PRELIMINARY DESIGN REVIEW

Design, Development, and Launch of a Reusable Rocket and Autonomous Ground Support Equipment

Payload Option 3.1.8 Centennial Challenge – MAV

Madison West High School *Non-Academic Team* November 6th 2015

Madison West High School, 30 Ash Street, Madison, Wisconsin

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Summary of PDR report

Team Summary

Team name and mailing address

Madison West High School
ATTN: Ms. Christine L. Hager
30 Ash Street
Madison, WI, 53726

Team mentor

Mr. Brent Lillesand
NAR# 79225
TRA# 8804
Level-3 HRP Certification

Launch Vehicle Summary

Length	87*in*
Diameter	3*in*
Liftoff Weight	13.4*lbs*
Recovery System	dual deployment 18*in* drogue parachute at apogee 60*in* main parachute at 700*ft* Fully redundant dual event altimeters
Flysheet	http://westrocketry.com/sli2016/MSRFS_PDR_MadisonWest2016_Martians.xls

Payload Summary

We are pursuing payload option 3.1.8: *Design, Development, and Launch of a Reusable Rocket and Autonomous Ground Support Equipment* (Centennial Challenge). The goal of the project is to develop a reusable rocket together with autonomous ground support equipment (AGSE). AGSE must be able to

- collect a container with soil sample from the ground
- insert the container into payload compartment in the rocket
- close the door of payload compartment
- raise the rocket into launch position of 5^{o} from vertical
- insert igniter to rocket motor

Changes made since Proposal

Changes made to vehicle criteria

- **Page 12:** Added verification plan and status
- **Page 14:** Added vehicle risk analysis
- **Page 16:** Added vehicle development schedule
- **Page 17:** Added vehicle maturity discussion
- **Page 18:** Updated mass statement
- **Page 19:** Changed launch vehicle design to 3" diameter vehicle to decrease overall size of AGSE
- **Page 20:** Added detailed dimensional drawing of the vehicle
- **Page 23:** Updated recovery table to include impact energy for all parts of the rocket
- **Page 24:** Added electrical schematic of deployment electronic
- **Page 25:** Updated drift calculations to include the upwind travel due to weathercocking
- **Page 26:** Added mission performance criteria
- **Page 26:** Updated performance predictions for new vehicle design
- **Page 30:** Updated primary propulsion choice to CTI K530SS and secondary to AT K535W
- **Page 31:** Added preliminary checklist for final assembly and launch procedures
- **Page 30:** Added description of interfaces
- **Page 35:** Added discussion of environmental concerns

Changes made to payload criteria

- **Page 45:** Replaced robotic arm with SCARA robot design to extend arm reach
- **Page 50:** Replaced end effector with passive gripper
- **Page 50:** Added pictures of payload bay pre-prototype
- **Page 50:** Updated design for payload door closure
- **Page 51:** Added tolerance analysis
- **Page 52:** Changed AGSE erection design from worm drive to electric linear actuator
- **Page 57:** Updated control system discussion
- **Page 67:** Updated AGSE mass statement
- **Page 70:** Added verification plan
- **Page 100:** Updated AGSE budget

Changes made project plan

- **Page 72:** Updated outreach information
- **Page 74:** Added verification method to each project requirement
- **Page 98:** Updated project budget

Vehicle Criteria

Selection, Design and Verification of Launch Vehicle

Mission Statement, Requirements, Success Criteria

We will use a single stage, K-class vehicle to deliver the standard MAV payload to the target altitude of 5,280*ft*. The rocket will land using dual deployment recovery and will be reflyable on the same day. The following criteria define successful mission for vehicle:

- Rocket safely launches from AGSE under 5^{o} angle from vertical
- Rocket reaches but will noy exceed target altitude of 5,280*ft*
- Rocket lands safely after deployment of drogue parachute at apogee and main parachute at 700*ft* AGL
- Rocket lands within the confines of launch area (1/2*mile* radius from launch site)
- Rocket is recovered with no damage and reflyable on the same day

System Level Overview

The following subsystems are necessary to accomplish the mission:

Subsystem	Addresses	Pages
Structural	Rocket construction, material selection	19-22
Propulsion	Motor choice, performance predictions	30
Recovery	Parachutes, deployment electronics	22-25
AGSE	Autonomous ground support equipment	36-71

Table 1: Vehicle subsystems

The requirements for each subsystem are addressed in its own section in the document.

Verification Plan and Status

Verification Matrix

The verification plan is constructed based on the project requirements, pages 74-81. Each of the requirements is addressed in list form, starting on page 74.

Further, for each of the requirements, we have identified

- Component addressed by a given requirement
- Test to perform to verify that a given requirement is satisfied

The verification components for the vehicle are:

C1: Flight Electronics
C2: Recovery Systems
C3: Motor
C4: Power Supply
C5: Ejection Charges
C6: Tracking and Telemetry
C7: Launch System

The verification procedures (tests) for the vehicle are:

V1/Functionality: Ensure satisfactory performance of components.
V2/Integrity: Application of force to verify durability.
V3/Integration: Ensures proper fit of component within its assigned compartment, free of interference of other components.
V4/Scale Model: Verifies the predicted performance of the vehicle.

Finally, the verification shows which test is applied to which component and which project requirement (identified by its number) is verified by carrying out that test.

	V1	V2	V3	V4
C1	1.2	2.5	2.4	1.2
C2	2.5	1.3	1.4	1.4
C3	1.5	2.5	1.12	1.2
C4	1.7	1.7	1.12	1.7
C5	2.2	2.5	1.12	1.13.1
C6	2.11	2.5	2.11	2.11
C7	1.8	2.5	1.8	1.8

Table 2: Verification matrix for vehicle

Currently, no tests have been carried out yet. The verification process will start upon successful completion of the Preliminary Design Review milestone and will follow the construction progress of the vehicle.

Project Requirements for Vehicle and Verification

The adherence to NASA mandated project requirements is in detailed discussed in the Project Requirements section on pages 74 to 81.

Vehicle Risks

We have over a decade of Student Launch experience and we work with highly experienced mentor and other engineers. The biggest risk is the weather that can severely limit our flight test opportunities. Motor availability and feature creep (unnecessary "just because we can" project scope expansion) have been identified as major risks as well. On the other hand, we have a 24/7 access to workshop and sufficient personnel to provide us with sufficient workshop time and all tools necessary for successful completion of vehicle construction and testing. We also work with several vendors to ensure the parts and supplies availability. The identified risks are sorted by the likelihood of each risk occurring.

Risk	Mitigation	Impact	Likelihood
Weather (affects test flights)	There is sufficient number of flight windows open in our area (about 3 windows each month). The team members are aware of the fact that some launch dates will be rescheduled due to bad weather. SL test flights are of high priority for all team members and there will sufficient ground personnel available for each launch window. We also have the option to ask a "one-time-favor" from owners of private launch sites.	**HIGH**	**MEDIUM**
Motor Supply	We work with several rocketry vendors to avoid "out-of-stock" situation. However, since the motors are produced by only a few manufacturers, this risk is higher than supply risk for parts and supplies.	**HIGH**	**MEDIUM**
Scope (feature creep)	The team will adhere to the requirements of the project and by CDR milestone will identify the minimum solution that satisfies all project requirements. Addition of features beyond this scope will not be allowed until the minimum solution is implemented and 100% functional. Mentor and educators will enforce the limits to project scope at all times.	**HIGH**	**MEDIUM**
Schedule (tasks taking longer than expected)	Team schedules workshop and classroom time according to the project status. If the project starts slipping behind original schedule, more work time will be scheduled.	**MEDIUM**	**LOW**
Budget overrun (team	The budget has been constructed and will be	**HIGH**	**LOW**

running out of money)	closely monitored as the project progresses. The team is participating in annual fundraising event to earn money and to increase community awareness of the project and its educational impact. After the conclusion of fundraising activities for this year, the team still has several options to raise more funds if needed.		
Team member injury	All team members, mentor and educators will utilize personal protective equipment for all activities. All safety related documentation is kept on hand for quick access. The team members are supervised by the mentor and educators at all times. The first aid kit is kept on-hand during all activities.	**HIGH**	**LOW**
Personnel (not being available)	We have several workshop supervisors that can work with the students and our workshop is accessible 24 hours, 7 days of week. Two or more students are assigned to each task to ensure that no task will stall because of personnel shortage. The school exam periods and break are accounted for in our schedule.	**MEDIUM**	**LOW**
Rocket Construction (the ability of the team to build a rocket that will be suitable for the mission)	The team is supervised by highly experienced mentor with previous Student Launch experience to ensure that the vehicle is constructed using proper construction techniques and materials and that sufficient time is allocated to each of the construction tasks.	**HIGH**	**LOW**
Rocket Performance	The team will perform several test flights to make sure that the rocket will reach but not exceed the target altitude. This will include computer simulations, half-scale model flights and full scale vehicle test flights. After each flight the collected data will be analyzed to evaluate the overall performance of the launch vehicle.	**MEDIUM**	**LOW**

Deployment Failure (damage to rocket, possible rocket loss)	Static ejection tests will be performed to make sure that the ejection charges are of correct size and the coupling surfaces are smooth enough. Fully redundant ejection electronics will be used to increase the probability of successful deployment of both the main and drogue parachute. The rocket flight preparations will be observed by the mentor and checklists will be used to prevent step omissions.	**HIGH**	**LOW**
Rocket Loss	The team is aware of possibility of losing the rocket during any of the test flights. A sufficient surplus of parts will be kept to allow for construction of the new vehicle. All test flights will be scheduled in sufficient advance of the final launch to allow team to recover from the rocket loss. The team mentor will supervise the team during all test flights to ensure the highest possible probability of favorable flight outcome. The weather situation will be critically evaluated before every test flight to balance the risk of rocket loss with the consequences of not making the test flight.	**HIGH**	**LOW**
Parts/Supplies Availability	We work with several vendors and use materials with normalized dimensions to avoid situations when the only vendor carrying a critical item runs out or the item is discontinued.	**HIGH**	**LOW**

Table 3: Project risks related to the vehicle

Preliminary Development Schedule for Vehicle

Detailed schedule of all our activities is shown starting on page 92. The date concerning the launch vehicle development are summarized in the table below. We have allocated 2 weeks for parts acquisition for each of two vehicles (half-scale and full-scale), followed by a three week (6 workshop sessions) manufacturing period and minimum of 2 days of ground/static testing and verification. Finally each vehicle has three launch windows available. We expect that we will need at least one launch of the half-scale vehicle and minimum two launches (one half impulse and one full impulse) of the full scale vehicle. This leaves us five weeks between final full scale vehicle test flight and departure for SL launch in Huntsville. These five weeks provide sufficient time to deal with possible problems discovered during full scale vehicle testing.

AGSE will be developed in parallel with the vehicle and we plan to have a launch capable structure by the time of second full scale vehicle launch (February 27th) to allow for at least one test flight launched from the AGSE.

There is task order dependency, half-scale vehicle construction, ground and flight testing must be completed before the full scale vehicle construction may start. The AGSE must be in launch capable state to finish the flight testing of the full scale vehicle.

All schedule items have a built-in safety cushion to mitigate possible delay. For example it usually takes one week from parts order to delivery and we need 2 weeks to build either the half scale or full scale vehicle.

Activity	Dates	Time allocated
Scale model parts acquisition	**11/7 to 11/21**	**2 weeks**
Scale model construction	11/21 to 12/10	3 weeks
Scale model ground tests, verification	12/10, 12/11	2 days
Scale model test flights	12/12 or 12/19 or 1/9	3 launch windows; one required
Full scale vehicle parts acquisition	1/9 to 1/23	2 weeks
Full scale vehicle construction	1/24 to 2/13	3 weeks
Full scale ground tests, verification	2/14 to 2/19	1 week
Full scale test flights (minimum 2 needed)	2/20, 2/27 or 3/5	3 launch windows, two required
Full scale vehicle final preparations for SL launch in AL	3/6 to 4/9	5 weeks

Table 4: Vehicle development schedule (preliminary)

Vehicle Design Maturity

At this point we consider the vehicle design sufficiently mature to start the scale model construction.

Target altitude: We have carried out flight simulations in OpenRocket software, with coefficient of drag set to 0.7, a typical value for single diameter, cylindrical rockets and the simulated apogee is very close to desired altitude target (target is 5280*ft,* and our simulations show predicted apogee of 5180*ft*). We have sufficient reserve in propulsion choices to cover for vehicle mass increase during development. The scale model flight results are needed to determine the actual vehicle coefficient of drag and to finalize the propulsion choice.

Flight safety parameters: the following table shows the flight safety parameters. Thrust to weight ratio is significantly above above the minimal required of 5, rocket has stability of 4.02*calibers* (stable) and the exit velocity of the 5*ft* rail is 36.2*mph* (above the minimum required value of 30*mph*).

Parameter	Value
Flight Stability Static Margin	4.02 *calibers*
Thrust to Weight Ratio	10
Velocity at Launch Guide Departure (5ft launch rail)	41.2 *mph*

Table 5: Vehicle flight safety parameters

Mission goal suitability: the vehicle was significantly redesigned to fit better the overall mission goals. The body diameter was decreased from 4*in* to 3*in* to allow the rocket become smaller and capable of taking off from a 5*ft* launch rail, thus significantly decreasing the AGSE footprint and volume. The rocket body is still wide enough to allow for easy payload insertion by a robotic arm while retaining sufficient robustness of the payload bay.

High wind performance: the rocket will lose about 4% of altitude when flying under 20*mph* wind conditions. We are considering decreasing the stability margin to about 3 calibers to improve resistance against weathercocking.

Recovery and drift: the parachute sizes and deployment altitudes were selected so the rocket will not drift for more than 0.5*mile* even when flying under 20*mph* wind conditions while obeying the constraint of 75*ft-lb.f* maximum kinetic energy on landing for any of its section.

Mass Statement

Estimated Mass: at this stage of development, the estimated mass (13.4*lbs*) is based solely on the information from OpenRocket, the CAD software that we use to design the rocket. The more accurate estimate, based on measures and weights of real parts, will be obtained after we acquire parts for full scale vehicle. In our experience, OpenRocket generally underestimates the rocket mass by 10-20%, however the more accurate assessment of OpenRocket rocket weight estimates will require possession of actual rocket parts.

Underpowered Rocket Margin: as currently designed, the rocket can gain over 13*lbs* before the thrust to weight ratio drops under 5, the minimum value for safe liftoff. However, are rocket is fairly is fairly small and we are using about 30% of allowed impulse limit. We will able to compensate for any rocket mass increase by increase in motor size.

We need to conduct measurements of actual parts used for building this rocket before we can finalize the mass statement. Even so, we are confident that the proposed launch vehicle is a sufficient first iteration of the launch vehicle.

Structural Subsystem

The rocket will be constructed from 3” thin-wall fiberglass tubing, using 3/32” G10 fins. The rocket will be robust enough to endure 25+*g* of acceleration and high power rocket flight and deployment stresses.

To have a successful mission the rocket must reach (but not exceed) altitude of one mile AGL and the avionics must function to ensure safe deployment and recovery. The rocket will be 87 inches long, with a 3.0 inch diameter. It has estimated liftoff mass of 13.4 pounds. The proposed vehicle and propulsion options are discussed in detail below. The primary propulsion choice is a K-class motor (CTI K530SS, 54*mm*) with total impulse of 1412*Ns*. The vehicle can launch from a standard size, 5*ft* launch rail.

The rocket will use dual deployment to minimize drift.

Dimensions

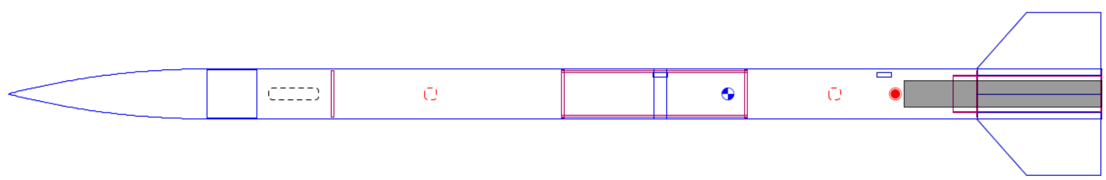

Figure 1: A two dimensional schematic of the entire rocket.

Dimensional Drawing of the Vehicle

The figure below show dimensioned drawing of the entire vehicle, including all major components and structurally important points (such as anchors for shockcords or bulkheads). The location of both parachutes, motor, payload and bay with deployment electronics is also shown.

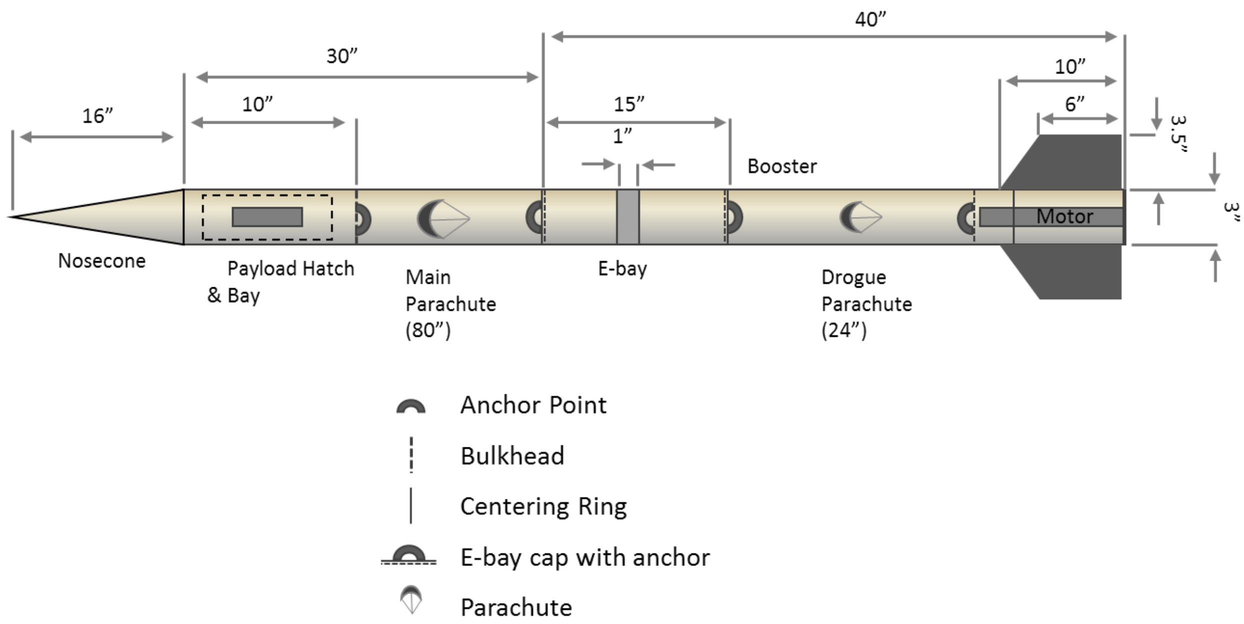

Figure 2: Dimensioned drawing of vehicle

Vehicle Parameters

The table below shows the primary design parameters of our vehicle.

Length *[in]*	Mass *[lbs]*	Diameter *[in]*	Motor Selection	Stability Margin *[calibers]*	Thrust to weight ratio *(g)*
87	13.4	3	CTI K530SS	4.0	10

Table 6: The rocket’s dimensions, stability, and primary propulsion

The following figure shows all compartments and sections of our rocket. The rocket separates into three tethered parts. The first part contains the nosecone, payload, and the main parachute. The second part contains deployment e-bay. The third part contains the drogue parachute and the rest of the vehicle. We will use standard dual deployment triggered by two fully redundant PerfectFlite StratoLogger altimeters.

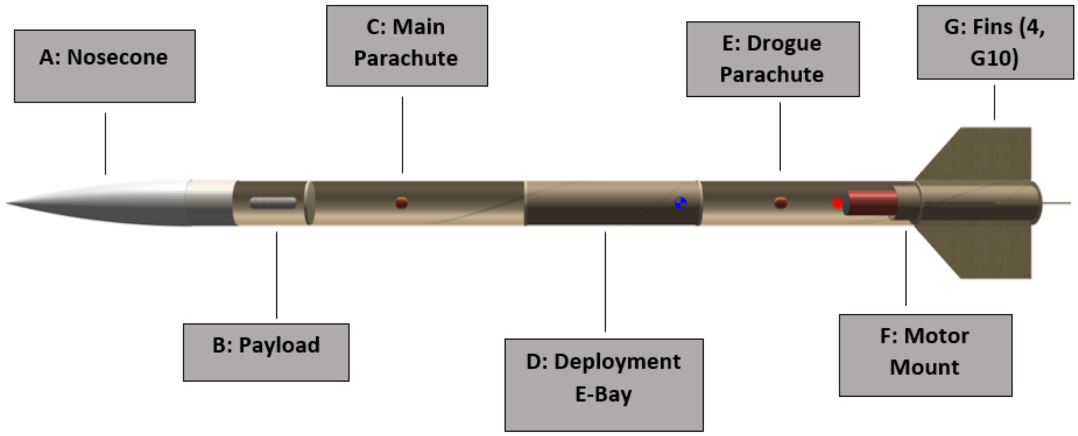

Figure 3: A three dimensional schematic of the entire rocket

Letter	Part
A	Nosecone
B	Payload
C	Main Parachute
D	Deployment E-Bay
E	Drogue Parachute
F	Motor Mount (75mm)
G	Fins (4, G10)

Table 7: Rocket sections and parts

Material Selection

The following table shows the selection of materials for the vehicle. We will use primarily fiberglass for vehicle construction because it is easily precisely machined and glued, is light and strong. Our vehicle is 4" in diameter and we have a sufficient total impulse allowance for fiberglass construction.

Rocket Part	Material
Nosecone	Fiberglass
Tubing	Thinwall fiberglass
Fins	3/32" G10 fiberglass, beveled
Parachutes	Ripstop Nylon
Couplers	Fiberglass
Motor Mount	Fiberglass
Centering Rings, Bulkheads	Aircraft Plywood
Anchors	¼" stainless steel U-bolts
Shockcords	½" tubular Kevlar
Tie-rods	¼" stainless steel threaded rods

Table 8: Material selection

In the construction of our vehicle, we will use only proven, reliable materials made by established manufacturers, under the supervision of our NAR mentor, Mr. Brent Lillesand. We will comply with all NAR standards regarding the materials and construction methods. Lightweight materials such as fiberglass tubing used in the construction of the rocket to ensure that the vehicle is under the engine's safe maximum liftoff weight. We will use primarily West System epoxy with appropriate fillers to ensure strong yet lightweight bonds between parts.

The computer programs RockSim and Open Rocket will be utilized to help design and pre-test the stability of our rocket so that no unexpected and potentially dangerous problems with the vehicle occur. Scale model of the rocket will be built and flown to prove the rocket stability.

Parachute System Design

The rocket separates into three tethered parts: upper section (containing the MAV payload), electronic bay (separating the main and drogue parachute compartments) and the booster section. The classic dual deployment scheme with drogue parachute in the lower compartment is used. Parachutes are deployed using black powder ejection charges triggered by two fully redundant barometric altimeters (PerfectFlite StratoLogger CF). The figure below illustrates the vehicle separation scheme.

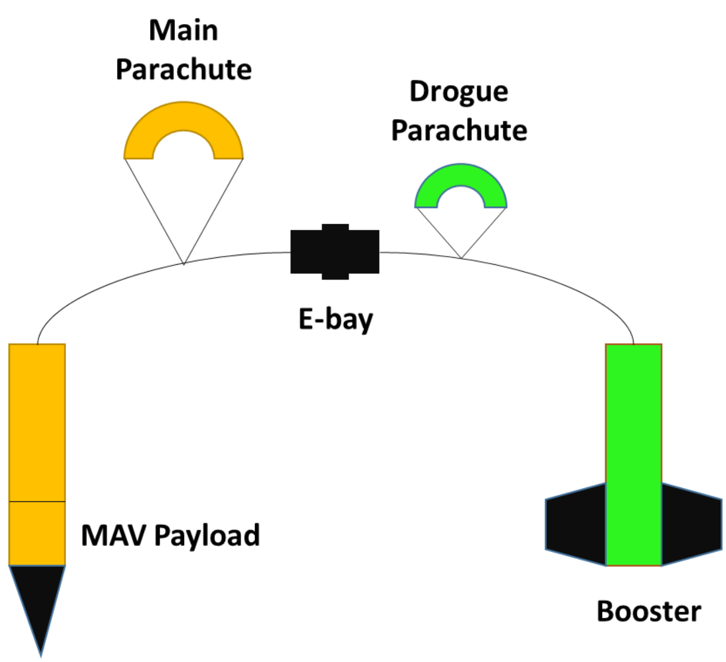

Figure 4: Vehicle separation scheme

Our rocket will use standard dual deployment. At apogee, the drogue parachute located directly below the payload will be deployed. The rocket will descend under the 24-inch parachute until 700 *ft* AGL, at which point the 22-inch main parachute will be deployed. The total kinetic energy for the rocket landing under 80-inch main parachute is 76.85*ft.lbf*. None of the three tethered parts lands with kinetic energy higher than 75*ft.lbf*.

Parachutes and Ejection Charges

Parachute	Diameter *[in]*	Descent Rate *[fps]*	Ejection Charge *[g]*	Deployment Altitude *[ft]*	Descent Weight *[lb]*		Impact Energy *[ft.lb f]*
Drogue	18	90.0	2.43	5247		13.51	964.4
Main	80	20.3	2.53	700	*E-bay*	1.68	9.54
					Payload	3.50	19.92
					Booster	8.33	47.39

Table 9: Parachute sizes, ejection charges and impact energy

The impact energy is calculated using the following formula:

$$E = \frac{1}{2} \cdot m \cdot v^2$$

Where

E	impact energy	*[ft.lb f]*
m	mass	*[slug]*
v	descent rate	*[ft/s]*

The ejection charge sizes are calculated using the following formula:

$$W = \frac{dP \cdot V}{R \cdot T} \cdot \frac{454}{12}$$

where

W	ejection charge size		*[g]*
dP	ejection pressure	15	*[psi]*
V	pressurized volume		*[in^3]*
R	universal gas constant	22.16	*[ft-lb ^{o}R^{-1} lb-mol^{-1}]*)
T	temperature	3307	*[^{o}R]*

The recovery system principal components are listed in the table below:

Component	Material, strength rating
Shockcords	½" tubular Kevlar, 2000*lbs* rating
Thermal protectors	Nomex sheets
Parachutes	Rip-stop nylon, nylon shroudlines
Anchors	¼" stainless steel U-bolts
Bulkheads (anchor hosts)	½" airfcraft plywood

Tie-rods	#8 stainless steel threaded rods
Tie-rod nuts	#8 brass knurled nuts
Electrical matches	M-tek, electrical current 0.3A no-fire, 0.7A all-fire
Terminal blocks	Nylon screw terminals

Table 10: Main components of recovery system

All components listed in the table above were recommended by our mentor and successfully tested on previous Madison West projects in NASA Student Launch program.

Electrical Schematics for Recovery System

The figure below shows fully redundant recovery electronics. Two fully independent circuits are used: primary and backup. Each circuit provides complete deployment functionality, including deployment of drogue and main parachutes. Each circuit has its own power source, external switch and set of ejection charges. The charges attached to the backup circuit are 25% larger than primary charges to provide additional deployment force should the primary deployment fail. If the primary deployment succeeds, the backup charges fire into open air, causing no damage.

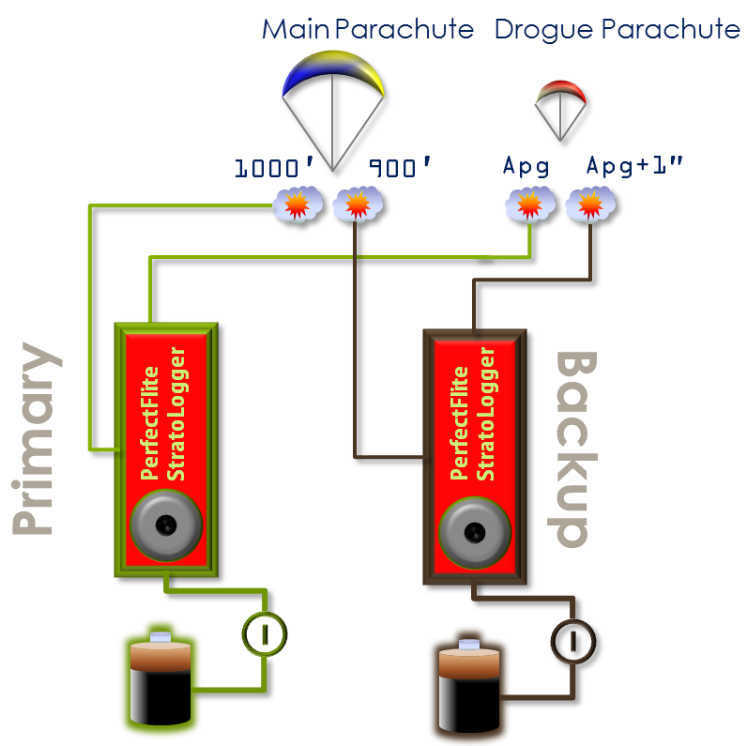

Figure 5: Recovery system electrical schematics (fully redundant deployment)

The following table shows drift estimates for wind speeds ranging from 0*mph* to 20*mph*. There are two components contributing to apparent drift (distance of the landing location from the launch pad). During ascent, the rocket travels upwind (against the wind) due to the weathercocking effect. After parachute deployment, the rocket travels downwind (drift). The distance from launch pad to the landing location is a sum of upwind travel (negative value) and downwind travel (positive value). The figure below illustrates this concept.

