of rocket
                Vel=Vel+Acc*dt; %velocity of rocket
                AD=Interp(4,EoR1+E0,[AirData(:,1),AirData(:,5)]); %density of air at
elevation
                drag=Cd*(.5*AD*Vel.^2*CSA); %drag of rocket
                EoR2=Vel*dt+EoR1; %elevation of rocket
            else
                Th=0; %Thrust of Rocket
                wR=wR3-wRPro; %weight of rocket
                dt=t-told; %change in time
                nf=Th-(drag+wR); %net force of rocket
                Acc=nf/(wR/g); %acceration of rocket
                Vel=Vel+Acc*dt; %velocity of rocket
                AD=Interp(4,EoR1+E0,[AirData(:,1),AirData(:,5)]); %density of air at
elevation
                drag=Cd*(.5*AD*Vel.^2*CSA); %drag of rocket
                EoR2=Vel*dt+EoR1; %elevation of rocket
            end
            dE=EoR2-EoR1; %change in elevation
            stuff=[EoR2*cosd(theta)];
            EoR1=EoR2;
            told=t;
            if dE>=0 %remove last data point if it has a negative dE
                E(s,:)=stuff;
            end
            s=s+1;
        end
        answer(II,JJ)=max(E);
    end
end
```

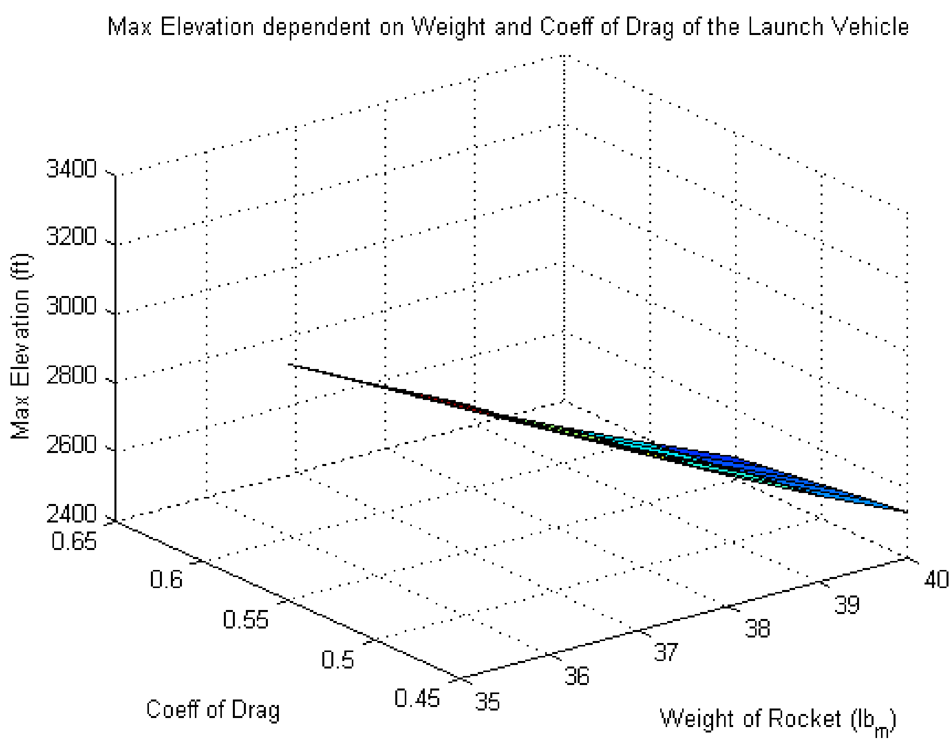
Graphs

```
figure (1)

subplot(1,2,1)

plot(TimeWeight(:,1),TimeWeight(:,2)+wRd,'o-')
title('Weight of Rocket vs Time')
xlabel('Time (s)')
ylabel('Weight of Rocket (lb)')
subplot(1,2,2)
plot(TimeThrust2(:,1),TimeThrust2(:,2),'o-')
title('Thrust of Motor vs Time')
```

```
xlabel('Time (s)')
ylabel('Thrust of Motor (lb)')

figure (2)
subplot(2,2,1)
plot(D(:,1),D(:,8),'g')
title('Elevation vs Time')
xlabel('Time (s)')
ylabel('Elevation (ft)')
subplot(2,2,2)
plot(D(:,1),D(:,6),'c')
title('Velocity vs Time')
xlabel('Time (s)')
ylabel('Velocity (ft/s)')
subplot(2,2,3)
plot(D(:,1),D(:,7),'r')
title('Acceleration vs Time')
xlabel('Time (s)')
ylabel('Acceleration (ft/s^2)')
subplot(2,2,4)
plot(D(:,1),D(:,7)/g,'m')
title('G Force vs Time')
xlabel('Time (s)')
ylabel('G Force')

figure(3)
plot(D(:,1),D(:,5))
title('Drag vs Time')
xlabel('Time (s)')
ylabel('Drag (lb)')

figure(4)
surf(35:S2:40,.45:S1:.55,answer)
title('Max Elevation dependent on Weight and Coeff of Drag of the Launch Vehicle')
xlabel('Weight of Rocket (lb_m)')
ylabel('Coeff of Drag')
zlabel('Max Elevation (ft)')
```


Weight of Rocket vs Time
Weight of Rocket (lb)
Time (s)
Thrust of Motor vs Time
Thrust of Motor (lb)
Time (s)
Elevation vs Time
Elevation (ft)
Time (s)
Velocity vs Time
Velocity (ft/s)
Time (s)
Acceleration vs Time
Acceleration (ft/s^2)
Time (s)
G Force vs Time
G Force
Time (s)


Drag vs Time
Drag (lb)
Time (s)
0
2
4
6
8
10
12
14


Max Elevation dependent on Weight and Coeff of Drag of the Launch Vehicle
Max Elevation (ft)
3400
3200
3000
2800
2600
2400
0.65
0.6
0.55
0.5
0.45
Coeff of Drag
35
36
37
38
39
40
Weight of Rocket (lb_m)

Display

```
disp('From SolidWorks')
disp('Weight of Rocket Before Burn (lb)')
disp(wR1)
disp('Weight of Rocket After Burn (lb)')
disp(wR2)
disp('Weight of Rocket Without Motor (lb)')
disp(wRd)
disp('Center of Mass of Rocket Before Burn (lb)')
disp(CoM1)
disp('Center of Mass of Rocket After Burn (lb)')
disp(CoM2)
disp(' ')

disp('From RockSim')
disp('Coefficient of Drag')
disp(Cd)
disp(' ')

disp('Fin Stuff')
disp('Number of Fins')
disp(NoF)
disp('Fin Tip Chord Length (in)')
disp(FTC)
disp('Fin Root Chord Length (in)')
disp(FRC)
disp('Fin Semi-Span Length (in)')
disp(FSS)
disp('Fin Height (in)')
disp(Hf)
disp('Fin Mid-Chord Line (in)')
disp(MCL)
disp('Fin Thickness (in)')
disp(FT)
disp(' ')

disp('Stability of Rocket')
disp('Center of Pressure (in)')
disp(CoP)
disp('Margin of Stability of Rocket Before Burn')
disp(MoS1)
disp('Margin of Stability of Rocket After Burn')
disp(MoS2)
disp(' ')

disp('Fin Flutter Speed (ft/s)')
disp(VFF)
disp(' ')
```

```
disp('Calculated Flight Data')
disp('Time to Apogee')
disp(max(D(:,1)))
disp('Apogee Elevation (ft)')
disp(max(D(:,8)))
disp('Max Velocity (ft/s)')
disp(max(D(:,6)))
disp('Max Acceleration (ft/s^2)')
disp(max(D(:,7)))
disp('Max G-Force')
disp(max(D(:,7))/g)
disp('Calculated Data')
disp('      Time(s)     Weight(lb)    Thrust(lb)  NetForce(lb)    Drag(lb)     Vel(ft/s)
Acc(ft/s^2)  Elevation(ft)')
disp(D)
disp(' ')
```

