STATEMENT OF WORK

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*** | **September 11th 2015**

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

Table of Contents

List of Figures

List of Tables

General Information

Organization Information

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

Educators

Joseph D. Schoneman
5160 E. Cheryl Pkwy, Madison, WI 53711
Phone : (608) 772-9616
E-mail : schoneman@wisc.edu

Dr. Robert Williamson
2730 Gregory St., Madison, WI 53711
Phone : (608) 213 7255
E-mail : iiiwsv@gmail.com

Safety Officer

Our Safety Officer is William (SL2015 participant)

Team Information

Leader: Mathilda (SL2015 participant) mmharris@madison.k12.wi.us
Number of team members: 10 (listed on the next page) and mentor Brent Lillesand

Team Members

Delivery Team: *responsible for vehicle design, flight safety parameters, altitude target, propulsion and launch operations*		
 **JASON** *Lead Vehicle Engineer*	 **MATHILDA** *Vehicle operations and safety, team leader*	 **RAMYASREE** *Vehicle construction*
Deployment Team: *responsible for deployment electronics, parachute selection and preparation, parachute and ejection charges calculation, ejection static testing, impact energy management*		
 **AASTHA** *Deployment and recovery*		 **SIYI** *Deployment and recovery*
AGSE Team: *responsible for development, testing and operation of autonomous ground support equipment*		
 **SEBASTIAN** *AGSE Construction Lead*	 **DAN** *Rapid prototyping, AGSE construction*	 **WILLIAM** *AGSE firmware Webmaster Safety Officer*
Telemetry Team: *responsible for maintaining wireless contact with the rocket, receiving data from on-board GPS, avionics and payload, tracking and locating the rocket*		
 **ERIC** *GPS/CAT tracking*		 **JEFF** *Radio and optical tracking*

Table 1: Team members and proposed duties

The table above shows all **10** team members and their proposed duties. Jason, Mathilda, Ramyasree, Sebastian, Dan and William participated in SL2015 program. Safety officer is William, team leader is Mathilda.

Supporting NAR/TRA Section

NAR Section #558 WOOSH
President: Mark Hackler
E-Mail: Mark.Hackler@att.net
http://www.wooshrocketry.org

Tripoli Wisconsin
President: Frank Nobile
http://tripoliwisconsin.com

Facilities and Equipment

Facilities

Planning, discussion, design concept and writing will occur at UW Madison, Dept. of Physics, Room #2223, located at Chamberlin Hall, 1150 University Avenue, Madison, Wisconsin, 53705, on the weekends. Our alternate classroom location (added this year) are various classrooms in Engineering Hall, 1415 Engineering Drive, Madison, Wisconsin, 53705.

Construction of the rocket will occur at a workshop at 3555 University Ave, Madison, Wisconsin, 53705, on the weekends or as necessary. We have a 24/7 access to this facility. The workshop has three connected rooms, one room dedicated to machinery, another being designated for electronics manufacturing and also serving as staging area and finally third room housing all our computers and also serving as the design and discussion area (with several whiteboards mounted on the walls).

Construction of the payload will also occur at a workshop at 3555 University Ave, Madison, Wisconsin, 53705, on the weekends. Preparation of the payload contents will occur at a workshop at 3555 University Ave, Madison, Wisconsin, 53705, on the weekends.

Team organizational meetings will occur during lunchtime every Monday in Room 365 of Madison West High School, 30 Ash Street, Madison, Wisconsin, 53726.

Launching of low-powered scale model rockets will occur on weekends from November through April, at Cross Plains site, located at 3876 Observatory Rd, Cross Plains, WI 53528]. Large Model Rocket Launch notification will be made to comply with FAA regulations Part 101. NFPA code 1122 and NAR Model Rocket Safety Code will be followed during these launches. Mentors will supervise all launches.

Launching of high-powered rockets will occur at Richard Bong Recreational Area located in Southeast Wisconsin at 26313 Burlington Road, Kansasville, Wisconsin, 53189. We will obtain Power Rocket Altitude waivers from the FAA prior to high power launches. High power launches will coincide with the high power launch of WOOSH, Section 558 of the NAR. Additional high power launches can be conducted at TRA QCRS (Tripoli Quad Cities) launches near Princeton, IL. Mentors will supervise all launches.

Hours

Workshop hours are set based on team member's availability and project needs. An example of our regular schedule (based on last year's data) is:

Day	From	To	Activity	Location
Monday	11:30AM	12:15PM	Organizational Meeting	Madison West HS, room #365
Thursday	05:00PM	09:00PM	Robotics and 3D printing workshop	Workshop, 3555 University Ave
Friday	05:00PM	10:00PM	Rocketry Workshop	Workshop, 3555 University Ave
Saturday	08:00AM	04:00PM	Launch	Cross Plains, Bong or Princeton
Sunday	10:00AM	04:00PM	SL Writing Session	Chamberlin Hall or Engineering Hall

Table 2: Facility hours

Personnel

We have five engineers working with students in workshop on regular basis:

Dr. Pavel Pinkas, chemical and software engineer, also trained in electronics design
Mr. James Guither, mechanical engineer, in charge of 3D printing and mechanical design
Mr. Joseph Schoneman, mechanical engineer, consulting and lead for SL teams
Dr. Robert Williamson, mechanical engineer, consulting and lead for SL teams
Mr. Brent Lillesand, mechanical engineer, high power rocket construction and flight tests

In classroom setting, the following educators work with students on regular basis:

Ms. Christine Hager, microbiologist and biology teacher, 11 years of SL experience
Dr. Pavel Pinkas, chemical and software engineer, 11 years of SL experience
Mr. Josheph Schoneman, mechanical engineer, 3 years of experience in high school education
Dr. Robert Williamson, mechanical engineer, several years of experience in K1-K12 education

Equipment

We have a fully equipped workshop, suitable for machining, electronics development and design meetings and discussions. The workshop has three rooms:

1. **Machinery room:** equipped with heavy machinery such as band saw, router, drill press, rotary saw, belt sander and jig saw. Also available are hand held power tools, such as corded and cordless drills, Dremel rotary tools and orbital sanders. Finally, we have the necessary collection of hand tools, including hacksaws, X-acto knives, box cutters, various clamps, screwdrivers, crescent wrenches, hammers, pliers, clippers and vices of several sizes. Gluing and assembly is also done in this room. Use of personal protective equipment is mandated in this room. This room has industrial strength air filtering.

2. **Electronics room:** this room is equipped for design and assembly of printed circuit boards, as well for miscellaneous soldering task. We have several solders with temperature control, hot air rework station, crimpers for various connectors, fluorescent lit magnifier lamps (for SMD assembly), vices to hold printed circuit boards during assembly and a selection of helping hand type grips. Use of personal protective equipment is mandated in this room. This room has sufficient filtering for soldering tasks and connects to the air-filtering circuit of machinery room.
3. **Computer and meeting room:** we have several computers available for computer aided design (RockSim, OpenRocket, SolidWorks, PCB Artist) and data analysis. We have 60 licenses to SolidWorks program that allow our students to explore the possibilities of rapid prototyping and 3D printing. Most of the wall space in this room is covered with whiteboards, allowing students to participate in design discussions and problem solving sessions.

Supplies

During the active season we maintain reasonable stock of common supplies and parts for rocket construction.

- **Rocket parts** are purchased on as-needed basis or selected from surplus from past projects. Fiberglass tubes are preferred (weight budget permitting) and fins are also mostly built from G10 sheets (acquired from McMaster-Carr company). We use commercially made plastic or fiberglass nosecones (purchased from Wildman Rocketry). We manufacture bulkheads and centering rings, either using router for plywood parts or 3D printer for PLA or ABS parts. Anchors and other hardware are purchased from local hardware stores (Ace, Home Depot, Menards). Parachutes are bought from online vendors (Giant Leap Rocketry for example). The shockcord (if not available from past projects) are purchased at local REI store (outdoor equipment).
- **Glues:** we stock several kinds of glue, including short- and long-cure epoxy, superglue and wood glue. We also maintain necessary assortment of tapes, including electrical tape, masking tape and double sided tape.
- **Electronic components** and soldering supplies are acquired from several online vendors, including superstores such as Mouser, DigiKey or Newark, smaller hobby oriented stores, for example SparkFun, AdaFruit and Parallax and the few remaining local RadioShack stores.
- **Miscellaneous** supplies such as notepads, rulers, pens, rubber gloves, safety goggles, solvents and batteries are procured from local department stores.

Safety

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.

Technical Design

Vehicle

We will use a single stage, K-class vehicle to deliver the standard MAV payload to the target altitude of 5,280*ft*. We will be measuring muon flux at different altitudes.

The rocket will be constructed from 4” 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 88 inches long, with a 4.0 inch diameter. It has estimated liftoff mass of 15.5 pounds. The proposed vehicle and propulsion options are discussed in detail below. The primary propulsion choice is a K-class motor (CTI K1620-VMax, 98*mm*) with total impulse of 1874*Ns*. The vehicle can launch from a standard size, 10*ft* launch rail.

The rocket will use dual deployment to minimize drift.

Dimensions

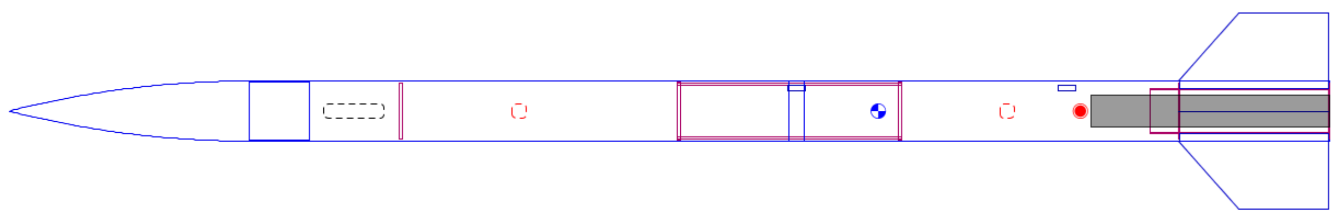

Figure 1: A two dimensional schematic of the entire rocket.

Vehicle Parameters

The table below shows the primary design parameter s of our vehicle.

Length *[in]*	Mass *[lbs]*	Diameter *[in]*	Motor Selection	Stability Margin *[calibers]*	Thrust to weight ratio *(g)*
88	15.5	4	CTI K740CS	3.37	12.82

Table 3: 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.

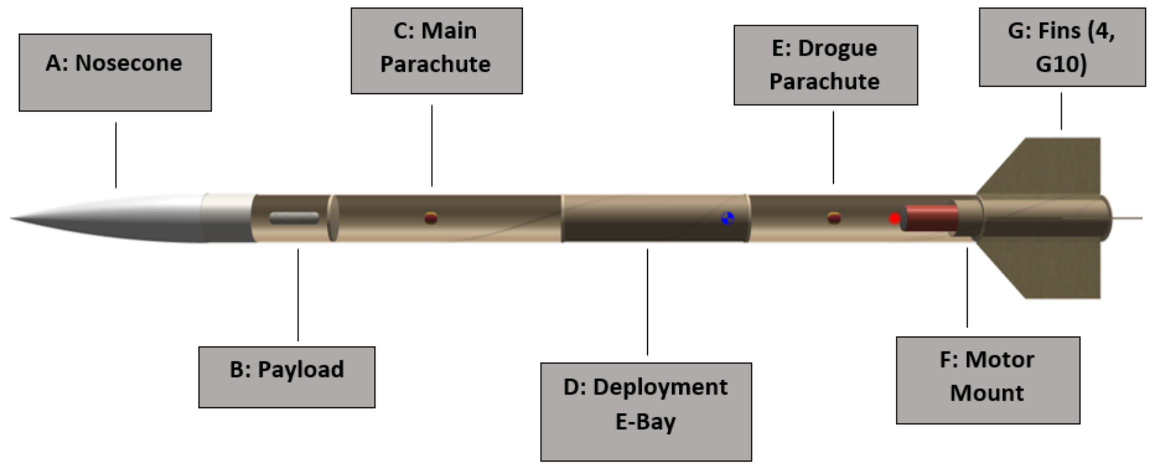

Figure 2: A three dimensional schematic of the entire rocket

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 4: 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	Aircraft Plywood
Anchors	¼” stainless steel U-bolts
Tie-rods	¼” stainless steel threaded rods

Table 5: 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.