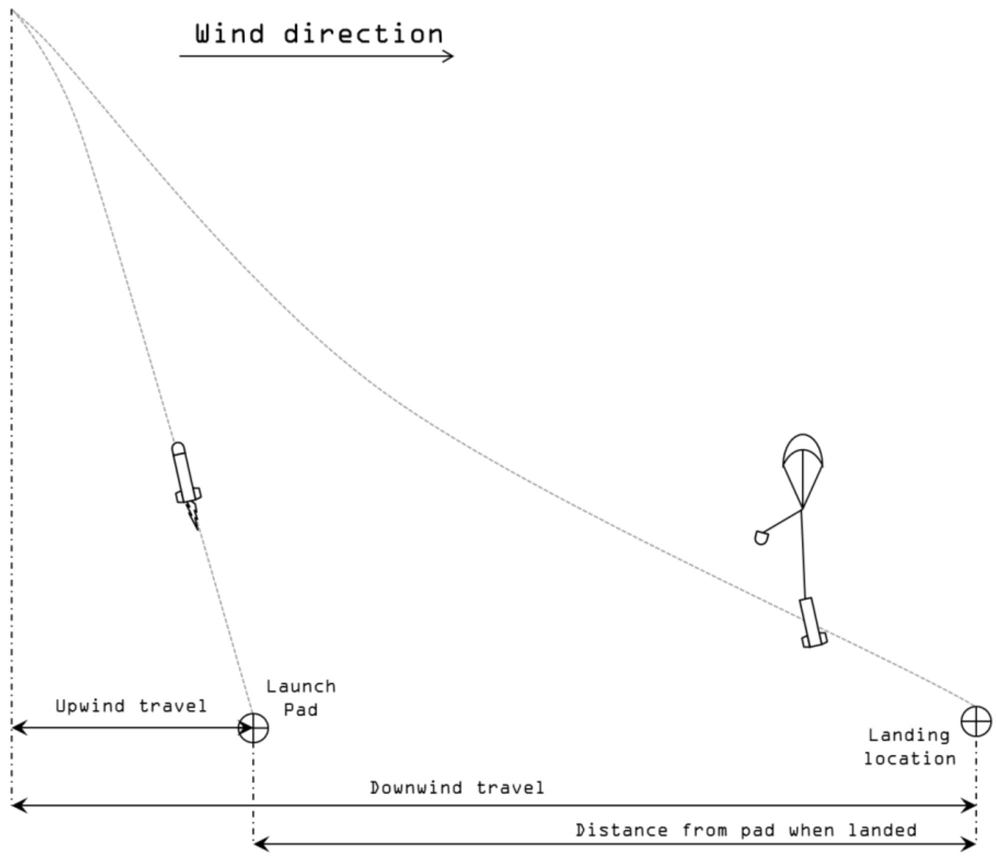

Figure 6: Drift calculations

We have calculated upwind and downwind components and the distance of landing location from the launch pad for wind speeds 0, 5, 10, 15 and 20mph. The upwind travel calculations are provided by OpenRocket software, assuming the 5^{o} downwind launch guide angle. The rocket will remain within the confines of the launch site even if the wind speed reaches 20*mph*.

Wind speed *[mph]*	Upwind Travel *[ft]*	Downwind Travel *[ft]*	Distance from pad when landed *[ft]*	Distance from pad when landed *[mile]*
0	25	0	25	0.005
5	1350	621	729	0.138
10	1550	1242	308	0.058
15	1700	1863	163	0.031
20	1750	2484	1234	0.234

Table 11: Estimated drift

Performance Predictions

We have used OpenRocket to carry out preliminary simulation of the proposed vehicle. The simulation results are discussed below.

Mission Performance Criteria

The delivery mission is successful if:

- Launch vehicle launches safely from AGSE
- Launch vehicle ascents in a stable manner
- Launch vehicle reaches but does not exceed target altitude of one mile
- Launch vehicle deploys drogue parachute at apogee and main parachute at 700*ft* AGL
- Launch vehicle lands safely and is reflyable on the same day

Altitude Profile

The graph below shows the simulated flight profile for the Cesaroni K530SS motor. The simulated vehicle reaches the apogee of 5246*ft* sixteen seconds after the ignition. For the purpose of this preliminary simulation the coefficient of drag is set to C_D = 0.7 (we have flown this type of vehicle during our prior SL projects and the collected flight data indicate that C_D = 0.7 a reasonable estimate of overall drag coefficient for a single diameter vehicle). The entire flight duration is estimated at 109*s* and the drift under 20*mph* wind conditions is 0.234*mi* (accounting for travel upwind due to weathercocking).

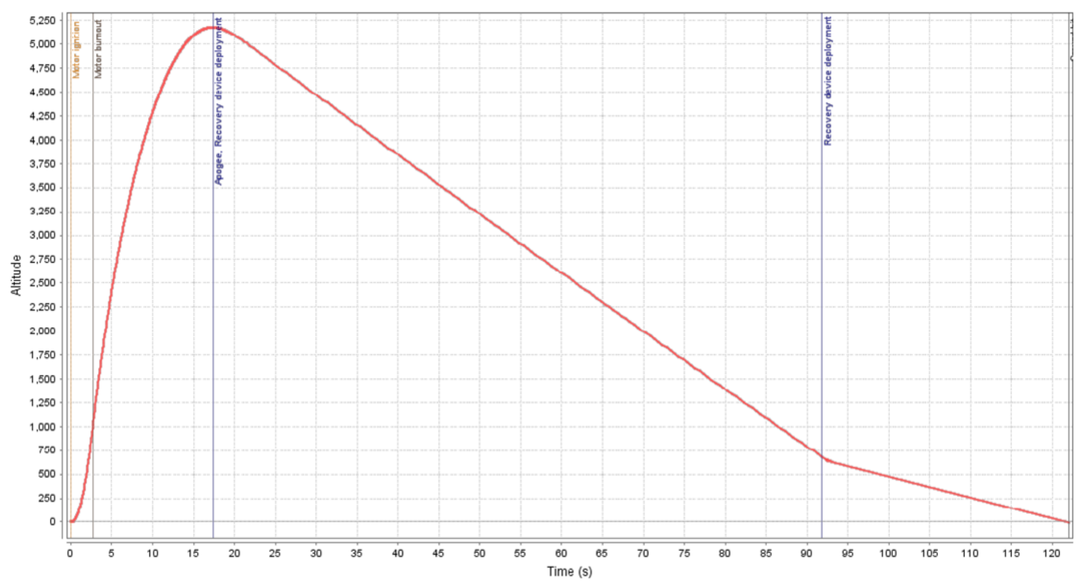

Figure 7: Simulated altitude profile for CTI-K530SS motor

The simulations indicate a small (less than 1%) undershoot of the target altitude (5,280*ft AGL),* however at this stage of the project we do not have enough information to decide whether this is a real issue or a simulation artifact. We will revise our simulations and make ballast decisions after we carry out both scale model and full scale vehicle test flights. Our final test flight before the SL launch will use the same motor as we will use for our flight in Huntsville to make sure that the rocket will not exceed the target altitude.

Wind Speed vs. Altitude

The effect of the wind speed on the apogee of the entire flight is investigated in the table below. Even under the worst possible conditions (wind speeds of 20*mph*, the NAR limit) the flight apogee will differ by less than 2.25% from the apogee reached in windless conditions.

Wind Speed *[mph]*	Altitude *[ft]*	Percent Change in Altitude
0	5247	0.00
5	5188	-1.12
10	5122	-2.38
15	5061	-3.53
20	5024	-4.23

Table 12: Flight apogee vs. wind speed

Thrust Profile

The graph below shows the thrust profile for the Cesaroni K530SS. The CTI K530SS motor reaches its maximum thrust of 596*N* after 0.05*s* and burns at approximately constant thrust level for about 2.5*s* (the average thrust-to-weight ratio is 9.8). The rocket requires a standard five-foot rail for sufficient stability on the pad and leaves the 5*ft* rail at about 41*mph*.

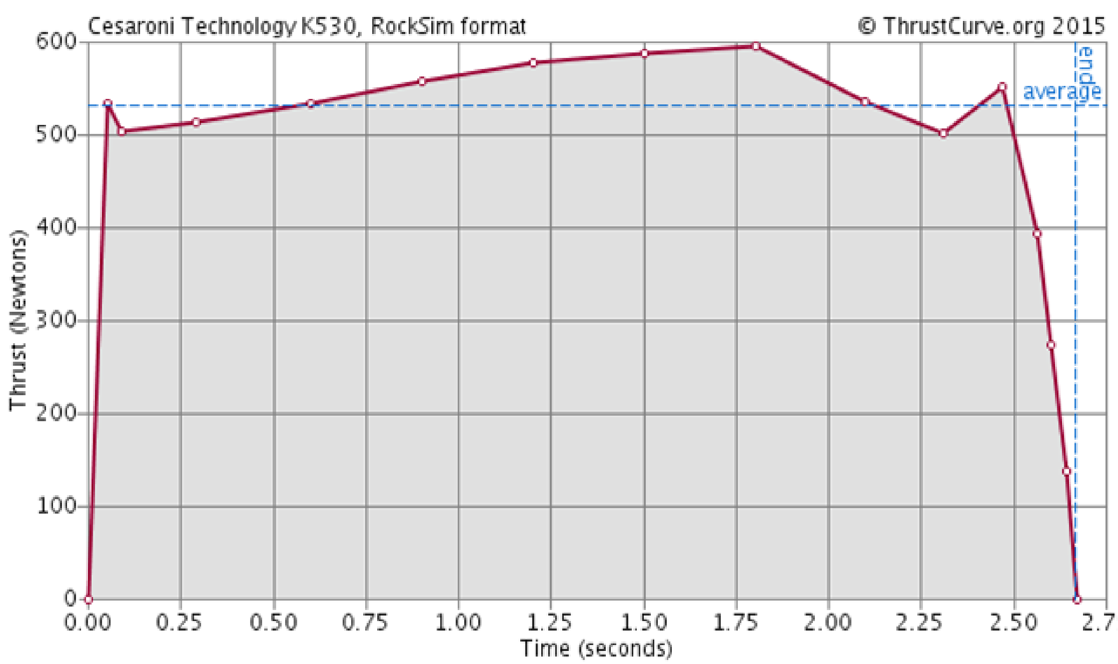

Figure 8: Thrust profile for CTI-K530SS motor

Velocity Profile

According to the velocity profile (next graph), the rocket will reach maximum velocity of 500 *ft/s* shortly before the burnout (2.7*s*). The rocket remains subsonic for the entire duration of its flight.

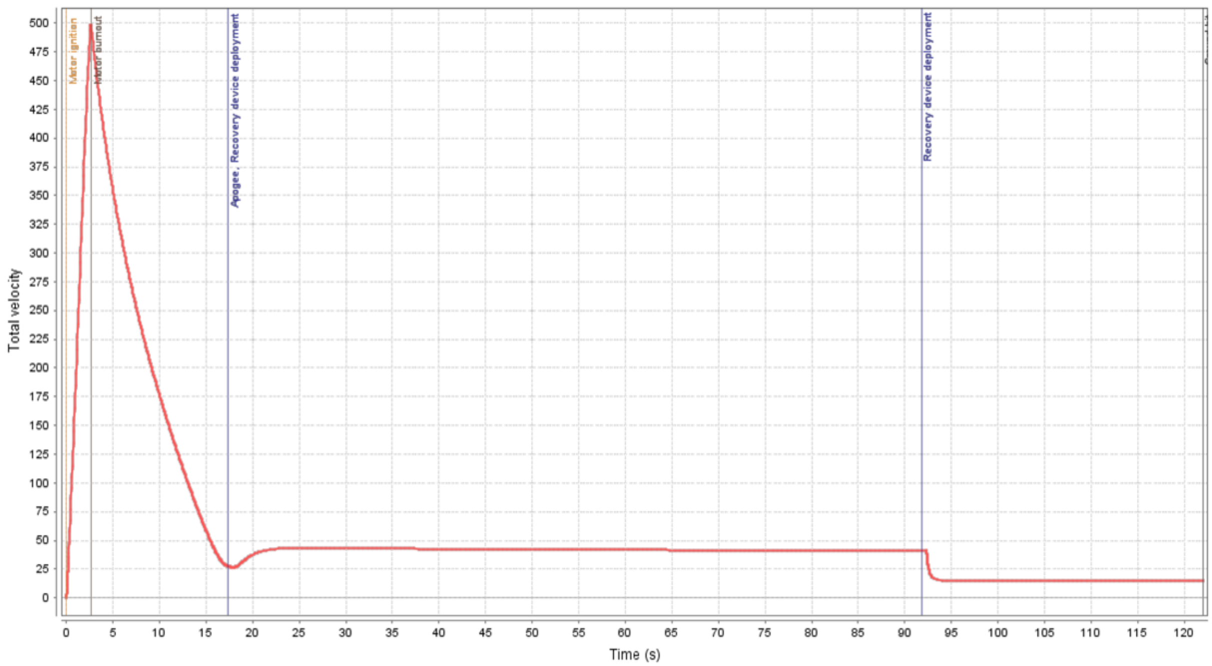

Figure 9: Velocity profile for CTI-K530SS motor

Acceleration Profile

The graph below shows that the rocket will experience maximum acceleration of about 10*g*. Our rocket will be robust enough to endure 25*g*+ acceleration shocks.

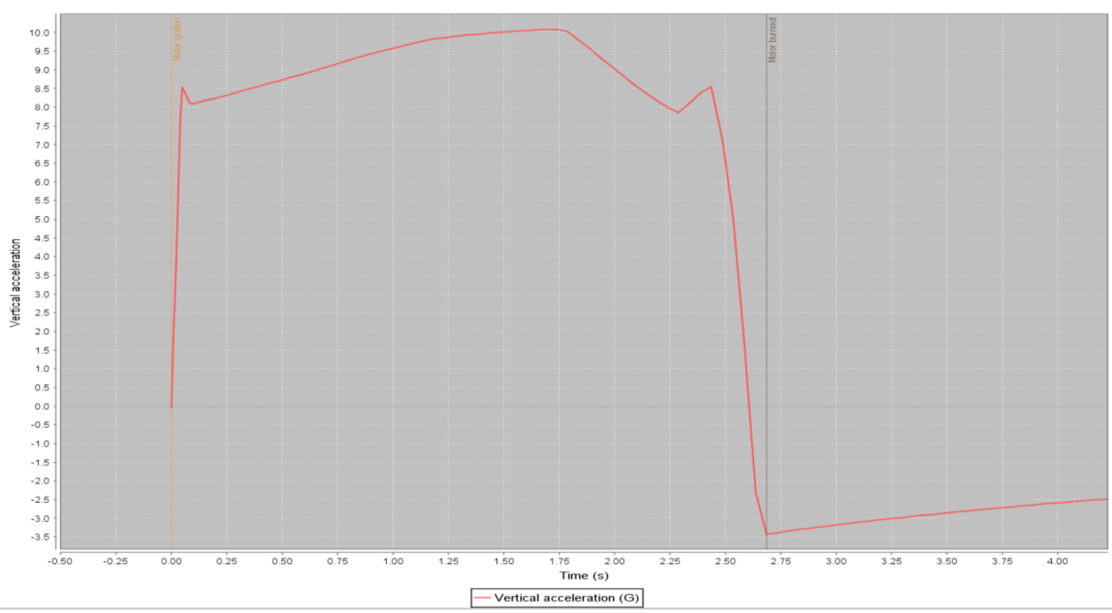

Figure 10: Acceleration profile for CTI-K530SS motor

Flight Sequence

The following figure and table describe the expected sequence of flight events. The motor burns out at 1200*ft* AGL and rocket will reach apogee in 17*s* after ignition. The drogue parachute is deployed at apogee and the rocket descent for 67*s* until reaching the main parachute deployment altitude of 700*ft*. The main parachute deploys at 700*ft* and the rocket lands approximately 109*s* after launch.

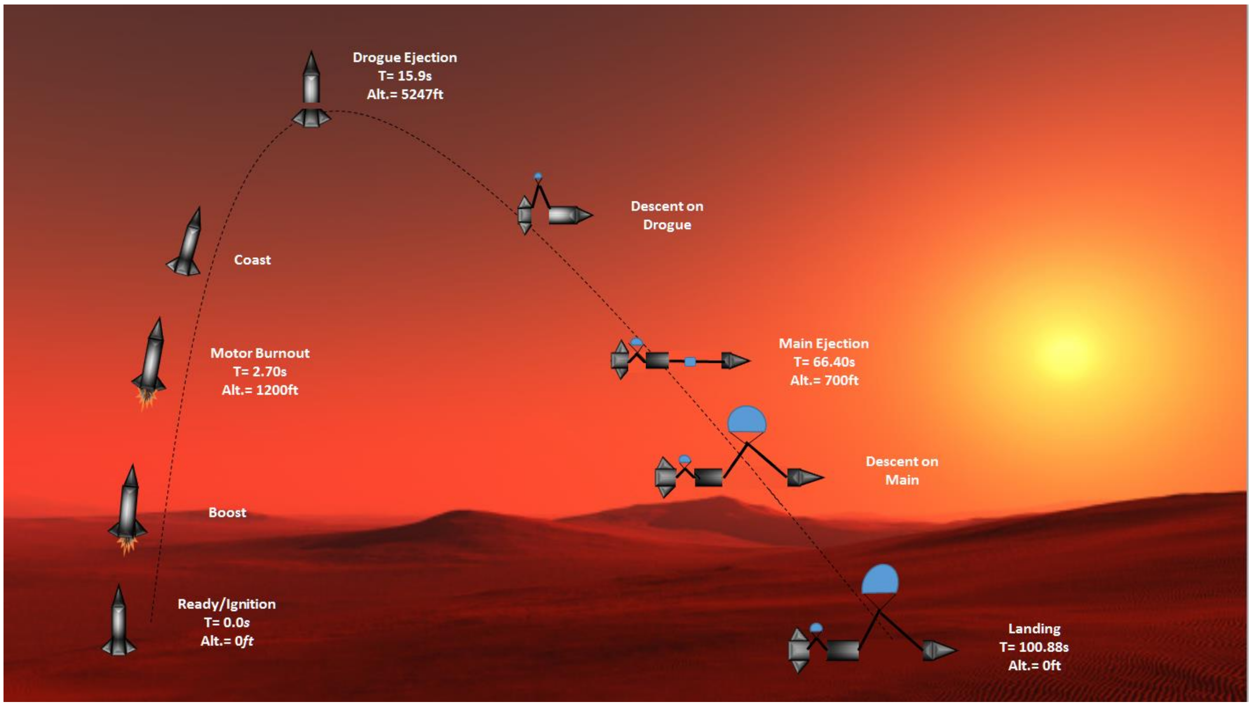

Figure 11: Mission Profile Chart

Event	Time *[s]*	Altitude *[ft]*
Ready	0.00	0
Ignition/Take-off	0.00	0
Motor Burnout	2.70	1200
Coast	2.570 to 15.90	1200 to Apogee
Drogue Ejection	15.90	5247
Descent on Drogue	15.90 to 66.40	5246 to 700
Main Ejection	66.40	700
Descent on Main	66.40 to 100.88	700 to 0
Landing	100.88	0

Table 13: Flight Events

Propulsion Selection

Based on the results of computer simulations we have selected CTI K530SS (54mm) motor as our primary propulsion choice. Our backup choices is AT K535 and CTI K671RR, both 54mm motors. Characteristic parameters for each motor are shown in the table below.

Motor	Diameter *[mm]*	Total Impulse *[Ns]*	Burn Time *[s]*	Stability Margin *[calibers]*	Thrust to weight ratio
CTI K530SS	54	1412	2.70	4.02	10.0
AT K535W	54	1429	2.80	4.03	11.2

Table 14: Motor selection, including backup choices

Interfaces

Interfaces and Integration

The payload is located in the booster section, above the motor and below both parachutes. The payload will be separated from the motor and parachute sections by plywood bulkheads. There are no electrical connections from payload to the rest of the rocket. The payload structural subsystem will be 3D printed and will fit perfectly (with no free play) inside the payload compartment in the rocket. Payload installation inside the rocket consists from payload insertion and securing of the bulkheads.

The only **internal interfaces** are electrical connections from deployment altimeters to ejection charges. These interfaces consist from terminal blocks mounted on the e-bay caps.

The **interfaces between launch vehicle and ground launch system** are rail buttons (for attachment of the rocket to launch rail). The rocket is fully autonomous and does not need any other interface.

The **interfaces between launch vehicle and ground** are radio beacons used for tracking the rocket and CAT (Cloud Aided Telemetry) system. Both interfaces are wireless.

Safety

Safety Officer

Safety officer for the team is William. He will supervised and tutored by the team's mentor, Mr. Brent Lillesand. The duties of safety officer are describe in the Project Requirements section, page 89.

Preliminary Checklists

Final Assembly

- Propulsion
  - ☑ Receive assembled motor from team's mentor
  - ☑ Insert motor to motor mount
  - ☑ Secure motor with retainer ring
  - ☑ Verify that the motor is secured and the retainer is tightened
- Drogue parachute
  - ☑ Using a QuickLink, attach drogue parachute to shockcord
  - ☑ Using the same QuickLink, attach Nomex sheet
  - ☑ Using a QuickLink, attach one end of shockcord to booster section anchor
  - ☑ Using a QuickLink, attach the other of shockcord to e-bay bottom anchor
  - ☑ Verify that parachute is 1/3 of shockcord length from e-bay and 2/3 of shockcord length from booster anchor
- Main parachute
  - ☑ Using a QuickLink, attach main parachute to shockcord
  - ☑ Using the same QuickLink, attach Nomex sheet (thermal protection)
  - ☑ Using a QuickLink, attach shockcord to e-bay top anchor
  - ☑ Using a QuickLink, attach shockcord to payload compartment bottom bulkhead anchor
  - ☑ Verify that that parachute is 2/3 of shockcord length from e-bay and 1/3 of shockcord length from payload bulkhead anchor
- Ejection charges
  - ☑ Receive assembled ejection charges from mentor
  - ☑ Put on goggles to protect eyes
  - ☑ Verify that all avionics is switched OFF
  - ☑ Attach primary drogue charge to terminal block marked D1 on bottom e-bay cap
  - ☑ Attach backup drogue charge to terminal block marked D2 on bottom e-bay cap
  - ☑ Attach primary main charge to terminal block marked M1 on top e-bay cap
  - ☑ Attach backup main charge to terminal block marked M2 on top e-bay cap
- Vehicle Assembly
  - ☑ Insert both drogue charges in the booster of the rocket, all the way to the motor top closure
  - ☑ Insert first 2/3 of drogue shockcord, neatly coiled, above the drogue charges
  - ☑ Pack the drogue parachute, wrap in Nomex sheet and insert above the bottom part of the shockcord
  - ☑ Neatly coil the remaining shockcord and insert on top of the parachute
  - ☑ Insert e-bay to booster section
  - ☑ Install booster section shear pins

- ☑ Insert both main charges all the way under the payload bay bulkhead
- ☑ Insert top 1/3 of main shockcord, neatly coiled, under main ejection charges
- ☑ Fold the main parachute, wrap in Nomex sheet and insert under the top part of the shockcord
- ☑ Neatly coil the remainin shockcord and insert under the main parachute
- ☑ Insert e-bay into the top portion of the launch vehicle
- ☑ Install top shear pins

Launch Procedure

- ❖ Payload loading
  - ☑ Verify the AGSE is OFF
  - ☑ Install rocket on the launch rail and verify that it is secure
  - ☑ Open the payload door
  - ☑ Put payload in starting position
  - ☑ Upon instruction from NASA, activate AGSE
  - ☑ Wait until the AGSE completes payload loading, launch rail erection and igniter insertion
  - ☑ Visually verify that the AGSE is in launch capable position
- ❖ Avionics check
  - ☑ Using external switch, activate primary altimeter
  - ☑ Verify drogue and main parachute deployment setting (reported by altimeter beeps)
  - ☑ Verify continuity of ejection charges (reported by altimeter beeps)
  - ☑ Switch primary altimeter OFF
  - ☑ Using external switch, activate secondary altimeter
  - ☑ Verify drogue and main parachute deployment setting (reported by altimeter beeps)
  - ☑ Verify continuity of ejection charges (reported by altimeter beeps)
  - ☑ Switch primary altimeter ON and allow it to complete its boot procedure
- ❖ Igniter continuity check
  - ☑ Notify the team mentor that the rocket is ready
  - ☑ Mentor will connect the igniter to alligator clips
  - ☑ Mentor or launch official will verify the continuity of the igniter
- ❖ Rocket Launch
  - ☑ All team members will retire to safe distance from the launch pad
  - ☑ Launch official will execute final countdown and launch the rocket
  - ☑ In event of misfire, the team will wait at least one minute and upon instruction from launch official the mentor will approach the rocket for connection check and igniter replacement
- ❖ Landing
  - ☑ After the rocket lands, the mentor will approach the rocket to switch avionics OFF and to remove all ejection charges that might have fail to fire during flight.
  - ☑ Team can now approach the rocket for postflight inspection

Preliminary Hazard Analysis

The table below shows the preliminary hazard analysis. Additionally, the following codes are observed to ensure safety all of participants:

- NAR Model Rocket Safety Code, http://www.nar.org/safety-information/model-rocket-safety-code/
- NAR High Power Rocket Safety Code, http://www.nar.org/safety-information/high-power-rocket-safety-code/
- FAR 14CFR F/101/C, http://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title14/14tab_02.tpl
- NFPA 1127 Code for High Power Rocket Motors, http://www.nfpa.org/codes-and-standards/document-information-pages?mode=code&code=1127

We maintain a collection of project related MSD sheets online to allow for easy access. A printed version of this collections is kept in the workshop.