```
From SolidWorks
Weight of Rocket Before Burn (lb)
       37.029

Weight of Rocket After Burn (lb)
        34.24

Weight of Rocket Without Motor (lb)
       32.173

Center of Mass of Rocket Before Burn (lb)
       70.843

Center of Mass of Rocket After Burn (lb)
       67.762


From RockSim
Coefficient of Drag
         0.55


Fin Stuff
Number of Fins
     3

Fin Tip Chord Length (in)
         3.75

Fin Root Chord Length (in)
    15

Fin Semi-Span Length (in)
        5.625

Fin Height (in)
```

7.5

Fin Mid-Chord Line (in)
5.9293

Fin Thickness (in)
0.125

Stability of Rocket
Center of Pressure (in)
91.189

Margin of Stability of Rocket Before Burn
3.9507

Margin of Stability of Rocket After Burn
4.5489

Fin Flutter Speed (ft/s)
541.74

Calculated Flight Data
Time to Apogee
13.8

Apogee Elevation (ft)
2865.4

Max Velocity (ft/s)
419.99

Max Acceleration (ft/s^2)
257.55

Max G-Force
8.0048

Calculated Data

Time (s)	Weight (lb)	Thrust (lb)	NetForce (lb)	Drag (lb)	Vel (ft/s)	Acc (ft/s^2)	Elevation (ft)
0	37.029	0	0	0	0	0	0
0.01	36.708	210.08	173.38	0.000183	1.5196	151.96	0.015138
0.05	36.662	330.13	293.47	0.011095	11.821	257.55	0.4862
0.1	36.566	300.12	263.54	0.043532	23.416	231.89	1.6525
0.15	36.466	290.12	253.61	0.095065	34.604	223.76	3.3762
0.25	36.257	280.11	243.76	0.25105	56.235	216.31	8.9783
0.75	35.288	280.11	244.57	2.2331	167.73	222.99	92.525
1.25	34.478	270.11	233.4	6.0591	276.63	217.8	230.31
1.5	34.137	260.11	219.91	8.5068	328.45	207.26	312.11
1.65	33.951	260.11	217.65	10.16	359.39	206.25	365.82
1.75	33.866	280.11	236.09	11.45	381.81	224.29	403.85
1.9	33.833	200.08	154.8	12.798	403.9	147.21	464.21
2.1	33.833	130.05	83.421	13.799	419.76	79.331	547.84
2.2	33.833	50.02	2.3886	13.779	419.99	2.2714	589.68
2.46	33.833	0	-47.612	13.002	408.22	-45.278	695.41
2.5	34.24	0	-47.242	12.848	406.44	-44.391	711.61

2.6	34.24	0	-47.088	12.564	402.02	-44.247	751.66
2.7	34.24	0	-46.804	12.276	397.62	-43.98	791.27
2.8	34.24	0	-46.516	11.994	393.25	-43.709	830.44
2.9	34.24	0	-46.234	11.716	388.9	-43.444	869.18
3	34.24	0	-45.956	11.444	384.58	-43.183	907.5
3.1	34.24	0	-45.684	11.178	380.29	-42.928	945.38
3.2	34.24	0	-45.418	10.916	376.02	-42.677	982.84
3.3	34.24	0	-45.156	10.659	371.78	-42.431	1019.9
3.4	34.24	0	-44.899	10.407	367.56	-42.19	1056.5
3.5	34.24	0	-44.647	10.16	363.37	-41.953	1092.7
3.6	34.24	0	-44.4	9.9171	359.19	-41.721	1128.5
3.7	34.24	0	-44.157	9.679	355.05	-41.493	1163.8
3.8	34.24	0	-43.919	9.4453	350.92	-41.269	1198.8
3.9	34.24	0	-43.685	9.2161	346.81	-41.049	1233.4
4	34.24	0	-43.456	8.9911	342.73	-40.834	1267.5
4.1	34.24	0	-43.231	8.7703	338.67	-40.623	1301.2
4.2	34.24	0	-43.01	8.5536	334.63	-40.415	1334.6
4.3	34.24	0	-42.794	8.341	330.61	-40.211	1367.5
4.4	34.24	0	-42.581	8.1323	326.6	-40.012	1400
4.5	34.24	0	-42.372	7.9276	322.62	-39.816	1432.2
4.6	34.24	0	-42.168	7.7266	318.66	-39.623	1463.9
4.7	34.24	0	-41.967	7.5294	314.72	-39.434	1495.3
4.8	34.24	0	-41.769	7.3359	310.79	-39.249	1526.2
4.9	34.24	0	-41.576	7.1461	306.89	-39.067	1556.8
5	34.24	0	-41.386	6.9597	303	-38.889	1587
5.1	34.24	0	-41.2	6.7769	299.12	-38.714	1616.8
5.2	34.24	0	-41.017	6.5975	295.27	-38.542	1646.2
5.3	34.24	0	-40.838	6.4215	291.43	-38.373	1675.2
5.4	34.24	0	-40.662	6.2488	287.61	-38.208	1703.9
5.5	34.24	0	-40.489	6.0794	283.81	-38.046	1732.2
5.6	34.24	0	-40.319	5.9132	280.02	-37.887	1760.1
5.7	34.24	0	-40.153	5.7501	276.25	-37.73	1787.6
5.8	34.24	0	-39.99	5.5901	272.49	-37.577	1814.7
5.9	34.24	0	-39.83	5.4332	268.75	-37.427	1841.5
6	34.24	0	-39.673	5.2793	265.02	-37.279	1867.9
6.1	34.24	0	-39.519	5.1283	261.3	-37.135	1893.9
6.2	34.24	0	-39.368	4.9803	257.61	-36.993	1919.6
6.3	34.24	0	-39.22	4.8351	253.92	-36.854	1944.9
6.4	34.24	0	-39.075	4.6927	250.25	-36.717	1969.8
6.5	34.24	0	-38.933	4.5531	246.59	-36.584	1994.4
6.6	34.24	0	-38.793	4.4162	242.94	-36.452	2018.6
6.7	34.24	0	-38.656	4.2821	239.31	-36.324	2042.4
6.8	34.24	0	-38.522	4.1505	235.69	-36.198	2065.9
6.9	34.24	0	-38.391	4.0216	232.08	-36.074	2089
7	34.24	0	-38.262	3.8953	228.49	-35.953	2111.8
7.1	34.24	0	-38.135	3.7715	224.91	-35.834	2134.2
7.2	34.24	0	-38.012	3.6502	221.33	-35.718	2156.2
7.3	34.24	0	-37.89	3.5314	217.77	-35.604	2177.9
7.4	34.24	0	-37.771	3.415	214.22	-35.492	2199.3
7.5	34.24	0	-37.655	3.301	210.69	-35.383	2220.3
7.6	34.24	0	-37.541	3.1894	207.16	-35.276	2240.9
7.7	34.24	0	-37.429	3.0801	203.64	-35.171	2261.2
7.8	34.24	0	-37.32	2.9731	200.13	-35.068	2281.1
7.9	34.24	0	-37.213	2.8684	196.64	-34.968	2300.7
8	34.24	0	-37.108	2.766	193.15	-34.869	2320
8.1	34.24	0	-37.006	2.6657	189.67	-34.773	2338.8
8.2	34.24	0	-36.906	2.5677	186.21	-34.679	2357.4
8.3	34.24	0	-36.808	2.4718	182.75	-34.587	2375.6
8.4	34.24	0	-36.712	2.3781	179.3	-34.497	2393.5

8.5	34.24	0	-36.618	2.2865	175.86	-34.409	2411
8.6	34.24	0	-36.526	2.1969	172.42	-34.322	2428.2
8.7	34.24	0	-36.437	2.1095	169	-34.238	2445
8.8	34.24	0	-36.349	2.024	165.59	-34.156	2461.5
8.9	34.24	0	-36.264	1.9406	162.18	-34.076	2477.6
9	34.24	0	-36.181	1.8592	158.78	-33.998	2493.5
9.1	34.24	0	-36.099	1.7798	155.39	-33.921	2508.9
9.2	34.24	0	-36.02	1.7023	152	-33.846	2524.1
9.3	34.24	0	-35.942	1.6267	148.62	-33.774	2538.9
9.4	34.24	0	-35.867	1.5531	145.25	-33.703	2553.4
9.5	34.24	0	-35.793	1.4814	141.89	-33.633	2567.5
9.6	34.24	0	-35.721	1.4115	138.53	-33.566	2581.3
9.7	34.24	0	-35.652	1.3435	135.18	-33.5	2594.8
9.8	34.24	0	-35.584	1.2774	131.84	-33.436	2607.9
9.9	34.24	0	-35.517	1.213	128.5	-33.374	2620.7
10	34.24	0	-35.453	1.1505	125.17	-33.314	2633.2
10.1	34.24	0	-35.391	1.0898	121.85	-33.255	2645.3
10.2	34.24	0	-35.33	1.0308	118.53	-33.198	2657.1
10.3	34.24	0	-35.271	0.97364	115.21	-33.143	2668.6
10.4	34.24	0	-35.214	0.9182	111.9	-33.089	2679.7
10.5	34.24	0	-35.158	0.86449	108.6	-33.037	2690.6
10.6	34.24	0	-35.104	0.81251	105.3	-32.986	2701
10.7	34.24	0	-35.053	0.76223	102.01	-32.937	2711.2
10.8	34.24	0	-35.002	0.71365	98.717	-32.89	2721
10.9	34.24	0	-34.954	0.66676	95.433	-32.845	2730.6
11	34.24	0	-34.907	0.62153	92.153	-32.801	2739.7
11.1	34.24	0	-34.862	0.57797	88.877	-32.758	2748.6
11.2	34.24	0	-34.818	0.53606	85.605	-32.717	2757.1
11.3	34.24	0	-34.776	0.49579	82.338	-32.678	2765.3
11.4	34.24	0	-34.736	0.45715	79.074	-32.64	2773.2
11.5	34.24	0	-34.697	0.42013	75.813	-32.604	2780.7
11.6	34.24	0	-34.66	0.38472	72.556	-32.569	2788
11.7	34.24	0	-34.625	0.35091	69.303	-32.536	2794.9
11.8	34.24	0	-34.591	0.3187	66.053	-32.504	2801.5
11.9	34.24	0	-34.559	0.28808	62.805	-32.473	2807.7
12	34.24	0	-34.528	0.25903	59.561	-32.445	2813.6
12.1	34.24	0	-34.499	0.23156	56.319	-32.417	2819.3
12.2	34.24	0	-34.472	0.20566	53.08	-32.392	2824.5
12.3	34.24	0	-34.446	0.18131	49.843	-32.367	2829.5
12.4	34.24	0	-34.421	0.15852	46.609	-32.344	2834.2
12.5	34.24	0	-34.399	0.13728	43.376	-32.323	2838.5
12.6	34.24	0	-34.377	0.11758	40.146	-32.303	2842.5
12.7	34.24	0	-34.358	0.099415	36.918	-32.284	2846.2
12.8	34.24	0	-34.339	0.082787	33.691	-32.267	2849.5
12.9	34.24	0	-34.323	0.067688	30.466	-32.252	2852.5
13	34.24	0	-34.308	0.054116	27.242	-32.238	2855.3
13.1	34.24	0	-34.294	0.042067	24.019	-32.225	2857.6
13.2	34.24	0	-34.282	0.031538	20.798	-32.214	2859.7
13.3	34.24	0	-34.272	0.022526	17.578	-32.204	2861.5
13.4	34.24	0	-34.263	0.015029	14.358	-32.195	2862.9
13.5	34.24	0	-34.255	0.009046	11.139	-32.188	2864
13.6	34.24	0	-34.249	0.004574	7.9211	-32.182	2864.8
13.7	34.24	0	-34.245	0.001613	4.7033	-32.178	2865.3
13.8	34.24	0	-34.242	0.000161	1.4858	-32.176	2865.4

C.1.1 Closest Function

```
function [B]=Closest(x,t,M)
%(x,t,M) t=temp, M matrix & closest x numbers
%1st column is given (Temp) & 2nd column is what needs to be interpolated (pressure)
[Rows,Cols]=size(M);
for n=1:Rows %find difference for each value in column
    dif(n,1)=abs(t-M(n,1));
end

for n=1:x %find locations of clostest points
    a=min(dif); %finds min value
    [i]=find(dif==a); %find min location
    i=i(1,1); %only uses the first value incase of multiple value that are the same
distance apart
    A(1,n)=i; %save location of closest values
    dif(i,1)=max(dif(:,1)); %removes closest values for next loop calculation
end
A=sort(A); % puts locations into accending order

for n=1:x
    B(1,n)=M(A(1,n),1); %finds temps from matrix A (locations matrix)
    B(2,n)=M(A(1,n),2); %finds pressures from matrix A (locations matrix)
end
end
```

C.1.2 Interp Function

```
function [F]=Interp(x,t,M)
%Interp(a,b,c)
%x=data pointd, t=thing to be interpolated, M=Matrix (1st col is b)
C=Closest(x,t,M); %function gives matrix with x closest points
for i=1:x %i postion
    for j=1:x %j postion
        if i==j%for diagonal values
            k(i,j)=1;
        else
            k(i,j)=(t-C(1,0+j))/(C(1,0+i)-C(1,0+j));
        end
    end
end
B=prod(k,2); %multiples across rows only
D=C(2,:).*B'; %mults pressures by constans
F=sum(D);%answer
end
```

C.2 Recovery Calculations

```
clc, clear
```

Parachute Diameters

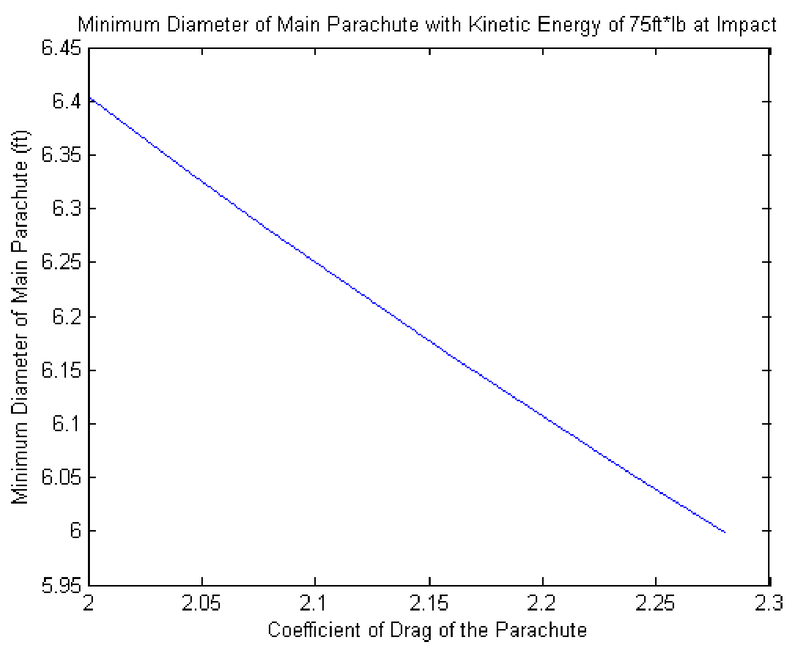
```
%Variables defined here
Air_density_1600 = .0703/32.174;%lb/ft^3 at 1600ft %alabama is 600ft above sea level
Air_density_3600 = .0653/32.174;%lb/ft^3 at 3600ft %alabama is 600ft above sea level
g = 32.174;%gravity ft/s^2
weight_aft = 12.486;%Variable for Aft section after burnout
weight_mid = 13.217;%Variable for Mid section after burnout
weight_aft_mid = weight_aft+weight_mid;
weight_payload = 8.689; %Variable for forward section weight after burnout
weight = weight_aft_mid + weight_payload; %Variable for rocket weight after burnout
mass_aft_mid = weight_aft_mid/32.174;
mass_aft = weight_aft/32.174;
mass_mid = weight_mid/32.174;
mass_payload = weight_payload/32.174;

%Main Chute Calulations
%Drag = Weight = .5*density*Area_chute*velocity^2
%Area of chute = (2*m*g)/(density_of_air*(velocity^2)*coefficent_drag)
%minimum velocity of Main chute, kinetic engergy should be less than 75 ft/lb
velocity_aft = ((75*2)/(mass_aft)).^.5;%feet per second
velocity_mid = ((75*2)/(mass_mid)).^.5;%feet per second
velocity=0;
if (velocity_mid < velocity_aft);%use the section that has the lowest velocity as the
limit
    velocity = velocity_mid;
end
if (velocity_aft < velocity_mid);%use the section that has the lowest velocity as the
limit
    velocity = velocity_aft;
end
Coefficient_drag = 2.0:.04:2.3;%range of Cd, it is really 2.2
Area = (2*mass_aft_mid*g)./(Air_density_1600*(velocity^2).*Coefficient_drag);%feet^2
diameters = 2*(Area/pi).^.5;
figure(1);
plot(Coefficient_drag,diameters);
title('Minimum Diameter of Main Parachute with Kinetic Energy of 75ft*lb at Impact');
```

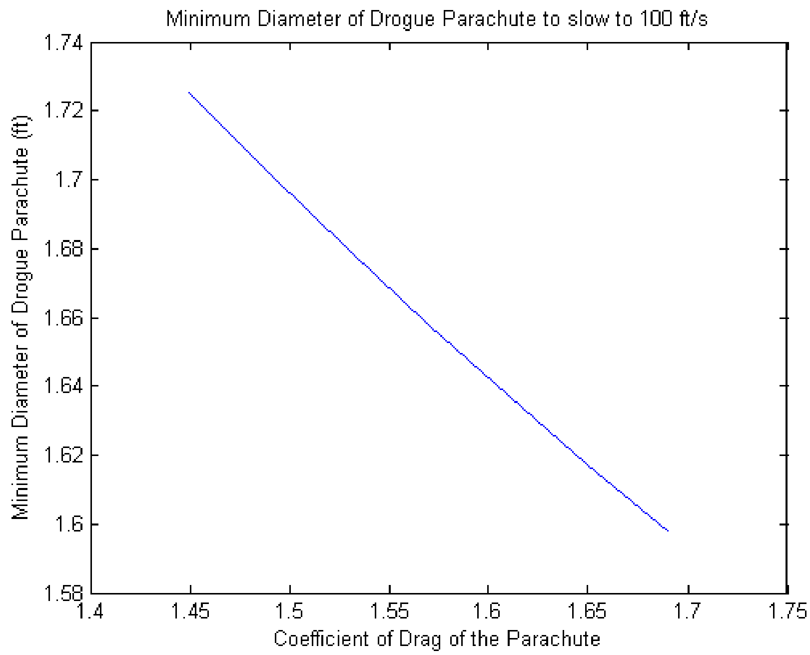
```
xlabel('Coefficient of Drag of the Parachute');
ylabel('Minimum Diameter of Main Parachute (ft)');