Performance Predictions

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

Altitude Profile

The graph below shows the simulated flight profile for the Cesaroni K740CS motor. The simulated vehicle reaches the apogee of 5246*ft* seventeen 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 15*mph* wind conditions is 0.452*mi.*

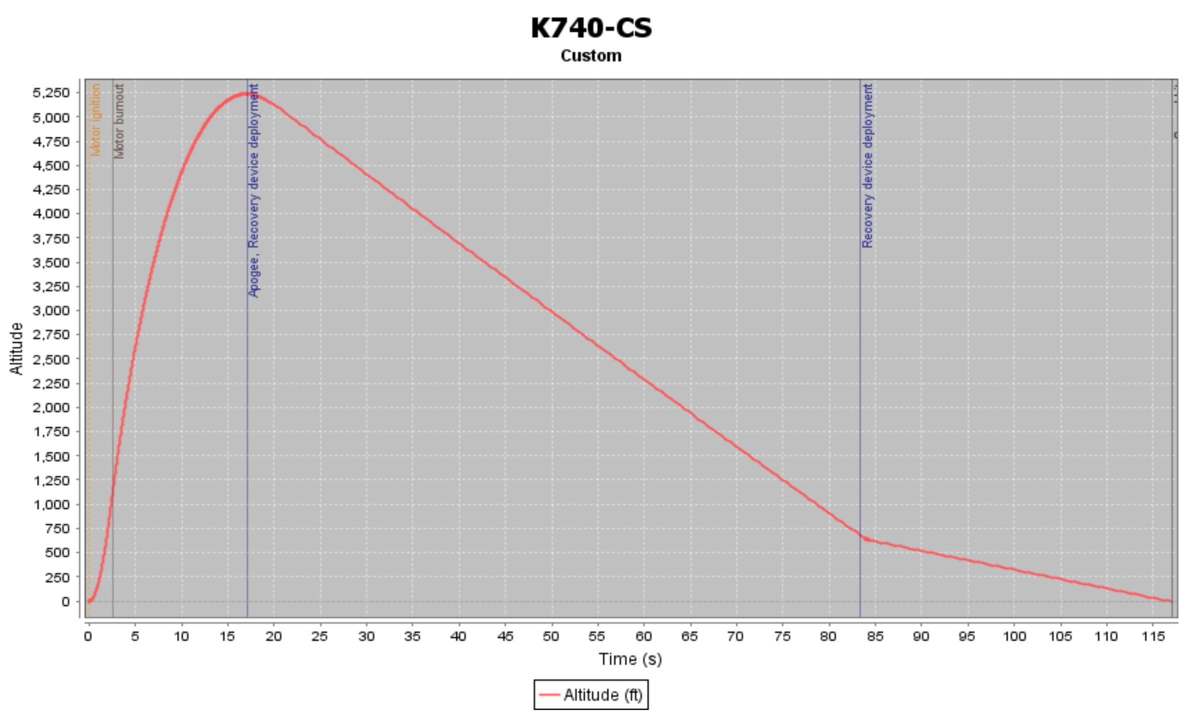

Figure 3: Simulated altitude profile for CTI-K740CS motor

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	5246	0.00
5	5238	-0.15
10	5210	-0.69
15	5168	-1.49
20	5129	-2.23

Table 6: Flight apogee vs. wind speed

Thrust Profile

The graph below shows the thrust profile for the Cesaroni K740CS. The CTI K740CS motor reaches its maximum thrust of 883.9*N* after 0.4*s* and burns at approximately constant thrust level for about 2.5*s* (the average thrust-to-weight ratio is 12.6). The rocket requires a standard ten-foot rail for sufficient stability on the pad and leaves the 10*ft* rail at about 60*mph*.

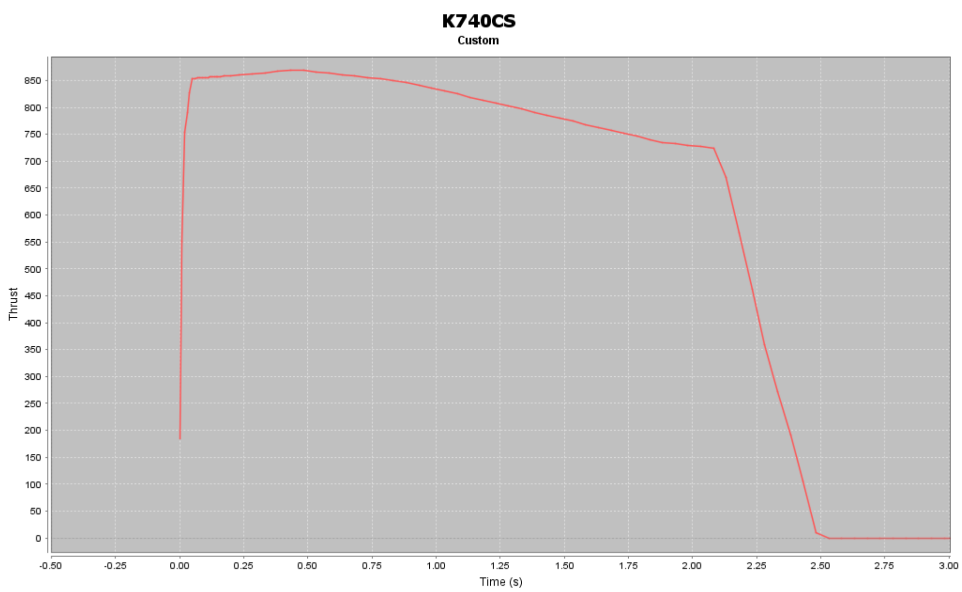

Figure 4: Thrust profile for CTI-K740CS motor

Velocity Profile

According to the velocity profile (next graph), the rocket will reach maximum velocity of 751 *ft/s* shortly before the burnout (2.5*s*). The rocket remains subsonic for the entire duration of its flight.

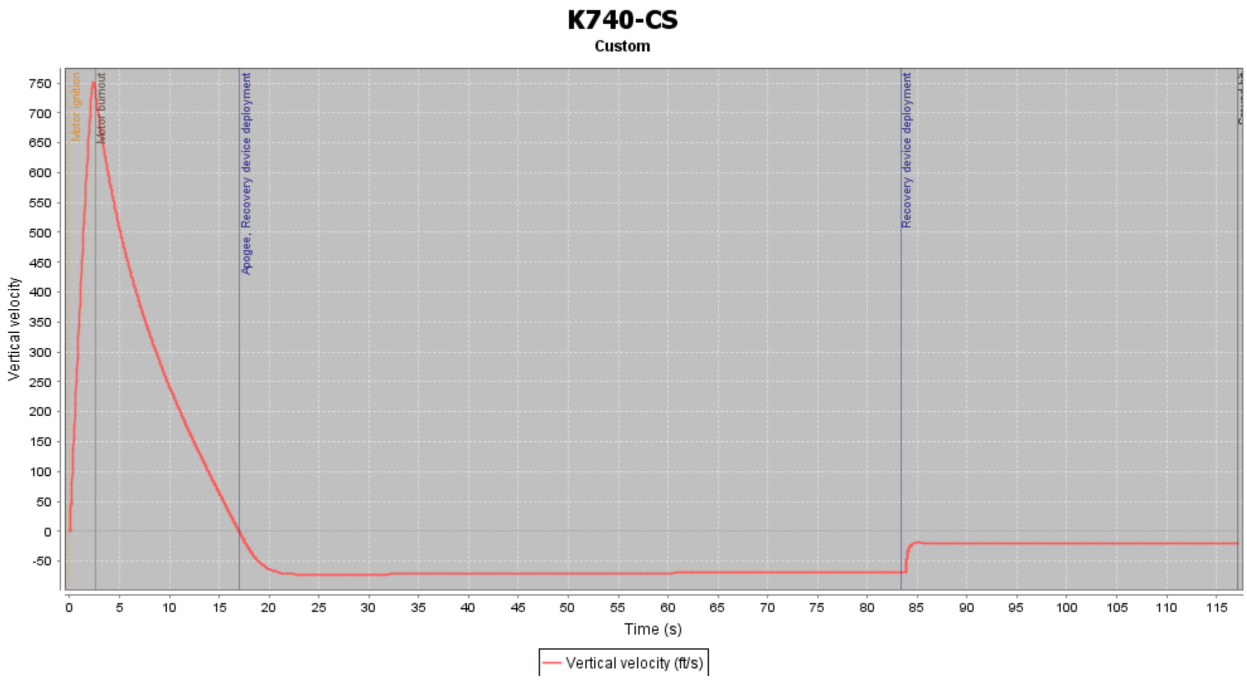

Figure 5: Velocity profile for CTI-K740CS motor

Acceleration Profile

The graph below shows that the rocket will experience maximum acceleration of about 12*g*. Our rocket will be robust enough to endure 25*g*+ acceleration shocks.

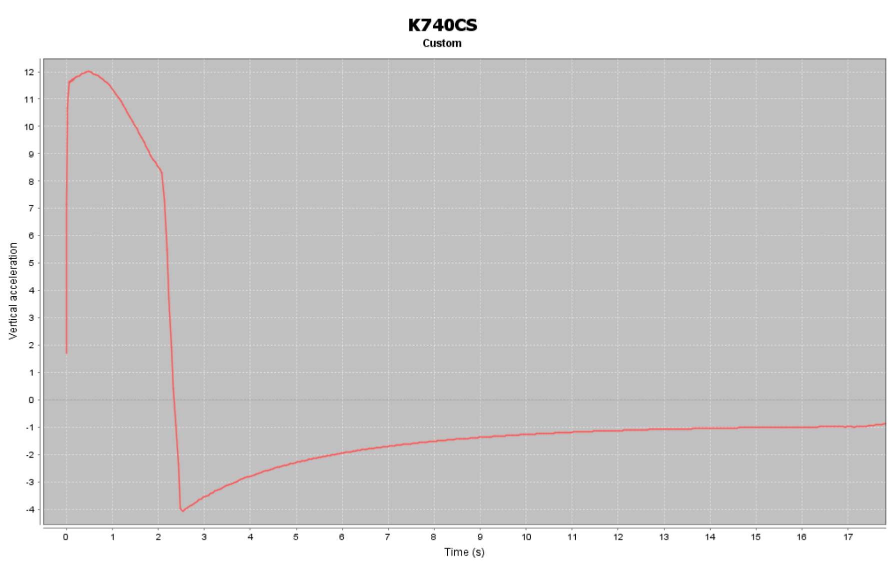

Figure 6: Acceleration profile for CTI-K740CS motor

Flight Sequence

The following figure and table describe the expected sequence of flight events. The motor burns out at 1000*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.

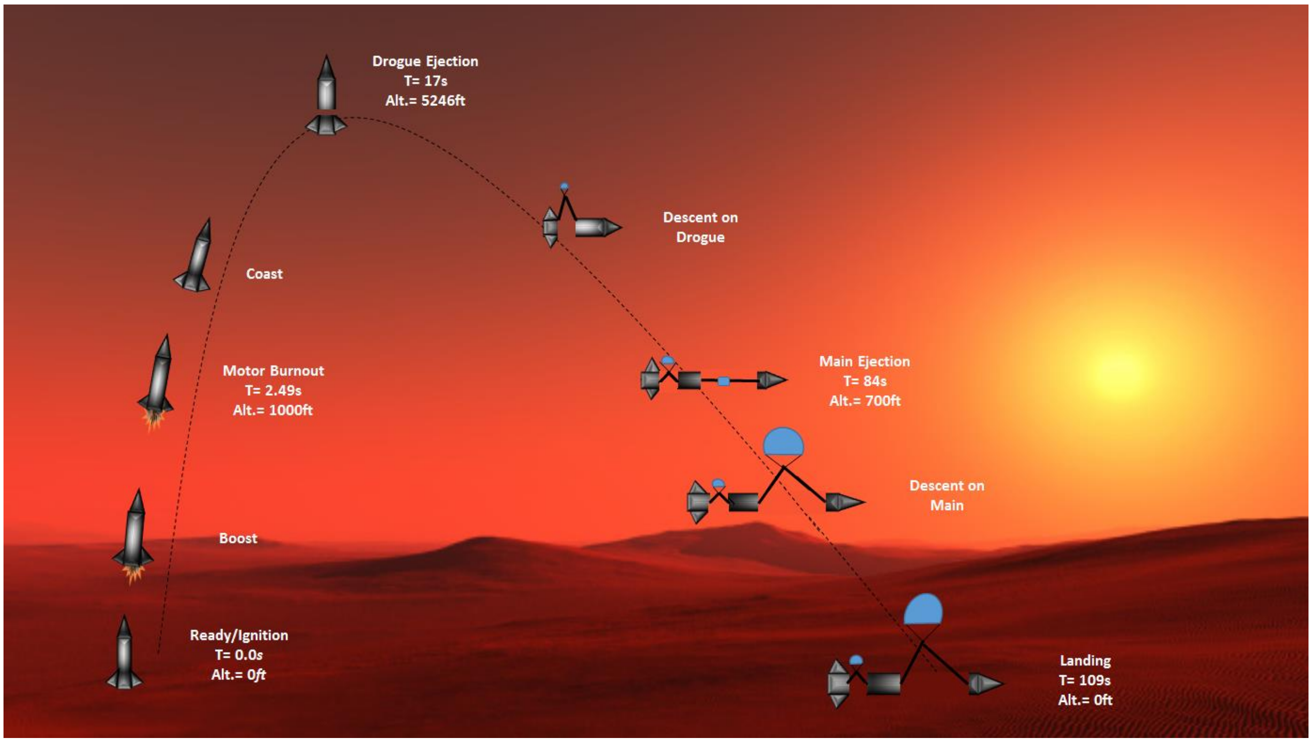

Figure 7: Mission Profile Chart

Event	Time [s]	Altitude [ft]
Ready	0.00	0
Ignition/Take-off	0.00	0
Motor Burnout	2.49	1000
Coast	2.50 to 17.00	1000 to Apogee
Drogue Ejection	17.00	5246
Descent on Drogue	17.00 to 84.00	5246 to 700
Main Ejection	84.00	700
Descent on Main	84.00 to 109.00	700 to 0
Landing	109.00	0

Table 7: Flight Events

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.