MSDS COLLECTION: http://westrocketry.com/sli2016/safety/safety2016r.php

Hazard	Mitigation	Likelihood	Severity
Workshop tools and machinery hazards	Personal Protective Equipment (PPE) will be used at all times in the workshop. All students will be periodically briefed on workshop safety procedures and supervised by adults at all times. First aid kit is on-hand.	**LOW**	**MEDIUM**
Dangerous substance hazards	MSD sheets are required for all chemicals use during the project. Appropriate protective equipment must be used when working with hazardous substances. Students will be supervised by adults at all times.	**LOW**	**HIGH**
Payload integration failure	Team will verify before every launch that the payload fits into payload compartment and that the payload door closes without any misalignment.	**LOW**	**HIGH**
Vehicle assembly failure	The day before every launch the team will run through complete vehicle assembly procedure, using a checklist, to verify that there are no problems that would prevent vehicle from being assembled into launch ready state.	**LOW**	**HIGH**
Missed procedure	Checklist will be used for all vehicle related operations and two members will run the same checklist in parallel. Mentor will provide additional	**MEDIUM**	**HIGH**

	checklist run after all operations were completed.		
Missed attachment	Checklist will be used to make sure that no attachment point was missed. After vehicle assembly mentor will go over the list of attachment points and verify that there all attachment points were addressed.	**MEDIUM**	**HIGH**
AGSE structural failure	AGSE will be inspected prior to every launch, both the night before and at the launch site.	**LOW**	**HIGH**
Unexpected ejection charge activation	Personal protective equipment will used at all times when handling the ejection charges. Mentor will be the only person handling ejection charges. Avionics will be only activated after the rocket has been placed into launch position.	**LOW**	**HIGH**
Unexpected motor ignition	Personal protective equipment will used at all times when handling motors. Mentor will be the only person handling motors. Motor nozzle will be always pointing away from people and the igniter will not be inserted until the rocket is in the launch position and the avionics has been activated.	**LOW**	**HIGH**
Electrical shock	Only properly insulated cables will be used. The ignition circuit will be activated only after the rocket is fully ready for launch and all connections have been made.	**LOW**	**HIGH**
Avionics powerup failure	Avionics batteries will be checked prior every launch and a fresh set of batteries will be used for each launch.	**LOW**	**HIGH**
Misfire	Alligator clips will be cleaned periodically and igniters will be expected before insertion into motor.	**MEDIUM**	**LOW**
Rail bite (poor takeoff)	Rail button alignment and launch rail condition will be checked prior every launch. The rail will be dry-lubricated and periodically cleaned.	**MEDIUM**	**MEDIUM**
Motor catastrophic failure	Only commercially produced motors will be used. Mentor will assure the proper assembly of the motor. All launches will be made from the safe	**LOW**	**HIGH**

	distance, as required by NAR HPR safety code.		
Deployment failure	Ejection charge connections will be checked prior each launch, using the altimeters continuity reports. Fully redundant deployment system will be used for all flights. Ejection charge sizes will be verified by static testing.	**LOW**	**HIGH**
Recovery system failure	Shockcords, Nomex protectors, attachment points and parachutes will be inspected prior each flight.	**LOW**	**HIGH**
Landing with live ejection charge	Ejection charge connections will be checked prior each launch, using the altimeters continuity reports. Mentor will be the first person to approach the rocket after landing to verify that all charges were fired or to safely remove remaining live charges. Mentor will wear PPE while inspecting rocket after landing.	**LOW**	**HIGH**
Landing in inaccessible location	Wind direction and weather conditions will be evaluated prior each launch. The minimum launch size distance will (according to NAR safety code) will be observed. The drift assessment will be made prior each launch to estimate the landing zone. NAR safety code regulations for rocket landed in inaccessible location will be strictly adhered to.	**MEDIUM**	**HIGH**

Table 15: Hazard analysis

Environmental Concerns

The vehicle will be built from inert materials which can last for long time in natural environment. Vehicle will not contain any chemicals that could quickly leach into environment and cause immediate problems, however all efforts will be made to recover the vehicle after each launch and leave no traces of our activities at the launch location. We are using attached Nomex sheets for thermal protection of parachutes (instead of wadding material that would be expelled into environment).The exhaust from rocket motor has not been identified as environmental concern by Department of Natural Resources in Wisconsin. We will follow all federal, state and local regulations for use of a given launch site (we mostly launch at dedicated launch site in Bong Recreation Area, Kansasville, WI or agricultural fields in Princeton, IL).

Payload and AGSE

Per section 3 of the requirements for non-academic teams, we choose payload Task 2, Centennial Challenge, option 3.1.8. The technical design for this task is discussed below.

Overall approach

The Maxi-MAV solution must not only address the core technical challenge but also the associated limitations associated with a very limited timeline and project budget. We plan to tackle all three of these aspects by maximizing the use of commercial-off-the-shelf (COTS) components and subsystems as much as possible and ensuring that the engineering team addresses the core requirements only, without allowing "scope creep" of additional features that are not required in the NASA specification. The focus of this document is to address SoW §3.3.3.1 although we necessarily refer to the launch vehicle in relation to the payload compartment and securing of the payload within the vehicle.

To this end, we divide the challenge into the following pieces:

- Vehicle design to meet payload, size, altitude, and landing requirements
- Payload compartment design including securing the payload and ensuring rocket integrity (door closure/sealing)
- Overall superstructure to support the vehicle and associated robotic elements, meeting envelope and mass requirements
- Payload acquisition, manipulation, and insertion
- Launch rail erection and securing
- Igniter insertion
- Autonomous control of subsystem, user interface, power control/management
- Safety (of motion control system, launch vehicle, as well as all materials used and electrical systems)

Each of these aspects can be separately developed, tested and proven by members or groups of members of the entire team before fully integrating all aspects. The subgroups are cross-functional and use modern cloud-based communication tools (e.g. Trello, Dropbox, Slack) to ensure that the subsystem developments are done in seamless concert with the overall goals of the system and avoid the pitfalls of silo-ing individual aspects of the development.

By selecting primarily commercially-available subsystems and materials, the focus of the engineering work can be upon seamless integration of the various subsystems via mechanical design of the superstructure, adapters to mate commercial items, and programming the microcontroller. We anticipate the bulk of the engineering effort to be mechanical and electrical integration, code development and debugging, and the mechanical design of a few key components needed to mate the various subsystems together reliably

Extensive testing both during development and of the completed system under a variety of conditions and initial payload placements will reinforce both the safety and efficacy of the system.

Payload compartment design

This subsection describes how the vehicle payload compartment will meet §3.3.5.1-.3 of the MAV statement of work and complies with the dimensions, mass, and other specified design aspects of the payload.

In addition to the explicit NASA-defined requirements, the payload compartment design must also address additional derived requirements:

- Balance the forces of inserting/retaining the payload against the force that the robotic arm and end effector (robotic gripper mechanism used to hold payload) are capable of sustaining
- Balance the force required to hold the door closed against the force allowed to be placed on the rocket
- Have an overall design methodology that is highly tolerant of placement error of the payload initial location, placement error owing to tolerances from the arm and end effector, and tolerant of the placement of the rocket on the launch rail, as well as potential variation from payload to payload.

To that end we intend to address the payload retention with a straightforward spring-based design. An early concept rendering is shown in Figure 12 below.

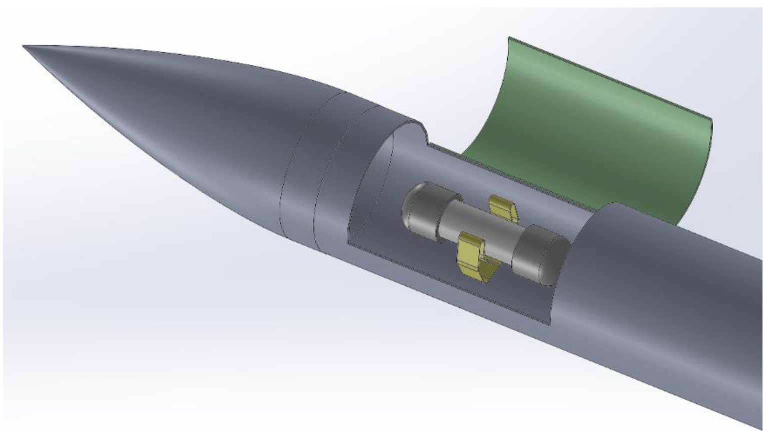

Figure 12. Detail showing 3D concept of payload retention in vehicle bay (foam and over-sprung mechanism not shown).

For ease of access by the end effector, we anticipate the door consuming 150° of the circumference of the rocket. With all-fiberglass construction, and minimal mass in the nosecone forward of the payload compartment, we anticipate that the walls of non-door portion of the rocket will have sufficient strength to support launch forces despite the inherent structural weakness induced by the large door opening. In addition, we plan to use the inner coupling section of the nose cone to support the forward end of the door section and a section of coupler tube to support the aft end of the door while closed. Figure 13 below calls out some of the key elements of this retention/enclosure design.

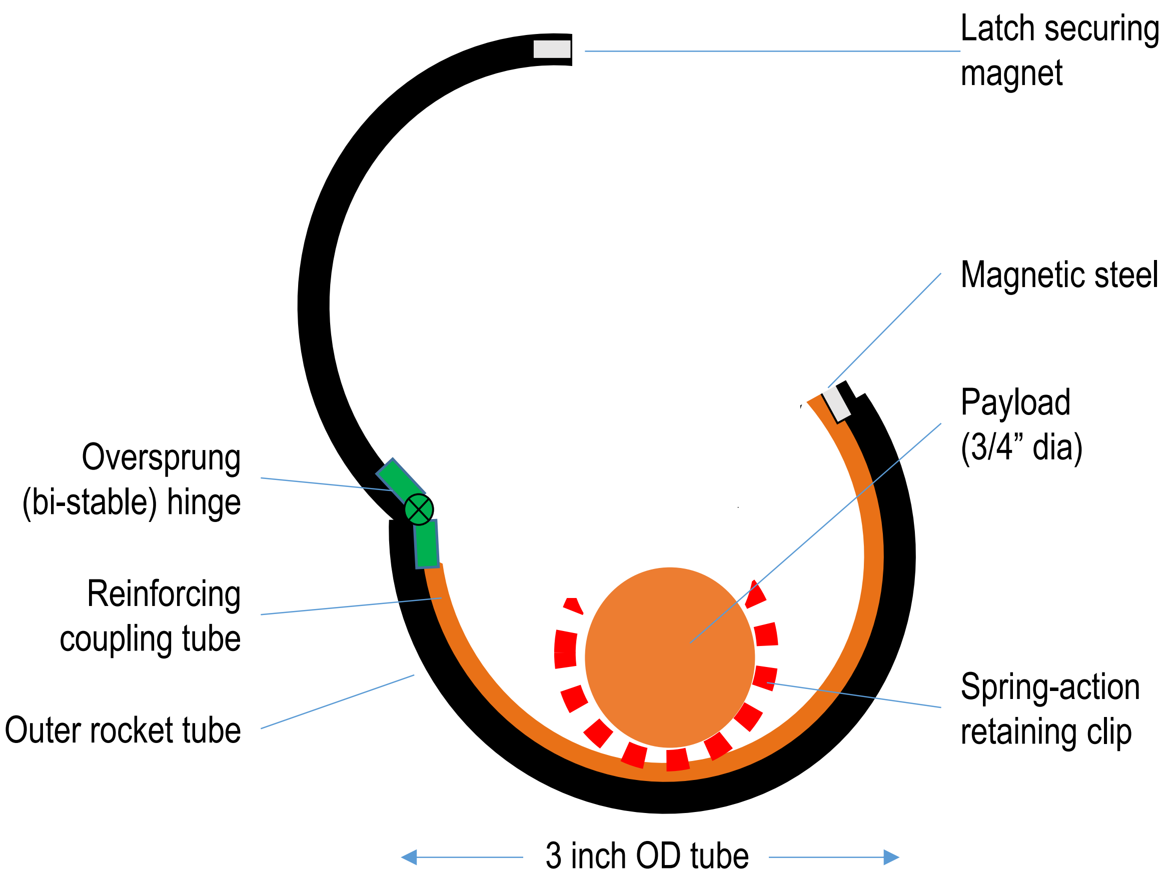

Figure 13. Cross-sectional schematic of payload retention and payload door closing/securing features.

The strength of the rocket tube will be maintained despite the door cut-out with the following design aspects:

> The compartment will span only 150° of the circumference, which will improve stiffness of the rocket body in the cut-out section.
>
> A fiberglass coupler tube with a rectangular cutout smaller than the payload door which will act as (a) a seat for the door when it's closed (b) a means to mount the magnets securely (c) a strengthening member where the tube is the weakest.

The payload compartment is something that will be tested in the scale model launches and will include all of the key features, scaled appropriately (door length and subtended arc, reinforcing coupler, struts, same epoxy, etc.)

The payload door will be hinged with an integral over-sprung mechanism, making it bistable (i.e., equally stable in the open or closed position). This aspect serves two key functions: ensuring that the door works well without the aid of gravity, and lowers the tolerances required by the robot arm and gripper in the process of the closing the door.

We will use the bistable hinge used in hard-shell glasses case; these are roughly 6 inches long and will open to about 100° and can close to 180° opening angle. We have already acquired these from donations and thrift shops, and the hinge is “harvested” from the case by removing fabric and removing the retaining metal flaps. It will be bonded to side of rocket tube with high-strength epoxy; holes in hinge provide plenty of bonding surface area. (Care will be taken not to get epoxy on moving part of hinge.)

Because we are using a 3" tube, great care will need to be taken with alignment of the launch buttons since the door, while open, may come close to the payload gripper.

The payload area will be reinforced with a coupling tube, cut to a slightly smaller rectangular hole, and aligned with the other open hole, to provide additional strength. In addition, we have determined that the door cut-out needs only to be 150° rather than a full 180° of the perimeter of the rocket, significantly improving the tube strength in that section.

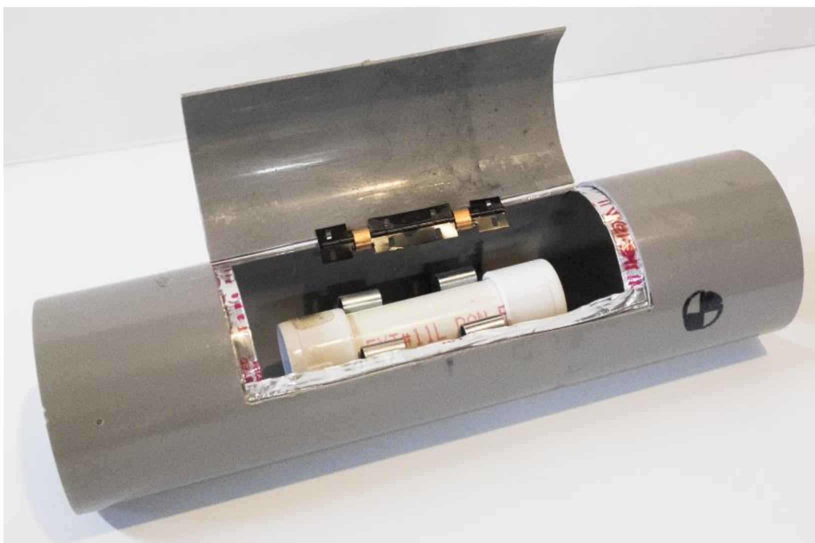

Figure 14. Image of pre-prototype showing key aspects of rectangular door, bistable hinge, retaining clips, metal strengthening seal (concept).

The spring force is sufficient to hold the lightweight door in the open or closed position, but will not be sufficient to secure it closed for launch. A dual magnetic and spring latch mechanism will secure the door closed for launch, with magnets on both the door and vehicle body (not pictured).

We will use a linear electric actuator attached to the AGSE frame to initiate the closing movement of the payload hatch. After the hatch passes its stable point, the bistable hinge will close it the rest of the way.

The bistable spring from the glasses case provides all of the force required to close the door, but given the forces that the rocket will endure during flight and the mass of the door, we decided to add magnets to secure the door once it is in the closed position.

Small, high-strength magnets are readily available and inexpensive. A simple magnetic steel shim can be used as the opposite pole since there is no holding force benefit to using magnets on both sides.

We plan to use three of the following magnets, described below. The pull force of each magnet should exceed 4.5 lbs once the door is closed, so 3 magnets will effect nearly 15 pounds of force retaining the door.

- Dimensions: 1" x 1/8" x 1/8" thick (±.004 in tolerance)
- Material: NdFeB, Grade N42
- Plating/Coating: Ni-Cu-Ni (Nickel)
- Magnetization Direction: Thru Thickness
- Weight: 1.92 g
- Pull Force, Case 1: 4.80 lbs
- $0.74 per magnet in small quantities

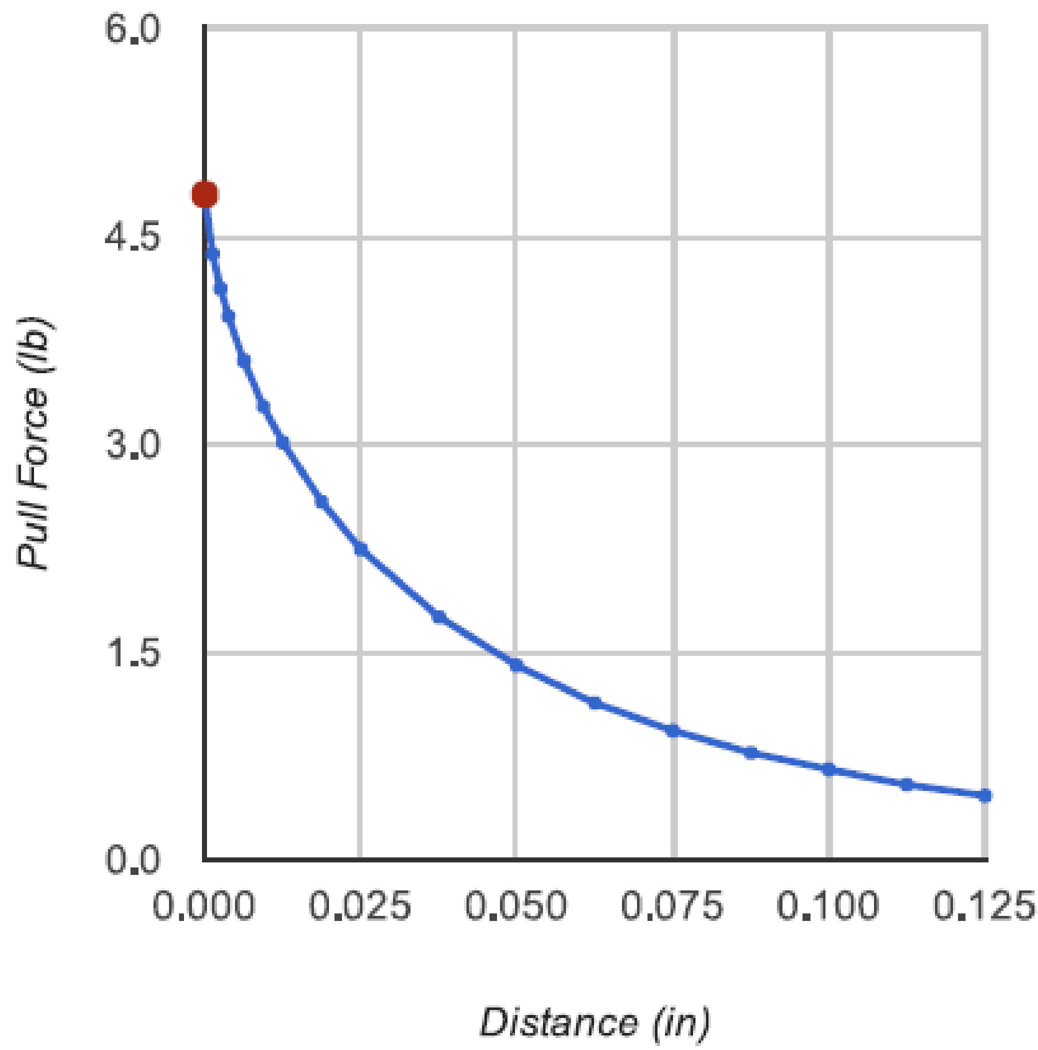

Figure 15. Pull force of single magnet to steel plate versus distance.

AGSE Superstructure

We anticipate using an all-aluminum bolted structure both to save mass and to enable ease of assembly and breakdown for travel to the launch and demonstration locations. Modular framing such as “80/20” has the appropriate strength-to-weight characteristics, cost, and modular aspects for this design. The team has several years of experience designing a variety of launch platforms with sufficient robustness for high power rockets of Level 1 (H-I class) and Level 2 (J-L class).

A concept rendering of the superstructure (sans motion stages, rocket, or control electronics), is shown in Figure 16 below. It is shown in the horizontal “loading” position, ready for the launch vehicle to be installed on the rail (§3.3.2.1.1).

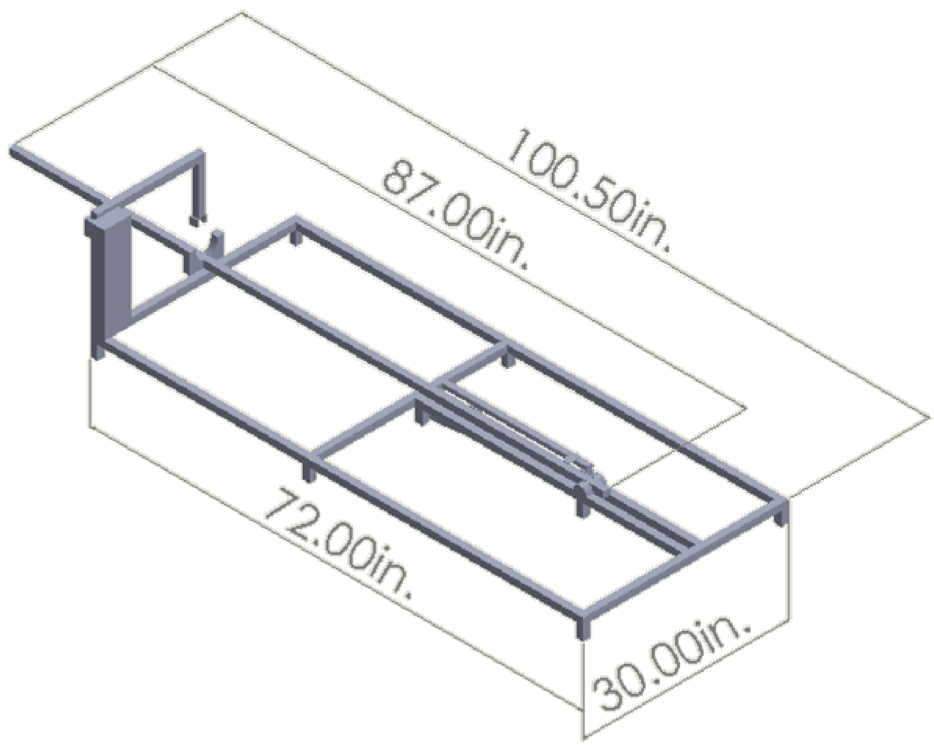

Figure 16. Concept rendering of AGSE superstructure in horizontal payload-loading configuration. The structure is 8.4 ft x 6 ft x 2.5 ft in the horizontal configuration. Concepts for payload manipulator robot arm and body tube stabilizer are shown. Linear actuator erection system, controller, blast shield, and details such as mounting brackets are not shown here.

The structure provides a reference point for the motion control elements: payload pickup and insertion, launch rail erection, and igniter insertion. Each of these tasks dictates a unique design element of the proposed superstructure.

The igniter insertion approach (detailed below) necessitates a launch platform that is approximately 45 cm (18 inches) above ground level. The requirement that the payload sit on the ground, at least 30 cm (12 inches) outside the AGSE envelope provides another constraint on the platform (SoW §3.3.5.4). The inherent benefit of short throw arms (which reduces torque and motor mass) for payload manipulation suggests an approach that places the payload compartment of the rocket as near to the ground as possible.

The concept image shown above illustrates some of the elements of the superstructure. Some of key aspects are:

- Use of lightweight modular “80/20” aluminum extrusions with low-cost off-the-shelf connecting mechanisms. Reinforcing triangular cross-bracing is used as necessary to provide strength against launch forces and torque during rail erection. A long extrusion is used as the guide rail for the launch vehicle.
- A small extension attached to the main superstructure will hold the payload insertion arm and end effector. This same extension will also have a “nest” to support the launch vehicle during payload insertion and prevent those forces from being entirely supported by the launch rail and rail buttons.
- An aluminum sheet blast shield. This is securely fixed to the launch rail with a hole for ignitor insertion. The shield provides sufficient area to protect the linear actuator for ignitor insertion and any associated micro switches and other gear near the blast area. Some customization or venting of the blast exhaust may be considered after completion of the detailed design.

The superstructure defines the overall envelope of the AGSE and in its current concept form, with the rocket and launch rail either in loading or launch configuration, falls well below the required dimensions specified in §3.3.3.3 of the SoW.

Body Tube Stabilizer

To ensure the rocket is both stable and does not experience untoward forces on the delicate rail launch buttons, a small plastic saddle will provide additional support to the rocket while it is in the pay-loading horizontal position. The body tube stabilizer will be a near half-circumference plastic tray affixed to the fixed lower portion of the AGSE superstructure. The launch rail will sit between the "halves" of the body tube stabilizer and support the outer diameter of the rocket only while the payload is being inserted and the door is being closed.

Its position and shape will serve to relieve stress on the launch buttons, prevent the rocket from rocking from side to side, and locate the rocket axially to reduce the variation in tolerances for payload insertion and alignment with our passive system.

The body tube stabilizer is a fixed plastic piece with loose tolerances and low strength requirements and thus likely can be rapid-prototyped at low cost directly in our workshop.

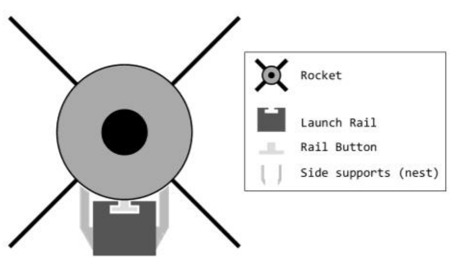

Figure 17. Body tube stabilizer (“saddle”).

Figure 17 shows how the rocket will restrained from roll motion when in horizontal position. This is important to protect the rail buttons and rail from damage, should the rocket roll to the side.

Payload transport and insertion

Concept and inspiration

Our approach to these tasks is to minimize the complexity of the motion control by (1) actively guiding the location of the initial payload placement and (2) maximizing the tolerances of the payload bay and capture mechanism. This allows for passive, non-guided motion control while ensuring that the payload is securely placed using positive latching mechanisms. Feedback from the motion control system's encoders as well as embedded switches ensure that every aspect of the payload grabbing and insertion complete correctly before proceeding to the next step.

During the PDR phase we carefully examined several of the commercially available off-the-shelf low-cost hobbyist robots that appeared to meet the specification requirements including reach, load capacity, cost, weight, and integration. The field of options meeting both cost and weight requirements limits the field considerably, despite there being a great deal of commercial activity in this area.

Robots that could meet our requirements fell into two rough classes: (a) fully capable of meeting the specifications for reach and payload mass (net torque) but utterly failing in total robot mass and robot cost, or (b) meeting the robot mass and cost requirements, but failing to meet the reach and payload mass (net torque) requirements.

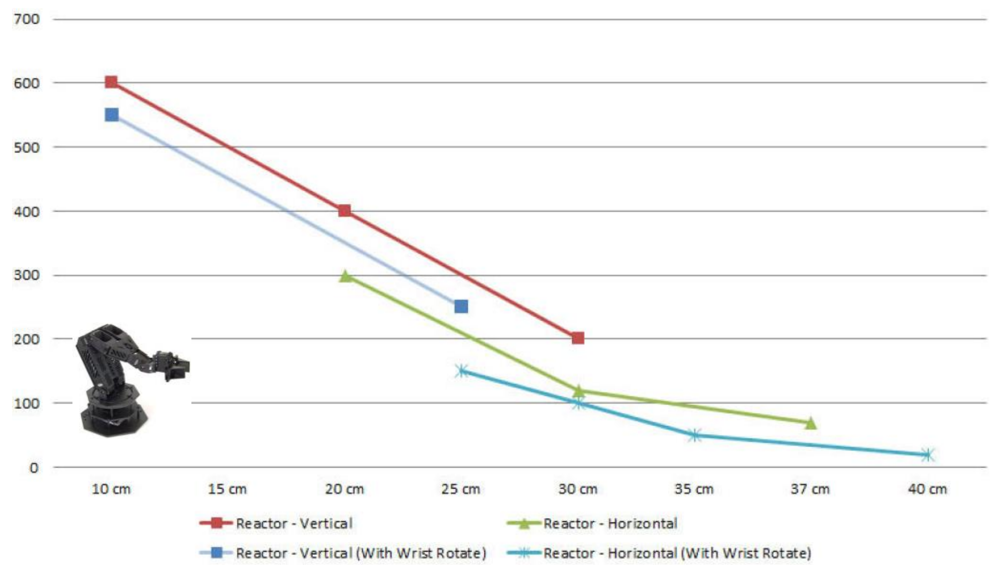

Figure 18. Strength (in grams) versus arm reach analysis of commercially available 5-axis hobbyist-class robot arm.

In particular, the robot put forward in the proposal just barely meets the reach and mass capabilities, with no margin for reach length or forces beyond the mass of the payload itself. We considered "post-purchase upgrades" to motors with more torque but this examination, along with a full mass/torque analysis for any type of multi-jointed arm emphasized the challenge of the competing parameters of motor mass, arm length, and motor torque capability for a flexible, multi-axis robot arm of this type.

Ultimately, along with several other design explorations, this analysis led us to consider a simplified SCARA (Selective Compliance Assembly Robotic Arm) robot. SCARA robots are widely used in industrial automation for placement of items on industrial conveyor-belt lines, semiconductor industry, and adhesive dispensing/assembly. One example is shown below, with the typical 4 axes (two rotary to move the arm into location, one vertical to move the end effector up and down, and a 4th rotary that moves the end effector in a circular fashion.)

Figure 19. Example of industrial SCARA robot.

What we proposed for the AGSE is a simplified version with only two axes: a single rotary motor, rotor vertical, placed ~18 inches from rocket center axis, riding on a vertically-mounted linear travel stage.