%Drogue Chute Calculations
%minimum velocity of Drogue chute
velocity = 100;%feet per second
Coefficient_drag = 1.45:.04:1.7;%range of Cd, it ranges from 1.5 to 1.6
Area = (2*(mass_aft_mid +
mass_payload)*g)./(Air_density_3600*(velocity^2)*Coefficient_drag);%feet^2
diameters = 2*(Area/pi).^.5;
figure(2);
plot(Coefficient_drag,diameters);
title('Minimum Diameter of Drogue Parachute to slow to 100 ft/s');
xlabel('Coefficient of Drag of the Parachute');
ylabel('Minimum Diameter of Drogue Parachute (ft)');

%Payload Chute calculations
%minimum velocity of Main chute, kinetic engergy should be less than 75 ft/lb
velocity_payload = ((75*2)/(mass_payload)).^.5;%meters per second
Coefficient_drag = 1.45:.04:1.7;%range of Cd, it ranges from 1.5 to 1.6
Area =
(2*mass_payload*g)./(Air_density_1600*(velocity_payload.^2)*Coefficient_drag);%feet^2
diameters = 2*(Area/pi).^.5;
figure(3);
plot(Coefficient_drag,diameters);
title('Minimum Diameter of Payload Parachute with Kinetic Energy of 75ft*lb at
Impact');
xlabel('Coefficient of Drag of the Parachute');
ylabel('Minimum Diameter of the Payload Parachute (ft)');

%Actual Velocity at different Stages
%Parachute areas by diameter
%Area = pi*(diameter/2)^2
Area_84 = pi*((84/24)^2);%ft^2
Area_96 = pi*((96/24)^2);%ft^2
Area_36 = pi*((36/24)^2);%ft^2
Area_42 = pi*((42/24)^2);%ft^2
Area_24 = pi*((24/24)^2);%ft^2
Coef_drag_84 = 2.2;%this is the known value of the coefficient of drag
Coef_drag_96 = Coef_drag_84;%96 inch and 84 inch parachutes have the same Coefficient
drag
Coef_drag = 1.5;%lowest end of drag coefficient range
velocity_main = ((mass_aft_mid*g*2)/((Air_density_1600*(Area_84)*Coef_drag_84)) +
(Air_density_1600*Area_24*Coef_drag))^.5;
%velocity of the main chute takes into account that the drogue will still be out
energy_impact = .5*(mass_aft_mid)*((velocity_main))^2;
energy_mid = .5*(mass_mid)*(velocity_main)^2;
```

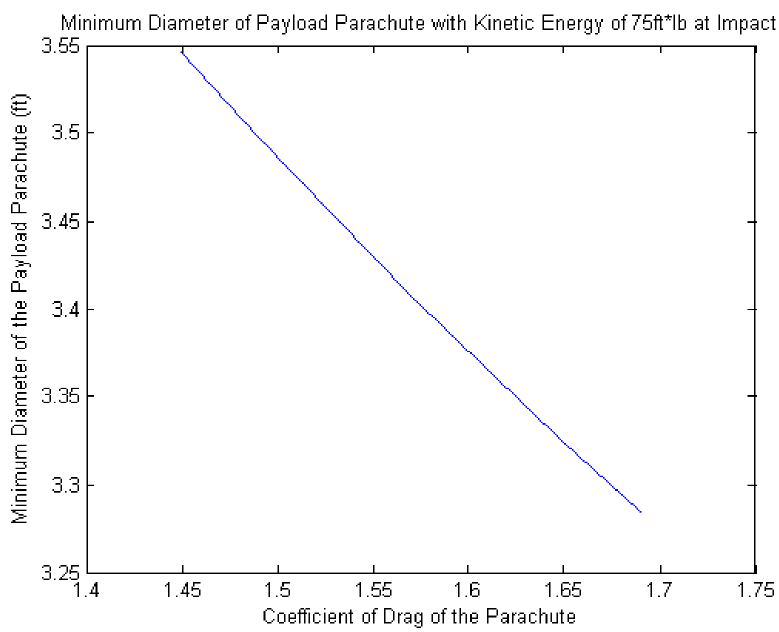
```
energy_aft = .5*(mass_aft)*(velocity_main)^2;
if (energy_mid < 75 & energy_aft < 75);%displays 84 inch parachute only if the energy
is sufficiently safe
    disp('Total Energy at impact with 84 inch main chute (ft*lb)')
    disp(energy_impact)
    disp('Speed of Mid and Aft Sections on descent (ft/s)')
    disp(velocity_main)
    disp('Energy of Mid Section at Impact')
    disp(energy_mid)
    disp('Energy of Aft Section at Impact')
    disp(energy_aft)
end
if (energy_mid >= 75 | energy_aft >= 75);% displays 96 inch parachute options if 84
inch fails to be safe enough
    velocity_main = ((mass_aft_mid*g*2)/((Air_density_1600*(Area_96)*Coef_drag_96) +
(Air_density_1600*Area_24*Coef_drag)))^.5;
    energy_impact = .5*(mass_aft_mid)*((velocity_main))^2;
    energy_mid = .5*(mass_mid)*(velocity_main)^2;
    energy_aft = .5*(mass_aft)*(velocity_main)^2;
    disp('Total Energy at impact with 96 inch main chute (ft*lb)')
    disp(energy_impact)
    disp('Speed of Mid and Aft Sections on descent (ft/s)')
    disp(velocity_main)
    disp('Energy of Mid Section at Impact')
    disp(energy_mid)
    disp('Energy of Aft Section at Impact')
    disp(energy_aft)
end
velocity_payload = ((mass_payload*g*2)/(Air_density_1600*Area_36*Coef_drag))^.5;
payload_energy = .5*mass_payload*velocity_payload^2;
if (payload_energy < 75);%displays numbers of 36 payload parachute only if it is
adaqute for the competition
    disp('Speed of forward Section on Impact with 36 inch chute')
    disp(velocity_payload)
    disp('Impact energy of Forward Section with 36 inch chute')
    disp(payload_energy)
end
if (payload_energy >= 75);%if a 36 inch chute won't work display the 42 parachute
numbers
    velocity_payload = ((mass_payload*g*2)/(Air_density_1600*Area_42*Coef_drag))^.5;
    payload_energy = .5*mass_payload*velocity_payload^2;
    disp('Speed of forward Section on Impact with 42 inch chute')
    disp(velocity_payload)
    disp('Impact energy of Forward Section with 42 inch chute')
    disp(payload_energy)
end
```

```
velocity_drogue = (((mass_aft_mid +
mass_payload)*g*2)/(Air_density_3600*Area_24*Coef_drag))^.5;
disp('Velocity of Rocket in Drogue Parachute phase')
disp(velocity_drogue)
energy_drogue = .5*(mass_payload + mass_aft_mid)*((velocity_drogue)^2);
disp('Kinetic energy with only a Drogue Parachute')
disp(energy_drogue)
```

```
Total Energy at impact with 84 inch main chute (ft*lb)
  110.9992

Speed of Mid and Aft Sections on descent (ft/s)
   16.6700

Energy of Mid Section at Impact
   57.0780

Energy of Aft Section at Impact
   53.9212

Speed of forward Section on Impact with 42 inch chute
   23.4756

Impact energy of Forward Section with 42 inch chute
   74.4161

Velocity of Rocket in Drogue Parachute phase
   84.8045

Kinetic energy with only a Drogue Parachute
   3.8438e+03
```







Black Powder Charge Calculations

```
%Variables
Nylon_shear_strength = 10500;%pounds per square inch
screw_diameter = .0641;%Minor thread diameter of a #2-56 screw
Combustion_temp = 3307;%Combustion Temperature for Black Powder in Rankine
Gas_constant = 22.16*12;%constant of lbf-inches/lbm
```

```
aft_screws = 6;%number of screws on the Aft Section
payload_screws = 6;%number of screws on the payload section
drogue_length = 14.875+11.65;%Length of drogue parachute bay in inches
payload_length = 26.75;%Length of payload parachute bay in inches

%Shear Strength Calaculations
area_2_56 = pi*(screw_diameter/2)^2;%cross sectional Area (using the minor thread
diameter) of a 2-56 nylon screw
%force = pressure*Area = (F/Area)*Area
shear_force = Nylon_shear_strength * area_2_56;%force taken to shear a #2-56 nylon
screw
shear_force_aft = aft_screws*shear_force;
shear_force_payload = payload_screws*shear_force;

%Powder Charge calculations
%Charge mass = (Shear Force * Length of Tube)/(gas constant * combustion temperature)
%in pounds
%Drogue Parachute Bay seperation charge
charge_aft_pounds = (shear_force_aft*drogue_length)/(Gas_constant*Combustion_temp);%in
pounds
charge_mass_aft = charge_aft_pounds*454;%Amount of Black Powder in grams
charge_aft_backup = charge_mass_aft*1.2;%backup charge is 20% more black powder
charge_aft_lb_backup = charge_aft_backup/454;
%Payload Parachute Bay seperation charge
charge_pay_pounds =
(shear_force_payload*payload_length)/(Gas_constant*Combustion_temp);%in pounds
charge_mass_payload = charge_pay_pounds*454;%Amount of Black Powder in grams
charge_payload_backup = charge_mass_payload*1.2;%backup charge is 20% more black
powder
charge_payload_lb_backup = charge_payload_backup/454;

%Print out information
disp('Amount of grains of Black Powder needed to eject the Aft Section')
disp(charge_mass_aft*15.43)%converting grams to grains
disp('Amount of grains of Black Powder of Backup Aft Section Charge')
disp(charge_aft_backup*15.43)%converting grams to grains
disp('Amount of grains of Black Powder needed to eject Forward Section')
disp(charge_mass_payload*15.43)%converting grams to grains
disp('Amount of grains of Black Powder of Backup Forward Section Charge')
disp(charge_payload_backup*15.43)%converting grams to grains
disp('Weight of Primary Drogue Powder Well in pounds')
disp(charge_aft_pounds)
disp('Weight of Backup Drogue Powder Well in pounds')
disp(charge_aft_lb_backup)
disp('Weight of Primary Main Powder Well in pounds')
disp(charge_pay_pounds)
disp('Weight of Backup Main Powder Well in pounds')
```

```
disp(charge_payload_lb_backup)
```

```
Amount of grains of Black Powder needed to eject the Aft Section
   42.9574

Amount of grains of Black Powder of Backup Aft Section Charge
   51.5489

Amount of grains of Black Powder needed to eject Forward Section
   43.3218

Amount of grains of Black Powder of Backup Forward Section Charge
   51.9862

Weight of Primary Drogue Powder Well in pounds
    0.0061

Weight of Backup Drogue Powder Well in pounds
    0.0074

Weight of Primary Main Powder Well in pounds
    0.0062

Weight of Backup Main Powder Well in pounds
    0.0074
```

C.3 Launch Rail System Calculations

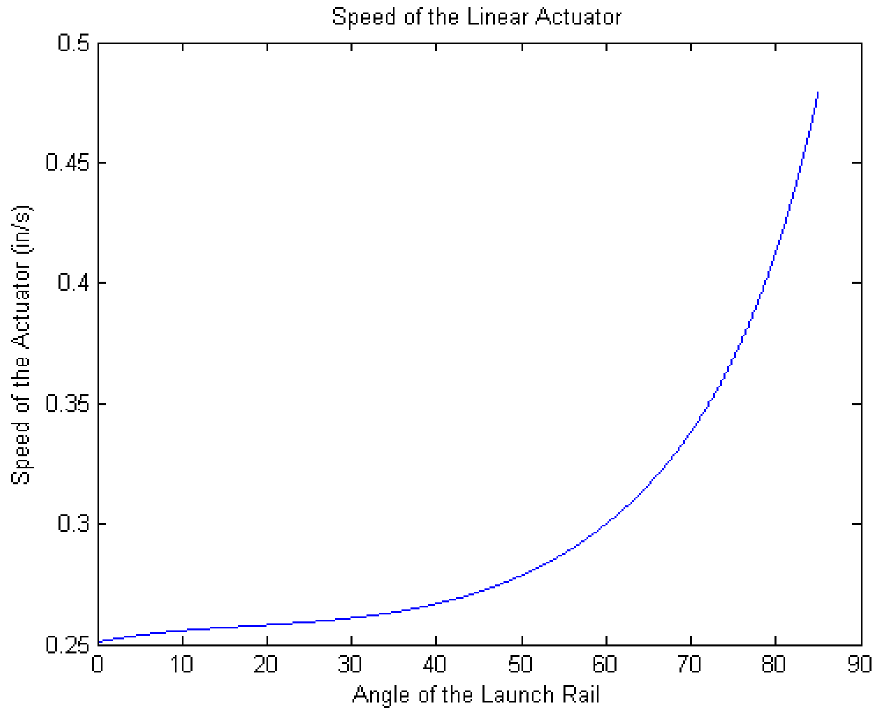
```
clear, clc