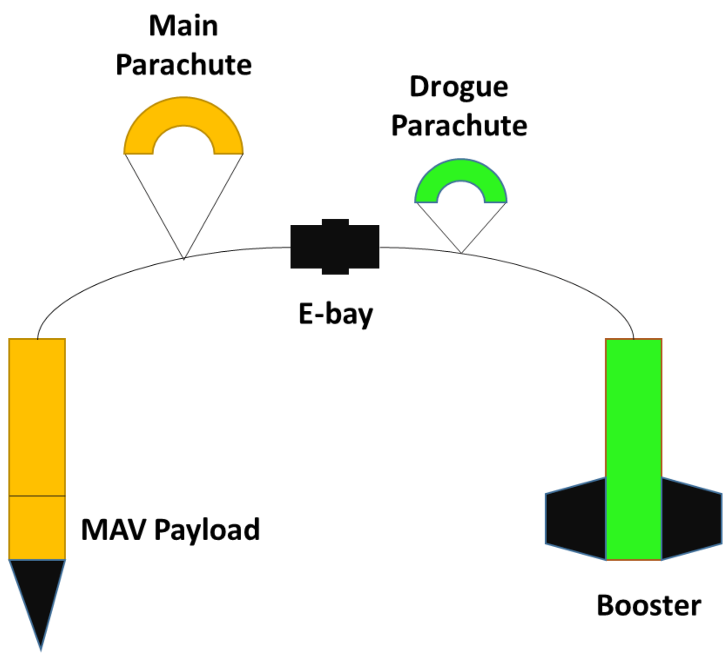

Figure 8: Vehicle separation scheme

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 96-inch main parachute will be deployed. The total kinetic energy for the rocket landing under 96-inch main parachute is 59.9*ft.lbf*, thus satisfying the requirement of no separate or tethered rocket part landing with impact energy more than 75*ft.lbf*.

Parachute	Diameter *[in]*	Descent Rate *[fps]*	Ejection Charge *[g]*	Deployment Altitude *[ft]*	Descent Weight *[lb]*	Impact Energy *[ft.lb f]*
Drogue	24	63.3	2.43	5346	13.51	964.4
Main	96	16.9	2.53	700	13.51	**59.9**

Table 8: Parachute sizes, ejection charges and impact energy

The following table shows drift estimates for wind speeds ranging from 0*mph* to 20*mph*. The rocket will remain within the confines of the launch site even if the wind speed reaches 15*mph*. Should the launch occur under 20*mph* wind speed conditions, we will decrease the main parachute deployment altitude to 300*ft* to avoid drifting outside the launch site.

Wind speed [MPH]	Drift[FT]	Drift [MI]
0	0	0
5	799	0.1513
10	1598	0.3027
15	2397	0.4539
20	3196	0.6053

Table 9: Estimated drift

Propulsion Selection

Based on the results of computer simulations we have selected CTI K740CS (54mm) motor as our primary propulsion choice. Our backup choices are CTI K580 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 K740CS	54	1855	2.50	3.37	12.6
CTI K580	54	1851	3.09	3.21	14.9
CTI K671RR	54	1802	2.62	3.17	11.2

Table 10: Motor selection, including backup choices

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.

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 (both of motion control system as well as materials)

By selecting primarily commercially available subsystems and materials, the focus of the engineering work can be upon seamless integration of the various subsystems via microcontroller. We anticipate the bulk of the engineering effort to be electrical integration, code development and debugging, the mechanical design of a few key components needed to mate the various subsystems together reliably, and an extensive testing of the completed system under a variety of conditions and initial payload placements.

Payload compartment design

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 (and available from the arm)
- Provide passive damping of the payload against launch forces and vibration as well as the possibility of unknown/undefined center of gravity (CG) of the payload
- 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. Furthermore, the payload compartment will have a viscoelastic polyurethane foam ("memory foam") which has very low resistance to the force of the end effector and payload, yet has sufficient vibration resistance and gap filling properties to allow for wide placement tolerance of the payload. An early concept rendering is shown in Figure 9 below.

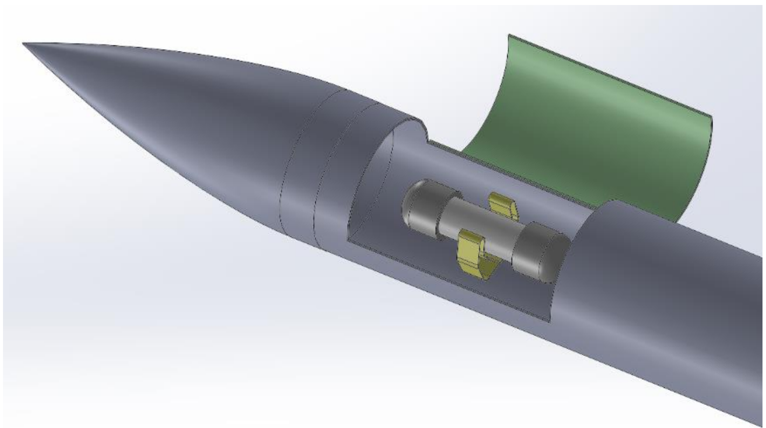

Figure 9: Detail showing 3D concept of payload retention in vehicle bay (foam and over-sprung mechanism not shown).

For ease of access by the end effector, we anticipate the door consuming nearly half 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 10 and Figure 11 below call out some of the key elements of this retention/enclosure design.

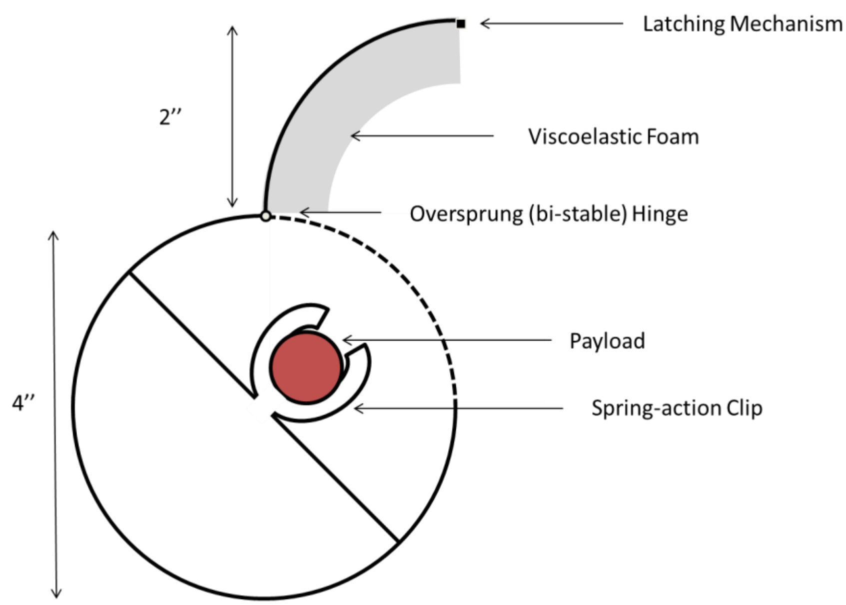

Figure 10: Cross-sectional view of payload retention scheme.

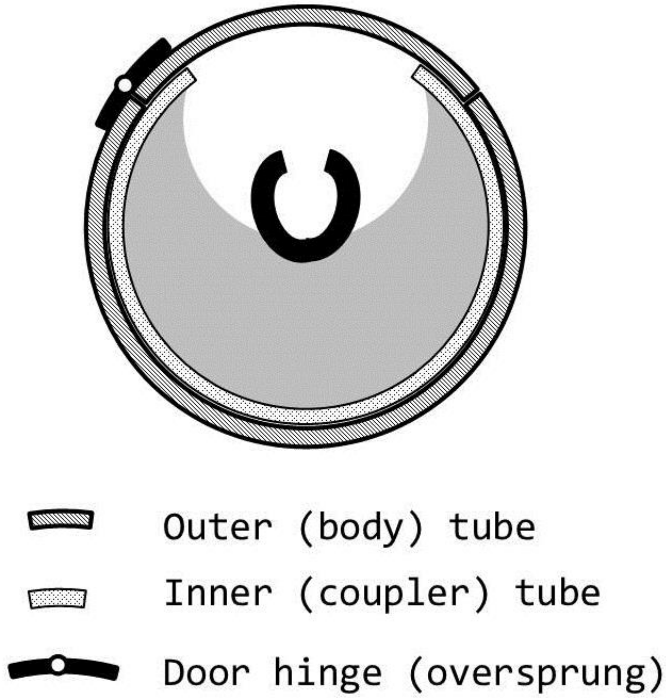

Figure 11: Cross-sectional view of payload door and supportive inner tube

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. The approach is shown schematically in Figure 12 and Figure 13 below.

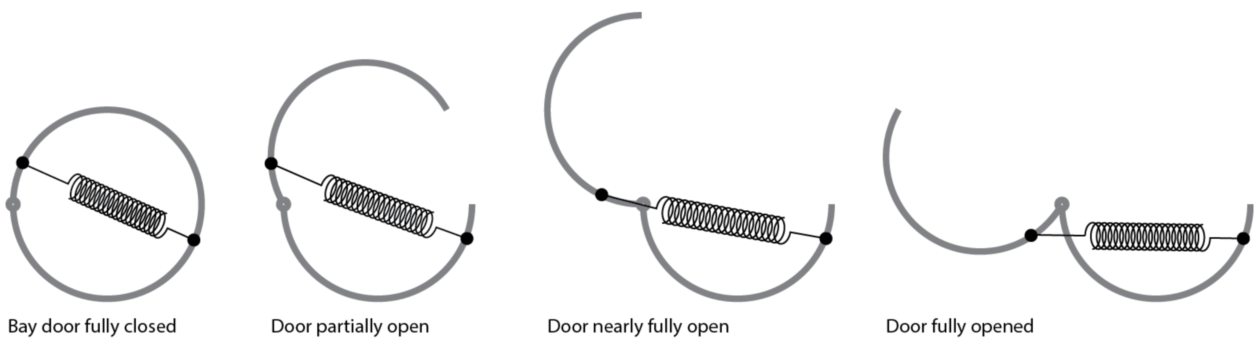

Figure 12: Side view showing key aspects of over-sprung bistable door closure mechanism varying from fully closed (far left) to fully open (far right).

The straight wire portion of the spring will slide in a very narrow slot in the payload door as shown below. Optionally, an additional spring may be added on the opposite side of the payload. It is also notable that using a smaller but stiffer spring may be used and this would allow the spring attachment points to sit much closer to the spring mechanism.

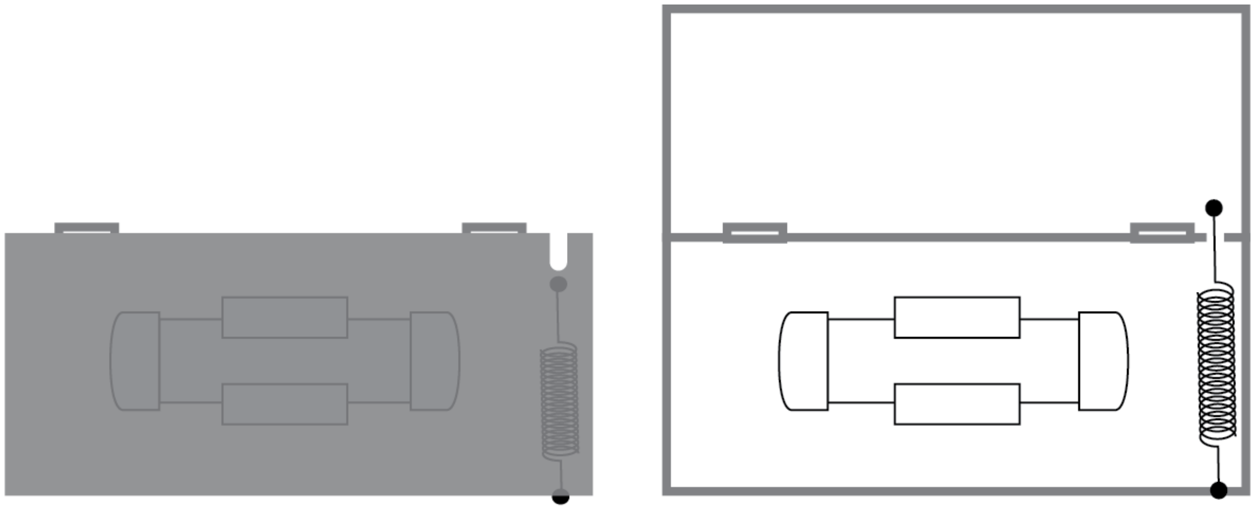

Figure 13: Top view showing over-sprung door mechanism with door closed (left) and open (right). Note the attachment points for the spring and the narrow slot to allow clearance for the straight wire portion of the spring when open.