Payload placement

To ensure the design requirement §3.3.5.4 of the MAV SoW is met, we intend to use laser triangulation to reinforce the proper location of the payload for pickup by the AGSE. (This aspect is not shown in concept rendering of the AGSE). This will use a widely available commodity structured laser light diffuser commonly used in drill presses and cutoff saws to place a laser "+" for payload placement prior to autonomous loading. This should ensure that the payload is within approximately ±0.5 cm (±0.2 in) of the required location and ensures that the payload sits fully beyond the 12 inch requirement.

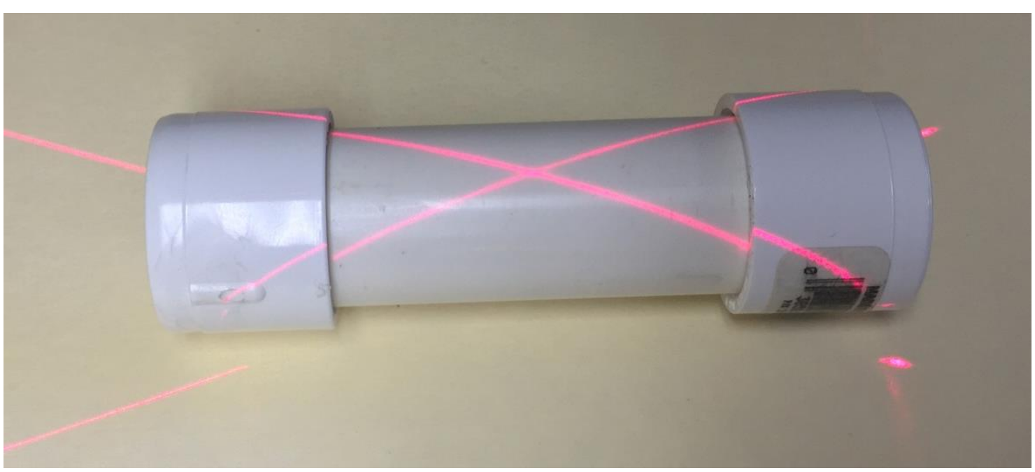

Figure 20. Photograph showing "pre-prototype" of household drill press with laser line projectors on dummy payload.

In Figure 20 above we show a photograph of a common laser line pair projector from a home workshop drill press showing the projected laser line image on the payload. This was photographed under ambient fluorescent lighting and demonstrates viability of the concept in the following ways:

- Laser line is clearly visible on white PVC payload under wide range of lighting conditions
- Projected line pair from unmodified subassembly has dimensions and crosshair angle that are compatible with the payload overall size.
- Placing payload outsize of projected laser zone is clearly obvious as being out of place laterally and having the wrong payload positioning angle.

The photograph below shows a low-cost, consumer-grade proposed laser line pair projection part that is readily available. It is important to note that another benefit of purchasing a consumer-grade item is that the lasers are eye-safe and fully compliant with FDA requirements. The module is self-contained, battery powered, and thus does not necessarily need to be integrated with the rest of the control system (but could be by wiring through the supplied on/off rocker switch).

Figure 21. Drill-press laser line projector pair (e.g. Craftsman p/n 089140301162)

Arm

In our efforts we did discover one hobbyist-class 3-axis SCARA robot that actually appears to meet our requirements on paper for reach, load capacity, and budget. Called the "Makerarm," this is a Kickstarter-funded effort that will not deliver their devices until October 2016. Below is an image of their prototype:

Figure 22. Prototype image of "Makerarm," a Kickstarter effort not shipping until October of 2016.

Even if this device were available for purchase in the time schedule of the SLI/MAV program, it would still need considerable effort to integrate mechanically with the AGSE superstructure, integrate our end effector, and interface with the high-level electrical interface and software controls. It does however, validate by example, our revised approach to payload transport described below.

We plan to use a commercial linear stage for the vertical motion, mounted to the AGSE with a fixed metal bracket. This vertical linear travel stage would have the required 8-10 inches of travel and possess a small pre-load since it will be operated vertically. The advantage here is that it can be acquired as a complete solution commercially for reasonable cost and the stage mass is less of a consideration.

A rotary stepper motor is mounted to the vertical travel stage, keeping all of the mass of this mechanism concentrated on the AGSE superstructure rather than cantilevered. The central rotary stepper motor moves an arm, approximately 18" long. The motor is operated in a common microstep configuration, providing sufficient angular resolution despite the roughly 18-inch radius of swing.

The passive gripper and arm may be made from lightweight aluminum and/or fiberglass. The cantilevered mass of this solution is considerably lower, reducing the requirements on the rotary motor, only adding to the load of the vertical linear stage.

Before the automatic cycle starts, the arm is swung inward, parallel the long axis of the AGSE (parallel to the rocket), maintaining the slim envelope of the AGSE.

The 18" swing arm will be fabricated from aluminum or possibly fiberglass struts or be a machined part. The arm is sufficiently long to meet the 12 inch envelope requirement yet short enough to use commonly available motors and materials and low-cost construction methods.

The stepper motor fits within the project budget but has sufficient lateral load capability that we anticipate it can be used directly without a separate rotary bearing to support the mass of the arm and outboard actuator. De-risking plans for this could be to include a counter-balance mass (changing lateral force to pure axial force on the motor shaft). An alternative would be to use a simple fixed bearing affixed to the AGSE superstructure plus a shaft coupler. Both add a small amount of mass and cost but reduce the stress on the motor housing.

Payload motion

In the payload acquisition (extended) position, the gripper sits over the payload. The controller actuates the linear stage downward, pushing the gripper on to the payload, securing it in the clamp. The "gripper" we propose to use is a passive spring clip nearly identical to that used to secure the payload in the launch vehicle. It is modified to reduce the spring force to be just sufficient to securely contain the payload mass during pick-up and transport.

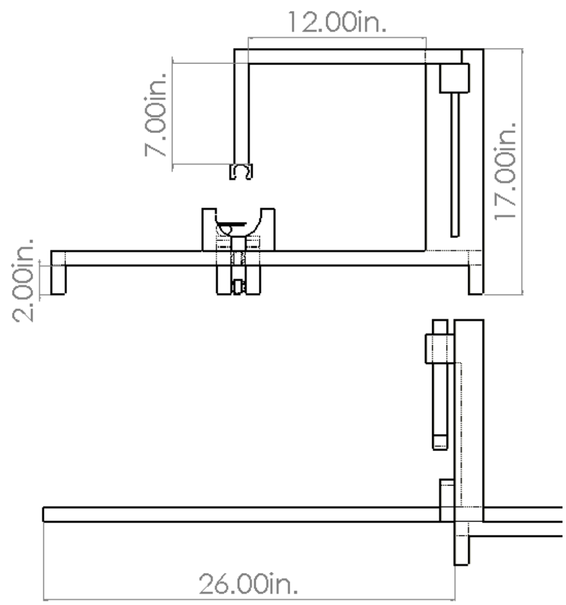

Figure 23. Scaled schematic views of the proposed payload transport and insertion system (top: end view showing rocket stabilizing saddle; bottom: side view showing launch rail across middle).

The downward force will be just a pound or two to overcome the passive retainer clip. The upward force required is the payload plus friction and the force required by the passive gripper, just a few pounds.

Once the payload is secured, we raise the vertical stage, then rotate the main arm 180°. Now the arm and payload sit atop the rocket payload compartment.

The linear vertical stage is moved down again, but only a short distance, to push the payload into the rocket. This requires a downward force of approximately 10 pounds to overcome the securing spring inside the payload compartment. Note that this ensure sequence does not rely on gravitational forces, meeting §3.3.5.5 of the SoW.

A proposed vertical stage that is both compact for mass, but also capable of the axial and torsional loads is shown below in Figure 24 (THK series 26 with stepper motor, 8.1" travel).

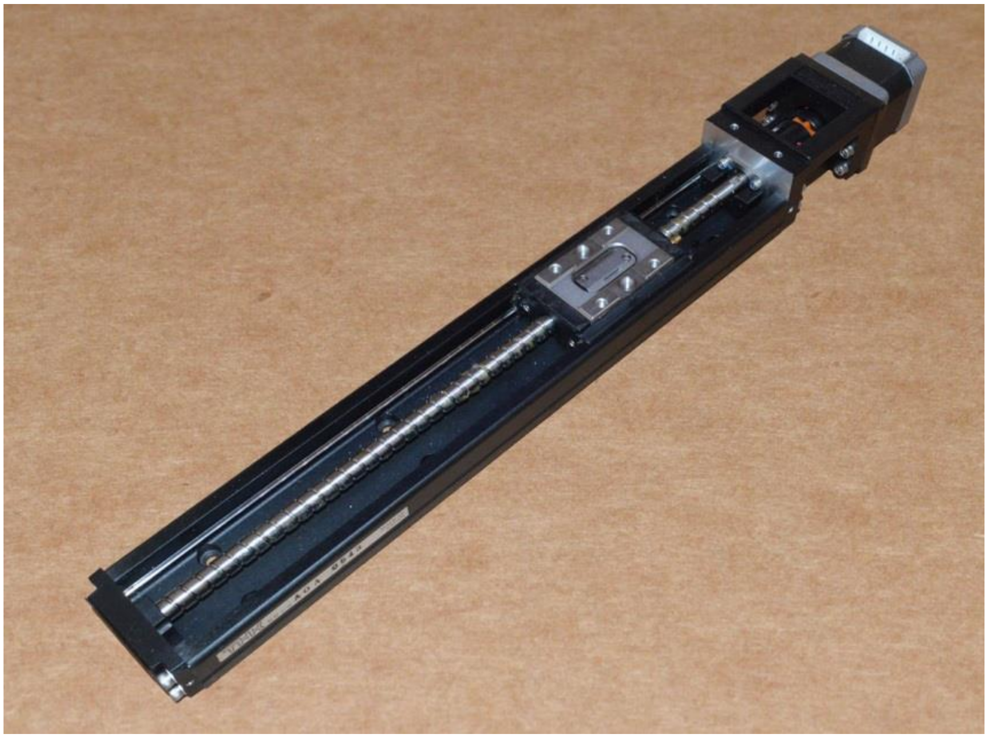

Figure 24. Compact linear stepper-motor driven vertical travel stage.

To this stage we propose to mount a rotary stepper motor to actuate the arm across a 180° arc, from the payload “pickup location” to the insertion and loading position into the launch vehicle. Based on the arm length, payload, arm, and gripper mass, and taking into account safety factors we anticipate using a NEMA 23-sized stepper motor. An example motor and off-the-shelf right-angle mounting bracket are shown in Figure 25 below.

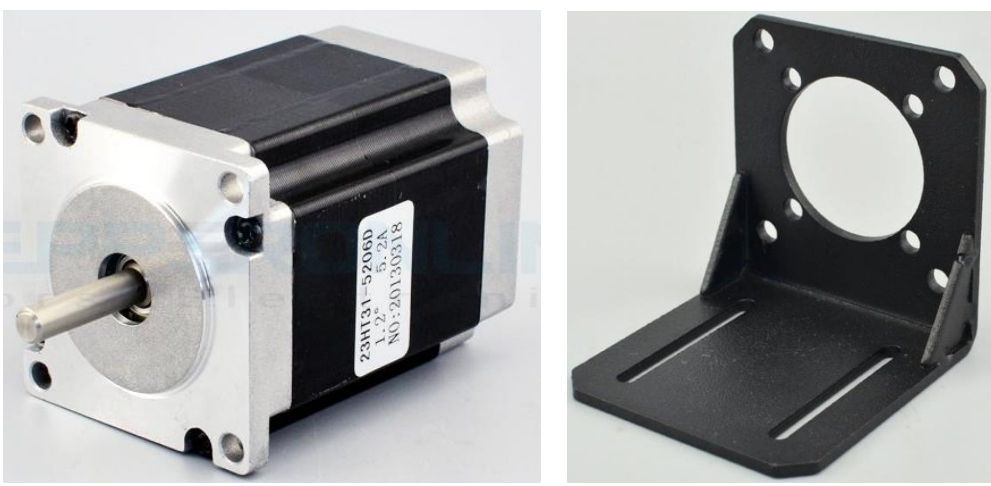

Figure 25. NEMA 23 sized stepper motor and accompanying angle mounting bracket.

The “cartoon” sequence shown in Figure 26 and its detailed caption below details the major steps in loading and unloading the payload with the 2-axis SCARA robot implementation. (Not shown are the “neutral rest state” of the arm before beginning and at the end of the sequence, where it is neither outboard of the AGSE nor located over the body of the rocket.)

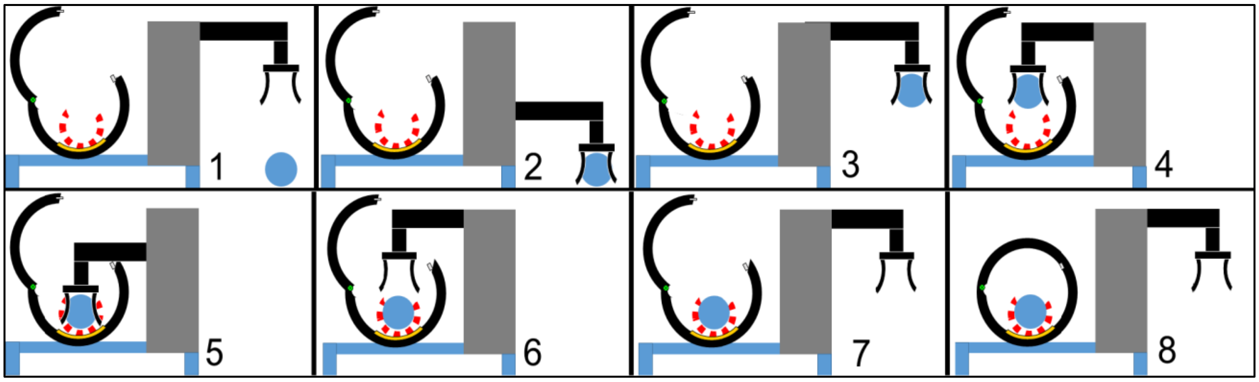

Figure 26. Payload pickup and insertion sequence. (1) arm extended to begin payload pickup. (2) vertical stage lowered over payload for pickup. (3) vertical stage raised with payload. (4) arm rotated 180° over vehicle payload compartment. (5) arm lowered to insert payload in compartment. (6) arm raised, leaving payload in compartment. (7) arm moved back to extended position, out of the way. (8) payload door closed.

To prove out the concept of the passive spring gripper and differential spring force we used the “pre-prototype” of the rocket payload section along with a pre-prototype gripper assembly. Figure 27 below shows both in schematic section view (top) and photographic 3D view (bottom) of this insertion sequence. This early pre-prototyping activity validated several key aspects of the concept:

- Using similar spring clips but with different retaining forces is quite robust in transferring from the “gripper” to the payload
- The tolerances of the clips and payload widths should be sufficient in the final design when the clip sizes are refined
- The passive means of securing the payload do work within the lateral, axial and rotational tolerances we anticipated
- Even a stout insertion arm will clear the payload door and compartment without issue
- The arm is able to transfer the vertical pressure to overcome the stiff payload slips

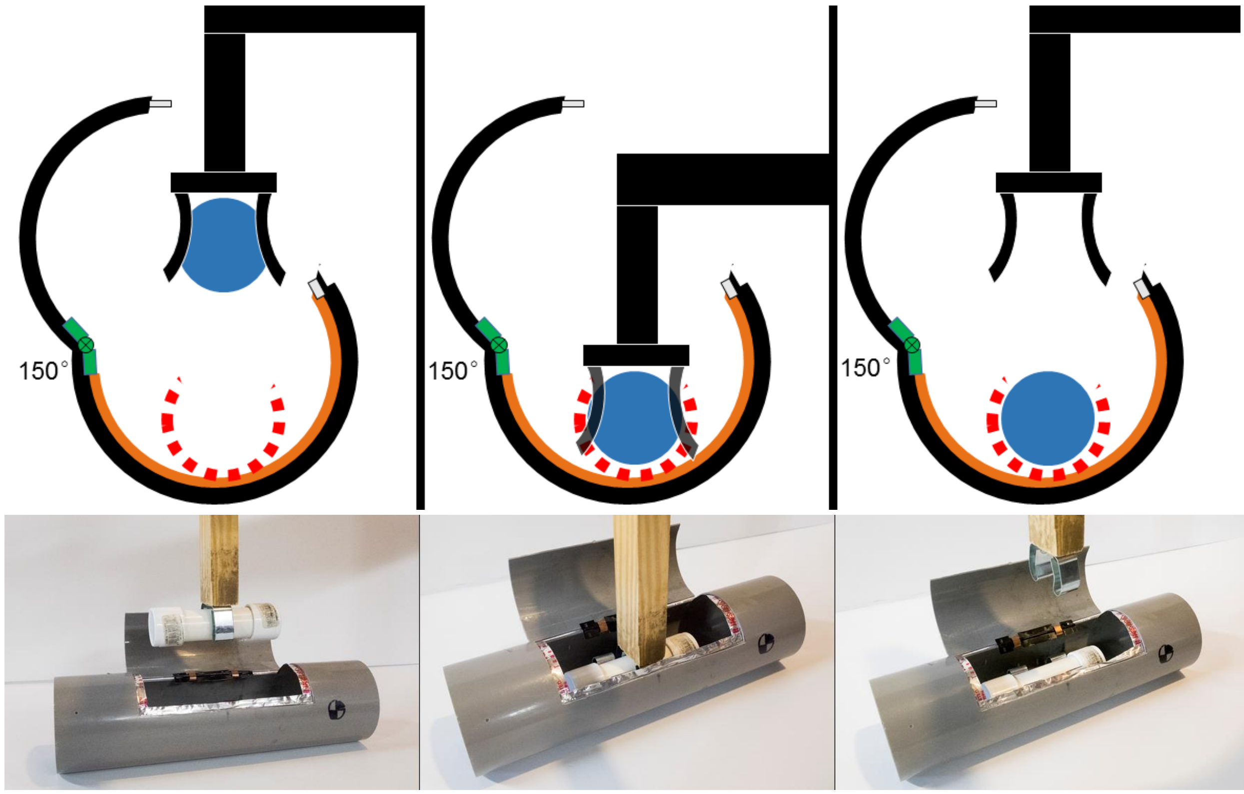

Figure 27. Picture series of payload integration using "pre-prototype."

Door closure

A short-throw linear electric motorized "piston" stage will be used to close the payload hatch. This is mounted in a fixed position to the AGSE superstructure beneath the launch rail and serves only to close the door, extending itself and pushing the payload door well past its bistable angle, then retracting.

The small linear actuator will be mounted at a roughly 45° angle to the rocket as shown in the figure, which maximizes the perpendicular force on the door while remaining out of the way at the end of the closure push cycle (above the payload door). Figure 28 shows an image of an actual 2-inch throw compact electric linear actuator suitable for this task.

Figure 28. Example short-throw (2" stroke) electric linear actuator for closing payload door.

The cartoon sequence in Figure 29 shows the operation of the linear piston to close the door and retreat. The door actuator will retract when the door is closed, completely out of the way of the rocket and fins during take-off.

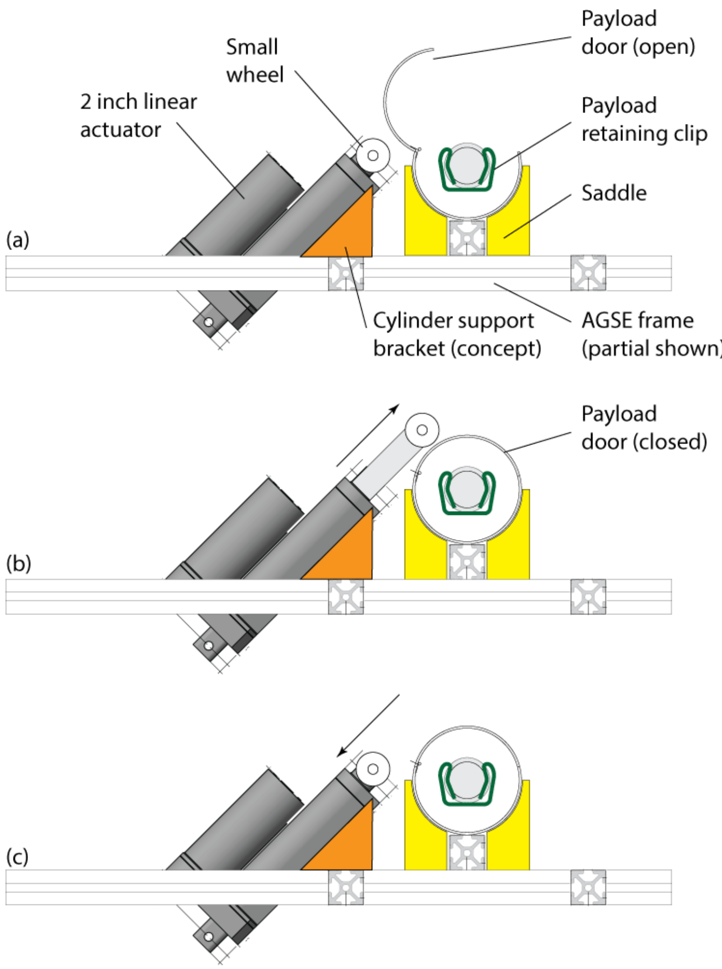

Figure 29. Sequence showing door-closing using linear cylinder.

Preliminary Tolerance Analysis

We have chosen a passive approach to acquiring and inserting the payload, relying upon careful placement of the payload and savvy choice of end effector and overall motion control design.

We must address the overall tolerances of the placement of the payload, both in the capture zone as well as the placement within the payload compartment.

Many linear dimensional factors will be taken into consideration:

- Placement error of the payload in the capture zone (axial, lateral, and angle)
- Error (absolute and repeatability) of the end effector, factoring in angular encoder error or the rotary motor, arm length, sag and linearity of the vertical stage, and mechanical tolerances of the parts themselves

- Size of the payload door/compartment (axial length and angular subtend of the door cut-out)
- Location and repeatability of the location of the rocket body on the rail/AGSE
- Location, spacing, and angle of the end effector/passive clip
- Location, spacing, and angle of the payload compartment retaining clips
- Payload-to-payload variability

And many mass and force factor will be taken into consideration:

- Mass and variability of the payload
- Center of gravity of the payload
- Insertion and retention force of the end effector clip (and variation with wear)
- Insertion and retention force of the payload retaining clips (and variation with wear and from prototype to prototype)
- Mass, axial load capability of the linear stage
- Mass, later load capability, axial (shaft) load capability of rotary motor
- Length and mass of manipulator arm

The dimensions, relative location, insertion/removal forces of the end effector and retaining clips will be readily adjustable through the prototyping phase, whereas due to time and budget constraints the limits of the linear and rotary stations will be locked early.

Based on very preliminary testing we believe we have roughly ±0.3 inch tolerances laterally and up to ±5, possibly ±10° laterally in passive payload placement. We are considering two options: One, we may consider using a template to place the payload in the appropriate capture zone. Two, we use a pair of simple line generators, commonly used in consumer drill presses, to provide visible triangulation point(s) to provide a visual placement guide for the payload.

Direction	**Payload Axial**	**Payload Radial**
Allowable Tolerance	±0.3 inches	±0.5 inches

Table 16. Payload placement/insertion estimated tolerances.

Rail erecting

After the payload has been inserted in the payload pay and payload door has been closed and latched, the controller will instruct the launch rail to erect. A range of approaches were examined for this task that meet the mass, size, cost, and complexity implied by the specification. Ultimately we settled upon a DC electric linear actuator. This mechanism is readily available and has the ideal specifications for this application: 12-volt DC motor, compact/low-mass mechanism, more than sufficient force for the rail length and rocket mass, and sufficient speed given the window for time completion of the entire task. The current required by such motors will be readily controlled with available relays.

Previously we had considered directly actuating the rail at the pivot, primarily to keep the rail and igniter insertion clear of interferences from other mechanisms. However, the combination of selecting a smaller rocket body diameter scaled the entire system down such that the rocket could feasibly be placed on the rail distant from the pivot, leaving a substantial lever arm and location to mount the pivot for a linear actuator. This significantly reduces the requirements on the motor required for erection as well as simplifies the control electronics and power requirements, while still using the same principle of a worm and rotary gear mechanism.

A schematic and key dimensions are shown below in Figure 30 and Figure 31. The chosen linear electric actuator is shown in Figure 32.

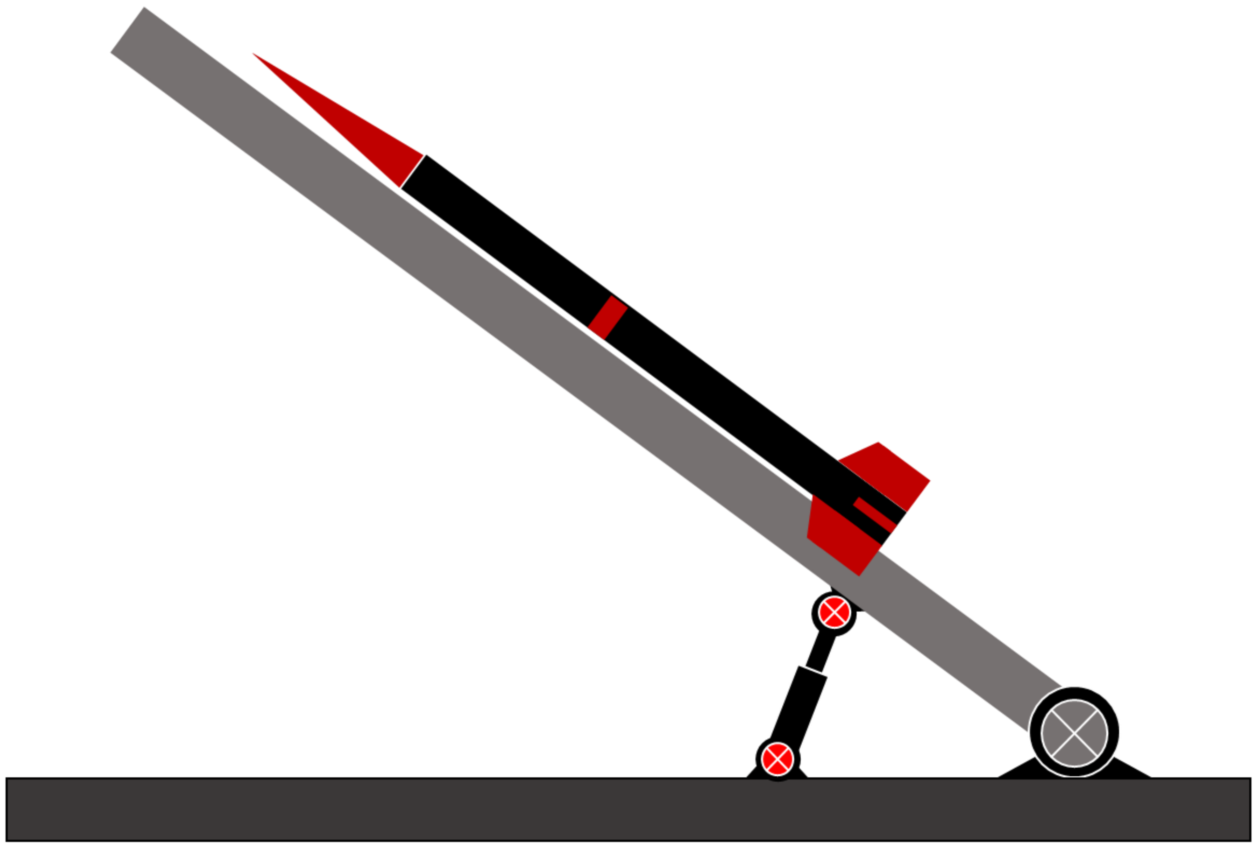

Figure 30. Schematic of launch erecting mechanism and approach.

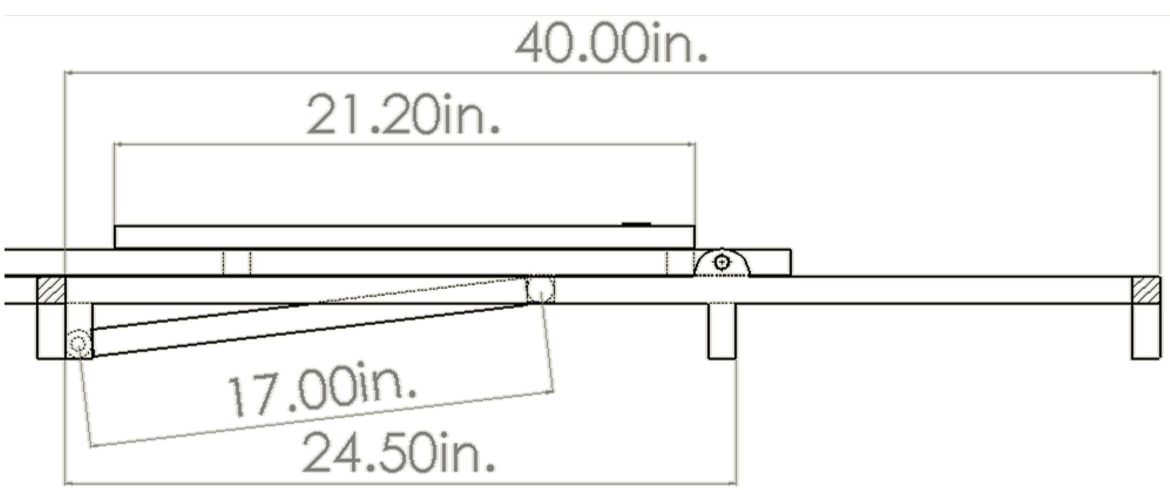

Figure 31. Key dimensions related to launch rail erection.