%variables defined by other calculations
weight = 50;%Launch Vehicle/Rail weight in lb
distance_mount=1.0;%Distance from the frame to the mounting bracket in feet
height =2.27;%this is the Height of the AGSE frame in feet
bracket_connector = .3715;%feet of distance from hole to hole on aluminum plate
actuator_length = 2.279;%This is the length of the linear actuator in feet
%pin_d below calculates the distance from the base of the rail to the linear actuator
attached Rail Bracket
pin_d = distance_mount - ((actuator_length-bracket_connector)^2 - (height-
bracket_connector)^2)^.5;
error=1; %inital error to start looping
col=100000; %intial amount of columns(decreases the computing time by setting at
100000, instead of starting at 1)
PrevAvgSpeed=1; %value for fist loop(avoid comparing nothing or a value that would
cause false approximations)

%integral approxiamation loop
while error>=.5e-4 %error between two integrals
    col=col+1; %adds a column each loop to increase accuracy
    step=85/col; %finds step amount
    theta=0:step:85; %range for launch rail angles
    beta=atand((height+(pin_d*sind(theta))-
(bracket_connector*cosd(theta)))./(distance_mount - (pin_d*cosd(theta)) -
(bracket_connector*sind(theta))));%this find the angle of the actuator
    force=(weight*5*cosd(theta))./(pin_d*sind(180-beta-theta));%this calculates force
    speed=(.59-.0011*force);%this find the speed of the actuator in in/s
    L=length(theta); %finds length of matrix theta
    m=mod(L,2); %0 is even, 1 is odd
    oddP=2:2:(max(L)-m);
        %finds odd postions not including 1st or last values
    evenP=3:2:(max(L)-m);
        %finds even postions not including 1st or last values

AvgSpeed=1/85*(step/3*(speed(1,1)+4*sum(speed(1,oddP))+2*sum(speed(1,evenP))+speed(1,L
)));%Simpsons 1/3 rule to approxiamate the integral
    error=abs(AvgSpeed-PrevAvgSpeed);%error between integrals calculated with the
difference
    PrevAvgSpeed=AvgSpeed;%set the average speed as the previous for the next loop
end

%Time and Stroke Length calculations
```

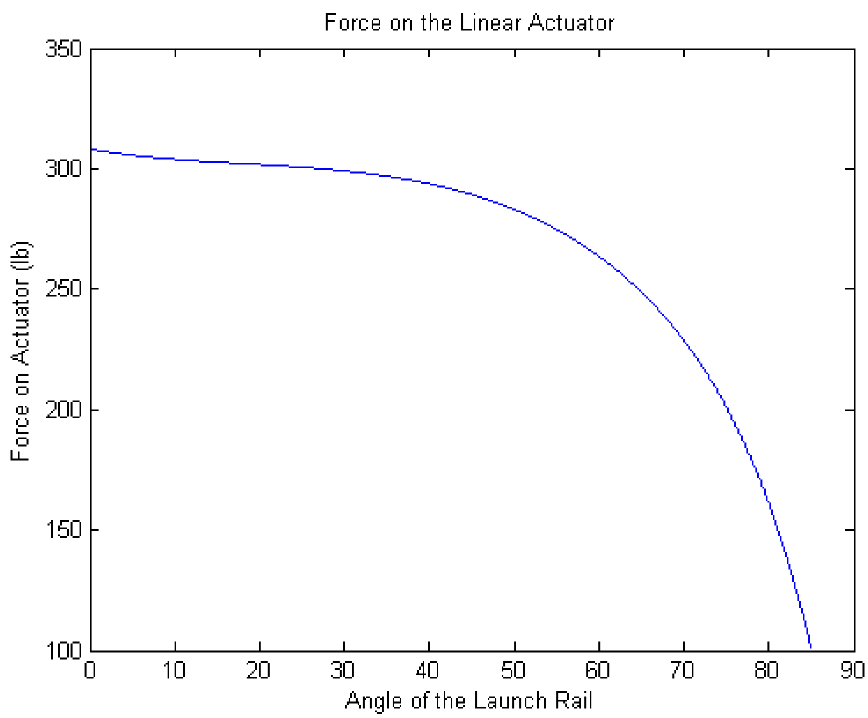
```
beta_max = atand((height + (pin_d*sind(85)) -
bracket_connector*cosd(85))/(distance_mount - (pin_d*cosd(85)) -
bracket_connector*sind(85)));%this calculates the final angle of the linear actuator
Stroke_length = 12*(((height + pin_d*sind(85) - bracket_connector*cosd(85)).^2 +
(distance_mount - pin_d*cosd(85) - bracket_connector*sind(85)).^2).^.5 -
(actuator_length - bracket_connector));%this calculates the Stroke_length needed
Time = Stroke_length/AvgSpeed;%this calculates the time taken to lift the launch rail
in seconds

%write the calculated values to command window
disp('Calculated Average Speed (in/s)')
disp(AvgSpeed)
disp('Seconds to Raise Launch Rail')
disp(Time)
disp('Stroke Length in inches')
disp(Stroke_length)
disp('Max Force on actuator')
disp(max(force))
disp('Distance to the Rail Bracket in inches')
disp(pin_d*12)
disp('Minimum Height of the AGSE frame in inches')
disp(height*12)
disp('distance to the mounting bracket in inches')
disp(distance_mount*12)
disp('Step Size (h)')%displays the finite small integration step size used
disp(step)%displays the finite small integration step size used
disp('Number of Columns (n)')%displays the accuracy the integral was approxiamated
with
disp(col)%displays the accuracy the integral was approxiamated with
disp('Error')%displays the error between the integrals in approxiamation
disp(error)%displays the error between the integrals in approxiamation

%Graphs of forces and speeds
figure(1)
plot(theta,force)%plots the graph of the force versus the angle of the launch rail
title('Force on the Linear Actuator')
xlabel('Angle of the Launch Rail')
ylabel('Force on Actuator (lb)')
figure(2)
plot(theta,speed)%plots the graph of the speed versus the angle of the launch rail
title('Speed of the Linear Actuator')
xlabel('Angle of the Launch Rail')
ylabel('Speed of the Actuator (in/s)')
distance_mount = .8:.1:1.4;%range of distances from the mount bracket
pin_d = distance_mount - ((actuator_length - bracket_connector)^2 - (height -
bracket_connector)^2)^.5;%calculate distance to pin for distance_mount
```

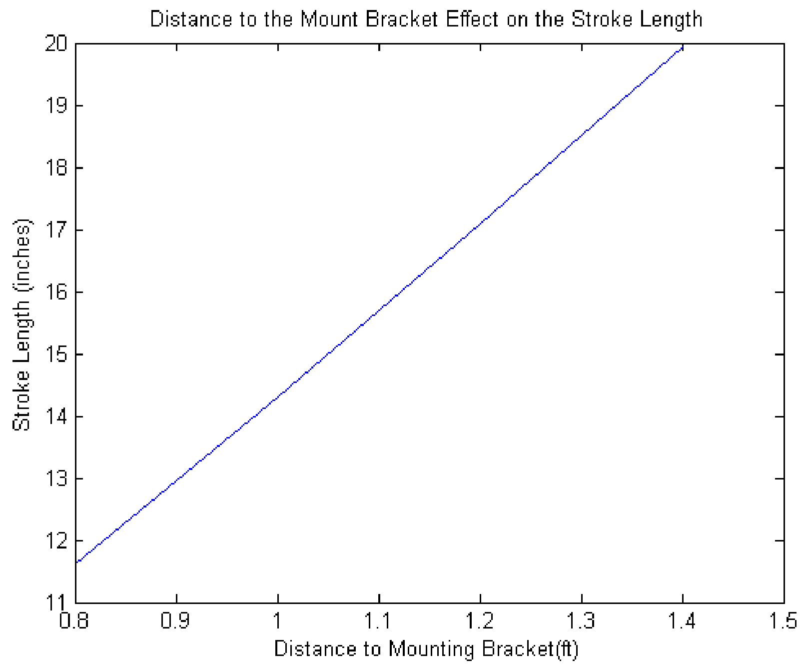
```
beta_max=atand((height+(pin_d*sind(85))-(bracket_connector*cosd(85)))./(distance_mount
- (pin_d*cosd(85)) - (bracket_connector*sind(85))));%this calculates the final angle
of the actautor
beta_min=atand((height+(pin_d*sind(0))-(bracket_connector*cosd(0)))./(distance_mount -
(pin_d*cosd(0)) - (bracket_connector*sind(0))));%this calculates the inital angle of
the actuator
force=(weight*5)./(pin_d.*sind(180-beta_min));%calculate max force on the linear
actuator for range of distance_mount
%this calculates the Stroke length needed over the range of distance to mounting
bracket
Stroke_length = 12*(((height + pin_d*sind(85) - bracket_connector*cosd(85)).^2 +
(distance_mount - pin_d*cosd(85) - bracket_connector*sind(85)).^2).^.5 -
(actuator_length - bracket_connector));%this calculates the Stroke_length needed
figure(3)
plot(distance_mount,Stroke_length);%plots the stroke length vs distance to mount
assuming height is constant
title('Distance to the Mount Bracket Effect on the Stroke Length')
xlabel('Distance to Mounting Bracket(ft)');
ylabel('Stroke Length (inches)');
figure(4)
plot(distance_mount,force);%plots the force vs distance to mount assuming height is
constant
title('Distance to the Mount Bracket Effect on the force')
xlabel('Distance to Mounting Bracket(ft)');
ylabel('Force on Actuator (lb)');
```

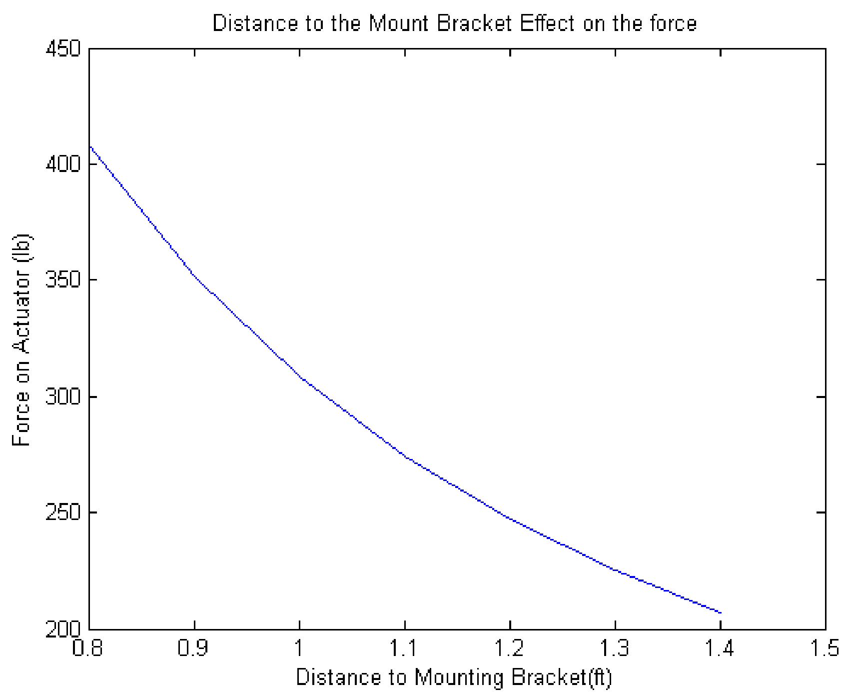
```
Calculated Average Speed (in/s)
    0.2945