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).

The robotic arm length and gripper claw have sufficient range of motion to reach past the payload door, and actuate it closed by an opening motion of the gripper. Note that the forces of these mechanisms are low enough to be overcome by the robotic arm and gripper yet strong enough to hold the door closed against any launch-induced forces (with the aid of magnetic and spring latch).

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).

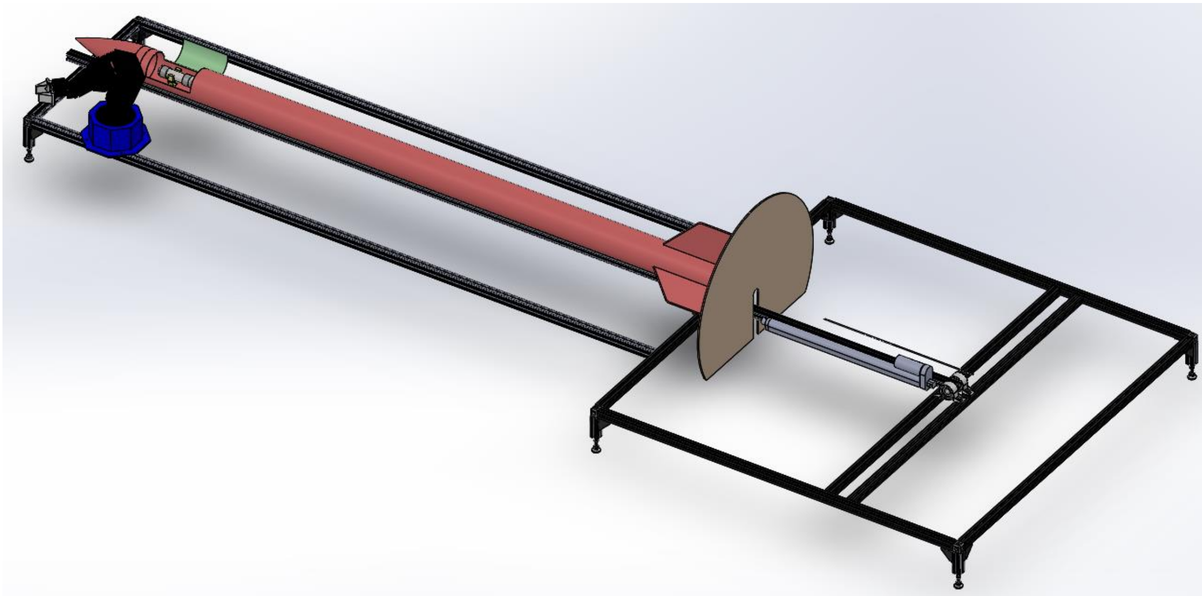

Figure 14. Early concept rendering of AGSE superstructure in horizontal payload-loading configuration. The structure is 11.5 ft x 4 ft x 2 ft in the horizontal configuration. Concepts for payload manipulator robot arm, ignitor insertion, and blast shield are shown. Worm-drive erection motor, controller, and details such as mounting brackets are not shown here.

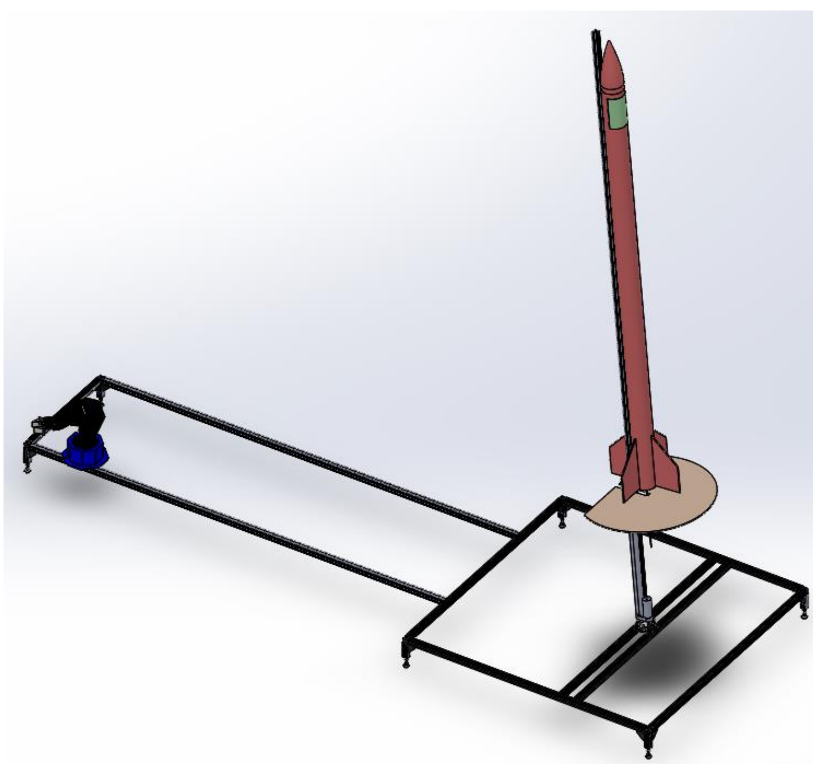

Figure 15. Early concept rendering of AGSE superstructure in launch configuration, with rocket 5° from vertical. The structure is 11.5 ft x 4 ft x 10.5 ft in the vertical configuration. Many details of the design are not shown here including rail angular travel hard stop.

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. 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.

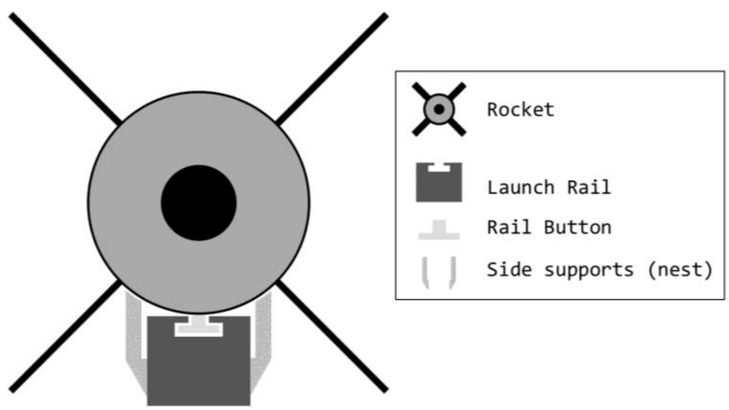

Figure 16: Anti-roll support of the rocket body during payload insertion.

Figure 16 shows how the rocket will restrained from roll motion when in horizontal position or during rail-raise step. This is important to protect the rail buttons and rail from damage, should the rocket roll to the side.

Payload acquisition and insertion

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.

To ensure this design guideline is met, we use laser triangulation to precisely indicate where to place the payload (not shown in concept rendering). This uses 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 ensures that the payload is within approximately ±1*cm* (±0.4*in*) of the required location.

We will use a commercially-available arm and gripper with a capacity of at least 2 times the mandated 4*oz* payload mass. This choice will enable the payload to be gathered and moved from a distance of 30 cm (12 inches) and inserted into the payload compartment. The gripper jaw range of motion (open to closed) is more than sufficient for the payload size. The excess range of motion is used to allow the payload to have lateral slop in placement, and as the jaw closes, the payload will slide/roll to the center of the gripper. This same design approach also allows for significant "yaw" angular slop in the placement of the payload as well.

The gripper ends will be customized both for the size of the PVC pipe payload but also to have appropriate level of compliance. The end effector will also be tolerant to errors in placement of the payload in the axial direction.

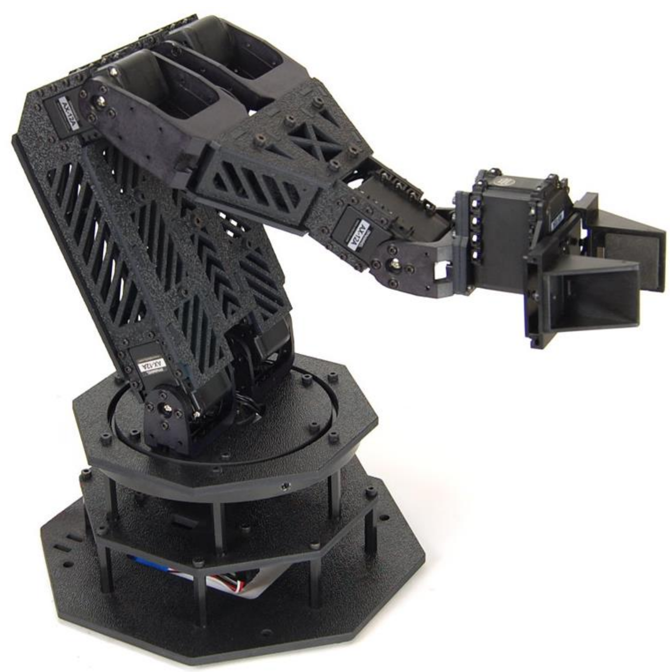

Figure 17: Arm and gripper meeting mass/reach/torque requirements.

A 3- or 4-axis approach is anticipated to be sufficient for the payload placement, however, many commercial arms and grippers come with a 5th axis available. We plan a design that is sufficient using 4 axes and leave the 5th axis unused or for managing unanticipated tolerances during development of the grabbing and placement process. The commercial arm assembly may require minor modification of the main arm length after the elbow to ensure the 12” reach requirement is met.

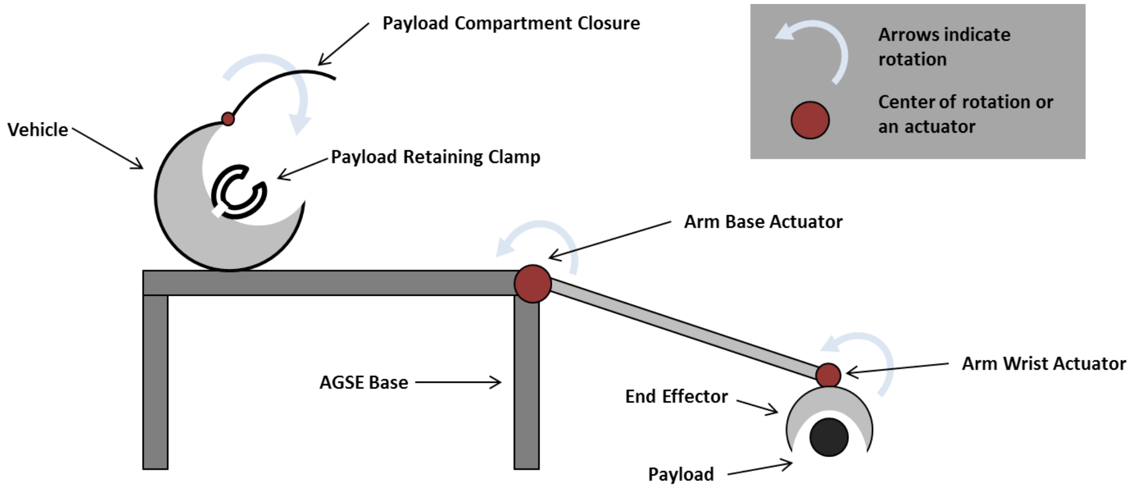

Figure 18: Schematic of approach to payload gripping and transport to payload bay.

The launch vehicle will be loaded on to the launch rail and the payload bay door will be open. As mentioned earlier, the vehicle will be “cradled” by a nest beneath the launch rail to support the rocket body tube and prevent rocket from rolling to the sides.

The arm and gripper begin the sequence in a neutral position (1, Figure 19 below). The payload will have been placed in a position delimited by an off the shelf laser line generator (commonly used in small drill presses).

The arm will then move toward the payload (2), placing the open gripper in position over the payload to close and grasp it (3). The arm will move the payload in an angular sweep to the payload bay (4) and push the payload into the compartment against the force of the retaining springs in the payload compartment (5). These springs will have a force of approximately 3 pounds against the end effector during insertion. The payload will also push against compliant viscoelastic polyurethane foam during insertion. Then, the gripper will open partially and retract from the body of the rocket (6).

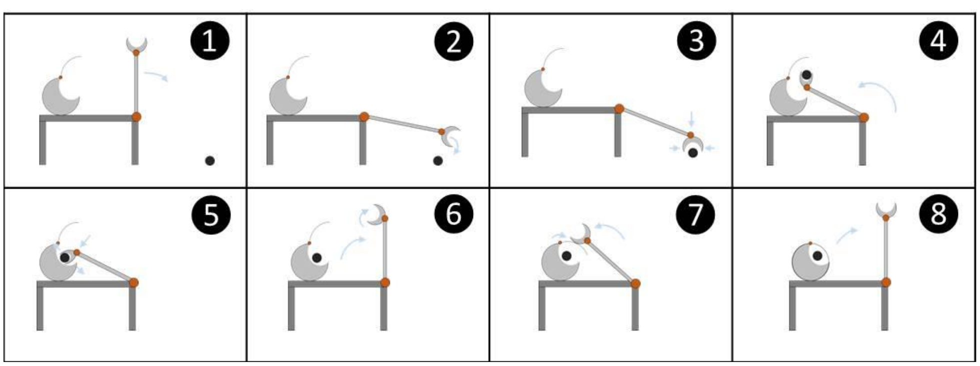

Figure 19: Payload pickup and insertion sequence: (1) neutral starting position; (2) elbow actuated toward payload; (3) wrist and gripper actuated; (4) elbow actuated toward vehicle; (5) wrist actuated toward vehicle and payload secured; (6) arm and wrist return to neutral position; (7) payload door pushed closed; (8) arm and wrist back in neutral position, payload loading sequence completed.