Figure 32. Long-stroke (20 inch) linear electric actuator for raising/lowering launch rail.

A simple sleeve or roller cartridge bearing will be used in association with the linear actuator mechanism to support the rotation of the rail and the launch forces of the rocket engine. If required, an axial coil spring may be optionally added to provide additional counter-torque when the rail is in the pay-loading position.

Figure 33. Key hardware elements used in rail pivot for erecting mechanism.

External micro-switches mounted to the superstructure will be used to provide location feedback on “raised” and “lowered” status. Rubber bumpers will be mounted as hard limit-stops in both locations.

Igniter insertion

A range of alternatives were explored for this task. Additional embedded constraints/requirements for this task beyond those provided by NASA are:

- Implicit self-restriction (for safety) to use the manufacturer-supplied ignitors and wiring without modification
- Stiffness and design of the ignitor and wiring
- Nozzle and bore diameter of the proposed rocket motor, and tolerances
- Depth of the rocket motor and required igniter insertion depth, and tolerances
- Conditions inside and outside the motor pre- and post-launch
- Safety considerations

After considering a range of mechanisms and methods, we have selected an electrically-driven linear actuator to move the igniter into position. This type of linear actuator is quite precise, low cost, and can be driven from a 12 or 24V DC supply with moderate currents. A variety are available that include 12, 15, 18 inch strokes or longer, and can be acquired with position indication in some cases. These are commonly used in high-end audiovisual installations or raising and lowering aerodynamic spoilers in sport road vehicles.

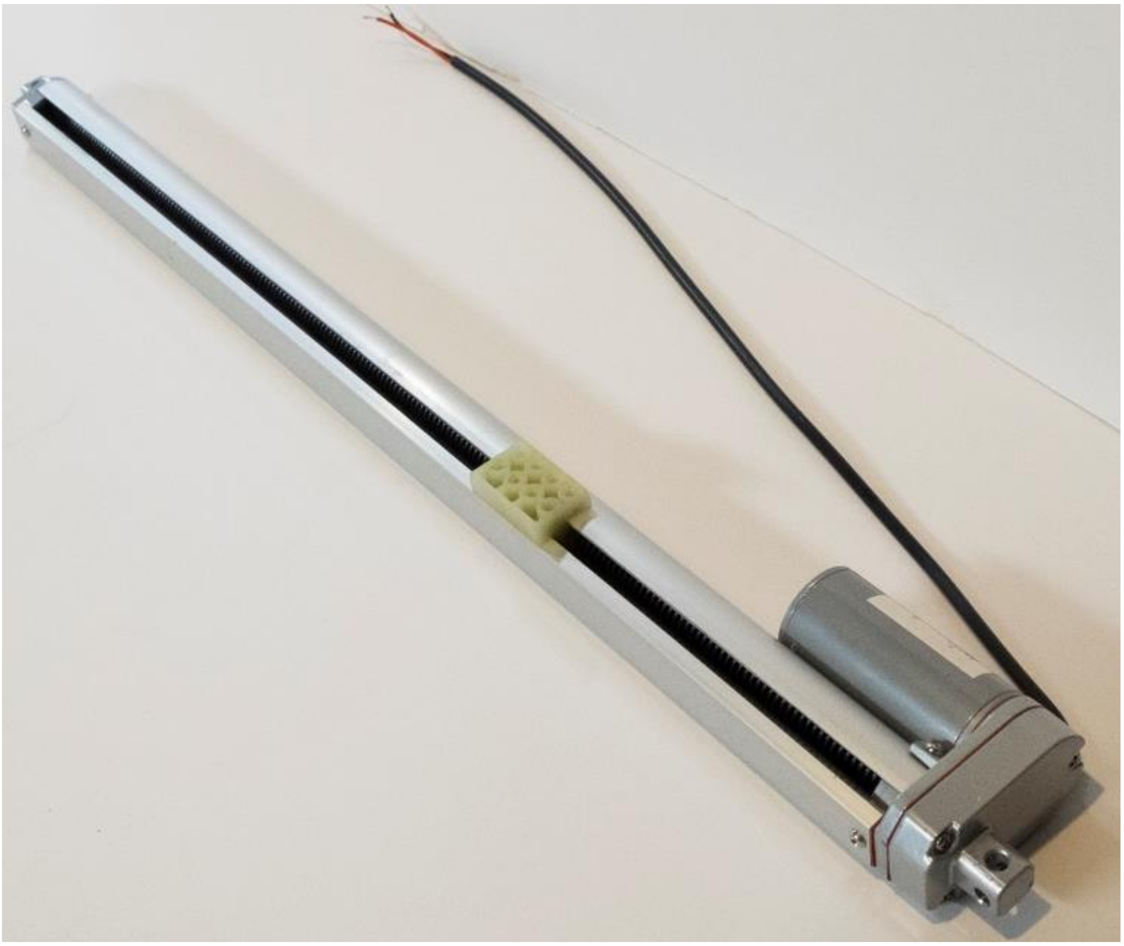

Figure 34. Photograph of actual igniter insertion linear stage.

Figure 34 above shows the actual selected insertion stage with 20 inches of travel. The stage has initial incoming testing performed and verified that the stage is compatible with the power from the 12Vdc gel-cell battery, and requires less than 1A current draw without any load. A load of approximately 10-20 pounds caused the motor to draw just over 2A momentarily. The stage is not expected to have loading beyond a pound or two owing to gravity on the ignitor, bracket, and carbon tube. The stage was measured to take approximately 16 seconds to move the entire 20 inch length with no added axial load.

Figure 35 below shows a schematic of the ignitor insertion approach and key support components.

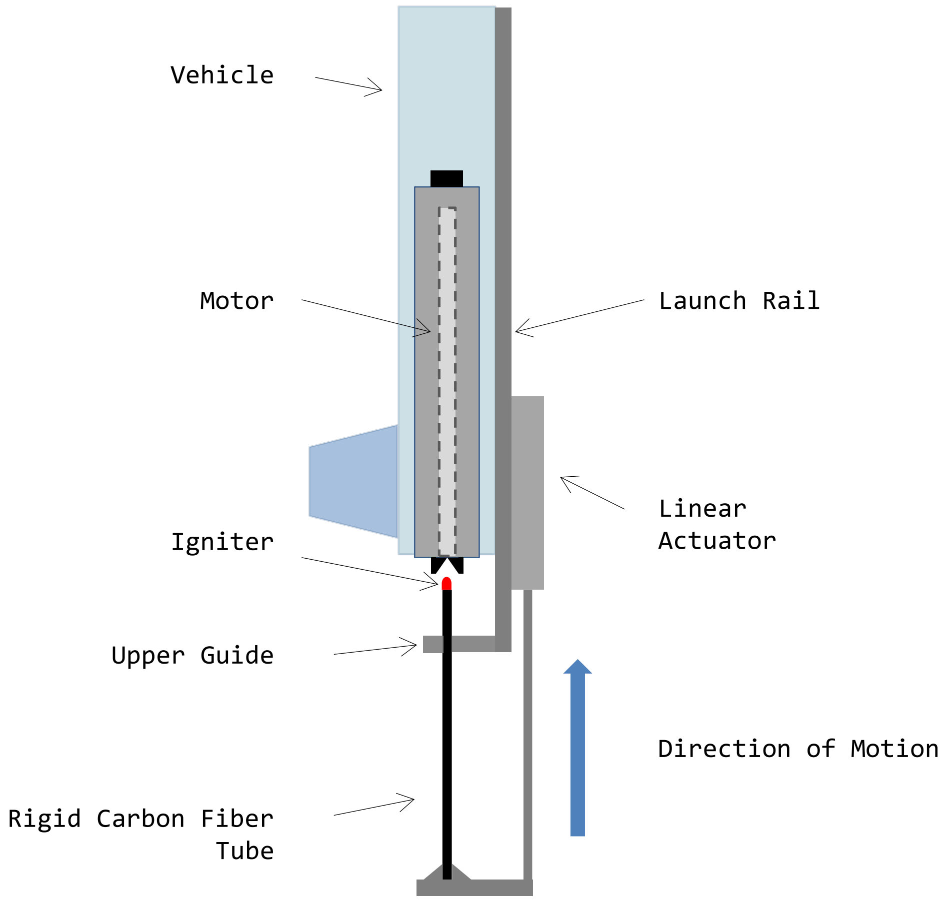

Figure 35. Schematic of igniter insertion approach.

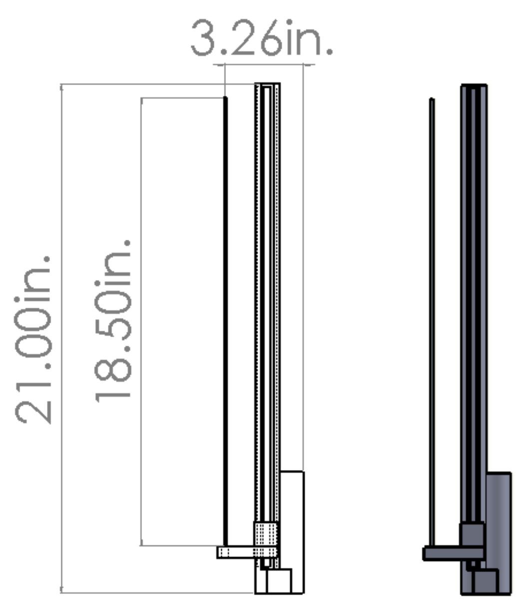

Figure 36. Dimensioned drawing of linear electric stage, igniter holder, and igniter.

The support for the igniter will be accomplished with a small-diameter (0.125” to 0.1875” outer diameter) carbon-fiber tube. These are low-cost, exceptionally stiff, hold acceptable straightness tolerances without modification, and are sufficiently sized to allow the igniter wiring to be threaded through the inner bore. The carbon-fiber tube OD (outer diameter) to rocket motor ID (inner diameter) tolerance is large (nozzle ID approximately 0.375 in and propellant bore ID approximately 0.75 inches). This tolerance, along with the travel straightness of the linear actuator, ensures that the ignitor will travel smoothly through the engine bore without getting caught.

Prior to the start sequence, the carbon tube will be loaded with the igniter and manually hand-test fitted into the engine and rocket already loaded on the launch platform. The depth will be manually adjusted with a simple slider and secure thumbscrew. This ensures that the final endpoint of the igniter rests precisely on the surface of the pellet, not lower or higher.

This end location is reinforced both with the fixed travel range of the linear actuator but also by a separate micro switch. This ensures that the microcontroller has positive feedback that the igniter has reached the required, safe location before the “sequence complete” LED is lit on the control panel.

The use of a small bore carbon tube to hold the igniter in place is considered safe as the additional material present in the bore is only slightly more than that of the igniter wire itself. The high carbon content of the tube ensures safety through limited volatility – the epoxy resin binder is less flammable than the igniter wire itself. A fresh carbon-fiber tube will be prepared and used for every launch (the carbon-fiber tube is considered disposable, like the igniter and wires themselves). It should be noted that the added cost per launch of the carbon-fiber tube is negligible compared to the cost of the expendable motor itself (less than $4 per tube length).

Control system

All of the subsystems described above will be tied together with an 8-bit Arduino-based control system. The benefits of this approach are low cost and simplicity of the code, as well as the rich ecosystem of Arduino-affiliated drivers and code libraries. This extends with the overall design philosophy of using off-the-shelf components, creatively combined to achieve the overall goals of the system.

Control

The control methodology will be based on an Arduino Uno or Mega 2560 control board, with stack-on shields for the SCARA payload manipulator arm and relay boards for all other actuators. These are low-cost, commonly available from many suppliers.

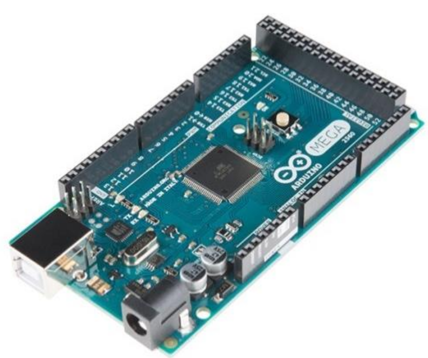

Figure 37. Arduino Mega 2560 R3 microcontroller board (e.g. Sparkfun Electronics).

We anticipate down-selecting well before the CDR. The primary trade space here is that the Mega variant offers many more IOs for not much added cost, but has the downside that the controller is not socketed/replaceable in case of damage. (The Arduino Uno uses a microcontroller DIP package with pins making replacement easy and costing only a few dollars). A more detailed control diagram laying out each and every IO signal pin will dictate this decision readily. If the Uno board is selected, it may be required to add an additional shield to manage the IO required from all of the micro-switch inputs, for example.

Drivers

The proposed system has five (5) active control output, 2 stepper motors and 3 DC motors in the linear actuators. A wide range of driver cards, both “Arduino shield” style as well as separate drivers, exist to perform this control.

We plan to use a relay shield card for the 3 DC motors, which minimizes wiring and component-level customization, and is advocated by several of the actuator manufacturers. The shields stack directly to the main Arduino board, and the relays on the boards directly drive the motors of the actuators from the 12-volt DC source.

Figure 38. Example of an Arduino-compatible "shield" containing relays suitable for powering the linear motorized actuators from the 12 Vdc supply (e.g. SeeedStudio SLD01101P).

A vast array of approaches are available for stepper motor control with a range of integration levels (stand-alone to build into the stepper motor housing) and control interface standards (serial, USB, Ethernet, CANbus). Because our system is low-cost and Arduino-based we are naturally confined to simple interface and are choosing to control these boards with a simple low-level serial UART or pulse step control. Because our control needs for the two stepper axes are very simple we do not need sophisticated motion profiling or feedback methods. We anticipate using a controller that will provide the microstep output required to the motor and read the encoder feedback.

Figure 39. Example of module stepper motor driver (e.g., Leadshine DM422C).

All of the stages/motors we are using basic self-protection limit switches built in to them; these are not accessible on the outside. We will add limiting micro-switches to each subsystem to provide active, direct feedback to the microcontroller on the status and progress of each stage. The micro-switch will positively indicate that the stage has reached the end of travel and completed its task, triggering the control algorithm to move on to the next stage of the sequence.

Power

The system will use a 12-volt or 24-volt DC bus for power, derived from a lead-acid gel cell battery, likely a motorcycle-type battery. This is a fully-sealed, reliable, low-cost, and commonly available battery type. Both the high peak currents (no more than 5A for the actuators and motors we have chosen) are satisfied readily with this type of battery with no degradation or need for secondary means of storing energy. The capacity (watt-hours/amp-hours) of this type of battery is more than sufficient to allow the entire sequence to run several times before a recharge is required.

Figure 40. Example of sealed gel-cell battery with appropriate peak current and power storage capability.

This choice forms a nice balance between cost of the power source and the convenience and risk related to operating and developing the system with a mixed set of skills and background. For example, we could choose to minimize the mass of the battery by using a lithium-polymer or other lithium-ion chemistry, however, the costs would be slightly higher and the risks of battery damage during development are much higher.

The power requirements for the Arduino microcontroller board will be derived from the 12V supply using high-efficiency buck converters to provide 3.3 and 5 V low-current bus voltages. The final decision on power approach/battery voltage will likely be dictated from the voltage required to power the two stepper motors in the payload handling arm. Strong preference is for an entirely 12V based system if this is possible; if not a high-efficiency DC-DC converter will be required as an additional step-up or step-down module to accommodate those devices.

Interface

A control box mounted on the AGSE superstructure will contain all of the switchgear and indicators required by the specification as well as house the drivers and power source and the connections to and from the system. In addition to the required indicators and switches, we will add:

- A hard emergency stop ("E-stop") locking pushbutton that immediately cuts power to the entire system. This is in addition to the Pause button required by the specification.
- A 4-line matrix LCD display to indicate details of the process, primarily for debugging but also for a richer set of information to the operator.
- Additional indicator LEDs beyond those required by the specification.

Figure 41 below shows a preliminary concept for the control box front interface.

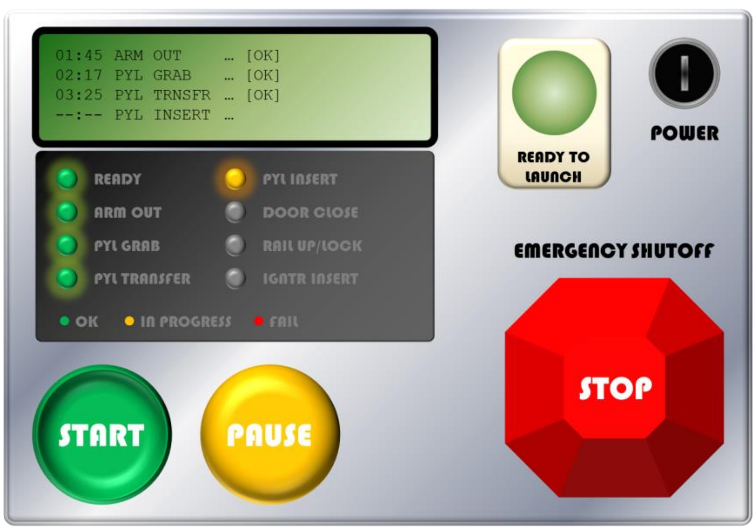

Figure 41. Concept of control box front panel.

This concept design for the control panel and the underlying implied firmware code to support the operation satisfy: §3.3.2.1.2 (start button), §3.3.2.1.3/§3.3.6.1.2 (pause button), §3.3.6.1.1 (master power switch).

To accomplish this interface with the least customization and cost, we intend to use an Arduino "shield" that contains the LED, backlight, driver, several pushbuttons, pluggable interface to the Arduino microcontroller board, and driver firmware.

Figure 42. Example backlit-LCD PCBA assembly that is an Arduino "shield" for rapid integration (Adfruit Industries model MKAD44).

The controller will have an emergency stop button such as the one shown in Figure 43 below. This would be intended only for emergency situations (prevent injury, damage, etc.) as this button would be wired to remove power from all systems, and thus recovery from this stop would require manual (human) intervention to restore the system to the correct sequence. This type of button is a latching button, so is simply requires a firm push to engage, but the button will stay seated (circuit open) until the knob is deliberately rotated to release the pushbutton.

Figure 43. Example emergency stop button.

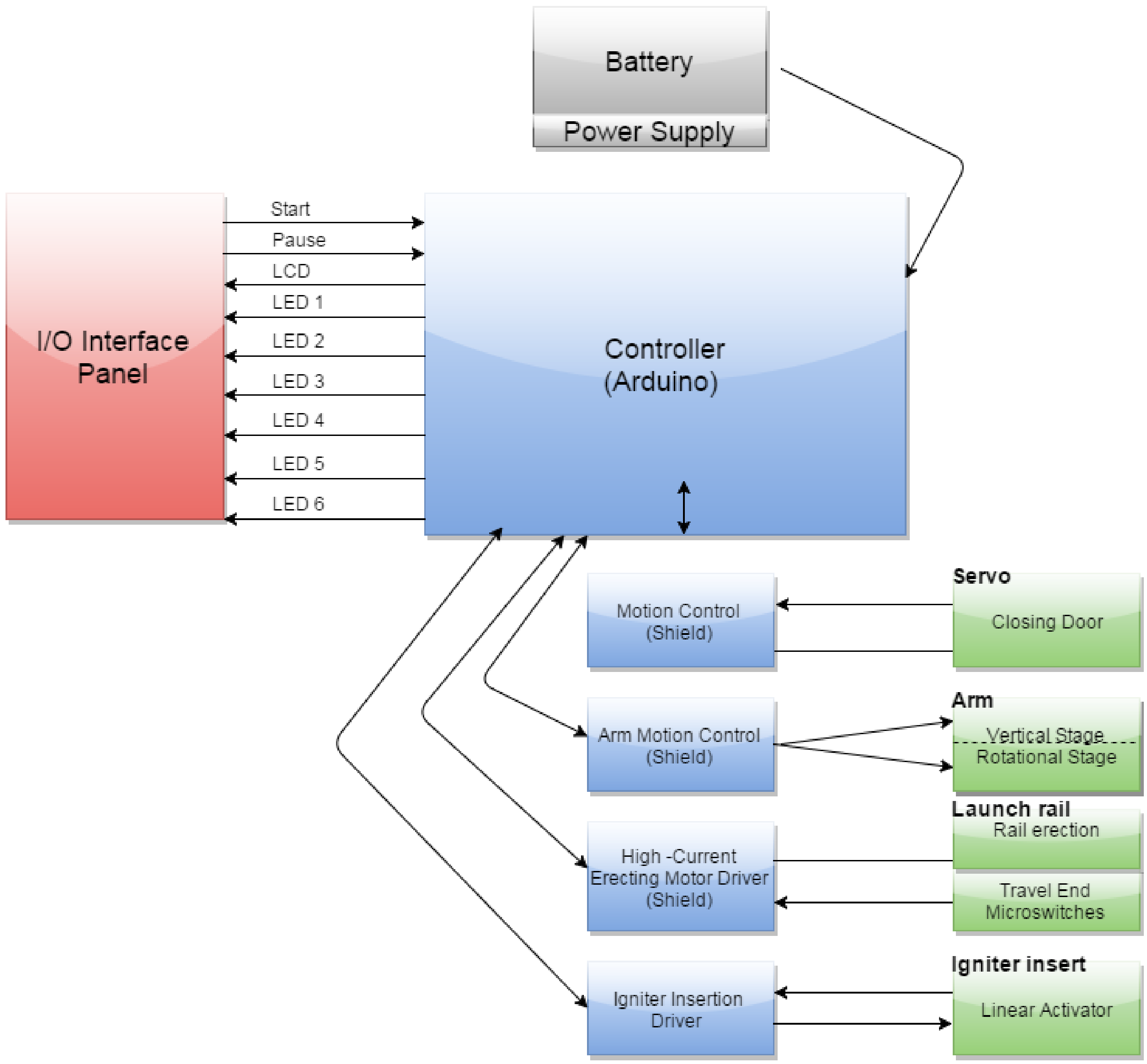

Figure 44. Block diagram of control system.

An Arduino Uno will be used with a stack of “shield” boards. The LCD driver is a small shield board and power the LCD described above. One or two low-power motor controller shields will be added to control the robotic arm axes, and the claw/end effector drive axes. A high-current 2-channel shield will be sufficient to drive the larger rail erection motor and linear drive for the igniter insertion.

An additional, important safety aspect of the control system is an industrial-style status indicator beacon pole (sometimes referred to as a “stacklight”), providing 360° visibility of the operational status of the AGSE. These are commonly used in industry, with the lights mounted atop a pole for visibility in the busy factory. Figure 45 below shows a concept of this for the AGSE. We anticipate using a low-cost LED indicator pole, driven via relay from the Arduino board in a similar fashion to the linear motor stages, but with lower current.

The indicators on this pole are intended to satisfy §3.3.6.1.3 (amber safety light, 1 Hz flash while AGSE is powered, solid when paused). The green light will be used to satisfy §3.3.6.1.4 (all systems go light). The remaining red light is envisioned to be used to indicate an error condition or failure code for the AGSE (reinforced with an error message on the LCD display).

Figure 45. Concept for status indicator beacon pole.

The entire sequence is pre-programmed and requires no human intervention after the start button is pressed (SoW §3.3.3.2).

Event Sequencing

The flowchart below shows the actions required to be performed by the controller code. The first column of actions are performed by the controller outside of the timed sequence, and serve to place the ASGE in the correct starting position, suitable for loading the launch vehicle and fresh igniter, as well as having the payload correctly placed.

The next column begins the timed, 10-minute limit sequence, triggered by the master control switch.

The third column outlines the key steps required of the robotic arm and gripper to grasp the payload and insert it into the rocket, secure it, close the door, and return to a neutral position.

The final column outlines the lifting of the launch rail to the required 5° vertical angle and igniter insertion sequences.

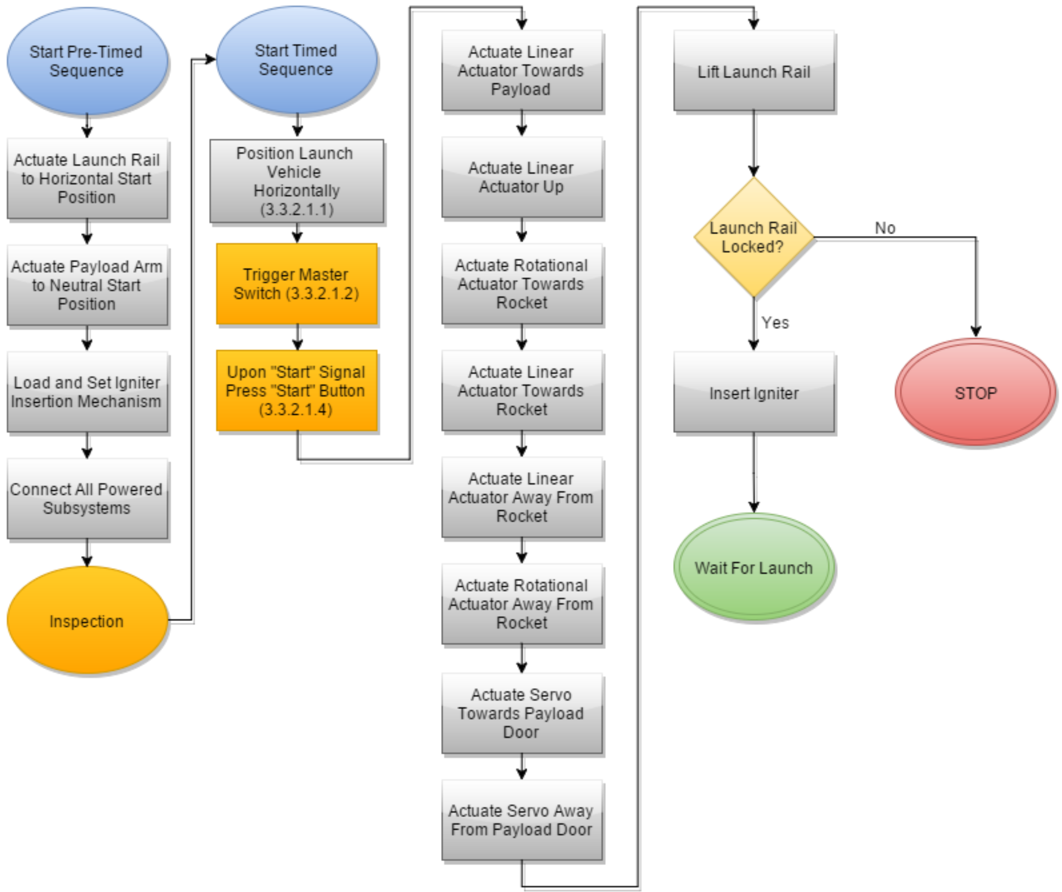

Figure 46. Flowchart for main process control; blue/red/green are start/end of sequence; orange reflects human interaction step.