Seconds to Raise Launch Rail
   48.5974

Stroke Length in inches
   14.3128

Max Force on actuator
  308.2323

Distance to the Rail Bracket in inches
    9.7791

Minimum Height of the AGSE frame in inches
   27.2400

distance to the mounting bracket in inches
    12

Step Size (h)
   8.4998e-04

Number of Columns (n)
       100002
```

```
Error
   4.7914e-06
```






Distance to the Mount Bracket Effect on the Stroke Length
Stroke Length (inches)
20
19
18
17
16
15
14
13
12
11
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
Distance to Mounting Bracket(ft)


Distance to the Mount Bracket Effect on the force
Force on Actuator (lb)
450
400
350
300
250
200
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
Distance to Mounting Bracket(ft)

Appendix D – MSDS

- AeroTech Rocketry
- Black Powder
- Car Battery
- Duracell Batteries (9 Volt)
- Fiberglass (G10 and G12)
- Loctite Epoxy Adhesive
-

AeroTech Division, RCS Rocket Motor Components, Inc.

Material Safety Data Sheet & Emergency Response Information

Prepared in accordance with 29 CFR § 1910.1200 (g)

Section 1. Product Identification

Model rocket motor, high power rocket motor, hobby rocket motor, composite rocket motor, rocket motor kit, rocket motor reloading kit, containing varying amounts of solid propellant with the trade names White Lightning™, Blue Thunder™, Black Jack™, Black Max™, Redline™, Warp-9™, Mojave Green™, Metalstorm™, Metalstorm DM™ or Propellant X™. These products contain varying percentages of Ammonium Perchlorate, Strontium and/or Barium Nitrate dispersed in synthetic rubber with lesser amounts of proprietary ingredients such as burn rate modifiers and metal fuels. Rocket motor ejection charges contain black powder.

Section 2. Physical Characteristics

Black plastic cylinders or bags with various colored parts, little or no odor

Section 3. Physical Hazards

Rocket motors and reload kits are flammable; rocket motors may become propulsive in a fire. All propellants give off varying amounts of Hydrogen Chloride and Carbon Monoxide gas when burned, Mojave Green propellant also produces Barium Chloride.

Section 4. Health Hazards

Propellant is an irritant in the case of skin and eye contact, may be extremely hazardous in the case of ingestion, and may be toxic to kidneys, lungs and the nervous system. Symptoms include respiratory irritation, skin irritation, muscle tightness, vomiting, diarrhea, abdominal pain, muscular tremors, weakness, labored breathing, irregular heartbeat, and convulsions. Inhalation of large amounts of combustion products may produce similar but lesser symptoms as ingestion.

Section 5. Primary Routes of Entry

Skin contact, ingestion, and inhalation.

Section 6. Permitted Exposure Limits

None established for manufactured product.

Section 7. Carcinogenic Potential

None known.

Section 8. Precautions for Safe Handling

Disposable rubber gloves are recommended for handling Mojave Green propellant. Keep away from flames and other sources of heat. Do not smoke within 25 feet of product. Do not ingest. Do not breathe exhaust fumes. Keep in original packaging until ready for use.

Section 9. Control Measures

See section 8.

Section 10. Emergency & First Aid Procedures

If ingested, induce vomiting and call a physician. If combustion products are inhaled, move to fresh air and call a physician if ill effects are noted. In the case of skin contact, wash area immediately and contact a physician if severe skin rash or irritation develops. For mild burns use a first aid burn ointment. For severe burns immerse the burned area in cold water at once and see a physician immediately.

Section 11. Date of Preparation or Revision

March 22, 2012

Section 12. Contact Information

AeroTech Division, RCS Rocket Motor Components, Inc.
2113 W. 850 N. St.
Cedar City, UT 84721
(435) 865-7100 (Ph)
(435) 865-7120 (Fax)
Email: customerservice@aerotech-rocketry.com
Web: http://www.aerotech-rocketry.com
Emergency Response: Infotrac (352) 323-3500

OWEN COMPLIANCE SERVICES, INC.

Material Safety Data Sheet
(MSDS-BP)

PRODUCT IDENTIFICATION	
Product Name	BLACK POWDER
Trade Names and Synonyms	N/A
Manufacturer/Distributor	GOEX, Inc. (Doyline, LA) & various international sources
Transportation Emergency	**800-255-3924 (24 hrs — *CHEM • TEL*)**

PREVENTION OF ACCIDENTS IN THE USE OF EXPLOSIVES

The prevention of accidents in the use of explosives is a result of careful planning and observance of the best known practices. The explosives user must remember that he is dealing with a powerful force and that various devices and methods have been developed to assist him in directing this force. He should realize that this force, if misdirected, may either kill or injure both him and his fellow workers.

WARNING

All explosives are dangerous and must be carefully handled and used following approved safety procedures either by or under the direction of competent, experienced persons in accordance with all applicable federal, state, and local laws, regulations, or ordinances. If you have any questions or doubts as to how to use any explosive product, **DO NOT USE IT** before consulting with your supervisor, or the manufacturer, if you do not have a supervisor. If your supervisor has any questions or doubts, he should consult the manufacturer before use.

HAZARDOUS COMPONENTS				
Material or Component	**%**	**CAS No.**	**TLV**	**PEL**
Potassium nitrate[1]	70-76	007757-79-1	NE	NE
Sodium nitrate[1]	70-74	007631-99-4	NE	NE
Charcoal	8-18	N/A	NE	NE
Sulfur	9-20	007704-34-9	NE	NE
Graphite[2]	Trace	007782-42-5	15 mppct (TWA)	2.5 mg/m^3
N/A = Not assigned NE = Not established				

[1] Black Powder contains either potassium nitrate ***or*** sodium nitrate in the percentages indicated. Black powder ***does not contain both***.

[2] Not contained in all grades of black powder.

PHYSICAL DATA	
Boiling Point	N/A
Vapor Pressure	N/A
Vapor Density	N/A
Solubility in Water	Good
Specific Gravity	1.70 - 1.82 (mercury method) ◆ 1.92 - 2.08 (pycnometer)
PH	6.0 - 8.0
Evaporation Rate	N/A
Appearance and Odor	Black granular powder. No odor detectable.

HAZARDOUS REACTIVITY	
Instability	Keep away from heat, sparks, and open flame. Avoid impact, friction, and static electricity.
Incompatibility	When dry, black powder is compatible with most metals; however, it is hygroscopic, and when wet, attracts all common metals except stainless steel. Black powder must be tested for compatibility with any material not specified in the production/procurement package with which they may come in contact. Materials include other explosives, solvents, adhesives, metals, plastics, paints, cleaning compounds, floor and table coverings, packing materials, and other similar materials, situations, and equipment.
Hazardous decomposition	Detonation produces hazardous overpressures and fragments (if confined). Gases produced may be toxic if exposed in areas with inadequate ventilation.
Polymerization	Polymerization will not occur.

FIRE AND EXPLOSION DATA	
Flashpoint	Not applicable
Auto ignition temperature	Approx. 464°C (867°F)
Explosive temperature (5 sec)	Ignites @ approx. 427°C (801°F)
Extinguishing media	Water
Special fire fighting procedures	**ALL EXPLOSIVES: DO NOT FIGHT EXPLOSIVES FIRES.** Try to keep fire from reaching explosives. Isolate area. Guard against intruders. Division 1.1 Explosives (heavily encased): Evacuate the area for 5000 feet (1 mile) if explosives are heavily encased. Division 1.1 Explosives (not heavily encased): Evacuate the area for 2500 feet (½ mile) if explosives are not heavily encased. Division 1.1 Explosives (all): Consult the *2000 Emergency Response Guidebook, Guide 112* for further details.
Unusual fire and explosion hazards	Black powder is a deflagrating explosive. It is very sensitive to flame and spark and can also be ignited by friction and impact. When ignited unconfined, it burns with explosive violence and will explode if ignited under even slight confinement.

HEALTH HAZARDS	
General	Black powder is a Division 1.1 Explosive, and detonation may cause severe physical injury, including death. All explosives are dangerous and must be handled carefully and used following approved safety procedures under the direction of competent, experienced persons in accordance with all applicable federal, state, and local laws, regulations, and ordinances.
Carcinogenicity	None of the components of Black powder are listed as a carcinogen by NTP, IARC, or OSHA.

FIRST AID	
Inhalation	*Not a likely route of exposure*. If inhaled, remove to fresh air. If not breathing, give artificial respiration, preferably by mouth-to-mouth. If breathing is difficult, give oxygen. Seek prompt medical attention.
Eye and skin contact	*Not a likely route of exposure*. Flush eyes with water. Wash skin with soap and water.
Ingestion	*Not a likely route of exposure*.. If ingested, induce vomiting immediately by giving two glasses of water and sticking finger down throat.
Injury from detonation	Seek prompt medical attention.

SPILL OR LEAK PROCEDURES	
Spill/leak response	Use appropriate personal protective equipment. Isolate area and remove sources of friction, impact, heat, low level electrical current, electrostatic or RF energy. Only competent, experienced persons should be involved in cleanup procedures. Carefully pick up spills with non-sparking and non-static producing tools.
Waste disposal	Desensitize by diluting in water. Open train burning, by qualified personnel, may be used for disposal of small unconfined quantities. Dispose of in compliance with federal regulations under the authority of the *Resource Conservation and Recovery Act* (40 CFR Parts 260-271).

SPECIAL PROTECTION INFORMATION	
Ventilation	Use only with adequate ventilation.
Respiratory	None
Eye	None
Gloves	Impervious rubber gloves.
Other	Metal-free *and* non-static producing clothes

SPECIAL PRECAUTIONS

- Keep away from friction, impact, and heat. Do not consume food, drink, or tobacco in areas where they may become contaminated with these materials.
- Contaminated equipment must be thoroughly water cleaned before attempting repairs.
- Use only non-spark producing tools.
- No smoking.

STORAGE CONDITIONS
Store in a cool, dry place in accordance with the requirements of *Subpart K, ATF: Explosives Law and Regulations* (27 CFR 55.201-55.219).

SHIPPING INFORMATION		
Proper shipping name	Black powder	
Hazard class	1.1D	
UN Number	UN0027	
DOT Label & Placard	DOT Label	EXPLOSIVE 1.1D
	DOT Placard	EXPLOSIVES 1.1
Alternate shipping information	Limited quantities of black powder may be transported as “Black powder for small arms”, NA0027, class 4.1 pursuant to U.S. Department of Transportation authorization EX-8712212.	

For further information contact:

David W. Boston, President
OWEN COMPLIANCE SERVICES, INC.
12001 County Road 1000
P.O. Box 765
Godley, TX 76044
Telephone number: 817-551-0660
FAX number: 817-396-4584

MSDS prepared by:

David W. Boston

Original publication date: 12/08/93
Revision date: 12/12/05
12/03/03

MATERIAL SAFETY DATA SHEET
LEAD ACID BATTERY WET, FILLED WITH ACID
(US, CN, EU Version for International Trade)

SECTION 1: PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: **Lead Acid Battery Wet, Filled With Acid**
OTHER PRODUCT NAMES: Electric Storage Battery, SLI or Industrial Battery, UN2794

MANUFACTURER: East Penn Manufacturing Company, Inc.
DIVISION: Deka Road
ADDRESS: Lyon Station, PA 19536 USA

EMERGENCY TELEPHONE NUMBERS:
US: CHEMTREC 1-800-424-9300
CN: CHEMTREC 1-800-424-9300
Outside US: 1-703-527-3887

NON-EMERGENCY HEALTH/SAFETY INFORMATION: 1-610-682-6361

CHEMICAL FAMILY: This product is a wet lead acid storage battery. May also include gel/absorbed electrolyte type lead acid battery types.

PRODUCT USE: Industrial/Commercial electrical storage batteries.

This product is considered a Hazardous Substance, Preparation or Article that is regulated under US-OSHA; CAN-WHMIS; IOSH; ISO; UK-CHIP; or EU Directives (67/548/EEC-Dangerous Substance Labelling, 98/24/EC-Chemical Agents at Work, 99/45/EC-Preparation Labelling, 2001/58/EC-MSDS Content, and 1907/2006/EC-REACH), and an MSDS/SDS is required for this product considering that when used as recommended or intended, or under ordinary conditions, it may present a health and safety exposure or other hazard.

Additional Information
This product may not be compatible with all environments, such as those containing liquid solvents or extreme temperature or pressure. Please request information if considering use under extreme conditions or use beyond current product labelling.

SECTION 2: HAZARDS IDENTIFICATION

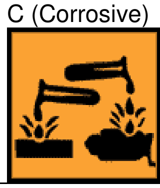
GHS Classification:

Health	Environmental	Physical
Acute Toxicity – Not listed (NL) Eye Corrosion – Corrosive* Skin Corrosion – Corrosive* Skin Sensitization – NL Mutagenicity/Carcinogenicity – NL Reproductive/Developmental – NL Target Organ Toxicity (Repeated) – NL	Aquatic Toxicity – NL	NFPA – Flammable gas, hydrogen (during charging) CN - NL EU - NL

*as sulfuric acid

GHS Label: Lead Acid Battery, Wet

Symbols: C (Corrosive)



Hazard Statements	Precautionary Statements
Contact with internal components may cause irritation of severe burns. Irritating to eyes, respiratory system, and skin.	Keep out of reach of children. Keep containers tightly closed. Avoid heat, sparks, and open flame while charging batteries. Avoid contact with internal acid.