The arm will re-position and open wider to capture the edge of the door and push it into the closed position (7), working against the force of the double-sprung spring mechanism. The arms and end effector will work in concert to finish pushing the door past the over-sprung stability angle and push the door closed until the integrated snap latch and magnets take over, pushing against the viscoelastic foam until the door is securely shut and latched. It should be noted that the over-sprung door mechanism provides the force to hold the door in the open, as well as pulls it toward the closed (but not yet latched) position. The arm serves to move the door between these two bi-stable positions.

The arm will then retract and return to a “neutral” position (8).

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 motor with high-ratio worm drive. We anticipate using the exact mechanism used in luxury automobiles that electrically raises and lowers the seatback, a reliable and proven solution for compact, slow, high-torque applications. This mechanism is readily available as an aftermarket replacement part and has the ideal specifications for this application: 12-volt DC motor, compact/low-mass mechanism, more than sufficient torque 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 FET-based motor controllers.

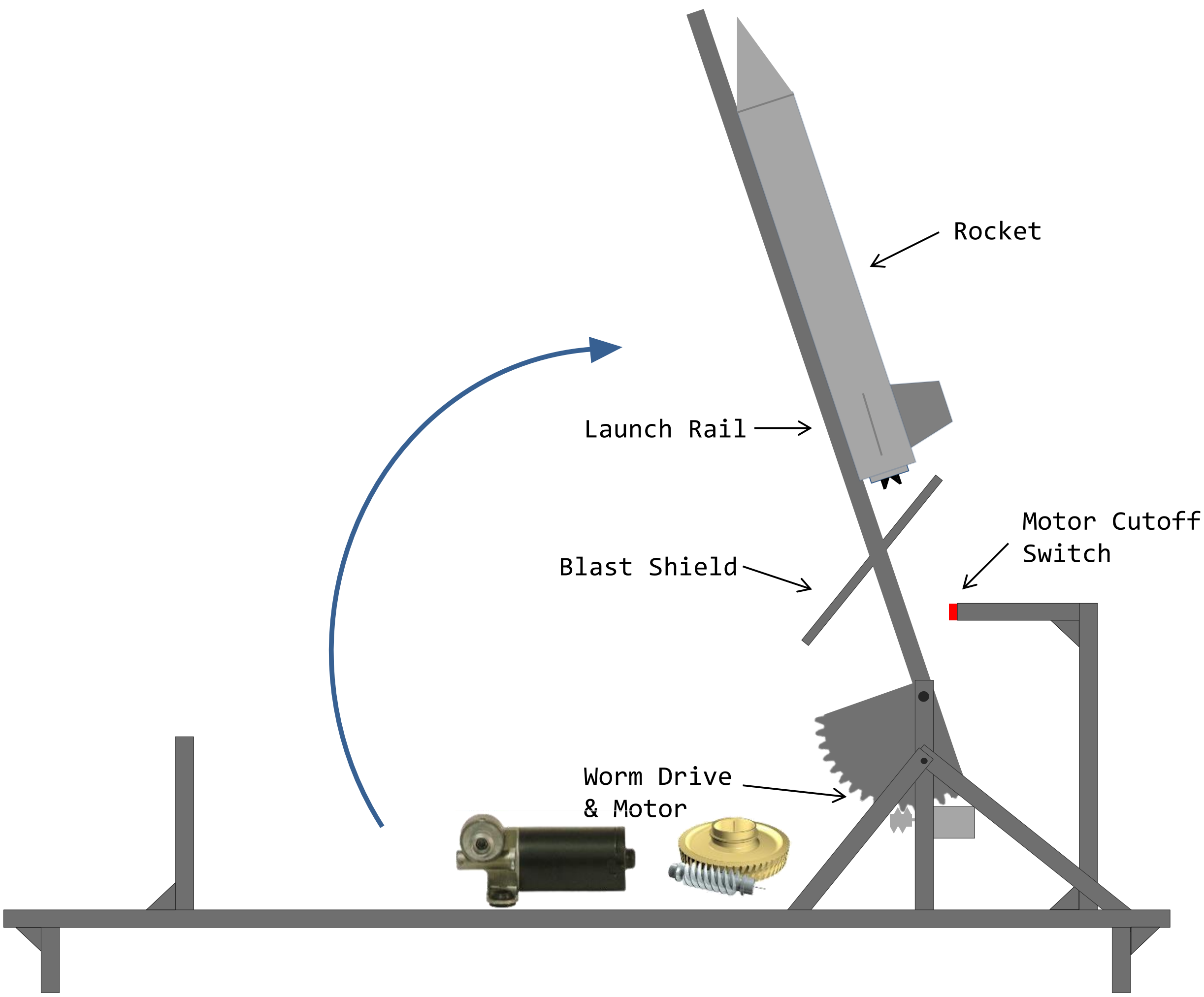

Figure 20: Schematic of launch erecting mechanism and approach.

(One alternative to the worm drive we may consider is a planetary drive mechanism. This too is common in luxury vehicle seat control and provides similar gear ratio, torque, size, and cost.)

A simple sleeve or roller cartridge bearing will be used in association with the worm drive 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.

External microswitches 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.

To determine the required motor specifications and appropriate level of mechanical advantage which will be necessary, a curve of torque at the pivot point was generated. This curve was computed by considering the weights of the launch rail and rocket, with their respective horizontal distances from the pivot point acting as the moment arm. These distances vary with the cosine of the rotation angle, as shown in Equation 1 below.

$$T(\theta) = \cos(\theta) \cdot D_{rail} \cdot W_{rail} + \cos(\theta) \cdot D_{rocket} \cdot W_{rocket} \quad (1)$$

The resulting curve for $D_{rail} = 60\ in$, $W_{rail} = 13.4\ lb$, $D_{rocket} = 30.1\ in$, and $W_{rocket} = 15.5\ lb$ is shown in Figure 21.

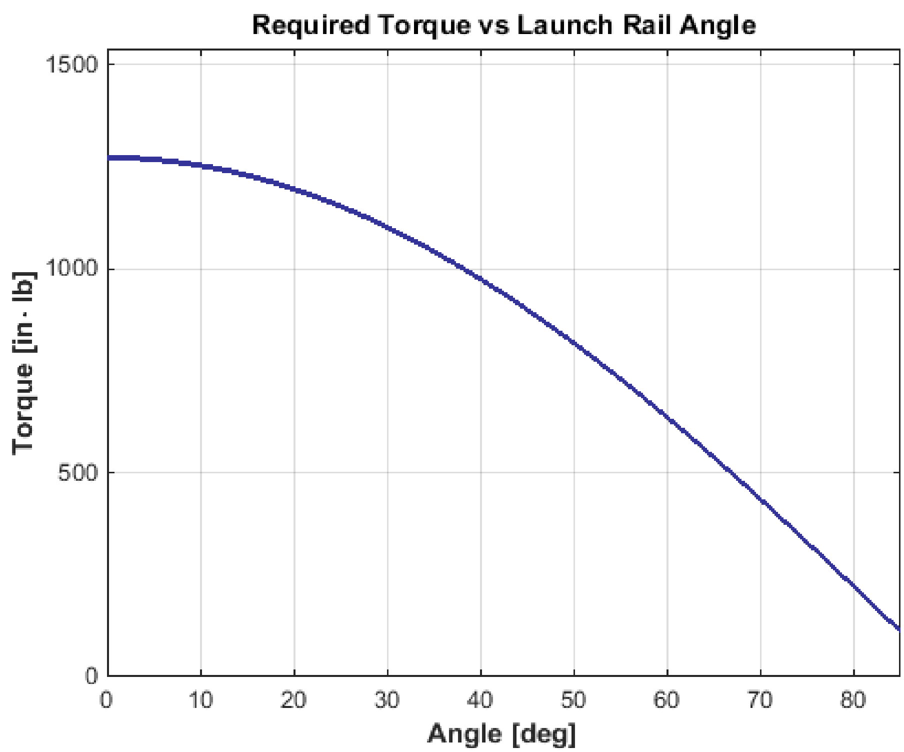

Figure 21. Plot of motor torque required versus rail angle.

Using a similar equation, the average power needed to lift the rocket in a given amount of time can also be computed. The total change in energy is the vertical change in height of the rocket and rail centers of gravity multiplied by their weights. The change in height is found by multiplying the center of gravity distance by the sine of the 85° final angle, as shown in Equation 2. This entire number is divided through by the total rise time, t, to find the average motor power requirement for a given erecting time. Additionally, a unit conversion factor is used to transfer from $in \cdot lb/s$ to the more useful Watt (W). It is important to realize that this is the delivered power requirement, and does not take into account any inefficiencies in the motor or electrical system.

$$\mathrm{P(t)} = \frac{\sin(\theta_f) \cdot D_{rail} \cdot W_{rail} + \sin(\theta_f) \cdot D_{rocket} \cdot W_{rocket}}{t} \cdot 0.113 \frac{W}{in \cdot lb/s} \tag{2}$$

The required power curve for times up to 300 seconds is shown in Figure 22. For times above about 30 seconds, the average draw power requirement is reasonable. The maximum power requirement might be higher, however, and will need more detailed study once a rail rise time is selected.

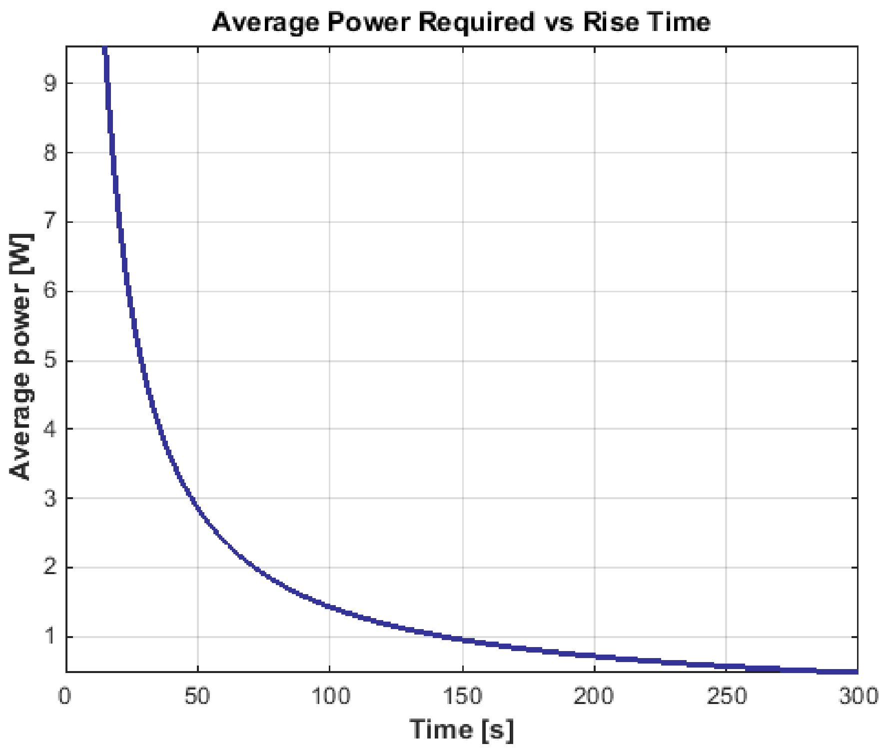

Figure 22: Average motor power versus time to raise.

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 vehicles.