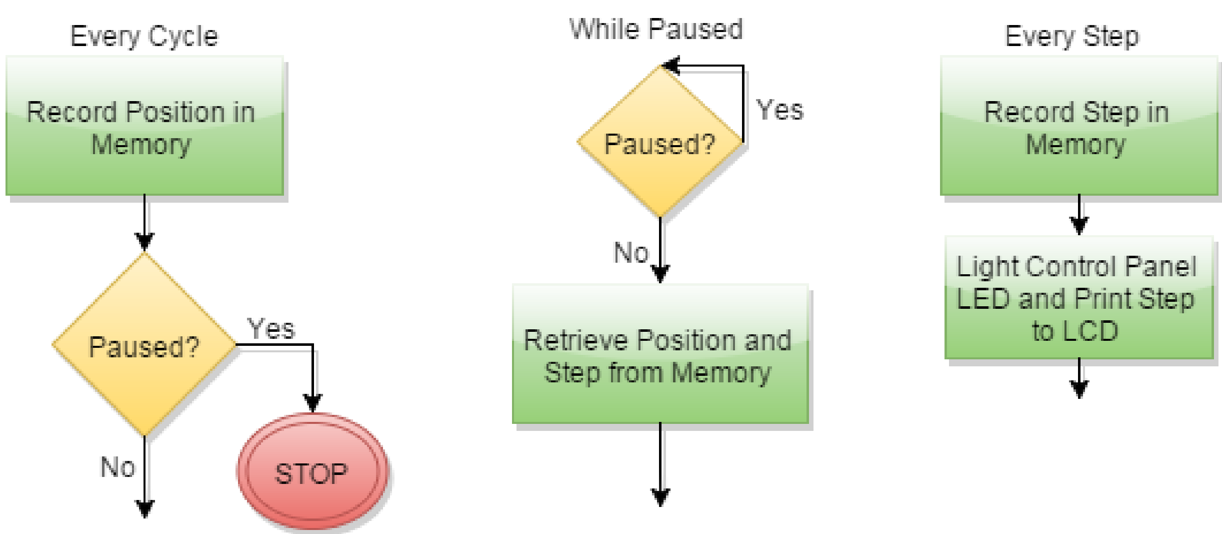

Figure 47. Safety and watchdog process flow diagrams.

The main Arduino board will be used to drive the LEDs and sense the input switches on the control panel. The micro switches and position indicators on the drive motors/actuators will be sensed from the shield boards primarily.

We anticipate implementing the pause functionality directly by wiring the pause button directly as a hard interrupt to the Arduino controller serving effectively as a “breakpoint” at every stage of the code. This ensures that the pause functionality has priority over all other microcontroller processes and is always able to halt the functionality of the system under any circumstances at any phase of the sequence. This should fully satisfy §3.3.2.1.4 of the SoW.

As a backup to provide an additional level of safety, the controller will possess a separate “hard E-stop” locking pushbutton which removes power from the controller and all motion control.

We have primarily chosen robotic actuators and systems that integrate well with the Arduino universe, limiting the need for custom driver development or writing “glue logic code” leaving the core of the programming tasks on implementing the core motion and sequencing algorithm and ensuring overall safety.

We have made a preliminary estimate of the time required to perform the entire task to assess the feasibility of the approach. Our estimates are purposely generous for each step. Our estimates come from both stage/motor manufacturer data or measurements of the actual stage motion in the workshop. We believe that even if our estimates are optimistic, we should be able to meet the SoW requirement of 10 minutes (§3.3.5.6).

Step #	Action	Duration (sec)	
1	Press button to start sequence	2	
2	Rotate arm 90° over payload	15	
2b	Check encoder	1	
3	Lower arm to engage payload	20	
3b	Check encoder	1	
4	Raise arm with payload	20	
4b	Check encoder	1	
5	Rotate arm 180° over vehicle	30	
5b	Check encoder	1	
6	Lower arm to push in payload	10	
6b	Check encoder	1	
7	Retreat vertically	10	
7b	Check encoder	1	
8	Rotate arm 90° to neutral position	10	
8b	Check encoder	1	
9	Push door closed	8	
9b	Check microswitches	1	
10	Retreat door push plunger	8	
10b	Check microswitches	1	
11	Erect launch rail	30	
11b	Check microswitches	1	
12	Insert igniter	18	
12b	Check microswitches	1	
13	Signal "complete"	1	
		193	**sec**
		3.2	**min**

Table 17: Estimate of time required to complete sequence.

Safety

We will address all aspects of safety through materials selection, process control, and by design of the controls and mechanisms. Provided elsewhere in this proposal are the MSDS sheets for the proposed materials used; this section focuses on the design aspects of safety.

A key safety aspect worth amplifying is that the control system proposed here does not include launch of the vehicle itself nor does it include anything addressing the aspects of ignition. The igniter, while inserted into the engine autonomously, is not electrically wired to the system nor is the system capable of firing the igniter.

As highlighted before, the physical aspects of safety related to motion-control system are addressed through a combination of active feedback from the motion stages (in some cases), integrated micro switches, and physical hard stops. Furthermore, the control box contains both a physical pause button to stop the code from executing as well as an E-stop that cuts power from the entire system. The code will be written in a fashion to enable the sequence to be stopped anywhere along the way in needed for safety reasons.

The control box, while mounted to the superstructure, is located well-away from the moving parts and any pinch points. Potential pinch points in all of the moving parts will be clearly labelled and/or painted brightly to call attention to that safety aspect.

As for electrical safety, the choice of a low-voltage, battery-based approach ensures fundamental safety to the students and educators during all phases of development. By using off-the-shelf drivers and relays to direct the higher currents required directly to the motors, this minimizes design work and interaction with the high-current parts of the circuits; the remaining aspects of the electrical work are lower voltage (3.3V) and lower current (<100mA).

The assembly and packaging of the electronics will be carefully overseen and inspected to ensure proper assembly, solder, and insulation techniques are used to prevent shorts or overheating of components or subsystems.

During assembly, test, and debug, safety of the team will be given the utmost importance, ranging from protocols for distance from the system envelope during operation to using non-live engine loads for insertion testing. Furthermore, given the 10-minute performance budget for the sequence, it is anticipated that all motion in the system will be slow and deliberate, giving any humans near the device time to move to safety in the unlikely case of collision.

Mass Statement

Using the draft concept detailed bill of materials we have revised our estimate of the mass of the structure and vehicle. This is still a preliminary estimate based on a mixture of actual measurements of acquired parts, datasheet statements of masses, and engineering estimates based on prior knowledge or common-sense based on the size and type of materials.

Analysis

The AGSE fixed superstructure is by far the largest contributor to the total system mass, primarily because of the scale of the design. The structure needs to be long enough to accommodate the length of the rocket plus igniter insertion, amplified by the fact that the payload will be inserted just below the vehicle nose cone, and thus all of the payload handling equipment is at the fore end of the rocket and the erection and igniter insertion are aft. Further constraints on the superstructure size are the need for stability of the ground interface footprint of the launch pad given the length of the rail and the thrust of the engine at take-off, and the distance of the structure’s feet from the axis of the launch rail.

The robotics and motion control for grabbing the payload, inserting it, and closing the door are the next major mass contributor, dominated by the sturdy stages needed to move the payload and effect the torque required to secure the payload in the rocket.

The rail erection and controller are the next major mass contributions. The erection motion control and brackets dominate that mass contribution, whereas the controller’s main contribution is the relatively dense gel-cell battery.

In Figure 48 and Table 18 below we summarize the latest, revised mass estimates for the entire system, vehicle and launch apparatus. We divide the aspects into the logical subsystems as described above, including separating vehicle-related and the payload aspects of the vehicle, and the logical subsystems required to support each of the motion control aspects.

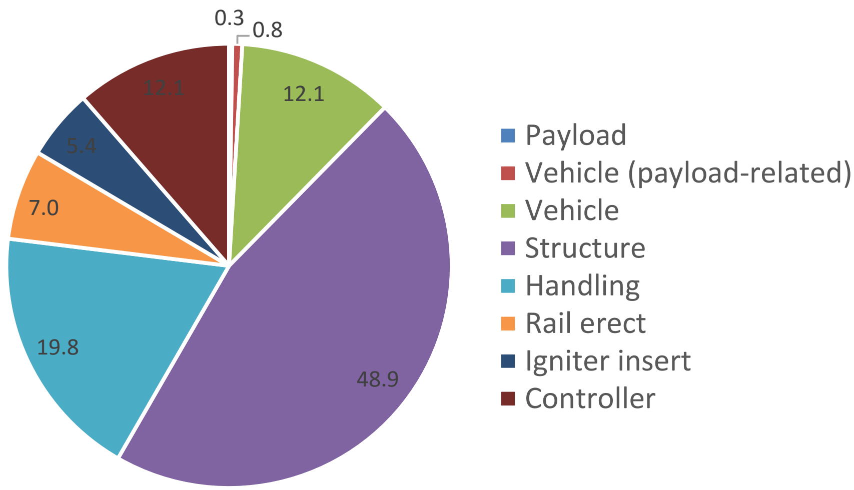

Figure 48. AGSE Mass Allocation.

Table 18. Summary of mass contributions to Maxi-MAV and AGSE.

Subsystem	Mass (lbs)	Comment
Payload	0.3	just the PVC payload and weighting
Vehicle (payload-related)	0.8	includes items required to retain and secure the payload
Vehicle	12.1	all aspects of the rocket including structure, propulsion, recovery, telemetry
Structure	48.9	the static superstructure of the ASGE
Handling	19.8	the robotic motion control for acquiring and depositing the payload
Rail erect	7.0	lifting the launch rail into a near-vertical position
Igniter insert	5.4	insertion of the igniter into the engine
Controller	12.1	all aspects of control including microcontroller, drivers, indicators, safety lights, housing, and po
TOTAL	**106.4**	

This is still a preliminary estimate of the masses, and puts us well under the 150 pound specification limit. Our estimate includes line items for mass overage error for each subsystem, roughly proportional to the mass of that subsystem, attempting to buffer against errors or creep as the design is fully developed and matured.

Examining each of the subsystem, we believe the highest-risk subsystem is the superstructure itself, not only because it is the largest contributor, but as the design is refined and built, it may be determined that additional cross-bracing or struts are needed beyond the current design plan to ward against twist/deformation during payload motion and insertion, as well as overall dimensional stability of the entire structure.

Because we estimate we are well below the specification budget, we see this as a low risk to meeting the specification, but constant focus is maintained on minimizing system mass as far below specification as possible. These estimates leave us confident that the system will end up below the SoW requirement of 150 pounds total (§3.3.3.3).

Key components and subsystems

The table below lists key components and subsystems that we have made a preliminary down-selection towards, and believe will support the overall goals of the Maxi-MAV challenge.

Table 19. List of selected key components.

Subsystem	Description	Manufacturer/Supplier	Model
Payload retention	Dowel holder / spring steel clip	True value	
Payload retention	Eyeglass case spring hinge	Donation from local Costco	n/a
Payload retention	Magnet	KH magnetics	
Structure	8020 rail	club inventory, McMaster-Carr	
Structure	8020 assembly hardware	McMaster-Carr	
Handling	Laser line generator	Craftsman/Amazon	
Handling	Gripper	True value	
Handling	Linear motor stage (8") / vertical	THK/eBay	N/A
Handling	Stepper motor with encoder	StepperOnline (NEMA 17/23 size)	N/A
Handling	Linear actuator (2") / door closer	Everest Supply or Firgelli	
Erection	Linear actuator (18")	Everest Supply or Firgelli	N/A
Erection	Pillow sleeve bearing	McMaster-Carr	
Erection	Shoulder bolt	McMaster-Carr	
Insertion	Linear actuator with track mount	Firgelli	
Insertion	Carbon-fiber tube	McMaster-Carr	
Controller	Microcontroller	Sparkfun	Arduino Uno R3
Controller	Relay shield	Sparkfun	
Controller	Stepper driver with microstep	TBD	
Controller	Battery, 12 Pb-acid/gel	Tenergy or similar	e.g., TB12120
Controller	Indicator tower	uxcell/Amazon	12V tricolor

During this phase, every key component has been defined, the requirements for that component and flow-down specifications unique to that component have been at least outlined and defined. We feel that a key driving principle of the design is to use simple passive components wherever possible, minimizing the number of active components and moving parts wherever possible.

None of the components used or subsystems we implement violate any of the subclauses of SoW §3.3.4.

A related aspect is “design re-use,” seeking to re-use or re-purpose components and subsystems wherever possible. This has a dual benefit, since this approach usually enables the use of consumer or hobbyist components which have a much higher production volume and therefore lower costs. Given the limited life and number of cycles required of the entire system, this is a very reasonable tradeoff.

Below we call out some of the specific component aspects in this regard:

Re-purposed/creative use

- Hard glasses case hinge/spring closing mechanism (payload compartment in vehicle)
- Spring clip used for retaining brooms/rakes (payload compartment and gripper)
- Laser line generator from drill press (payload location)

Surplus

- Linear vertical motion stage (payload transport)
- 8020 construction rail (AGSE superstructure, payload transport, erection and launch rail)

Traditional components applied in a novel fashion

- Linear actuators (often used in home automation/audiovisual systems, race car spoiler raise/lowering) used for igniter insertion, rail erection, payload door closure
- Pillow bearings/shoulder screws used for launch rail pivot
- Low-cost stack lights from industrial machinery
- Low-cost high-strength magnets used to retain payload door during launch

Verification plan

Components tested

Below we list the key subsystems/components that will be tested for efficacy and ability to meet the statements of work clauses/specifications:

- **C1:** AGSE Frame
- **C2:** Rail Erection System
- **C3:** End Effector
- **C4:** Payload Retrieval System
- **C5:** Igniter Insertion System
- **C6:** Control Panel
- **C7:** Emergency Stop Button
- **C8:** Power Source

Verifications

We have defined the following suite of tests to verify that the AGSE meets the SoW requirements. Many of these tests are a general class of tests that will be applied to every applicable subsystem. For example, the integrity test will be applied to many different actuators used in the system and the forces applied may vary depending on the actuator type or motion; the power draw test will be applied to each powered stage of the sequence separately.

- **V1 Integrity Test:** applying force to verify durability.
- **V2 Force Stall Test:** applying force to verify stall force of motor.
- **V3 Holding Force Test:** applying force to verify holding force of motor.
- **V4 Time Test:** verifying time taken for action.
- **V5 Functionality Test:** test of basic functionality of a device on the ground.
- **V6 Power Draw Test:** determining the amount of power required to sustain this component for a certain amount of time.
- **V7 Conditions Test:** verifying that components will function in launch conditions.

- **V8 Hard Stop Test:** verifying that all hard stops function.
- **V9 Weight Test:** verifying that the AGSE remains under 150 pounds
- **V10 Volume Test:** verifying that the AGSE does not surpass the allowable volume

Verification Matrix

The below matrix shows which verifications apply to each subsystem or component.

Table 20. Verification matrix for AGSE.

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
C1	3.1	3.3.2.1.3	3.3.2.1.3		3.3.3.2	3.3.6.1.1	3.3.4	3.3.2.1.3	3.3.3.3	3.3.3.3
C2	3.1	3.3.2.1.3	3.3.2.1.3	3.3.5.6	3.3.3.2	3.3.6.1.1	3.3.4	3.3.2.1.3	3.3.3.3	3.3.3.3
C3	3.1	3.3.2.1.3	3.3.2.1.3		3.3.3.2	3.3.6.1.1	3.3.4	3.3.2.1.3	3.3.3.3	
C4	3.1	3.3.2.1.3	3.3.2.1.3	3.3.5.6	3.3.3.2	3.3.6.1.1	3.3.4	3.3.2.1.3	3.3.3.3	3.3.3.3
C5	3.1	3.3.2.1.3	3.3.2.1.3	3.3.5.6	3.3.3.2	3.3.6.1.1	3.3.4	3.3.2.1.3	3.3.3.3	3.3.3.3
C6	3.1	3.3.2.1.3	3.3.2.1.3		3.3.3.2	3.3.6.1.1	3.3.4	3.3.2.1.3	3.3.3.3	
C7	3.1	3.3.2.1.3	3.3.2.1.3		3.3.2.1	3.3.6.1.1	3.3.4	3.3.2.1.3	3.3.3.3	
C8	3.1	3.3.2.1.3	3.3.2.1.3		3.3.3.2	3.3.6.1.1	3.3.4	3.3.2.1.3	3.3.3.3	

As the design is refined and revised towards the CDR phase, the detailed explicit tests and test limits will be expounded upon and refined as a result of this matrix approach.

Requirements

All payload requirements are in detail addressed in Project Requirements section, with Payload Requirements starting on page 82. The detailed description of the proposed payload starts on page 71.

Major Technical Challenges and Solutions

The technical challenges related to selected payload option (Task 2, Centennial Challenges) are described together with suggested solutions earlier in the above section (pages 71-67). The proposed design has been checked for compliance for with project requirements.

Educational Engagement

Status

We have already participated in three outreach events:

1. **Boy Scouts Pack #302:** we have displayed many of our rockets and payloads, helped the participant to build and launch pneumatic rockets and participated in about a 30 minute long discussion about our program and projects. *Estimated reach of 50 people.*
2. **Homecoming Parade:** the parade is traditionally held in October and it is an opportunity to inform Madison Community about our projects in a fun and visual-rich way. *Estimated reach of 200 people.*
3. **Wisconsin Science Festival:** is a major outreach events held in many location across Wisconsin. Our station was located in Wisconsin Institute of Discovery, Madison, WI. We have displayed several of our past Student Launch projects, helped participants to build and launch pneumatic rockets and engaged in impromptu discussions with all interested festival visitors. *Estimated reach of 3000 people over two days.*

We have also helped with construction tasks at new Madison Museum of Science and in connection with this volunteer activity we have been awarded a grant from Madison Civics Club, while the club members were afforded the opportunity to meet with Mimi Gardner Gates, a stepmother of Bill Gates. The grant will help us to improve the displays and activities that we offer at our outreach events. The first project related to this grant will be a working display of a plasma thruster, built in cooperation with Prof. Amy Wendt from Dept. of Engineering at UW, Madison.

Overall Plan

Each year we participate in numerous outreach events, ranging from a single classroom activity to large public events, such as Physics Open House at UW Madison or multiday state-wide Wisconsin Science Festival. For years we have been steadily building selection of outreach opportunities and now we reach approximately 3,000 people each year. We provide all supplies and materials for our outreach events, utilizing minimum cost designs (such as pneumatic rockets) or surplus materials from our previous season.

We keep in contact with our local communities via our *Raking for Rockets* fundraising program. Last year the students in our program rake close to 100 yards in exchange for donations to their projects. Several times during our fundraising season (October-December) our raking and yardwork teams help those who could not afford yardwork services otherwise.

Besides these programs, we continuously recruit new members for our club at Madison West High School (our current membership is above 50 students mark) in a number of recruitment events which include organized recruitment events and posters advertising the location and time of the first informational meeting. Our major source of new members comes from personal referrals, either students bringing their friends or parents sharing information about our club with other families or neighbors.

The table below shows the outreach programs that we have planned for this year. The programs target primarily elementary and middle schools. We will most likely add several events to this program as the year progresses (we have become well known for our outreach activities and are steadily receiving requests from schools and organization that we have never worked with before).

Date	School	Outreach	# of People (estimated)
Oct. 8, 2015	Boy Scouts	Pneumatic rockets, Alka-Seltzer rockets	50
Oct. 16, 2015	Randall Elementary	School Homecoming Parade	200
Oct. 24/25, 2015	Wisconsin Science Festival	Pneumatic rockets, Alka-Seltzer rockets	3000
Feb. 13, 2016	Physics Open House	Displays, pneumatic rockets	300
Mar. 12, 2016	Randall and Franklin Elementary – Super Science Saturday	Pneumatic rockets, Alka-Seltzer rockets	100
Mar. 19, 2016	O'Keeffe Middle School Super Science Saturday	Pneumatic rockets, Alka-Seltzer rockets	80
April 1, 2016	Kids Express	Pneumatic rockets, Alka-Seltzer rockets	50
			Total: 3780

Table 21: Planned outreach events

Project Plan

Project Requirements

The following is a list of all vehicle related project requirements, listing the requirement itself (in **bold**), how the requirement will be addressed (in plain text) and how it will be verified (where applicable, in *italics*).

1.1. The vehicle shall deliver the payload to an apogee altitude of 5,280 feet above ground level (AGL).
The current simulation predicts that the rocket will reach 5,264*ft*. The coefficient of drag is set to C_D = 0.7. We have obtained this experimentally measured value from our previous experiments using a similar constant diameter K-class delivery vehicle. The performance predictions will be updated as data from scale model flight and half-impulse flight become available. If necessary, the rocket will be ballasted to prevent it from exceeding altitude of 1 mile. The amount of ballast will not exceed 10% of rocket liftoff weight. – *Verified by computer simulations and test flights*

1.2. The vehicle shall carry one commercially available, barometric altimeter for recording the official altitude used in the competition scoring. The altitude score will account for 10% of the team's overall competition score. Teams will receive the maximum number of altitude points (5,280) if the official scoring altimeter reads a value of exactly 5,280 feet AGL. The team will lose two points for every foot above the required altitude, and one point for every foot below the required altitude. The altitude score will be equivalent to the percentage of altitude points remaining after any deductions.
The vehicle will carry two identical barometric altimeters (PerfectFlite StratoLogger CF), each capable of serving the role of official scoring altimeter. The team will designate and visually identify one of the altimeters as the official scoring altimeter, before the actual flight. – *Verified be visual inspection, checklist and audio feedback when the altimeters are powered up before flight.*

1.2.1. The official scoring altimeter shall report the official competition altitude via a series of beeps to be checked after the competition flight.
We will use PerfectFlite StratoLogger CF altimeter which satisfies this requirement. – *Verified by inspection*

1.2.2. Teams may have additional altimeters to control vehicle electronics and payload experiment(s).
We will have two fully redundant barometric altimeters to ensure successful deployment of parachutes. – *Verified by inspection and checklist*

1.2.2.1. At the Launch Readiness Review, a NASA official will mark the altimeter that will be used for the official scoring.
We will select our scoring altimeter prior to the Launch Readiness Review to enable NASA officials to mark the altimeter. – *Verified by inspection*

1.2.2.2. At the launch field, a NASA official will obtain the altitude by listening to the audible beeps reported by the official competition, marked altimeter.

Following the recovery of our vehicle, we will report to NASA officials so they may record the altitude of our flight. – *Verified by postflight checklist*

1.2.2.3. At the launch field, to aid in determination of the vehicle's apogee, all audible electronics, except for the official altitude-determining altimeter shall be capable of being turned off.
All of our flight electronics will have individual switches which will allow us to turn off the altimeters. – *Verified by preflight inspection*

1.2.3. The following circumstances will warrant a score of zero for the altitude portion of the competition:

1.2.3.1. The official, marked altimeter is damaged and/or does not report an altitude via a series of beeps after the team's competition flight.
We will take proper precautions to ensure no altimeters are damaged during the flight. – *Verified by preflight inspection*

1.2.3.2. The team does not report to the NASA official designated to record the altitude with their official, marked altimeter on the day of the launch.
After recovery of our vehicle, we will report to the NASA official designated to record the altitude. – *Verified by postflight checklist*

1.2.3.3. The altimeter reports an apogee altitude over 5,600 feet AGL.
Test flights and computers simulations will be performed prior the official SL launch to ensure that our rocket does not exceed the target altitude of 5,600 feet AGL.

1.2.3.4. The rocket is not flown at the competition launch site.
Our rocket will be flown at the competition launch site.

1.3. The launch vehicle shall be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.
The vehicle is designed as reusable and can be launched several times a day. The maximum flight preparation time is 2 hours. – *Verified by postflight checklist*

1.4. The launch vehicle shall have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.
The vehicle consists of three tethered sections (nose cone, compartment housing both the payload and main parachute and the booster section). – *Verified by design and inspection*

1.5. The launch vehicle shall be limited to a single stage.
Our launch vehicle will utilize only one stage throughout the duration of the flight. – *Verified by design*

1.6. The launch vehicle shall be capable of being prepared for flight at the launch site within 2 hours, from the time the Federal Aviation Administration flight waiver opens.

The maximum preparation time for the rocket is 2 hours. The team will practice the vehicle preparation in order to assure their ability to ready the vehicle for launch within allocated time. – *Verified by dry runs and during test flights (the preparation period will be timed)*

1.7. The launch vehicle shall be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board component.

The launch vehicle can remain in launch ready configuration for several hours. The altimeters are rated for 24 hours of wait time. Battery capacities and available standby time will be tested extensively during project development. – *Verified by test in workshop*

1.8. The launch vehicle shall be capable of being launched by a standard 12 volt direct current firing system. The firing system will be provided by the NASA-designated Range Services Provider.

The vehicle is using Cesaroni motor which is compatible with 12V igniters. Electrical current of 3A is sufficient to fire the igniter. The vehicle can be launched from the standard 12V launch system. – *Verified during test flights*

1.9. The launch vehicle shall use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).

Only motors satisfying this performance target are used in design, testing and operation of the vehicle. Currently, Cesaroni K530SS motor is the primary propulsion choice. – *Verified by inspection and design*

1.9.1. Final motor choices must be made by the Critical Design Review (CDR).

We will select our final motor prior to the Critical Design Review. – *Will be verified by documentation review prior CDR package submission*

1.9.2. Any motor changes after CDR must be approved by the NASA Range Safety Officer (RSO), and will only be approved if the change is for the sole purpose of increasing the safety margin.

If a change of motor is necessary after the CDR, we will communicate with the NASA Range Safety Officer in order to have the modification approved. We will comply with instructions given by NASA.

1.10. The total impulse provided by a launch vehicle shall not exceed 5,120 Newton-seconds (L-class).

Our primary propulsion choice is CTI K530SS with 1412Ns of total impulse. – *Verified by manufacturer's provided motor data*

1.11. Pressure vessels on the vehicle shall be approved by the RSO and shall meet the following criteria:

Not applicable.

1.11.1. The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) shall be 4:1 with supporting design documentation included in all milestone reviews. Any pressure vessels in our vehicle will have a factor of safety above the minimum requirement of 4:1.
Not applicable.

1.11.2. Each pressure vessel shall include a pressure relief valve that sees the full pressure of the tank.All pressure vessels will include a pressure relief valve which sees the full pressure of the tank.
Not applicable.
1.11.3. Full pedigree of the tank shall be described, including the application for which the tank was designed, and the history of the tank, including the number of pressure cycles put on the tank, by whom, and when.
Not applicable.

1.12. All teams shall successfully launch and recover a subscale model of their full-scale rocket prior to CDR. The subscale model should resemble and perform as similarly as possible to the full-scale model, however, the full-scale shall not be used as the subscale model.
We will construct a subscale model of our rocket and launch it prior to the CDR. Our subscale model will be a one half scale representation of our full vehicle as accurately as possible. Test flight of a subscale model is a standard part of our project development cycle. – *Verified by scale model test flight, project log and documentation review*

1.13. All teams shall successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown at FRR must be the same rocket to be flown on launch day. The purpose of the full-scale demonstration flight is to demonstrate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at a lower altitude, functioning tracking devices, etc.). The following criteria must be met during the full scale demonstration flight:
We plan to conduct at least one test of a subscale vehicle and two test flights of the full scale vehicle prior the FRR due date. The final test flight will be in full vehicle/payload configuration using the full impulse motor. – *Verified by full scale vehicle flights, project log and documentation review*

1.13.1. The vehicle and recovery system shall have functioned as designed.
The vehicle recovery system will be operated in full configuration on all planned test flight. – *Verified during half scale and full scale vehicle test and static ejection tests on the ground*

1.13.2. The payload does not have to be flown during the full-scale test flight. The following requirements still apply:

1.13.2.1. If the payload is not flown, mass simulators shall be used to simulate the payload mass.
Before the payload is ready for flight, payload will be simulated by mass simulators during test flights. – *Verified by inspection prior each test flight*

1.13.2.2. The mass simulators shall be located in the same approximate location on the rocket as the missing payload mass.
Payload mass simulators, if used, will represent the predicted mass of the payload and will be located at the payload's intended location within the vehicle to maintain the same mass distribution. – *Verified by inspection prior each test flight*

1.13.2.3. If the payload changes the external surfaces of the rocket (such as with camera housings or external probes) or manages the total energy of the vehicle, those systems shall be active during the full-scale demonstration flight.

Our payload does not change any of the external surfaces and it does not manage the total energy of the vehicle. Not applicable.–

1.13.3. The full-scale motor does not have to be flown during the full-scale test flight. However, it is recommended that the full-scale motor be used to demonstrate full flight readiness and altitude verification. If the full-scale motor is not flown during the full-scale flight, it is desired that the motor simulate, as closely as possible, the predicted maximum velocity and maximum acceleration of the competition flight.
We intend to fly our demonstration flight with the exactly same motor that will be used for our flight at the SLI launch in Huntsville. – *Verified by the flight data from final test flight of the full scale vehicle*

1.13.4. The vehicle shall be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the same amount of ballast that will be flown during the competition flight.
The vehicle will be fully ballasted (if ballast is necessary) for the final full scale test flight. Requirement 1.13 will be observed. – *Verified by preflight inspection and checklist*

1.13.5. After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components shall not be modified without the concurrence of the NASA Range Safety Officer (RSO).
Except for necessary repairs, there will not be any changes made to the launch vehicle after the full scale demonstration flight. If any repairs are necessary, the NASA Range Safety Officer will be contacted before making any changes to the vehicle. – *Verified by documentation review*

1.14. Each team will have a maximum budget of $7,500 they may spend on the rocket and its payload(s). (Exception: Centennial Challenge payload task. See supplemental requirements at: http://www.nasa.gov/mavprize for more information). The cost is for the competition rocket and

payload as it sits on the pad, including all purchased components. The fair market value of all donated items or materials shall be included in the cost analysis. The following items may be omitted from the total cost of the vehicle:

- **Shipping costs**
- **Team labor costs**

Our budget will not exceed $7,500 for construction and flight of the rocket and payload. – *Verified by detailed accounting of all project expenses*

1.15. Vehicle Prohibitions

1.15.1. The vehicle shall not utilize forward canards.

Vehicle does not have forward canards.