EMERGENCY OVERVIEW: May form explosive air/gas mixture during charging. Contact with internal components may cause irritation or severe burns. Irritating to eyes, respiratory system, and skin. Prolonged inhalation or ingestion may result in serious damage to health. Pregnant women exposed to internal components may experience reproductive/developmental effects.

POTENTIAL HEALTH EFFECTS:

EYES: Direct contact of internal electrolyte liquid with eyes may cause severe burns or blindness.

SKIN: Direct contact of internal electrolyte liquid with the skin may cause skin irritation or damaging burns.

INGESTION: Swallowing this product may cause severe burns to the esophagus and digestive tract and harmful or fatal lead poisoning. Lead ingestion may cause nausea, vomiting, weight loss, abdominal spasms, fatigue, and pain in the arms, legs and joints.

INHALATION: Respiratory tract irritation and possible long-term effects.

ACUTE HEALTH HAZARDS:
Repeated or prolonged contact may cause mild skin irritation.

CHRONIC HEALTH HAZARDS:
Lead poisoning if persons are exposed to internal components of the batteries. Lead absorption may cause nausea, vomiting, weight loss, abdominal spasms, fatigue, and pain in the arms, legs and joints. Other effects may include central nervous system damage, kidney dysfunction, and potential reproductive effects. Chronic inhalation of sulfuric acid mist may increase the risk of lung cancer.

MEDICAL CONDITIONS GENERALLY AGGRAVATED BY EXPOSURE:
Respiratory and skin diseases may predispose the user to acute and chronic effects of sulfuric acid and/or lead. Children and pregnant women must be protected from lead exposure. Persons with kidney disease may be at increased risk of kidney failure.

Additional Information
No health effects are expected related to normal use of this product as sold.

SECTION 3: COMPOSITION/INFORMATION ON INGREDIENTS

INGREDIENTS (Chemical/Common Names):	CAS No.:	% by Wt:	EC No.:
Lead, inorganic	7439-92-1	43–70 (average: 65)	231-100-4
Sulfuric acid	7664-93-9	20–44 (average: 25)	231-639-5
Antimony	7440-36-0	0-–4 (average: 1)	231-146-5
Arsenic	7440-38-2	<0.01	231-148-6
Polypropylene	9003-07-0	5–10 (average: 8)	NA

NA: Not applicable; ND: Not determined

Additional Information
These ingredients reflect components of the finished product related to performance of the product as distributed into commerce.

SECTION 4: FIRST AID MEASURES

EYE CONTACT: Flush eyes with large amounts of water for at least 15 minutes. Seek immediate medical attention if eyes have been exposed directly to acid.

SKIN CONTACT: Flush affected area(s) with large amounts of water using deluge emergency shower, if available, shower for at least 15 minutes. Remove contaminated clothing. If symptoms persist, seek medical attention.

INGESTION: If swallowed, give large amounts of water. Do NOT induce vomiting or aspiration into the lungs may occur and can cause permanent injury or death.

INHALATION: If breathing difficulties develop, remove person to fresh air. If symptoms persist, seek medical attention.

SECTION 5: FIRE-FIGHTING MEASURES

SUITABLE/UNSUITABLE EXTINGUISHING MEDIA:
Dry chemical, carbon dioxide, water, foam. Do not use water on live electrical circuits.

SPECIAL FIREFIGHTING PROCEDURES & PROTECTIVE EQUIPMENT:
Use appropriate media for surrounding fire. Do not use carbon dioxide directly on cells. Avoid breathing vapours. Use full protective equipment (bunker gear) and self-contained breathing apparatus.
UNUSUAL FIRE AND EXPLOSION HAZARDS:
Batteries evolve flammable hydrogen gas during charging and may increase fire risk in poorly ventilated areas near sparks, excessive heat or open flames.
SPECIFIC HAZARDS IN CASE OF FIRE:
Thermal shock may cause battery case to crack open. Containers may explode when heated.

Additional Information
Firefighting water runoff and dilution water may be toxic and corrosive and may cause adverse environmental impacts.

SECTION 6: ACCIDENTAL RELEASE MEASURES

PERSONAL PRECAUTIONS:
Avoid Contact with Skin. Neutralize any spilled electrolyte with neutralizing agents, such as soda ash, sodium bicarbonate, or very dilute sodium hydroxide solutions.
ENVIRONMENTAL PRECAUTIONS:
Prevent spilled material from entering sewers and waterways.
SPILL CONTAINMENT & CLEANUP METHODS/MATERIALS:
Add neutralizer/absorbent to spill area. Sweep or shovel spilled material and absorbent and place in approved container. Dispose of any non-recyclable materials in accordance with local, state, provincial or federal regulations.

Additional Information
Lead acid batteries and their plastic cases are recyclable. Contact your East Penn representative for recycling information.

SECTION 7: HANDLING AND STORAGE

PRECAUTIONS FOR SAFE HANDLING AND STORAGE:
- Keep containers tightly closed when not in use.
- If battery case is broken, avoid contact with internal components.
- Do not handle near heat, sparks, or open flames.
- Protect containers from physical damage to avoid leaks and spills.
- Place cardboard between layers of stacked batteries to avoid damage and short circuits.
- Do not allow conductive material to touch the battery terminals. A dangerous short-circuit may occur and cause battery failure and fire.

OTHER PRECAUTIONS (e.g.; Incompatibilities):
Keep away from combustible materials, organic chemicals, reducing substances, metals, strong oxidizers and water.

SECTION 8: EXPOSURE CONTROLS/PERSONAL PROTECTION

ENGINEERING CONTROLS/SYSTEM DESIGN INFORMATION:
Charge in areas with adequate ventilation.
VENTILATION:
General dilution ventilation is acceptable.
RESPIRATORY PROTECTION:
Not required for normal conditions of use. See also special firefighting procedures (Section 5).
EYE PROTECTION:
Wear protective glasses with side shields or goggles.
SKIN PROTECTION:
Wear chemical resistant gloves as a standard procedure to prevent skin contact.
OTHER PROTECTIVE CLOTHING OR EQUIPMENT: Chemically impervious apron and face shield recommended when adding water or electrolyte to batteries.
Wash Hands after handling.
EXPOSURE GUIDELINES & LIMITS:

OSHA	Permissible Exposure Limit (PEL/TWA)	Lead, inorganic (as Pb)	0.05 mg/m^3
		Sulfuric acid	1.00 mg/m^3

EXPOSURE GUIDELINES & LIMITS:

ACGIH	2007 Threshold Limit Value (TLV)	Antimony	0.50 mg/m^3	
		Arsenic	0.01 mg/m^3	
		Lead, inorganic (as Pb)	0.05 mg/m^3	
		Sulfuric acid	0.20 mg/m^3	
Quebec	Permissible Exposure Value (PEV)	Antimony	0.50 mg/m^3	
		Arsenic	0.01 mg/m^3	
		Lead, inorganic (as Pb)	0.15 mg/m^3	
		Sulfuric acid	1.00 mg/m^3	TWA
			3.00 mg/m^3	STEV
Ontario	Occupational Exposure Level (OEL)	Antimony	0.50 mg/m^3	
		Arsenic	0.10 mg/m^3	
		Lead (designated substance)	0.10 mg/m^3	
		Sulfuric acid	1.00 mg/m^3	TWAEV
			3.00 mg/m^3	STEV
Netherlands	Maximaal Aanvaarde Concentratie (MAC)	Antimony	0.50 mg/m^3	
		Arsenic (designated substance)	0.01 mg/m^3	
		Lead, inorganic (as Pb)	0.15 mg/m^3	
		Sulfuric acid	1.00 mg/m^3	
Germany	Maximale Arbeitsplatzkonzentrationen (MAK)	Lead, inorganic (as Pb)	0.10 mg/m^3	
		Sulfuric acid	1.00 mg/m^3	TWA
			2.00 mg/m^3	STEL
		Antimony	0.50 mg/m^3	
United Kingdom	Occupational Exposure Standard (OES)	Lead	0.15 mg/m^3	
		Antimony	0.50 mg/m^3	
		Arsenic	0.10 mg/m^3	

TWA: 8-Hour Time-Weighted Average; STE: Short-Term Exposure; mg/m^3: milligrams per cubic meter of air; NE: Not Established; STEV: Short-Term Exposure Value; TWAEV: Time-Weighted Average Exposure Value; STEL: Short-Term Exposure Limit

Additional Information
- Batteries are housed in polypropylene cases which are regulated as total dust or respirable dust only when they are ground up during recycling. The OSHA PEL for dust is 15 mg/m^3 as total dust or 5 mg/m^3 as respirable dust.
- May be required to meet Domestic Requirements for a Specific Destination(s).

SECTION 9: PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE:	Industrial/commercial lead acid battery
ODOUR:	Odourless
ODOUR THRESHOLD:	NA
PHYSICAL STATE:	Sulfuric Acid: Liquid; Lead: solid
pH:	<1
BOILING POINT:	235-240° F (113-116° C) (as sulfuric acid)
MELTING POINT:	NA
FREEZING POINT:	NA
VAPOUR PRESSURE:	10 mmHg
VAPOUR DENSITY (AIR = 1):	> 1
SPECIFIC GRAVITY (H_2O = 1):	1.27–1.33
EVAPORATION RATE (n-BuAc=1):	< 1
SOLUBILITY IN WATER:	100% (as sulfuric acid)
FLASH POINT:	Below room temperature (as hydrogen gas)
AUTO-IGNITION TEMPERATURE:	NA
LOWER EXPLOSIVE LIMIT (LEL):	4% (as hydrogen gas)
UPPER EXPLOSIVE LIMIT (UEL):	74% (as hydrogen gas)
PARTITION COEFFICIENT:	NA
VISCOSITY (poise @ 25° C):	Not Available

DECOMPOSITION TEMPERATURE: Not Available

FLAMMABILITY/HMIS HAZARD CLASSIFICATIONS (US/CN/EU): As sulfuric acid
HEALTH: 3 FLAMMABILITY: 0 REACTIVITY: 2

SECTION 10: STABILITY AND REACTIVITY

STABILITY:	This product is stable under normal conditions at ambient temperature.
INCOMPATIBILITY (MATERIAL TO AVOID):	Strong bases, combustible organic materials, reducing agents, finely divided metals, strong oxidizers, and water.
HAZARDOUS DECOMPOSITION BY-PRODUCTS:	Thermal decomposition will produce sulfur dioxide, sulfur trioxide, carbon monoxide, sulfuric acid mist, and hydrogen.
HAZARDOUS POLYMERIZATION:	Will not occur
CONDITIONS TO AVOID:	Overcharging, sources of ignition

SECTION 11: TOXICOLOGICAL INFORMATION

ACUTE TOXICITY (Test Results Basis and Comments):

Sulfuric acid:	LD50, Rat: 2140 mg/kg
	LC50, Guinea pig: 510 mg/m^3
Lead:	No data available for elemental lead

SUBCHRONIC/CHRONIC TOXICITY (Test Results and Comments):
Repeated exposure to lead and lead compounds in the workplace may result in nervous system toxicity. Some toxicologists report abnormal conduction velocities in persons with blood lead levels of 50 µg/100 ml or higher. Heavy lead exposure may result in central nervous system damage, encephalopathy and damage to the blood-forming (hematopoietic) tissues.

Additional Information

- Very little chronic toxicity data available for elemental lead.
- Lead is listed by IARC as a 2B carcinogen: possible carcinogen in humans. Arsenic is listed by IARC, ACGIH, and NTP as a carcinogen, based on studies with high doses over long periods of time. The other ingredients in this product, present at equal to or greater than 0,1% of the product, are not listed by OSHA, NTP, or IARC as suspect carcinogens.
- The 19^{th} Amendment to EC Directive 67/548/EEC classified lead compounds, but not lead in metal form, as possibly toxic to reproduction. Risk phrase 61: May cause harm to the unborn child, applies to lead compounds, especially soluble forms.

SECTION 12: ECOLOGICAL INFORMATION

PERSISTENCE & DEGRADABILITY:
Lead is very persistent in soils and sediments. No data available on biodegradation.
BIOACCUMULATIVE POTENTIAL (Including Mobility):
Mobility of metallic lead between ecological compartments is low. Bioaccumulation of lead occurs in aquatic and terrestrial animals and plants, but very little bioaccumulation occurs through the food chain. Most studies have included lead compounds, not solid inorganic lead.
AQUATIC TOXICITY (Test Results & Comments):

Sulfuric acid:	24-hour LC50, fresh water fish *(Brachydanio rerio)*: 82 mg/l
	96-hour LOEC, fresh water fish *(Cyprinus carpio)*: 22 mg/l (lowest observable effect concentration)
Lead (metal):	No data available

Additional Information

- No known effects on stratospheric ozone depletion.
- Volatile organic compounds: 0% (by Volume)
- Water Endangering Class (WGK): NA

SECTION 13: DISPOSAL CONSIDERATIONS

WASTE DISPOSAL METHOD:	Following local, State/Provincial, and Federal/National regulations applicable to end-of-life characteristics will be the responsibility of the end-user.

MATERIAL SAFETY DATA SHEET
LEAD ACID BATTERY WET, FILLED WITH ACID
(US, CN, EU Version for International Trade)

HAZARDOUS WASTE CLASS/CODE: US - Not applicable to finished product as manufactured for distribution into commerce.
CN – Not applicable to finished product as manufactured for distribution into commerce.
EWC – Not applicable to finished product as manufactured for distribution into commerce.

Additional Information
Not Included – **Recycle** or dispose as allowed by local jurisdiction for the end-of-life characteristics as-disposed.

SECTION 14: TRANSPORT INFORMATION

GROUND – US-DOT/CAN-TDG/EU-ADR/APEC-ADR:

Proper Shipping Name	Batteries, Wet, Filled with Acid		
Hazard Class	8	ID Number	UN2794
Packing Group	III	Labels	Corrosive

AIRCRAFT – ICAO-IATA:

Proper Shipping Name	Batteries, Wet, Filled with Acid		
Hazard Class	8	ID Number	UN2794
Packing Group	III	Labels	Corrosive

Reference IATA packing instructions 870

VESSEL – IMO-IMDG:

Proper Shipping Name	Batteries, Wet, Filled with Acid		
Hazard Class	8	ID Number	UN2794
Packing Group	III	Labels	Corrosive

Reference IMDG packing instructions P801

Additional Information

Transport requires proper packaging and paperwork, including the Nature and Quantity of goods, per applicable origin/destination/customs points as-shipped.

SECTION 15: REGULATORY INFORMATION

INVENTORY STATUS:
All components are listed on the TSCA; EINECS/ELINCS; and DSL, unless noted otherwise below.

U.S. FEDERAL REGULATIONS:

TSCA Section 8b – Inventory Status: All chemicals comprising this product are either exempt or listed on the TSCA Inventory.

TSCA Section 12b – Export Notification: If the finished product contains chemicals subject to TSCA Section 12b export notification, they are listed below:

Chemical	CAS #
None	NA

CERCLA (COMPREHENSIVE RESPONSE COMPENSATION, AND LIABILITY ACT)

Chemicals present in the product which could require reporting under the statute:

Chemical	CAS #
Lead	7439-92-1
Sulfuric acid	7664-93-9

SARA TITLE III (SUPERFUND AMENDMENTS AND REAUTHORIZATION ACT)