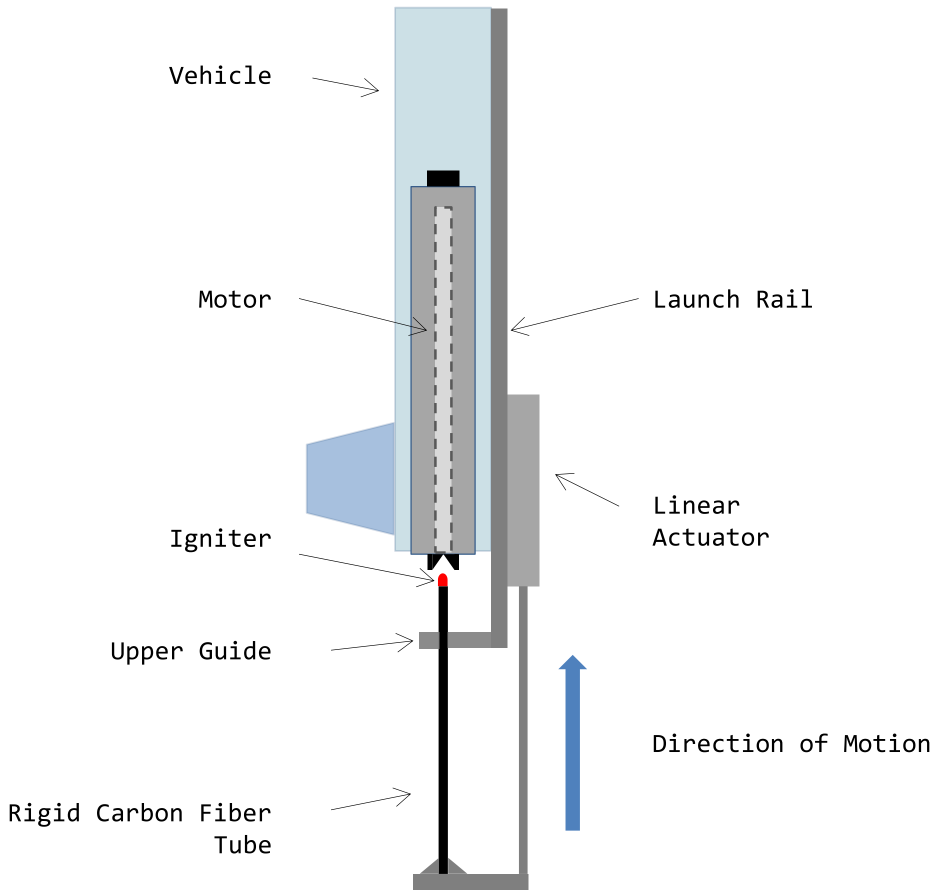

Figure 23: Schematic of igniter insertion approach.

The support for the ignitor will be accomplished with a small-diameter (0.125” to 0.1875” OD) carbon-fiber tube. These are low-cost, exceptionally stiff, hold acceptable straightness tolerances without modification, and are sufficiently sized to allow the ignitor 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 0.375in 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 ignitor 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 ignitor 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 ignitor 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 ignitor in place is considered safe as the additional material present in the bore is only slightly more than that of the ignitor wire itself. The high carbon content of the tube ensures safety through limited volatility – the epoxy resin binder is less flammable than the ignitor wire itself. A fresh carbon-fiber tube will be prepared and used for every launch (the carbon-fiber tube is considered disposable, like the ignitor and wires themselves).

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.

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 (cf. Figure 24). 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

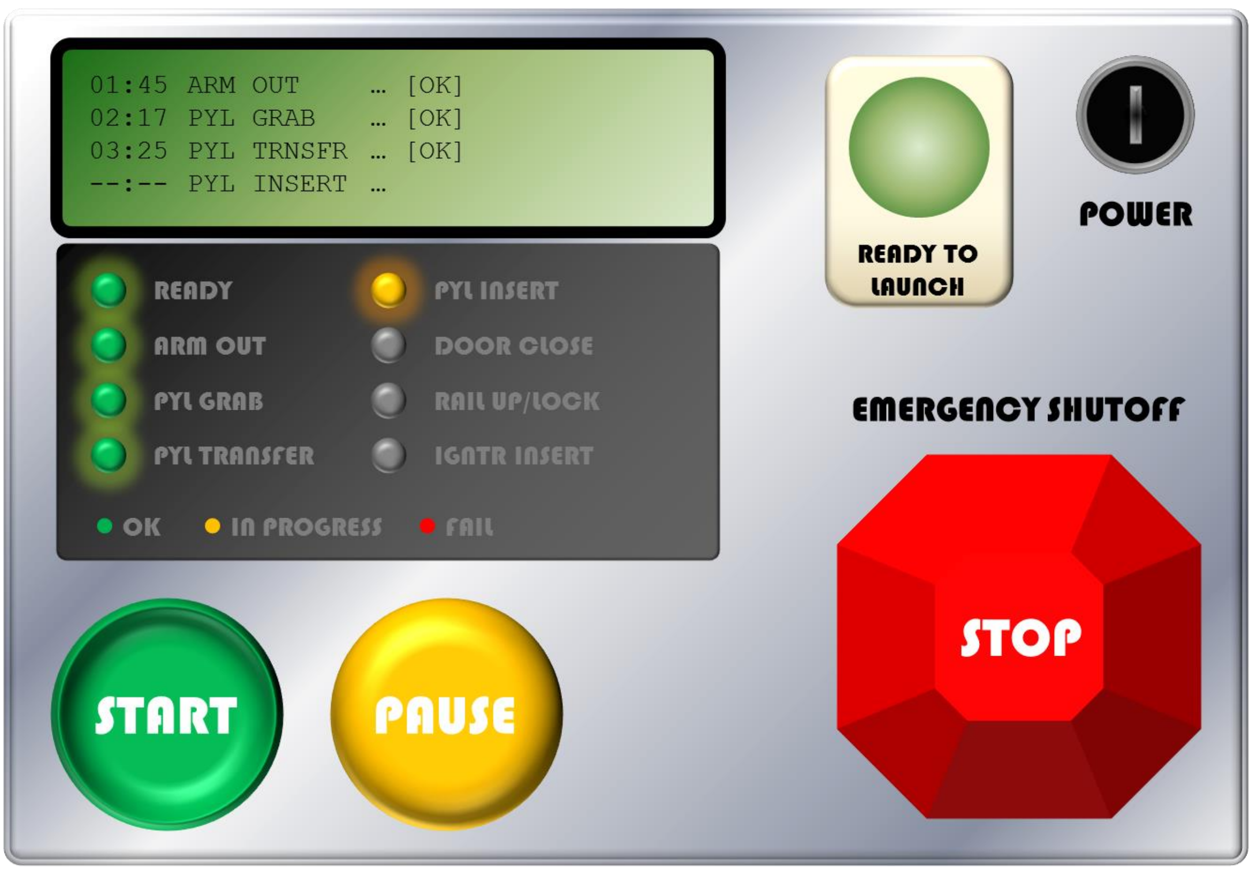

Figure 24: Concept of control box front panel.

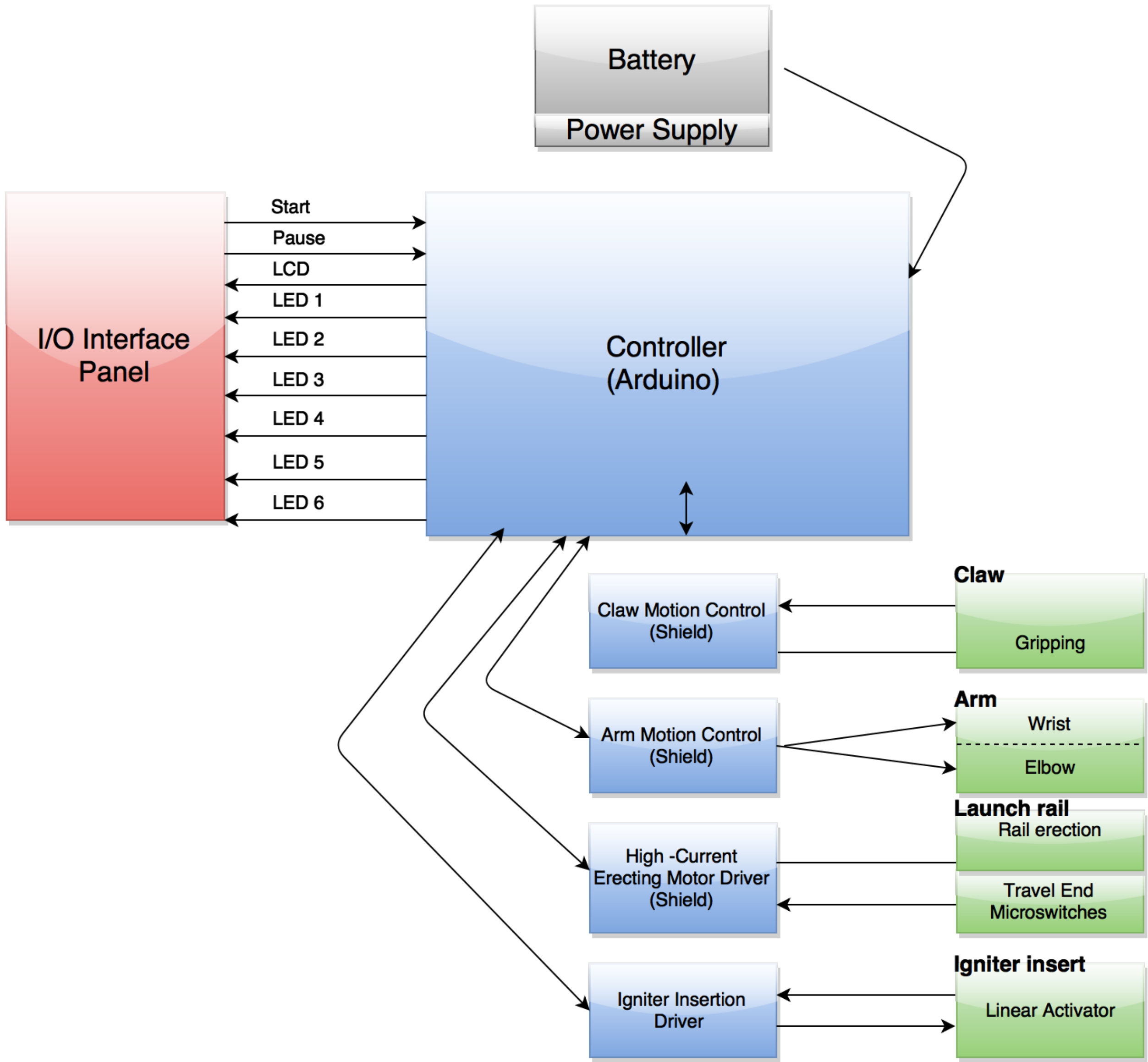

Figure 25: Block diagram of control system.

An Arduino Uno or Due 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 ignitor insertion.

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.

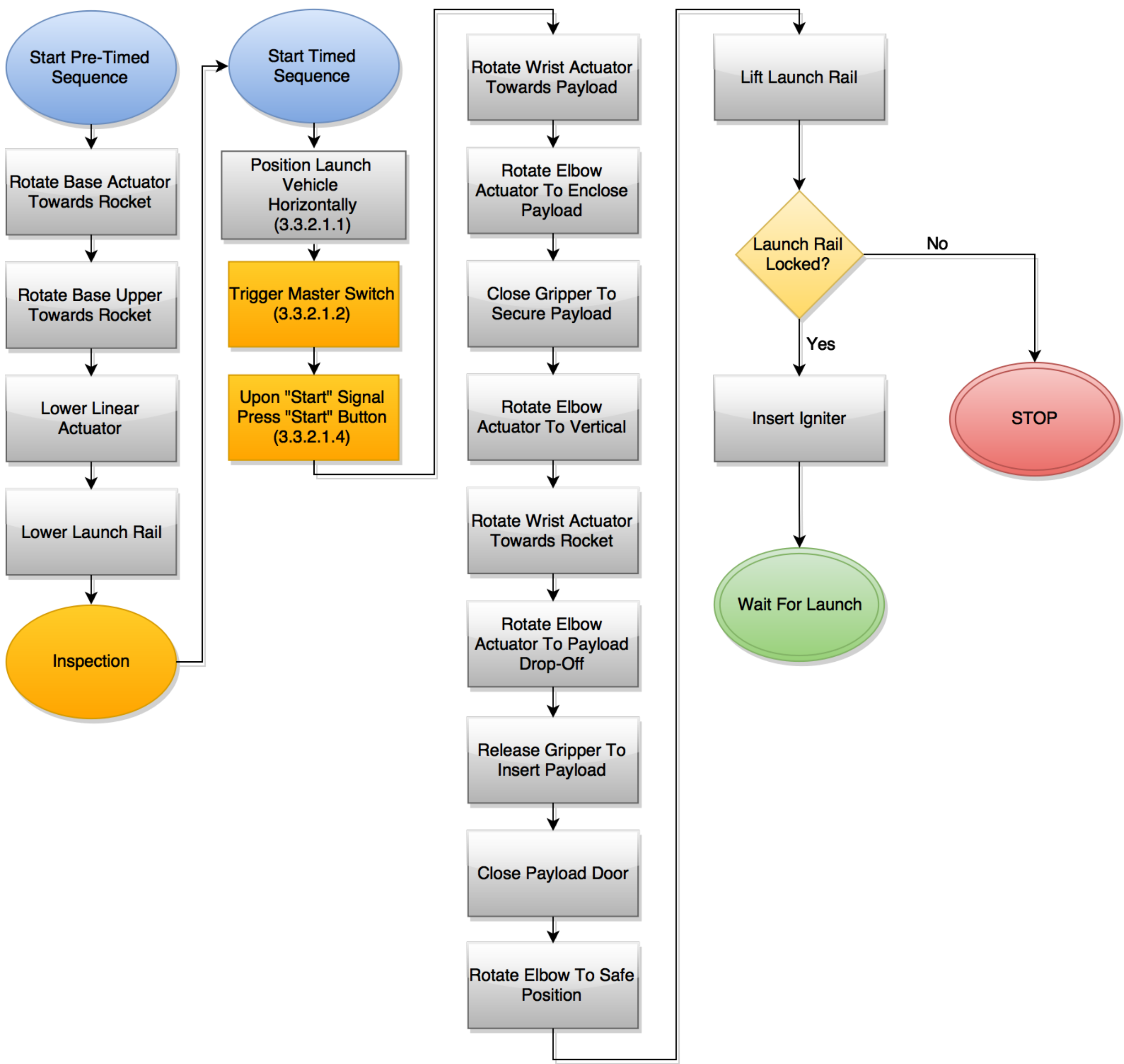

Figure 26: Flowchart for main process control; blue/red/green are start/end of sequence; orange reflects human interaction step.