1.15.2. The vehicle shall not utilize forward firing motors.

Vehicle does not utilize forward firing motors.

1.15.3. The vehicle shall not utilize motors which expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)

Sparky motors are not used.

1.15.4. The vehicle shall not utilize hybrid motors.

Hybrid motors are not used.**1.15.5 The vehicle shall not utilize a cluster of motors.**

The vehicle is propelled by a single motor.

2. Recovery System Requirements

2.1. The launch vehicle shall stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a much lower altitude. Tumble recovery or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue-stage descent is reasonable, as deemed by the Range Safety Officer.

Dual deployment recovery method is used for the vehicle (drogue parachute deploys at apogee and main parachute 700*ft* (or other predetermined altitude). The vehicle has two fully independent and redundant deployment circuits. The backup charges are 25% larger than primary charges to increase the chance of deployment in the event of primary charge failure. – *Verified by preflight inspection and checklist*

2.2. Each team must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full scale launches.

Static ejection test are the standard step in our vehicle development process, starting with the subscale model and extending to the full scale vehicle as well.

2.3. At landing, each independent sections of the launch vehicle (as described in requirement 1.5) shall have a maximum kinetic energy of 75 ft-lbf.

The parachute sizes will be so chosen than no section of the rocket lands with kinetic energy greater than 75*ft-lbf*. – *Verified by measurement and calculations after the completion and first test flight of the full scale vehicle. Mass of each section and descent rates need to be measured to complete this verification. Preliminary verification has been completed using data from OpenRocket software.*

2.4. The recovery system electrical circuits shall be completely independent of any payload electrical circuits.

This performance target is a standard requirement for all Madison West projects and will be satisfied. – *Verified by inspection and preflight checklist.*

2.5. The recovery systems shall contain redundant, commercially available altimeters. The term "altimeters" includes both simple altimeters and more sophisticated flight computers.

We only use commercially available altimeters for deployment of recovery devices. Full redundancy of deployment electronics is a standard requirement for all Madison West sounding rocket projects. This performance target will be satisfied and documented. – *Verified by inspection and preflight checklist*

2.6. Motor ejection is not a permissible form of primary or secondary deployment.

Motor ejection charges are not used for the deployment, all deployment events are triggered by barometric altimeters. – *Verified by documentation review and preflight checklist and inspection. The motor charge will be removed from the motor.*

2.7. Each altimeter shall be armed by a dedicated arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.

Independent external switches are standard requirement for all Madison West sounding rocket projects. This performance target will be satisfied and documented. – *Verified by design and preflight inspection*

2.8. Each altimeter shall have a dedicated power supply.

Independent and dedicated power supplies for each deployment altimeter are standard requirement for all Madison West sounding rocket projects. This performance target will be satisfied and documented. – *Verified by design and preflight inspection*

2.9. Each arming switch shall be capable of being locked in the ON position for launch.

We use switches operated by a key. None of the switches can be moved after the key has been removed. None of the switches is momentary. – *Verified by preflight inspection*

2.10. Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment.

Removable shear pins will be used at all separation points. The shear pins will be tested during static ejection tests to assure that they will hold but not interfere with the separation of the corresponding compartment. – *Verified by preflight checklist and inspection*

2.11. An electronic tracking device shall be installed in the launch vehicle and shall transmit the position of the tethered vehicle or any independent section to a ground receiver.

Each section of the rocket is equipped by one radio and one sonic beacon. – *Verified by preflight checklist and inspection*

2.11.1. Any rocket section, or payload component, which lands untethered to the launch vehicle shall also carry an active electronic tracking device.
Target satisfied within 2.11.

2.11.2. The electronic tracking device shall be fully functional during the official flight on launch day.
All tracking devices will fully operational during official flight in Huntsville and if possible for all full scale vehicle test launches. – *Verified by preflight test and checklist*

2.12. The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight (from launch until landing).
There will be no interference between recovery deployment circuitry and payload or tracking circuitry. Shielding will be used as necessary. – *Verified during vehicle development and prior each flight.*

2.12.1. The recovery system altimeters shall be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.
The recovery system altimeters are housed in a dedicated e-bay, separate from all other electronics. – *Verified by inspection*

2.12.2. The recovery system electronics shall be shielded from all onboard transmitting devices, to avoid inadvertent excitation of the recovery system electronics.
Shielding will be used as necessary. All electronics will be ground tested for possible interference. – *Verified by inspection*

2.12.3. The recovery system electronics shall be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.
There are no magnetic wave generators on-board.

2.12.4. The recovery system electronics shall be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.
Shielding will be used as necessary. All electronics will be ground tested for possible interference. – *Verified by inspection and ground tests*

3. Competition and Payload Requirements

Each team shall choose any 2 payloads from Task 1, or have the choice to participate in the Centennial Challenge competition (Task 2).

We chose Task 2, the Centennial Challenge. Our rocket will be flown with a standard Centennial Challenge payload. – *Verified by project documentation review*

3.1. The payload shall be designed to be recoverable and reusable. Reusable is defined as being able to be launched again on the same day without repairs or modifications.
We will launch our rocket with a standard Centennial Challenge payload provided by a NASA official. – *Verified by postflight inspection*

3.2. (Task1) The team may choose to participate in 2 of the following payload options.
Not applicable.

3.2.1. A payload that shall gather data for studying the atmosphere during descent and after landing, including measurements of pressure, temperature, relative humidity, solar irradiance and ultraviolet radiation.
Not applicable.

3.2.1.1. Measurements shall be made at least once every second during descent, and every 60 seconds after landing. Data collection shall terminate 10 minutes after landing.
Not applicable.

3.2.1.2. The payload shall take at least 2 pictures during descent, and 3 after landing. The payload shall remain in orientation during descent and after landing such that the pictures taken portray the sky towards the top of the frame and the ground towards the bottom of the frame.
Not applicable.

3.2.1.3. The data from the payload shall be stored onboard and transmitted wirelessly to the team's ground station at the time of completion of all surface operations.
Not applicable.

3.2.2. A payload that scans the surface continuously during descent in order to detect potential landing hazards.

Not applicable.

3.2.2.1. The data from the hazard detection camera shall be analyzed in real time by a custom designed on-board software package that shall determine if landing hazards are present.
Not applicable.

3.2.2.2. The data collected shall be stored on board and transmitted wirelessly to the team's ground station.
Not applicable.

3.2.3. Liquid sloshing research in microgravity to support liquid propulsion systems.
Not applicable.

3.2.4. Structural and dynamic analysis of airframe, propulsion, and electrical systems during boost.
Not applicable.

3.2.4.1. The team must use and array of electrical sensors to measure structural vibration and to measure the stress and strain of the rocket in the axial and radial directions.
Not applicable.

3.2.4.2. At a minimum, structural analysis shall be performed on the fins/fin joints, all separation points, and the nose cone.
Not applicable.

3.2.5. A payload fairing design and deployment mechanism.
Not applicable.

3.2.5.1. The fairings and payload must be tethered to the main body to prevent small objects from getting lost in the field.
Not applicable.

3.2.6. An aerodynamic analysis of structural protuberances.
Not applicable.

3.2.7. Design your own payload (limit of 1). Must be approved by NASA review team.
Not applicable.

3.3. (Task 2) Centennial Challenge NASA University Student Launch Initiative is collaborating with the NASA Centennial Challenges Mars Ascent Vehicle (MAV) Project to offer teams the chance to design and build autonomous ground support equipment (AGSE). The Centennial Challenges Program, part of NASA's Science and Technology Mission Directorate, awards incentive prizes to generate revolutionary solutions to problems of interest to NASA and the nation. The goal of the MAV and its AGSE is to capture a simulated Martian payload sample, seal it within a launch vehicle, and prepare the vehicle for launch without the input from a human operator. For specific rules regarding the MAV project, and to learn more about Centennial Challenges, please visit the Centennial Challenge website at http://www.nasa.gov/mavprize and review their project handbook.

NOTE: The Centennial Challenge handbook is meant to be a complement to this handbook. If a team chooses to participate in the Centennial Challenge, they must abide by all the rules presented in this document.

3.3 Student Launch (Task 2) Centennial Challenge

3.3.1 Introduction

3.3.2 MAV Project – Competition and AGSE Requirements

3.3.2.1 The MAV Project will provide each team with the opportunity to develop a unique method to capture, contain, and launch a payload with limited human intervention. In addition, teams will develop a launch system that erects a rocket from a horizontal to vertical position, and has its igniter autonomously installed. The AGSE will be demonstrated at LRR and will follow this general procedure.

Requirements 3.3.2.1.1 – 3.3.2.1.4 shall be conducted autonomously from start to finish within a 10 minute time limit. The only allowed human interaction is the activation of the master switch.

Requirements 3.3.2.1.1 - 3.3.2.1.4 will be conducted autonomously from start to finish within a 10 minute time limit, and only activation of the master switch will involve human interaction. – *Verified by design and inspection*

3.3.2.1.1 Teams will position their launch vehicle horizontally on the AGSE.

Our launch vehicle will be positioned horizontally on the AGSE before demonstration. – *Verified by inspection before AGSE activation*

3.3.2.1.2 A master switch will be activated to power on all autonomous procedures and subroutines.

The central control will have a master switch that will be used to power on all autonomous procedures and subroutines. The controller is depicted on Figure 41, page 60. – *Verified by design and inspection*

3.3.2.1.3 All AGSEs will be equipped with a pause switch in the event that a judge needs the AGSE to be temporarily halted for any reason. The pause switch halts all AGSE procedures and subroutines. Once the pause switch is deactivated the AGSE resumes operation.

Our AGSEs will have a pause switch that halts all AGSE procedures and subroutines temporarily for any reason. Once the pause switch is deactivated all AGSEs will resume its operation. Cf. Figure 41, page 60. – *Verified by design and inspection*

3.3.2.1.4 Once the judge signals "START", the AGSE will begin its autonomous functions in the following order: 1) capture and containment of the payload; 2) erection of the launch platform from horizontal to 5.0 degrees off vertical (85.0 degrees), 3) insertion of the motor igniter. The judge may re-enable the pause switch at any time at his/her discretion. If the pause switch is re-enabled all systems and actions shall cease immediately. The judge will only do this if there is a question about safe operation of the AGSE. The judge and team leader will discuss and decide if the team will be allowed to continue their attempt. No modifications to the hardware or software will be allowed prior to a rerun.

The AGSE will proceed with its autonomous functions in the following order:

1) Capture and containment of the payload

2) Erection of the launch platform from horizontal to 5.0 degrees off vertical (85.0 degrees)
3) Insertion of the motor igniter once the start signal is given.

3.3.3 The Autonomous Ground Support Equipment (AGSE)

3.3.3.1 For the purpose of this challenge, the AGSE is defined as all mechanical and electrical components not part of the launch vehicle, and is provided by the teams. This includes, but is not limited to, the payload containment and igniter installation devices, computers, electric motors, batteries, etc.

We understand that the AGSE includes all mechanical and electrical components not part of the launch vehicle and will be provided by our team. – *Verified by inspection*

3.3.3.2 All AGSE systems shall be fully autonomous. The only human interaction will be if the judge pauses the AGSE.

All our AGSE systems will be fully autonomous and will not require any human interaction. The AGSE is fully described on pages 71-67 in this document. – *Verified by inspection*

3.3.3.3 The AGSE shall be limited to a weight of 150 pounds or less and volume of 12 feet in height x 12 feet in length x 10 feet in width.

Our AGSE will meet all weight, volume, and height requirements. Preliminary design has length of 11.5*ft*, width 4*ft* and height 10.5*ft*. – *Verified by measurement and inspection*

3.3.4 Prohibited Technology for AGSE

3.3.4.1.1 As one of the goals of this competition is to develop equipment, processes, and technologies that could be implemented in a Martian environment, the AGSE and any related technology cannot employ processes that would not work in such environments. Therefore, prohibited technologies include:

The following prohibited technologies (3.3.4.1.2- 3.3.4.1.6) will not be included in our AGSE or any related technology.

3.3.4.1.2 Sensors that rely on Earth's magnetic field

3.3.4.1.3 Ultrasonic or other sound-based sensors

3.3.4.1.4 Earth-based or Earth orbit-based radio aids (e.g. GPS, VOR, cell phone).

3.3.4.1.5 Open circuit pneumatics

3.3.4.1.6 Air breathing systems

None of the listed prohibited technologies is used in AGSE. Cf. pages 71-67 for full description of AGSE and technologies used. – *Verified by inspection*

3.3.5 Payload

3.3.5.1 Each launch vehicle must have the space to contain a cylindrical payload approximately 3/4 inch inner diameter and 4.75 inches in length. The payload will be made of ¾ x 3 inch Schedule 40 PVC tubing filled primarily with sand and may include BBs, weighing approximately 4 ounces and capped with domed PVC end caps. Each launch vehicle must be able to seal the payload containment area autonomously prior to launch.

The launch vehicle will have the space to contain a cylindrical payload approximately ¾ inch inner diameter and 4.75 inches in length. The payload will be made of Schedule 40 PVC tubing with the required elements. The launch vehicle shall be able to seal the payload containment area autonomously prior to launch. – *Verified by design and inspection*

3.3.5.2 A diagram of the payload and a sample payload will be provided to each team at time of acceptance into the competition. In addition, teams may construct practice payloads according to the above specifications; however, each team will be required to use a regulation payload provided to them on launch day.

A regulation payload will be used on launch day. – *Verified by inspection*

3.3.5.3 The payload will not contain any hooks or other means to grab it.

Our payload does not contain any hooks or other means to grab the payload. A gripper is used to grab the payload. Cf. **Error! Reference source not found.** on page **Error! Bookmark not defined.** for proposed gripper. – *Verified by inspection*

3.3.5.4 The payload shall be placed a minimum of 12 inches away from the AGSE and outer mold line of the launch vehicle in the launch area for insertion, when placed in the horizontal position on the AGSE and will be at the discretion of the team as long as it meets the minimum placement requirements.

Our payload shall meet the minimum placement requirements. – *Verified by measurement*

3.3.5.5 Gravity-assist shall not be used to place the payload within the rocket. If this method is used no points shall be given for payload insertion.

Gravity-assist is not used to place the payload within the rocket. The proposed AGSE can fully function without gravity. – *Verified by design and observation of AGSE functioning*

3.3.5.6 Each team will be given 10 minutes to autonomously capture, place, and seal the payload within their rocket, and erect the rocket to a vertical launch position five degrees off vertical. Insertion of igniter and activation for launch are also included in this time. Going over time will result in the team's disqualification from the MAV Project competition.

We will only require up to 10 minutes to autonomously capture, place, and seal the payload within their rocket, and erect the rocket to a vertical launch position five degrees off vertical. Preliminary calculations were made to assure that this constrain can be satisfied by proposed AGSE (cf. page **Error! Bookmark not defined.**-54). – *Verified by timing of the AGSE operation*

3.3.6 Safety and AGSE Control

3.3.6.1 Each team must provide the following switches and indicators for their AGSE.

3.3.6.1.1 A master switch to power all parts of the AGSE. The switch must be easily accessible and hardwired to the AGSE.

We will have a master switch to power all parts of the AGSE. It will be easily accessible and hardwired to the AGSE. Cf. Figure 41. – *Verified by inspection*

3.3.6.1.2 A pause switch to temporarily terminate all actions performed by AGSE. The switch must be easily accessible and hardwired to the AGSE.

A pause switch will be created which will temporarily terminate all actions performed by the AGSE. The switch will be easily accessible and hardwired to the AGSE. Cf. Figure 41. – *Verified by inspection*

3.3.6.1.3 A safety light that indicates that the AGSE power is turned on. The light must be amber/orange in color. It will flash at a frequency of 1 Hz when the AGSE is powered on, and will be solid in color when the AGSE is paused while power is still supplied.

We will have an amber/orange safety light which indicates that the power on the AGSE is turned on. It will flash at a frequency of 1 Hz when the AGSE is powered on, but will be solid in color when the AGSE is paused while power is still supplied. This is currently not shown on the pictures illustrating the AGSE but will be part of the AGSE. – *Verified by inspection*

3.3.6.1.4 An all systems go light to verify all systems have passed safety verifications and the rocket system is ready to launch.

We will have an all systems go light which will verify that all systems have passed safety verifications and the rocket system is ready to launch. This is currently not shown on the pictures illustrating the AGSE but will be part of the AGSE. – *Verified by inspection*

3.3.7 Failure of the MAV Project

3.3.7.1 Any team who fails to complete any of the procedures in requirement 3.3 will be ineligible of obtaining Centennial Challenges prizes.

We understand that any team who fails to complete any of the procedures in requirement 3.3 will be ineligible of obtaining Centennial Challenge prizes.

3.3.7.2 The head judge and the MAV Project Manager will have the final decision authority to determine if the procedures in requirement 3.3 have been met.

We understand that the head judge and the MAV Project Manager will have the final decision authority to determine if the procedures in requirement 3.3 have been met.

3.3.8 General Requirements Unique to Centennial Challenge MAV Project

3.3.8.1 Any academic team or non-academic team may participate in the MAV Project, however, to be eligible for prize money, less than 50% of the team make-up may be foreign nationals and the team entity must be a United States entity.

The team entity is a US entity (Madison West High School) and the team has less than 50% of foreign national students.

3.3.8.2 Name of person or business or entity who will be receiving the award check in the event the team places in the competition and address. If a business or other entity is to receive the check then also provide a tax identification number.

Ms. Christine Hager
Madison West High School
30 Ash St, Madison, WI 53726

3.3.8.3 In addition to SL requirements, for the CDR presentation and report, teams shall include estimated mass properties for the AGSE.

Our team shall include estimated mass properties for the AGSE. The current estimate is 106lbs. – *Verified by documentation*

3.3.8.4 In addition to SL requirements, for the FRR presentation, teams shall include a video presented during presentation of an end-to-end functional test of the AGSE. The video shall be posted on the team's website with the other FRR documents. Teams shall also include the actual mass properties for the AGSE.

We will produce a video which will be presented of an end-to-end functional test of the AGSE. We will post the video on the team's website with other FRR documents. – *Verified by website inspection*

4. Safety Requirements

4.1. Each team shall use a launch and safety checklist. The final checklists shall be included in the FRR report and used during the Launch Readiness Review (LRR) and launch day operations.
We will use a launch and safety checklist. The final checklist will be included in the Launch Readiness Review, and our list will be used during launch day operations. – *Verified by documentation review*

4.2. For all academic institution teams, a student safety officer shall be identified, and shall be responsible for all items in section 4.3. For competing, non-academic teams, one participant who is not serving in the team mentor role shall serve as the designated safety officer.
We will select a student safety officer, who will be responsible for all items in section 4.3. – *Verified by documentation review*

4.3. The role and responsibilities of each safety officer shall include but not limited to:
4.3.1. Monitor team activities with an emphasis on Safety during:
4.3.1.1. Design of vehicle and launcher
4.3.1.2. Construction of vehicle and launcher
4.3.1.3. Assembly of vehicle and launcher
4.3.1.4. Ground testing of vehicle and launcher
4.3.1.5. Sub-scale launch test(s)
4.3.1.6. Full-scale launch test(s)
4.3.1.7. Competition launch
4.3.1.8. Recovery activities
4.3.1.9. Educational Engagement activities
4.3.2. Implement procedures developed by the team for construction, assembly, launch, and recovery activities.
4.3.3. Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data.
4.3.4. Assist in the writing and development of the team's hazard analyses, failure modes analyses, and Procedures.

Our team's safety officer, William, will complete the listed tasks. William will be supervised by both official educators, Dr. Williamson and Mr. Schoneman.

4.4. Each team shall identify a "mentor." A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with the school, institution, or organization. The mentor shall be certified by the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle, and the rocketeer shall have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to the launch at the competition launch site. One travel stipend will be provided per mentor regardless of the number of teams he or she supports. The stipend will only be provided if the team passes FRR and the team and mentor attend launch week in April.

Mr. Brent Lillesand will serve as a mentor for this team. He is L3 certified, and is a member of both NAR and TRA. He will accompany the team to SL launch In Huntsville.

4.5. During test flights, teams shall abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA University Student Launch Initiative competition launch does not give explicit or implicit authority for teams to fly those certain vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.

During all test launches, we will abide by the rules and guidance of the RSO. Prior to any launch, we will communicate with the RSO to ensure that we will be able to test our vehicle as we require.

4.6. Teams shall abide by all rules and regulations set forth by the FAA.
We will abide by all rules and regulations set forth by the FAA.

5. General Requirements

5.1. Team members (students if the team is from an academic institution) shall do 100% of the project, including design, construction, written reports, presentations, and flight preparation. The one exception deals with the handling of black powder, ejection charges, and installing electric matches. These tasks shall be performed by the team's mentor, regardless if the team is from an academic institution or not.
Students will do 100% of the work on our vehicle, except for all tasks involving energetics. These tasks will be performed by our mentor.

5.2. The team shall provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assigned, educational engagement events, and risks and mitigations.
We will maintain a project plan, which will include all of the required information listed above.

5.3. Each team shall successfully complete and pass a review in order to move onto the next phase of the competition.
We will complete and pass each review prior to continuing the next phase of the competition.

5.4. Foreign National (FN) team members shall be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during launch week due to security restrictions. In addition, FN's will be separated from their team during these activities. If participating in the MAV task, less than 50% of the team make-up may be foreign nationals.
All foreign national team members will be identified prior to the Preliminary Design Review.

5.5. The team shall identify all team members attending launch week activities by the Critical Design Review (CDR). Team members shall include:

5.5.1. Students actively engaged in the project throughout the entirety of the project lifespan and currently enrolled in the proposing institution.
The team members are listed in **Error! Reference source not found.** on page **Error! Bookmark not defined.**.

5.5.2. One mentor (see requirement 4.4).
Mr. Brent Lillesand is the mentor for the team.

5.5.3. No more than two adult educators per academic team.

Not applicable.

All team members will be identified prior to the Preliminary Design Review.

5.6. The team shall engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics (STEM) activities, as defined in the Educational Engagement form, by FRR. An educational engagement form shall be completed and submitted within two weeks after completion of each event. A sample of the educational engagement form can be found in the handbook.

Our education engagements plan includes over 2500 students from local elementary and middle schools. At least 300 of those are middle school students. Educational engagement form will be completed and submitted within two weeks of each event's completion.

5.7. The team shall develop and host a Website for project documentation.

We will develop and host a Website for project documentation.

5.8. Teams shall post, and make available for download, the required deliverables to the team Web site by the due dates specified in the project timeline.

All required documents will be made available for download on our Website by the due date as specified in the project timeline.

5.9. All deliverables must be in PDF format.

All documents on our Website will be available in PDF format.

5.10. In every report, teams shall provide a table of contents including major sections and their respective sub-sections.

Every report will contain a table of contents listing major sections and all sub-sections.

5.11. In every report, the team shall include the page number at the bottom of the page.

Every report will contain the page number at the bottom of the page.

5.12. The team shall provide any computer equipment necessary to perform a video teleconference with the review board. This includes, but not limited to, computer system, video camera, speaker telephone, and a broadband Internet connection. If possible, the team shall refrain from use of cellular phones as a means of speakerphone capability.

We will be using fully equipped teleconference rooms in Engineering Hall at UW Madison.

5.13. Teams must implement the Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standards

The Section 508 is in detailed described on page 103.

Development Schedule

	NASA Date (documentation deadline, teleconference, SL2016 events)
	Classroom (writing session, data analysis, design meeting)
	Launch (test flight)
	Fundraising activity (raking or other manual work)
	Outreach event
	Workshop session (rocket building or repair, launch preparations)
	Organizational meeting (scheduling, past events review)
	Vacation time (holidays, school breaks)

Table 22: Color code for timeline

Project Timeline

	August 2015
Aug 7	RFP goes out
Aug 9	Writing Session
Aug 16	Writing Session
Aug 23	Writing Session
Aug 30	Writing Session
	September 2015
Sep 3	Robotics Workshop
Sep 4	Workshop
Sep 6	Writing Session
Sep 7	Organizational Meetings
Sep 10	Robotics Workshop
Sep 11	**SOW due**
Sep 11	Workshop
Sep 13	Writing Session
Sep 14	Organizational Meeting
Sep 17	Robotics Workshop
Sep 18	Workshop
Sep 20	Writing Session
Sep 21	Organizational Meeting
Sep 24	Robotics Workshop

Sep 25	Workshop
Sep 27	Writing Session
Sep 28	Organizational Meeting
	October 2015
Oct 1	Robotics Workshop
Oct 2	Awarded proposals announced
Oct 2	Outreach
Oct 2	Workshop
Oct 4	Writing Session
Oct 5	Organizational Meeting
Oct 7	Kickoff and PDR Q&A
Oct 8	Outreach
Oct 8	Robotics Workshop
Oct 9	Workshop
Oct 10	Fundraising (raking)
Oct 11	Writing Session
Oct 12	Organizational Meeting
Oct 15	Robotics Workshop
Oct 16	Workshop
Oct 17	Fundraising (raking)
Oct 18	Writing Session
Oct 19	Organizational Meeting
Oct 22	Robotics Workshop
Oct 23	**Team web presence established**
Oct 23	Workshop
Oct 24	Fundraising (raking)
Oct 24	Outreach
Oct 25	Writing Session
Oct 25	Outreach
Oct 26	Organizational Meeting
Oct 29	Robotics Workshop
Oct 30	Workshop
Oct 31	Fundraising (raking)
	November 2015
Nov 1	Writing Session
Nov 2	Organizational Meeting
Nov 5	Robotics Workshop
Nov 6	**PDR due**
Nov 6	Workshop

Nov 7	PDP practice
Nov 7	Fundraising (raking)
Nov 8	Writing Session
Nov 9	Organizational Meeting
Nov 12	Robotics Workshop
Nov 13	Workshop
Nov 14	Fundraising (raking)
Nov 9-20	PDP teleconferences
Nov 15	Writing Session
Nov 16	Organizational Meeting
Nov 19	Robotics Workshop
Nov 20	Workshop
Nov 21	Fundraising (raking)
Nov 22	Writing Session
Nov 23	Organizational Meeting
Nov 26	Robotics Workshop
Nov 27	Workshop
Nov 28	Fundraising (raking)
Nov 29	Writing Session
Nov 30	Organizational Meeting
Nov 21-Dec 11	Scale Model Building
	December 2015
Dec 3	Robotics Workshop
Dec 4	CDR Q&A
Dec 4	Workshop
Dec 5	Fundraising (raking)
Dec 6	Writing Session
Dec 7	Organizational Meeting
Dec 10	Robotics Workshop
Dec 11	Workshop
Dec 12	Scale Model Flight
Dec 13	Analysis of Flight Data
Dec 14	Organizational Meeting
Dec 17	Robotics Workshop
Dec 18	Workshop
Dec 20	Writing Session
Dec 27	Writing Session
	January 2016
Jan 3	Writing Session

Jan 4	Organizational Meeting
Jan 7	Robotics Workshop
Jan 8	Workshop
Jan 10	Writing Session
Jan 11	Organizational Meeting
Jan 14	Robotics Workshop
Jan 15	**CDR due**
Jan 15	Workshop
Jan 16	CDP practice
Jan 17	Writing Session
Jan 18	Organizational Meeting
Jan 21	Robotics Workshop
Jan 22	Workshop
Jan 24	Writing Session
Jan 19-29	CDP teleconferences
Jan 25	Organizational Meeting
Jan 28	Robotics Workshop
Jan 29	Workshop
Jan 30	Outreach
Jan 19- Feb 19	Full Scale Building
	February 2016
Feb 1	Organizational Meeting
Feb 3	FRR Q&A
Feb 4	Robotics Workshop
Feb 5	Workshop
Feb 7	Writing Session
Feb 8	Organizational Meeting
Feb 11	Robotics Workshop
Feb 12	Workshop
Feb 13	Outreach
Feb 14	Writing Session
Feb 15	Organizational Meeting
Feb 18	Robotics Workshop
Feb 19	Workshop
Feb 20	Full Scale Half Impulse Flight
Feb 21	Analysis of Flight Data
Feb 22	Organizational Meeting
Feb 25	Robotics Workshop
Feb 26	Workshop

Feb 27	Full Scale Full Impulse Flight #1
Feb 28	Analysis of Flight Data
Feb 29	Organizational Meeting
	March 2016
Mar 3	Robotics Workshop
Mar 4	Workshop
Mar 5	Full Scale Full Impulse Flight #2
Mar 6	Analysis of Flight Data
Mar 7	Organizational Meeting
Mar 10	Robotics Workshop
Mar 11	Workshop
Mar 12	Outreach
Mar 13	Writing Session
Mar 14	**FRR due**
Mar 14	Organizational Meeting
Mar 19	FRP practice
Mar 19	Outreach
Mar 21	Organizational Meeting
Mar 17-30	FRP teleconferences
Mar 28	Organizational Meeting
	April 2016
Apr 1	Outreach
Apr 4	Organizational Meeting
Apr 11	Organizational Meeting
Apr 13	Teams travel to Huntsville, AL
Apr 13	LRR's
Apr 14	Safety Briefings
Apr 14	LRR's
Apr 15	Rocket Fair
Apr 16	Launch Day
Apr 17	Back-up Launch Day
Apr 18	West Rocketry travels home
Apr 23	Writing Session
Apr 24	Writing Session
Apr 25	Organizational Meeting
Apr 29	**PLAR due**

Table 23: Project timeline

Gantt Chart

GANTT chart below shows the sequence, dependencies, overlaps and possible conflicts between different phases of the project. We use this chart to determine optimal schedule that will lead to successful and timely completion of our project.