The finished product contains chemicals subject to the reporting requirements of Section 313 of SARA Title III.

Chemical	CAS #	% wt
Lead	7439-92-1	65
Sulfuric acid	7664-93-9	25

CERCLA SECTION 311/312 HAZARD CATEGORIES: Note that the finished product is exempt from these regulations, but lead and sulfuric acid above the thresholds are reportable on Tier II reports.

Fire Hazard	No
Pressure Hazard	No
Reactivity Hazard	No
Immediate Hazard	Yes (Sulfuric acid is Corrosive)
Delayed Hazard	No

STATE REGULATIONS (US):

California Proposition 65

The following chemicals identified to exist in the finished product as distributed into commerce are known to the State of California to cause cancer, birth defects, or other reproductive harm:

Chemical	CAS #	% Wt
Arsenic (as arsenic oxides)	7440-38-2	<0.1
Strong inorganic acid mists including sulfuric acid	NA	25
Lead	7439-92-1	65

California Consumer Product Volatile Organic Compound Emissions
This Product is not regulated as a Consumer Product for purposes of CARB/OTC VOC Regulations, as-sold for the intended purpose and into the industrial/Commercial supply chain.

INTERNATIONAL REGULATIONS (Non-US):

Canadian Domestic Substance List (DSL)

All ingredients remaining in the finished product as distributed into commerce are included on the Domestic Substances List.

WHMIS Classifications

Class E: Corrosive materials present at greater than 1%

This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations (CPR) and the MSDS contains all the information required by the Controlled Products Regulations.

NPRI and Ontario Regulation 127/01

This product contains the following chemicals subject to the reporting requirements of Canada NPRI +/or Ont. Reg. 127/01:

Chemical	CAS #	% Wt
Lead	7439-92-1	65
Sulfuric acid	7664-93-9	25

European Inventory of Existing Commercial Chemical Substances (EINECS)

All ingredients remaining in the finished product as distributed into commerce are exempt from, or included on, the European Inventory of Existing Commercial Chemical Substances.

European Communities (EC) Hazard Classification according to directives 67/548/EEC and 1999/45/EC.

R-Phrases	S-Phrases
35, 36, 38	1/2, 26, 30, 45

Additional Information
This product may be subject to Restriction of Hazardous Substances (RoHS) regulations in Europe and China, or may be regulated under additional regulations and laws not identified above, such as for uses other than described or as-designed/as-intended by the manufacturer, or for distribution into specific domestic destinations.

SECTION 16: OTHER INFORMATION

OTHER INFORMATION:

Distribution into Quebec to follow Canadian Controlled Product Regulations (CPR) 24(1) and 24(2).

Distribution into the EU to follow applicable Directives to the Use, Import/Export of the product as-sold.

Sources of Information:

International Agency for Research on Cancer (1987), *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Overall Evaluations of Carcinogenicity: An updating of IARC Monographs Volumes 1-42, Supplement 7, Lyon,* France.

Ontario Ministry of Labour Regulation 654/86. Regulations Respecting Exposure to Chemical or Biological Agents.

RTECS – Registry of Toxic Effects of Chemical Substances, National institute for Occupational Safety and Health.

MSDS/SDS PREPARATION INFORMATION:

DATE OF ISSUE: ***30 April 2013*** SUPERCEDES: ***16 December 2011***

DISCLAIMER:

This Material Safety Data Sheet is based upon information and sources available at the time of preparation or revision date. The information in the MSDS was obtained from sources which we believe are reliable, but are beyond our direct supervision or control. We make no Warranty of Merchantability, Fitness for any particular purpose or any other Warranty, Expressed or Implied, with respect to such information and we assume no liability resulting from its use. For this and other reasons, we do not assume responsibility and expressly disclaim liability for loss, damage or expense arising out of or in any way connected with the handling, storage, use or disposal of the product. It is the obligation of each user of this product to determine the suitability of this product and comply with the requirements of all applicable laws regarding use and disposal of this product. For additional information concerning East Penn Manufacturing Co., Inc. products or questions concerning the content of this MSDS please contact your East Penn representative.

END

Safety Data Sheet

SECTION 1: IDENTIFICATION OF THE SUBSTANCE/PREPARATION AND OF THE COMPANY/UNDERTAKING

Product Name: DURACELL® ALKALINE BATTERIES
Product Identification: Alkaline Manganese Dioxide Cells –
Tradenames: Plus, Ultra, Simply

Product Use: Energy Source
SDS Date of Preparation: November 2, 2009; Updated May 19, 2010

Duracell Designations:

Name/Size	Duracell Designation	Voltage	IEC Designation
Duracell Plus/Simply D	MN1300	1,5	LR20
Duracell Ultra D	MX1300	1,5	LR20
Duracell Plus/Simply C	MN1400	1,5	LR14
Duracell Ultra C	MX1400	1,5	LR14
Duracell Plus/Simply AA	MN1500	1,5	LR6
Duracell Ultra AA	MX1500	1,5	LR6
Duracell Plus/Simply AAA	MN2400	1,5	LR03
Duracell Ultra AAA	MX2400	1,5	LR03
Duracell Plus/Simply 9V	MN1604	9	6LR61
Duracell Ultra 9V	MX1604	9	6LR61
Duracell 4.5V	MN1203	4,5	3LR12
Duracell AAAA	MN2500	1,5	
Duracell MN11	MN11	6	
Duracell MN9100 N	MN9100	1,5	LR1
Duracell 7K67 J	7K67J	6,2	4LR61

Company Identification:

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Procter & Gamble UK.
The Heights, Brooklands
Weybridge, Surrey
KT13 0XP UK
Telephone: +44-1-93-289-6000

Switzerland Office
Procter& Gamble
Switzerland SARL
Route de Saint-Georges 47
1213 Petit-Lancy, 1, Geneva,
Telephone: +41-58-004-6111

US Office
Duracell, a division of P&G
Berkshire Corporate Park
Bethel, CT 06801 USA
Telephone: 203-796-4000

Emergency Phone Number: INFOTRAC 24-Hour Emergency Response Hotline: 1-352-323-3500 (United States of America)

SECTION 2: HAZARDS IDENTIFICATION

Physical Appearance: Copper top battery.

CAUTION: May explode or leak, and cause burn injury, if recharged, disposed of in fire, mixed with a different battery type, inserted backwards or disassembled. Replace all used batteries at the same time. Do not carry batteries loose in your pocket or purse. Do not remove the battery label.

EU Classification of Preparation: Not classified as a dangerous preparation.

SECTION 3: COMPOSITION/INFORMATION ON INGREDIENTS

Chemical Name	CAS Number	EINECS Number	Amount	Classification
Manganese Dioxide	1313-13-9	215-202-6	35-40 %	Xn, R20/22
Zinc	7440-66-6	231-175-3	10-25 %	N, R50/53
Potassium Hydroxide (35 %)	1310-58-3	215-181-3	5-10 %	C, Xn, R22, R35
Graphite (natural or synthetic)	7782-42-5, 7440-44-0	231-955-3 231-153-3	1-5 %	None

Note: Some Duracell alkaline batteries contain a Duracell Power Check™ battery energy gauge, which is a small conductive strip located underneath the PVC battery label that indicates the amount of charge in the battery. It is composed of minute quantities of conductive materials. Due to the small quantity of materials and their solid form, a health or environmental risk is unlikely.

SECTION 4: FIRST AID MEASURES

General Advice: The chemicals and metals in this product are contained in a sealed can. Exposure to the contents will not occur unless the battery leaks, is exposed to high temperatures or is mechanically, physically, or electrically abused. Damaged battery will release concentrated potassium hydroxide, which is caustic. Anticipated potential leakage of potassium hydroxide is 2 to 20 ml, depending on battery size.

Eye Contact: If battery is leaking and material contacts the eye, flush thoroughly with copious amounts of running water for 30 minutes. Seek immediate medical advice.

Skin Contact: If battery is leaking and material contacts the skin, remove any contaminated clothing and flush exposed skin with copious amounts of running water for at least 15 minutes. If irritation, injury or pain persists, seek medical advice.

Inhaled: If battery is leaking, contents may be irritating to respiratory passages. Move to fresh air. If irritation persists, seek medical advice.

Swallowed: If battery contents are swallowed, do not induce vomiting. If the victim is alert, have them rinse their mouth are the surrounding skin with water for at least 15 minutes. Seek immediate medical attention.

Note: This SDS does not include or address the small button cell batteries which can be ingested.

SECTION 5: FIRE FIGHTING MEASURES

Fire and Explosion Hazards: Batteries may burst and release hazardous decomposition products when exposed to a fire situation.

Extinguishing Media: Use any extinguishing media that is appropriate for the surrounding fire.

Special Fire Fighting Procedures: Firefighters should wear positive pressure self-contained breathing apparatus and full protective clothing. Fight fire from a distance or protected area. Cool fire exposed batteries to prevent rupture. Use caution when handling fire-exposed containers (containers may rocket or explode in heat of fire).

Hazardous Combustion Products: Thermal degradation may produce hazardous fumes of zinc and manganese; hydrogen gas, caustic vapors of potassium hydroxide and other toxic by-products.

SECTION 6: ACCIDENTAL RELEASE MEASURES

Notify safety personnel of large spills. Caustic potassium hydroxide may be released from leaking or ruptured batteries. Clean-up personnel should wear appropriate protective clothing to avoid eye and skin contact and inhalation of vapors or fumes. Increase ventilation. Carefully collect batteries and place in an appropriate container for disposal.

SECTION 7: HANDLING AND STORAGE

Avoid mechanical or electrical abuse. DO NOT short circuit or install incorrectly. Batteries may explode, pyrolize or vent if disassembled, crushed, recharged or exposed to high temperatures. Install batteries in accordance with equipment instructions. Do not mix battery systems, such as alkaline and zinc carbon, in the same equipment. Replace all batteries in equipment at the same time. Do not carry batteries loose in a pocket or bag. Do not remove battery tester or battery label.

Storage: Store batteries in a dry place at normal room temperature. Do not refrigerate – this will not make them last longer.

SECTION 8: EXPOSURE CONTROLS/PERSONAL PROTECTION

The following occupational exposure limits are provided for informational purposes. No exposure to the battery components should occur during normal consumer use. **Refer to specific country regulations for additional exposure limit information.**

Chemical Name	Exposure Limits
Manganese Dioxide	0,5 mg/m^3 TWA UK WEL 0,5 mg/m^3 TWA (inhalable) DFG MAK 0,2 mg/m^3 VL Belgium 0,2 mg/m^3 TWA Denmark LV
Zinc	None established for zinc metal
Potassium Hydroxide	2 mg/m^3 STEL UK WEL 2 mg/m^3 VCD Belgium 2 mg/m^3 Ceiling Denmark LV
Graphite	4 mg/m^3 TWA UK WEL (respirable dust) 10 mg/m^3 TWA UK WEL (inhalable dust) 1,5 mg/m^3 TWA DFG MAK (respirable dust) 4 mg/m^3 TWA DFG MAK (inhalable dust) 2 mg/m^3 VL Belgium (respirable dust)

Ventilation: No special ventilation is needed for normal use.

Respiratory Protection: None required for normal use.

Skin Protection: None required for normal use. Use neoprene, rubber or latex gloves when handling leaking batteries.

Eye Protection: None required for normal use. Wear safety goggles when handling leaking batteries.

SECTION 9: PHYSICAL AND CHEMICAL PROPERTIES

Appearance and Odor: Copper top battery.
Water Solubility: Insoluble

SECTION 10: STABILITY AND REACTIVITY

Stability: This product is stable.

Incompatibility/Conditions to Avoid: Contents are incompatible with strong oxidizing agents. Do not heat, crush, disassemble, short circuit or recharge.

Hazardous Decomposition Products: Thermal decomposition may produce hazardous fumes of zinc and manganese; caustic vapors of potassium hydroxide and other toxic by-products.

Hazardous Polymerization: Will not occur

SECTION 11: TOXICOLOGICAL INFORMATION

Potential Health Effects:

The chemicals and metals in this product are contained in a sealed can. Exposure to the contents will not occur unless the battery leaks, is exposed to high temperatures or is mechanically, physically, or electrically abused. Damaged battery will release concentrated potassium hydroxide, which is caustic. Anticipated potential leakage of potassium hydroxide is 2 to 20 ml, depending on battery size.

Eye Contact: Contact with battery contents may cause severe irritation and burns. Eye damage is possible.

Skin Contact: Contact with battery contents may cause severe irritation and burns.

Inhalation: Inhalation of vapors or fumes released due to heat or a large number of leaking batteries may cause respiratory and eye irritation.

Ingestion: Swallowing is not anticipated due to battery size. Choking may occur if smaller AAA batteries are swallowed. Ingestion of battery contents (from a leaking battery) may cause mouth, throat and intestinal burns and damage.

Acute Toxicity Data:
Manganese Dioxide: LD50 oral rat >3478 mg/kg
Potassium Hydroxide: LD50 oral rat 273 mg/kg

Chronic Effects: The chemicals in this product are contained in a sealed can and exposure does not occur during normal handling and use. No chronic effects would be expected from handling a leaking battery.

Target Organs: Skin, eyes and respiratory system.

Carcinogenicity: None of the components of this product are listed as carcinogens by the EU Directive on the classification and labeling of substances.