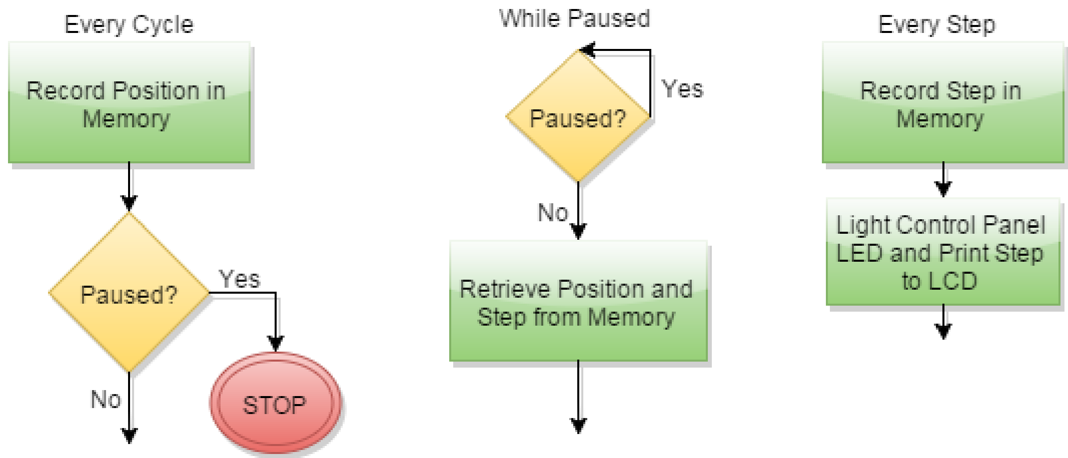

Figure 27: Safety and watchdog process flow diagrams.

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.

The power requirements for the system will be satisfied by a rechargeable lithium-ion battery pack. The primary power requirements driving the final choice of battery is the erecting motor, while the linear actuator is the second highest current consumption device. The remaining servo motors consume considerably less current. Buck and buck-boost converters will be chosen to provide 3.3 low-current and 5 and 12V high-current bus voltages for the controllers and servo motors.

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. 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.

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 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.

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 Budget

AGSE Subassembly	Qty	Each *[lb]*	Mass *[lb]*
Superstructure			
Legs/feet	4	2.2	8.8
Frame (Length)	2	13.4	26.9
Frame (Width)	2	6.7	13.4
Launch rail	1	13.3	13.3
Fastener Set	1	6.2	6.2
Sub Total			**68.6**
Payload insertion			
End effector	1	0.6	0.6
Arm	1	4.3	4.3
Battery	1	1.2	1.2
Support/integration	1	3.6	3.6
Sub Total			**9.7**
Erection			
Motor	1	13.7	13.7
Battery	1	1.2	1.2
Gearset	1	3.1	3.1
Support/integration	1	7.3	7.3
Sub Total			**25.3**
Igniter insertion			
Battery	1	1.2	1.2
Igniter	1	0.1	0.1
Igniter Inserter	1	3.7	3.7
Support/integration	1	3.2	3.2
Sub Total			**8.2**
Electronics			
Battery	12	0.4	4.8
Indicators	4	0.2	0.8
Control Unit	1	2.2	2.2
PCBAs, Wiring Set	1	2.5	2.5
Sub Total			**10.3**
TOTAL			**122.1**

Table 11 : AGSE Weight budget

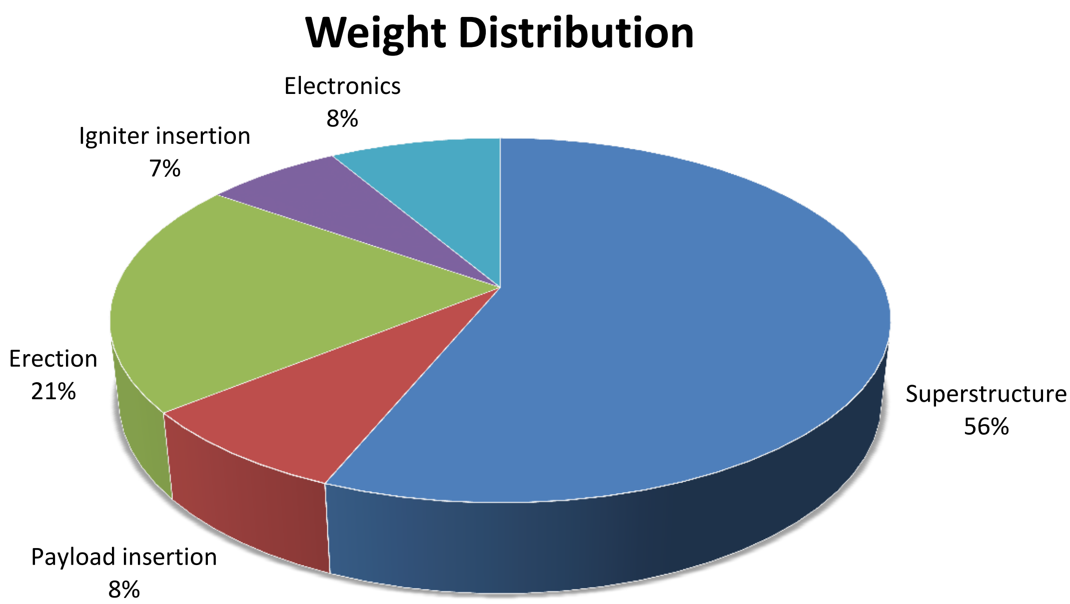

Figure 28: AGSE Weight Distribution

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.

Purpose	Description	Manufacturer/Supplier	Model
AGSE superstructure	80/20 rail, precut various lengths	Thorlabs	e.g., XE25L48
Payload transport/insertio	Robotic arm and gripper	Trossen Robotics	PhantomX Reactor
Launch rail erection	Gearhead/wormdrive power seat motor	ACDelco	AC89039409
Ignitor insertion	Linear electric actuator, 15" stroke	Firgelli Automations	FA-35-TR-12-15
Ignitor insertion	Carbon fiber rod	McMaster-Carr	2153T31
Controller	Microcontroller	Sparkfun	Arduino Uno R3
Controller	Low-current motor driver shield	Sparkfun	09815
Controller	10A motor driver shield	RobotShop	RB-Cyt-116

Table 12: List of selected key components

Requirements

Vehicle

All vehicle requirements are in detail addressed in Project Requirements section, with Vehicle Requirements starting on page 62. The vehicle itself is described in the Technical Design section, starting on page 19.

Recovery System

All recovery system requirements are in detail addressed in Project Requirements section, with Recovery System Requirements starting on page 67. The detailed description of the recovery system starts on page 25.

Payload/AGSE

All payload requirements are in detail addressed in Project Requirements section, with Payload Requirements starting on page 71. The detailed description of the proposed payload starts on page 27.

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 27-44). The proposed design has been checked for compliance for with project requirements.

Educational Engagement

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	2000
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: 2780

Table 13: Planned outreach events

Project Plan

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 14: 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 15: 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.

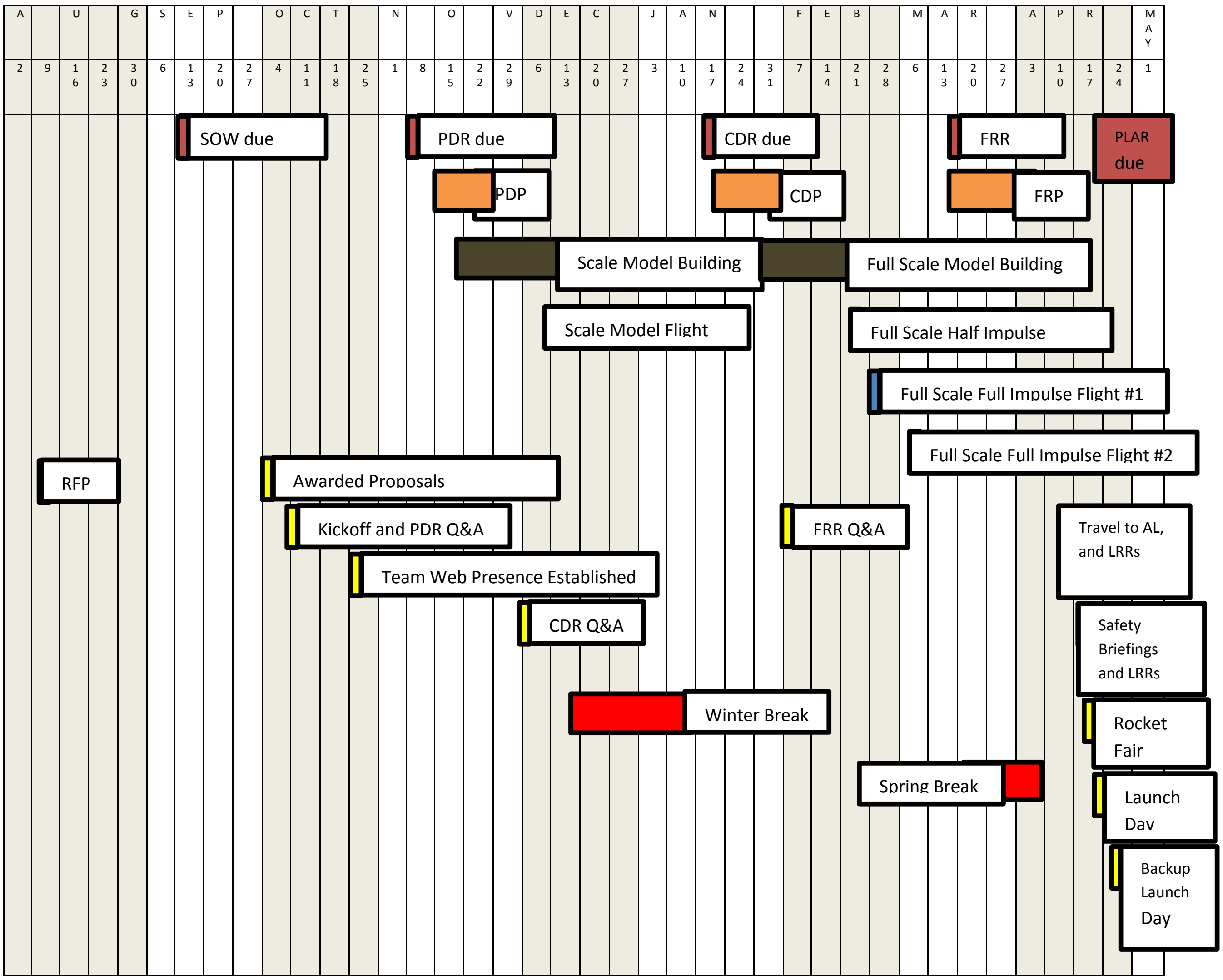

Figure 29: GANTT chart for SL2016 project

Project and Travel Budgets

AGSE	
Superstructure	
Feet	$60
Nuts and Bolts	$8
8020 singles for frame	$264
8020 singles for legs	$36
8020 singles for support	$60
8020 doubles for launch rail	$90
Hinge hardware	$100
Hardware	$400
Other	$100
Superstructure Subtotal	**$1,118**
Payload Insertion	
Gripper	$200
Driver	$100
Wiring	$80
Arm body	$500
Pivot elbow	$200
Pivot wrist	$200
Driver kit	$250
Custom mechanical bits	$300
Hardware	$50
Other	$150
Payload Insertion Subtotal	**$2,030**
Erection	
Motor	$200
Gearset	$350
Support/Integration	$400
Other	$150
Erection Subtotal	**$1,100**
Igniter Insertion	
Rod	$80
Linear electric actuator	$150
Wiring/connectors	$20
Bracket for motor	$20
Hardware	$40
Custom rod for actuator part	$150
Other	$150
Igniter Insertion Subtotal	**$610**
Electronics	
Battery	$75
Chassis	$100
Arduino mainboard (already in possession)	$0
High-current motor driver	$30
Low-current actuator driver	$30

Robot interface board	$150
Wiring, connectors	$50
Indicator LED's	$50
Switchgear	$50
Other	$50
Electronics Subtotal	**$585**
Vehicle	
Tubing, bulkheads, nose cone	$300
Fin materials (G10 fiberglass)	$150
Paint and primer	$50
PerfectFlite Stratologger Altimeter (2), already in possession	$0
Motor retention	$50
Motor Casing (already in possession)	$0
Parachutes, recovery equipment	$200
Epoxy	$100
Beacons (already in possession)	$0
GPS (already in possession)	$0
Miscellaneous supplies (tools, batteries, wires, hardware)	$300
Vehicle Sub-total	**$1,150**
Scale Model	
Paper tubing	$50
Parachutes, recovery equipment	$100
Fin materials (G10 fiberglass)	$50
Scale Model Sub-total	**$200**
Motors	
Scale model motors	$50
Full scale motors	$320
Motors Sub-total	**$370**
TOTAL	**$6,045**

Table 16: 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 17: 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	$6,045.00	
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	***$17,809***	
Funds		
Raking fundraiser	$3,000.00	
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	***$18,364.00***	

Table 18: Funding plan

Community Support

After thirteen years of the club's existence, we are well known at various departments of the UW and many researchers are eager to work with us. During our ten years of participation in SLI we have met with a number of people from various departments within the University of Wisconsin-Madison, including Professor McCammon from the department of Physics, Professor Eloranta from the department of Atmospheric Sciences, Professor Pawley from the department of Zoology, and Professors Anderson and Bonazza from the department of Mechanical Engineering. Two years ago we have added Prof. Fernandez and Prof. Gilroy from the department of Botany, and Prof. Masson from the department of genetics. Last year Prof. Özdoğan from Nelson Institute for Sustainability and Global Environment joined our ranks as an expert on remote sensing and image analysis. New this year is Prof. Sebastian Bednarek (Dept. of Biochemistry), who has helped us with many aspects of our project. These contacts have been incredibly helpful in designing and refining our original experimental ideas and creating an experiment that will return meaningful data.