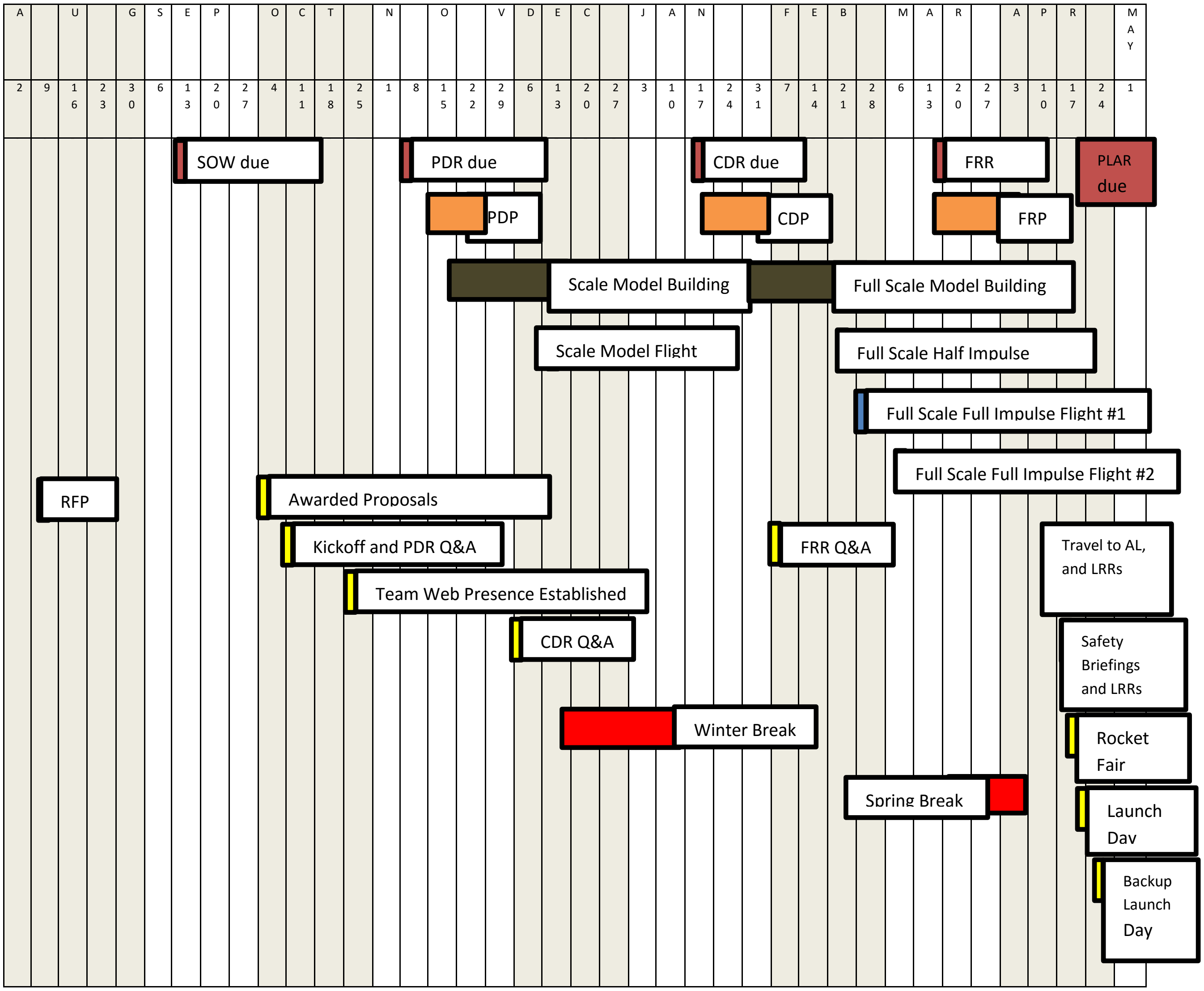

Figure 49: GANTT chart for SL2016 project

Project and Travel Budgets

We have assembled a detailed Bill of Materials (BOM) for the entire Maxi-MAV including payload, rocket, and AGSE. This is still in draft proposal form but this table attempts to anticipate every item required for the construction of the system, and specifies many key components or subsystems.

Methodology

We have broken down the anticipated costs of the delivered by subsystem and show a summary of those costs both in tabular and chart form below. Our methodology for this analysis has been to consider only the parts that will appear in the final Maxi-MAV system (vehicle and autonomous ground support). Therefore we include just one instance of expendable items (charges, rocket motors, ignitors). We do not include costs related to purchasing items due to minimum order quantities (e.g., nuts and bolts) nor do we include prototyping yield losses or related prototyping costs (buying multiple Arduino controller boards to cover damage and allowing for parallel development of subsystems.)

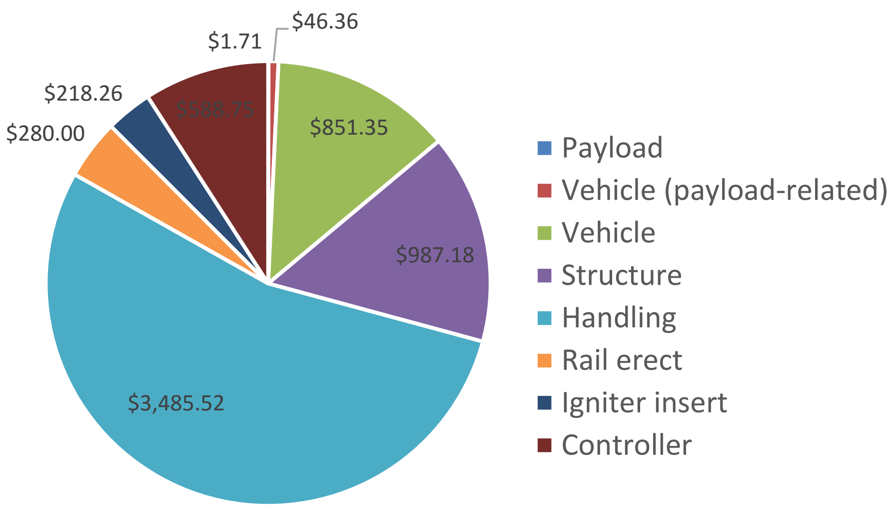

Figure 50. Cost breakdown by subsystem.

Table 24. List of costs for delivered prototype.

Subsystem	Cost	Comment
Payload	$1.71	just the PVC payload and weighting
Vehicle (payload-related)	$46.36	includes items required to retain and secure the payload
Vehicle	$851.35	all aspects of the rocket including structure, propulsion, recovery, telemetry
Structure	$987.18	the static superstructure of the ASGE
Handling	$3,485.52	the robotic motion control for acquiring and depositing the payload
Rail erect	$280.00	lifting the launch rail into a near-vertical position
Igniter insert	$218.26	insertion of the igniter into the engine
Controller	$588.75	all aspects of control including microcontroller, drivers, indicators, safety lights, housing, and po
	$6,459.12	

Materials Acquisition

Due to the cost constraints of the program budget we use commercially available off-the-shelf items (COTS) wherever possible. We have generally focused on vendors who serve the hobbyist market and consumer markets and thus have lower costs. One advantage of this approach is that these vendors all tend to provide accessories compatible with the components being purchased, limiting the number of custom parts required to assemble the system.

Our detailed BOM lists many of the key vendors anticipated to be used, many of which the team has a lot of experience with already.

A vast majority of the BOM must be purchased commercially and we will use club funds to obtain these parts – these fundraising activities are described elsewhere. Some commercial items, such as 8020 rail, mechanical hardware, and some piece parts have been donated by parents or local businesses, and the AGSE design intends to re-use/incorporate these parts as much as the design will allow.

The team's workshop has basic tools for modifying plastic and metal parts suitable for some of the customizations and fabrications. The workshop also owns several ABS-based extrusion-type rapid-prototyping machines that will be used to fabricate small or low-strength parts for the vehicle and some parts for the AGSE. Costs included in the budget are estimates for the raw material (e.g., ABS filament for the 3D printers or metal stock to be machined or modified) but not the depreciation of the machines used to perform the fabrication.

Although the overall design minimizes the need for custom parts, a few key high-strength/durability parts will need to be designed by the team and purchased as a machined part. We have good relationships with local and low-cost rapid-turn machine shops to minimize the out-of-pocket costs of these parts.

These custom efforts and designs are supported indirectly by the solid modelling capability of the team, with sufficient academic licenses for multiple team members to contribute directly to the mechanical design of the rocket and AGSE, and generate the files required for our rapid prototyping machine shop vendors and the 3D printers in the shop.

Description	QTY	uom	Cost ea	Cost extend	Status
Payload				$1.71	
PVC pipe, schedule 40	0	ft	$1.50	$0.50	Spec Locked
PVC end cap	2	ea	$0.32	$0.64	Spec Locked
Bead shot, copper/lead	0.05	bottle	$5.49	$0.27	Concept
RTV, silicone	0.05	tube	$6.00	$0.30	Concept
Vehicle - Payload retention				$46.36	
Clip, payload retention, chrome steel	2	ea	$0.95	$1.90	Engineering
Magnet, high-strength	4	ea	$0.79	$3.16	Spec Locked
Magnet mount	1	ea	$4.00	$4.00	Concept
Steel shim	1	ea	$2.00	$2.00	Concept
Mounting boss	1	ea	$10.00	$10.00	Concept
Eyeglass hinge	1	ea	$0.50	$0.50	Engineering
Length of tube coupler, cut out	6	in	$0.80	$4.80	Concept
Other	1	lot	$20.00	$20.00	Concept
Vehicle				$851.35	
Tube, fiberglass, 3 inch OD	78	in	$0.80	$62.40	Engineering
Nose cone	1	ea	$30.00	$30.00	Engineering
Payload door	1	ea	$3.00	$3.00	Engineering
Fin	4	ea	$5.00	$20.00	Engineering
Altimeter	2	ea	$55.00	$110.00	Engineering
Locator beacon/radio	1	ea	$80.00	$80.00	Engineering
Battery	1	ea	$5.00	$5.00	Engineering
Switchgear/wiring	1	ea	$20.00	$20.00	Engineering
Parachute, main	1	ea	$35.00	$35.00	Engineering
Parachute, drogue	1	ea	$25.00	$25.00	Engineering
Ejection charge	1	ea	$3.00	$3.00	Engineering
Motor casing	1	ea	$30.00	$30.00	Engineering
Motor	1	ea	$112.95	$112.95	Engineering
Rail bead	2	ea	$1.50	$3.00	Engineering
Altimeter bracket	1	ea	$12.00	$12.00	Engineering
Other	1	lot	$300.00	$300.00	Engineering
AGSE Superstructure				$987.18	
Foot, swivel	6	ea	$5.20	$31.20	Engineering
Angle bracket	12	ea	$17.15	$205.80	Concept
Corner cube	6	ea	$4.83	$28.98	Concept
8020 rail, main support, 6 x 48 in each	288	in	$0.27	$79.16	Concept
8020 rail, legs, 6 x 2 in each	12	in	$0.27	$3.30	Concept
8020 rail, extenders, 2 x 72 in ea	144	in	$0.27	$39.58	Concept
8020 rail, robot support, 4 x 36 in	144	in	$0.27	$39.58	Concept
8020 rail, launch	96	in	$0.27	$26.39	Concept
8020 rail, other/brackets	48	in	$0.27	$13.19	Concept
Blast deflector shield	1	ea	$75.00	$75.00	Concept
Blast deflector bracket	1	ea	$15.00	$15.00	Concept
Screws and bolts	1	lot	$100.00	$100.00	Concept
Nest, plastic, for rocket body	1	ea	$30.00	$30.00	Concept
Braces and brackets, misc	1	lot	$100.00	$100.00	Concept
Other	1	lot	$200.00	$200.00	Concept
Payload handling				$3,485.52	
Laser, structured lighting	1	ea	$38.62	$38.62	Concept
Bracket, laser to frame	1	ea	$12.00	$12.00	Concept
Vertical linear motion stage, >8" travel	1	ea	$1,500.00	$1,500.00	Concept
Rotary stepper motor, NEMA housing	1	ea	$80.00	$80.00	Concept
Vertical mounting bracket	1	ea	$350.00	$350.00	Concept
Motor to linear stage mounting bracket	1	ea	$250.00	$250.00	Concept
Arm, >18" long	1	ea	$250.00	$250.00	Concept
Payload clip	1	ea	$0.95	$0.95	Concept
Payload vertical extender	1	ea	$50.00	$50.00	Concept
Payload door closure linear cylinder	1	ea	$41.95	$41.95	Concept
End ball or roller	1	ea	$10.00	$10.00	Concept
End mount bracket	1	ea	$15.00	$15.00	Concept
Door closure cylinder mounting	1	ea	$35.00	$35.00	Concept
Braces and brackets, misc	1	lot	$250.00	$250.00	Concept
Screws and bolts	1	lot	$100.00	$100.00	Concept
Cable ties for wire retention	1	lot	$2.00	$2.00	Concept
Other	1	lot	$500.00	$500.00	Concept

Description	QTY	uom	Cost ea	Cost extend	Status
Rail erecting				$280.00	
Pivot bearing, pillow	2	ea	$8.00	$16.00	Concept
Shoulder bolts for shaft	2	ea	$6.00	$12.00	Concept
Microswitch	2	ea	$3.00	$6.00	Concept
Linear actuator, 15" stroke	1	ea	$120.00	$120.00	Engineering
Rubber bumper hard stop	2	ea	$4.00	$8.00	Concept
Latch/retainer	1	ea	$30.00	$30.00	Concept
Wiring harness, erecting	1	ea	$10.00	$10.00	Concept
Bracket, motor to superstructure	2	ea	$8.00	$16.00	Concept
Screws and bolts	1	lot	$10.00	$10.00	Concept
Cable ties for wire retention	1	lot	$2.00	$2.00	Concept
Other	1	lot	$50.00	$50.00	Concept
Igniter insertion				$218.26	
Carbon tube, cut to length	0.3	ea	$10.89	$3.27	Engineering
Linear actuator, 20" stroke	1	ea	$119.99	$119.99	Received
Wiring harness, igniter insertion	1	ea	$5.00	$5.00	Concept
Bracket, actuator to rail	2	ea	$8.00	$16.00	Concept
Bracket, tube to actuator	1	ea	$12.00	$12.00	Concept
Screws and bolts	1	lot	$10.00	$10.00	Concept
Cable ties for wire retention	1	lot	$2.00	$2.00	Concept
Other	1	lot	$50.00	$50.00	Concept
Controller and interface				$580.10	
Project housing	1	ea	$35.00	$35.00	Concept
Battery	1	ea	$30.00	$30.00	Engineering
Arduino Uno R3	1	ea	$24.95	$24.95	Engineering
Shield, relay driver	3	ea	$15.75	$47.25	Concept
Stepper driver	2	ea	$24.95	$49.90	Concept
LCD display with driver	1	ea	$25.00	$25.00	Engineering
E-stop button	1	ea	$25.00	$25.00	Concept
Pushbutton	1	ea	$8.00	$8.00	Concept
LED, tricolor, with bezel	1	ea	$5.00	$5.00	Concept
Connector, panel, payload	1	ea	$15.00	$15.00	Concept
Connector, panel, erector	1	ea	$15.00	$15.00	Concept
Connector, panel, igniter insertion	1	ea	$15.00	$15.00	Concept
Indicator tower LEDs	3	ea	$3.00	$9.00	Concept
Plastic containers for tower indicator	3	ea	$2.00	$6.00	Concept
Pole for indicator tower	1	ea	$3.00	$3.00	Concept
Wire harnesses	1	ea	$50.00	$50.00	Concept
Connector, power (battery)	1	ea	$5.00	$5.00	Concept
Mounting for Arduino and shields	1	ea	$50.00	$50.00	Concept
Bracket from housing to 8020	1	ea	$100.00	$100.00	Concept
Screws and bolts	1	lot	$10.00	$10.00	Concept
Cable ties for wire retention	1	lot	$2.00	$2.00	Concept
Other	1	lot	$50.00	$50.00	Concept

Other costs

Not included in the total costs for the single AGSE + Maxi-MAV "deliverable" are the prototyping costs, shipping charges and estimated local sales taxes where applicable. Nearly all items will be acquired through on-line retailers located out of state so only a portion of the purchased BOM is subject to in-state taxes.

We estimate these additional (not part of project budget limit of $7500) costs as follows:

- Scale model costs $350
- Motors for test flights $370
- Shipping (30 shipments from 12 different vendors $350
- Sales taxes (5.5% on 10% of BOM expenditures) $50
- Other $500
- **TOTAL $1620**

Table 25: Project budget

Travel Budget	
Flight	
$400/Person * 13 People	$5,200.00
Rooms	
$119/Room * 7 Rooms * 5 Nights	$3,094.00
Car Rental (Ground Support Vehicle)	
$500 rental+ $600 gas	$1570.00
Total	$9,864.00
Cost per Team Member	**$ 986.40**

Table 26: Travel Budget

Funding Plan

Madison West Rocket Club has sufficient money earning opportunities (raking leaves/yardwork and donations from families or local companies) to earn enough money to cover the estimated budget and cover for possible discrepancies between the estimated budget and actual project expenses. Additionally, it is our policy to provide necessary economic help to all SLI students who cannot afford the travel expenses associated with the program. Every year we award several full expense travel scholarships both to our SLI and TARC students. The monetary amounts and the names of recipients are not disclosed.

SL program is extremely well received by Madison community and we enjoy significant support from local companies, families of students and researchers and labs at University of Wisconsin. We maintain and expand our network of supporters via various venues, mostly through our participation in public outreach events.

Based on our last year data and estimated costs for this years, we expect the following breakdown of funds and expenses:

Expenses		
Project cost	$6,500.00	
Workshop rental	$1,000.00	
Workshop insurance	$400.00	
Teleconferencing fees	$0.00	Venue and equipment provided at no cost by Chemical Engineering Dept.
Outreach costs	$500.00	
Travel expenses	$9,864.00	
Total Expenses	***$18,264.00***	
Funds		
Raking fundraiser	$4,000.00	
Donations from families	$3,000.00	
Material support from companies	$1,500.00	
Material support from UW	$1,000.00	
Travel funds	$9,864.00	Students pay the travel expenses associated with SL launch
Total Funds	***$19,364.00***	

Table 27: Funding plan

Safety and Risks (project-wide)

Written Safety Plan

Safety officer responsible for enforcement of the safety plan is William. He will be aided and supervised by educators, Dr. Rob Williamson, Mr. Joseph Schoneman and mentor Mr. Brent Lillesand.

We have identified the following risks that could endanger the successful completion of our project (listed with proposed mitigations):

- **Facility Risks:**
  - ***Workshop inaccessible:*** we have singed rental agreement for our workshop space and should it become temporarily inaccessible, we will work with our landlord to resolve the issue in a timely manner. Rocket construction can be also temporarily moved to Mr. Lillesand's house.
  - ***Classrooms unavailable:*** the classrooms are provided by Engineering Dept. and Physics Dept. of UW, Madison. This provides sufficient redundancy. We can also utilize other options, such as reserving meeting room in a local library or temporarily meeting in club member's house.
  - ***Launch site unavailable/inclement weather:*** we routinely schedule redundant launch windows to ensure that we will have enough opportunities to carry out all necessary flights. We are currently working with three rocketry organizations (NAR Section WOOSH, TRA WI and TRA QCRS) to maximize our launch opportunities.

- **Project Risks:**
  - ***Project behind schedule:*** project progress is constantly compared against list of required milestones and working hours are extended as necessary to meet all milestones. All deadlines are considered hard.
  - ***Key team member unavailable:*** no task is assigned to a single team member; all tasks are carried out by a pair or small group of equally knowledgeable students. Students are not allowed to limit their participation in the project to a single area of expertise.
  - ***Unsolvable technical problem:*** a thorough feasibility review is conducted before the Statement of Work is submitted. Alternative solutions will be sought.
  - ***Unresolvable personal disagreements:*** should the students involved fail to reach an acceptable compromise, the educators will protect the progress of the project, regardless of the interests of the parties in the dispute. All students were informed of this rule before admission to the program.
  - ***Part unavailability:*** all purchasing is conducted as soon as practically possible. We are also working with several vendors, trying to maintain part availability redundancy as much as possible.
  - ***Budget overrun:*** the initial fundraising goal is set at 140% of estimated project expense.

- **Vehicle risks:**

- **Repeated test flight failure:** rocket design review, performance prediction evaluation, static stability check and static ejection tests will be carried out before each test flight. A due consideration will be given to weather conditions to maximize the probability of safe flight and successful recovery. All flight data will be analyzed to identify problems before next flight.
- **Vehicle lost/irreparably damaged during test flight:** a sufficient time reserve will be built into project schedule to allow for vehicle replacement. All team members will participate in additional workshop hours. The airborne vehicle will be tracked using three different methods: CAT (Cloud Aided Telemetry), radio beacon and sonic beacon.

- **AGSE Risks:**
  - ***Mechanical runaway, failure to pause:*** the system will be equipped with an emergency stop button that will physically cut all power to the AGSE. The pause functionality will be implemented in AGSE firmware, the emergency stop functionality will be a physical disconnection from power source. There are no moving parts that can be moved by gravity force alone, once the power is cut from the system, all movement stops immediately.
  - ***Failure to stop motion:*** should any of the end-stop microswitches fail, the operator still retains the option of pausing or completely stopping the system. System can continue operation from a paused state, however it will reset from the stopped state, before it can start the operation again (a system self-check at power up will recognize this state).
  - ***Structural failure:*** the superstructure of the AGSE will be inspected prior each demonstration for weakened parts or loosened screws.
  - ***Electrical shock:*** AGSE power comes from batteries and all electrical connections will be properly insulated and inspected on regular basis. AGSE will not be powered up until all team members are in the safe distance. Fuses will be used to prevent short-circuits.
  - ***Unauthorized use of AGSE or accidental activation:*** the control panel has a key operated master switch, preventing unauthorized use.

- **Personal risks:**
  - ***Physical injury:*** the use of Personal Protective Equipment is mandated during all construction tasks and preparation of the rocket for flight or static test. Adult supervision is provided at all times. The use of headphones and personal electronics during rocketry activities and workshop hours is strictly prohibited. The safe distance from AGSE will be maintain at all times when the AGSE is powered.
  - ***Toxicity:*** MSDS documentation is available for all chemicals used in the project and dangerous chemicals are avoided as much as possible. Adult supervision is provided at all times, PPE use is mandated.

NAR/TRA Personnel

Mr. Brent Lillesand (L3 certified, NAR and TRA member) is the mentor for the team and designated owner of the rocket for liability purposes. Mr. Lillesand will accompany the team to Huntsville, AL.

All hazardous materials will be purchased, handled, used, and stored by Mr. Lillesand or project educators (Dr. Williamson or Mr. Schoneman). Mr. Lillesand will be the only person purchasing and handling energetics. The use of hazardous chemicals in the construction of the rocket, will be carefully supervised by NAR mentor and project educators. MSDS data will be available both as a hardcopy and online materials.

In the construction of our vehicle, only proven, reliable materials made by established manufacturers, will be used under the supervision of the mentor and educators. We will comply with all NAR standards regarding the materials and construction methods. Reliable, verified methods of recovery will be exercised during the retrieval of our vehicle. Motors will be used that fall within the NAR HPR Level 2 power limits as well as the restrictions outlined by the SL program.

Additionally, All HPR flights will be conducted only at public launches covered by an HPR waiver (mostly the WOOSH/NAR Section #558 10,000ft MSL waiver for Richard Bong Recreation Area launch site and 15,000ft MSL waiver for Princeton, IL, TRA QCRS site). We will be assisted by members of hosting section (WOOSH, TRA WI or TRA QCRS) and follow all instructions provided by their range personnel and our mentor.

All LMR flights will be conducted only at the launches with the FAA notification phoned in at least 24 hours prior to the launch. NAR and NFPA Safety Codes for model rockets and high power rockets will be observed at all launches.

Team Members Safety Briefing

Mentor, educators and experienced rocketry team members will take time to teach new members the basics of rocket safety. All team members will be taught about the hazards of rocketry and how to respond to them; for example, fires, errant trajectories, and environmental hazards. Students will attend mandatory meetings and pay attention to pertinent emails prior participation in any of our launches to ensure their safety. A mandatory safety briefing will be held prior each launch. During the launch, adult supervisors will make sure the launch area is clear and that all students are observing the launch. Our NAR mentor will ensure that any electronics included in the vehicle are disarmed until all essential pre-launch preparations are finished. All hazardous and flammable materials, such as ejection charges and motors, will be assembled and installed by our NAR-certified mentor, complying with NAR regulations. Each launch will be announced and preceded by a countdown (in accordance with NAR safety codes)

Safety Documentation Procedures

In all working documents, all sections describing the use of dangerous chemicals will be highlighted. Proper working procedure for such substances will be consistently applied, including the required PPE (Personal Protective Equipment), such as using protective goggles and gloves while working with chemicals such as epoxy. MSDS sheets will be on hand at all times to refer to for safety and emergency procedures. All work done on the building of the vehicle will be closely supervised by adult mentors, who will make sure that students use proper protection and technique when handling dangerous materials and tools necessary for rocket construction.

Compliance with Federal, State and Local Laws

All team members and mentors will conduct themselves responsibly and construct the vehicle and payload with regard to all applicable laws and environmental regulations. We will make sure to minimize the effects of the launch process on the environment. All recoverable waste will be disposed properly. We will spare no efforts when recovering the parts of the rocket that drifted away. Properly inspected, filled and primed fire extinguishers will be on hand at the launch site.

The team is cognizant and will abide with the following federal, state and local laws regarding unmanned rocket launches and motor handling:

- Use of airspace: Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C
- Handling and use of low explosives: Code of Federal Regulation Part 55
- Fire Prevention: NFPA1127 Code for High Power Rocket Motors

All of the publications mentioned above are available to the team members and mentors via links to the online versions of the documents.

http://westrocketry.com/sli2016/safety/safety2016r.php

Energetics Purchase, Storage, Transport and Use

NAR/TRA mentor, Mr. Lillesand, holds a Level 3 HPR certification. Mr. Lillesand has Low Explosives User Permit (LEUP). If necessary, the team can store propellant with Mr. Goebel (Level-3 certified), who owns a BATFE approved magazine for storage of solid motor grains containing over 62.5 grams of propellant. In most cases, the motors and electrical matches are purchased from the on-site vendor, Mr. Tim Lehr of Wildman Rocketry and used on the same day. Mr. Lillesand will be the sole person to purchase and handle energetics (motors, ejection charges and igniters). Mr. Lillesand will be responsible for depositing unused propellant with Mr. Goebel, should the need arise. Only NAR/TRA certified motors will be used.

Written Safety Statement

All team members and educators understand and will unconditionally abide by the following safety regulations

Range Safety Inspection

Range safety inspections of each rocket before it is flown. Each team shall comply with the determination of the safety inspection.

RSO Ruling Compliance

The Range Safety Officer has the final say on all rocket safety issues. Therefore, the Range Safety Officer has the right to deny the launch of any rocket for safety reasons.

Team Compliance with Safety Requirements

Any team that does not comply with the safety requirements will not be allowed to launch their rocket.