SECTION 12: ECOLOGICAL INFORMATION

No ecotoxicity data is available. This product is not expected to present an environmental hazard.

SECTION 13: DISPOSAL INFORMATION

Disposal should be in accordance with national and local regulations. Do not incinerate except for disposal in a controlled incinerator.

Duracell alkaline manganese dioxide batteries are labeled in compliance with EU Battery Directive 2006/66.

SECTION 14: TRANSPORT INFORMATION

Transportation Information – Products covered by this SDS, in their original form, are considered "dry cell" batteries and are not regulated as "DANGEROUS GOODS" for transportation.

For finished packaged product transported by ground (ADR/RID): – not regulated
For finished packaged product transported by sea (IMDG) – not regulated
For finished packaged product transported by air (IATA): – not regulated

SECTION 15: REGULATORY INFORMATION

EU Classification of Preparation: Not classified as a dangerous preparation.

REACH: These products are manufactured articles and not subject to REACH registration requirements.

EU Labeling: None Required
Labeling is not required because batteries are classified as articles under the both REACH and the Dangerous Preparations Directive and as such are exempt from the requirement for labeling.

SECTION 16: OTHER INFORMATION

P&G Hazard Rating: Health: 0 Fire: 0 Reactivity: 0

EU Classes and Risk Phrases for Reference (See Sections 2 and 3)
C Corrosive
N Dangerous for the Environment
Xn Harmful
R20/22 : Harmful by inhalation and if swallowed.
R22 Harmful if swallowed.
R35 Causes severe burns
R50/53 : Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.
==

Data supplied is for use only in connection with occupational safety and health.

DISCLAIMER: This SDS is intended to provide a brief summary of our knowledge and guidance regarding the use of this material. The information contained here has been compiled from sources considered by Procter & Gamble to be dependable and is accurate to the best of the Company's knowledge. It is not meant to be an all-inclusive document on worldwide hazard communication regulations.

This information is offered in good faith. Each user of this material needs to evaluate the conditions of use and design the appropriate protective mechanisms to prevent employee exposures, property damage or release to the environment. Procter & Gamble assumed no responsibility for injury to the recipient or third persons, or for any damage to any property resulting from misuse of the product.

Material Safety Data Sheet

Infosafe No™ LPZ79	Issue Date : July 2010	ISSUED by HENKELPS

Product Name **LOCTITE E-120HP EPOXY ADHESIVE**

1. IDENTIFICATION OF THE MATERIAL AND SUPPLIER

Product Name	LOCTITE E-120HP EPOXY ADHESIVE
Product Code	237130 (PART NO. 29355), 237128 (PART NO. 29353)
Company Name	HENKEL AUSTRALIA PTY. LIMITED (ABN 82 001 302 996)
Address	135-141 Canterbury Road KILSYTH VICTORIA 3137 Australia
Emergency Tel.	(03) 9724 6556 (24 hour)
Telephone/Fax Number	Tel: (03) 9724 6444
Recommended Use	Two part epoxy adhesive

2. HAZARDS IDENTIFICATION

Hazard Classification	Classified as Hazardous according to criteria of Safe Work Australia (formerly the National Occupational Health & Safety Commission, Australia (NOHSC)). Not classified as Dangerous Goods according to the Australian Code for the Transport of Dangerous Goods by Road and Rail.
Risk Phrase(s)	R36/38 Irritating to eyes and skin. R43 May cause sensitization by skin contact. R51/53 Toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.
Safety Phrase(s)	S23 Do not breathe gas/fumes/vapour/spray S24/25 Avoid contact with skin and eyes. S37/39 Wear suitable gloves and eye/face protection. S46 If swallowed, seek medical advice immediately and show this container or label.

3. COMPOSITION/INFORMATION ON INGREDIENTS

Ingredients

Name	CAS	Proportion
Phenol, polymer with formaldehyde, glycidyl ether	28064-14-4	30-60 %
Epichlorohydrin-4,4'-Isopropylidene diphenol resin	25068-38-6	30-60 %
Non-hazardous ingredients		Balance

4. FIRST AID MEASURES

Inhalation	If inhaled, remove affected person from contaminated area. Apply artificial respiration if not breathing. Seek medical attention.
Ingestion	Do not induce vomiting. Wash out mouth thoroughly with water. If symptoms develop seek medical attention.
Skin	Wash affected area thoroughly with soap and water. Remove contaminated clothing and wash before reuse or discard. Seek medical attention.
Eye	If in eyes, hold eyelids apart and flush the eyes continuously with running water. Continue flushing for several minutes until all contaminants are washed out completely. Seek medical attention.
First Aid Facilities	Eye wash and normal washroom facilities.
Advice to Doctor	Treat symptomatically.
Other Information	For advice in an emergency, contact a Poisons Information Centre (Phone Australia 13 1126) or a doctor at once.

5. FIRE FIGHTING MEASURES

Suitable Extinguishing Media	Use water spray or fog, carbon dioxide, dry chemical or foam.

Hazards from Combustion Products	Under fire conditions this product may emit toxic and/or irritating fumes and gases including oxides of carbon, aldehydes, acids and irritating organic fragments.
Specific Hazards	Combustible liquid. This product will readily burn under fire conditions.
Precautions in connection with Fire	Fire fighters should wear Self-Contained Breathing Apparatus (SCBA) operated in positive pressure mode and full protective clothing to prevent exposure to vapours or fumes. Water spray may be used to cool down heat-exposed containers.

6. ACCIDENTAL RELEASE MEASURES

Emergency Procedures	Wear appropriate personal protective equipment and clothing to prevent exposure. Extinguish or remove all sources of ignition and stop leak if safe to do so. Increase ventilation. Evacuate all unprotected personnel. If possible contain the spill. Place inert absorbent, non-combustible material onto spillage. Use clean non-sparking tools to collect the material and place into suitable labelled containers for subsequent recycling or disposal. Dispose of waste according to the applicable local and national regulations. If contamination of sewers or waterways occurs inform the local water authorities and EPA in accordance with local regulations.

7. HANDLING AND STORAGE

Precautions for Safe Handling	Use only in a well ventilated area. Keep containers sealed when not in use. Prevent the build up of mists or vapours in the work atmosphere. Avoid inhalation of vapours and mists, and skin or eye contact. Do not use near ignition sources. Do not pressurise, cut, heat or weld empty containers as they may contain hazardous residues. Maintain high standards of personal hygiene ie. Washing hands prior to eating, drinking, smoking or using toilet facilities.
Conditions for Safe Storage	Store in cool, dry, well-ventilated area away from sources of ignition, strong oxidising agents, strong acids, strong bases, amines, foodstuffs, and clothing. Provide a catch-tank in a bunded area. Avoid sparks, flames and other ignition sources. Store away from incompatible materials. Do NOT pressurise, cut, heat or weld empty containers as they may contain hazardous residues. Keep containers closed when not in use and securely sealed and protected against physical damage. Inspect regularly for deficiencies such as damage or leaks. Have appropriate fire extinguishers available in and near the storage area. Take precautions against static electricity discharges. Use proper grounding procedures. For information on the design of the store-room reference should be made to Australian Standard AS1940 - The storage and handling of flammable and combustible liquids and AS 3780-2008 The storage and handling of corrosive substances. Reference should also be made to all Local, State and Federal regulations.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

National Exposure Standards	No exposure value assigned for this specific material by Safe Work Australia.
Biological Limit Values	No biological limit available.
Engineering Controls	Provide sufficient ventilation to keep airborne levels as low as possible. Where vapours or mists are generated, particularly in enclosed areas, and natural ventilation is inadequate, a local exhaust ventilation system is required.
Respiratory Protection	If engineering controls are not effective in controlling airborne exposure then an approved respirator with a replaceable organic vapour filter should be used. Reference should be made to Australian/New Zealand Standards AS/NZS 1715, Selection, Use and Maintenance of Respiratory Protective Devices; and AS/NZS 1716, Respiratory Protective Devices, in order to make any necessary changes for individual circumstances.
Eye Protection	Safety glasses with side shields or chemical goggles should be worn. Final choice of appropriate eye/face protection will vary according to individual circumstances. Eye protection devices should conform with Australian/New Zealand Standard AS/NZS 1337 - Eye Protectors for Industrial Applications.
Hand Protection	Wear gloves of impervious material. Final choice of appropriate gloves will vary according to individual circumstances i.e. methods of handling or

Body Protection	according to risk assessments undertaken. Reference should be made to AS/NZS 2161.1: Occupational protective gloves - Selection, use and maintenance. Suitable protective workwear, e.g. cotton overalls buttoned at neck and wrist is recommended. Chemical resistant apron is recommended where large quantities are handled. Industrial clothing should conform to the specifications detailed in AS/NZS 2919: Industrial clothing.

9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance	Pale yellow liquid
Odour	Faint, epoxy
Melting Point	Not available
Boiling Point	>149°C
Solubility in Water	Not miscible or difficult to mix.
Specific Gravity	Not available
pH Value	Not applicable
Vapour Pressure	Not available
Vapour Density (Air=1)	Not available
Flash Point	>93.33°C (Setaflash closed cup)
Flammability	Combustible liquid
Auto-Ignition Temperature	Not available
Flammable Limits - Lower	Not available
Flammable Limits - Upper	Not available
Other Information	VOC content 1%: <10 g/l (Estimated)

10. STABILITY AND REACTIVITY

Chemical Stability	Stable under normal conditions of storage and handling.
Conditions to Avoid	Heat and other sources of ignition. Avoid mixing resin (Part A) and curing agent (Part B), unless you plan to use immediately Failure to observe these precautions may result in excessive heat build-up.
Incompatible Materials	Oxidizing agents, strong acids, strong bases and amines.
Hazardous Decomposition Products	Thermal decomposition may result in the release of toxic and/or irritating fumes and gases including oxides of carbon, aldehydes, acids and irritating organic fragments.
Hazardous Polymerization	Reaction with some curing agents may produce an exothermic reaction which in large masses could cause runaway polymerization.

11. TOXICOLOGICAL INFORMATION

Toxicology Information	Acute toxicity data for this product: LD50 (Oral, Rat): >5,000 mg/kg LD50 (Oral, Rabbit): >2,000 mg/kg
Inhalation	Inhalation of product vapours may cause irritation of the nose, throat and respiratory system.
Ingestion	Ingestion of this product may irritate the gastric tract causing nausea and vomiting.
Skin	Irritating to skin. Skin contact will cause redness, itching and swelling.
Eye	Irritating to eyes. On eye contact this product will cause tearing, stinging, blurred vision, and redness.
Chronic Effects	Prolonged or repeated skin contact may lead to allergic contact dermatitis and sensitisation in some individuals.

12. ECOLOGICAL INFORMATION

Ecotoxicity	No ecological data are available for this material.
Persistence / Degradability	Not available
Mobility	Not available
Environ. Protection	Do not discharge this material into waterways, drains and sewers.

13. DISPOSAL CONSIDERATIONS

Disposal Considerations	The disposal of the spilled or waste material must be done in accordance with applicable local and national regulations.

14. TRANSPORT INFORMATION

Transport Information	Not classified as Dangerous Goods according to the Australian Code for the Transport of Dangerous Goods by Road and Rail. (7th edition)

15. REGULATORY INFORMATION

Regulatory Information	Classified as Hazardous according to criteria of Safe Work Australia. Classified as a Scheduled Poison according to the Standard for the Uniform Scheduling of Drugs and Poisons (SUSDP).
Poisons Schedule	S5
Hazard Category	Irritant,Dangerous for the environment

16. OTHER INFORMATION

Date of preparation or last revision of MSDS	MSDS Created: July 2010
Other Information	DISCLAIMER: The percentage weight (% w/w) of ingredients is not to be taken as a specification guaranteed by Henkel Australia Pty. Limited, but only as an approximate guide to the content of hazardous ingredients in the material. The information contained herein does not constitute a guarantee by Henkel Australia Pty. Limited concerning the properties of the material. This information is not to be construed as a representation that the material is suitable for any particular purpose or use except those conditions and warranties implied by either Commonwealth or State statutes. Customers are encouraged to make their own enquiries as to the material's characteristics and, where appropriate, to conduct their own tests in the specific context of the material's intended use. ...End Of MSDS...