Last year two new educators joined our team: Dr. Rob Williamson from AlfaLight and Joseph Schoneman, currently a student at UW Madison. Both Rob and Joe are mechanical engineers and they have brought new level of expertise and set of skills to teach to our students. They will both continue their involvement with our program this entire season.

We are now officially affiliated with UW Madison and our research meetings are now held in Chamberlin Hall, Dept. of Physics and classrooms in Engineering Hall. This provides us with state of art classrooms, including projection technology and document camera that we can use during our meeting. We are also participating in UW outreach activities, such as Physics Open House, Super Science Saturdays (in summer) and most importantly Wisconsin Science Festival, where we can reach over 2,000 people. Additionally, UW Madison now provides teleconferencing venue and equipment, saving us over $2,000.00 in teleconferencing expenses.

Every year we raise funds by raking leaves during autumn in local neighborhoods. We find this is an excellent way to earn the support of the community and increase our visibility.

The club also provides a steady stream of volunteers for public television and public radio fundraising drives. While this is not a direct display of our work or interests, it gives us the opportunity to provide public service in the name of our club.

In 2009 many club members gave back to the community by helping build a fence in the local soccer park where we also happen to launch our TARC practice flights in the winter.

In 2012 we have won TARC national contest for second time in our club history. This has brought our club into spotlight and we have received communications from senators, mayor, Dane County board and others. NBC channel broadcasted a 4 minute documentary about our club and Wisconsin State Journal printed a full length article. We are also scheduled for an hour long show at local community radio station (WORT 89.9FM).

We have established our Twitter and Facebook presence and at peak times our postings reach over 2,500 people.

Sustainability of Rocket Science Program

The rocketry program at Madison West High School is now in its thirteenth year, and it provides a strong, compelling incentive for students to research unique science concepts and enhance their problem-solving skills.

Incoming students are enrolled in the TARC program, where they attend classroom sessions taught by the mentors in order to learn the basic rocketry knowledge and methodologies essential to the contest. Our TARC program is currently enjoying a streak of success at national finals, placing in top 10 for last four consecutive years.

While dormant in 2015, Rockets For Schools is a program that has been beneficial to our members and efforts. We truly hope that it will be back for 2016 season. In this contest, students are given a high-power rocket kit and asked to design a scientific payload to be flown from Sheboygan, WI over Lake Michigan. Not only does this project offer good training for the process of obtaining an SLI grant, it also gives an additional activity option to first-year club members: while they are not allowed to participate in SLI, our highest-level project, they may participate in the R4S competition. We have modeled our R4S program after the SLI program, placing emphasis on the scientific project and development process. All R4S students are encouraged to seek L1 HPR certification as a part of the R4S program. Our first five R4S teams (2010, 2011, 2012) consisted of all first-year members, and their high scores won additional SLI invitations for the club for 2011, 2012, 2013 and 2015 seasons.

This year we have again continued our summer HPR L1/L2 Certifications program. A number of L1 certifications were obtained by younger club members. This highly successful summer L1 program (outside school year) was invented, coordinated and administered by the SLI-2008, SLI-2009 and SLI-2010 participant, Ms. Zoë Batson, until her departure to college, after which we continued program on our own because of its massive popularity.

Madison West Rocketry actively recruits new members in the fall season: the Freshman Club Carnival, West Fest, Homecoming parade, and daily announcements, all showcase our club’s achievements, appealing to interested individuals.

We collaborate extensively with experts at the University of Wisconsin (UW). During our meetings we are able to have analytical discussions with professionals regarding the feasibility and limitations of various potential experimental payloads. We have developed such relationships with several departments; this variety provides us with experiences perspectives on our design and objectives.

We now have five committed mentors who aid our group throughout all the stages of our well-established rocketry program. They patiently teach us and guide us in the planning, processing, writing, building, organization, and launching of our project. Our mentors dedicate much time and effort throughout the year- we greatly value their compassion and support.

An increasing number of parents are taking interest in supporting our club's meetings, fundraisers, outreach projects, and launches. They provide us with food and transportation during the cold winter events and launches, and are a great source of encouragement.

This year we expect to add another room to our workshop facility (making it four rooms total). We are bringing in more computers, 3D printers and we will continue exploration of plastic part molding and casting. We have 55 licenses for Solid Works CAD and the interest in 3D printing is growing faster than we ever expected. We have also built our own 3D printer (in addition to the 3D printers that were already purchased). We run an active and successful program that teaches students the basics of PCB (printed circuit board) design and manufacturing, taking them from pencil sketch all the way to the finished and programmed board.

Section 508 Compliance

Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standards (36 CFR Part 1194)

The team will implement required parts of Section 508, namely

- § 1194.21 Software applications and operating systems (all items)
- § 1194.22 Web-based intranet and internet information and applications (all items)
- § 1194.26 Desktop and portable computers (all items)
  - § 1194.23 Telecommunications products (items (k)(1) through (4)) as referenced by § 1194.26

The team carefully reviewed the above listed sections and consulted the same with two senior software engineers at DNASTAR, Inc. (a bioinformatics software company).

Re: § 1194.21: The team is using MS Windows and Mac OS-X based computers. Both Microsoft and Apple are strong supporters of Section 508 and all installation of MS Windows and Mac OS-X are complete including the access assistive features. All third party software used in the SLI project is claimed as Section 508 compliant by the software company producing the software (Microsoft, Apple, and Adobe).

Software and firmware developed by the students during the project will be verified for Section 508 compliance by senior software engineers from DNASTAR Inc. All found violations will be fixed prior software deployment.

Re: § 1194.22: The rocket club website (http://www.westrocketry.com) has been checked for Section 508 compliance using various automated validators (such as http://section508.info). No violations have been found.

The website specific to the proposed project will be periodically subjected to the same selection of tests and the webmaster will remove all found violations in a timely manner.

Re: § 1194.26: All computers used by the team members and educators are Section 508 compliant. No computer has been modified beyond the manufacturer approved upgrades.

Project Requirements

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 5,264ft. 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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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).

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.

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.

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.

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.

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 K1620-VMax motor is the primary propulsion choice.

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.

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 K740CS with 1874Ns of total impulse.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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*. Our simulations show that the

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.

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.

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.

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.

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.

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.

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.

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.

We will use both an on-board GPS receiver transmitting its location via wireless XBee modem and a radio beacon both in the vehicle and the payload probe. Additionally we will use our CAT (Cloud Aided Telemetry) system that is utilizing cellular networks to transmit and receive data. Finally, each section of the rocket is equipped by one radio and one sonic beacon.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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 24, page 40.

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 24, page 40.

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.

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 27-44 in this document.

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*.

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 27-44 for full description of AGSE and technologies used.

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.

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.

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. Figure 17 on page 33 for proposed gripper.

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.

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.

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 37-38).

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 24.

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 24.

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.

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.

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 121.2lbs.

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.

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.

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.

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 Table 1 on page 9.

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 61.

Supplementary Information

Team Members Resumes

Resume for Aastha

Academic Experience
East Elementary School, Kindergarten-2nd Grade (Athens, OH)
Irving Elementary School 3rd-5th Grade (Bozeman, MT)
Sacajawea Middle School 6th-7th Grade (Bozeman, MT)
Hamilton Middle School 7th-8th Grade (Madison, WI)
Madison West High School 9th- 12th Grade (Madison, WI)

Languages
English
Hindi
French (5th Year)

Honors and AP Classes
Geometry Honors
Biology Honors
Algebra 2 Trig Honors
English 2 Honors
Trends in 20th Century Literature Honors
AP Chemistry
AP Statistics
AP Calculus AB
AP Environmental Science
AP French Language

Clubs
Rocket Club
Science Olympiad
Math Team

Volunteer Work
St. Mary's Hospital, 2013-Present
Madison Public Library: Sequoya Branch, Summer 2014
MSCR Summer Camp, Summer 2014
Academic Peer Tutoring, 2013-Present

Sports
Tennis

Other
Lab Work – UW Madison Department of Bacteriology, Currie Lab
Summer Science Internhip – UW Madison Department of Human Oncology, Kimple Lab

Awards and Achievements
TARC 2013 (29^{th} place)
TARC 2014 (11^{th} place)
R4S 2013 (2^{nd} place)
R4S 2014 (1^{st} place)
Academic Honor Roll
National Honor Society
French Honor Society

Experience
TARC (2013,2014)
R4S (2013, 2014)

Interests
Reading, Tennis, Molecular Biology, Rocketry

Resume for Dan

Academic Experience
Chengde Elementary School (2004-2007)
Wilson Elementary School (2007-2008)
Shorewood Elementary School (2008-2010)
Hamilton Middle School (2010-2012)
West High School (2012-present)

Language
Mandarin
English (7 years)
Spanish (4 years)

Clubs
Madison West Rocketry
Skills USA
Greens Club

Music
Violin (4 years)
Guitar (2 years)
Sports
Football (1 year)
Tennis (2 years)

Other
Volunteering at Vilas Zoo
Volunteering at Engineering Center
Engineering Teacher Assistant
Help at UW research department
High School Summer Research Internship at UW-Madison
Cashier at Copps

Awards and Achievements
Rockets For Schools (1st place)
TARC (Nationals, 20th place)
PLTW Alumni

Honor/ AP Classes
Algebra Honors
Geometry Honors
Trigonometry Honors
AP Calculus AB
AP Calculus BC
AP Physics
AP Computer Science
AP Chemistry
English 2 Honors

Western Civilization Honors
Intro to Engineering (AP Credit)
Principle of Engineering (AP Credit)
Engineering Design and Drafting (AP Credit)

Interests
Aerospace Engineering
Biomedical Engineering
Computer Science
Mechanical Engineering

Resume for Eric

Academic Experience
Stoner Prairie Elementary School (2004-2008)
Core Knowledge Charter School (elementary and middle school) (2008-2012)
Madison West High School (2012-Present)

Languages
Chinese (Fluent)
English (Fluent)
Spanish (learning in school)

Rocketry
Madison West Rocket Club (2012-Present)
TARC Finals 2013
TARC Finals 2014 (Top 25 – 11th place)
TARC Finals 2015 (Top 10 – 7th place)

Music
Middle School Band (2010-2012)
High School Concert Band (2012-Present)

Sports
Karate (2010-2014)

Other
Science Olympiad (2013-Present)
Student Council (2012-Present)

Achievements
Madison West Honor Roll (2012-2014)
Student Council President (2013-2014)

Volunteer Experience
MACCO – Madison Area Chinese Community Organization Madison West High School New Team SL 2015 SOW
Chinese Culture Festival
Sino Language
Total English Immersion
Chinese Book Reading
St. Mary's Hospital (80+ Hours)
Hospital Volunteering
Student Council (10+ Hours)
Food Drive Coordination

Honors Classes
Geometry Honors (9th Grade)
Pre-Calc Honors (10th Grade)
English 9 Honors (9th Grade)
English 10 Honors (10th Grade)
English Literature Honors (11^{th} Grade)
US History 9 Honors (9th Grade)
Biology Honors (9th Grade)
Interests
Reading, writing, basketball, karate, drawing, metalworking

Resume for Jason

Academic Experience
Kempsville Elementary School (2003-2006)
Lincoln Elementary School (2006-2007)
Randall Elementary School (2007-2010)
Velma Hamilton Middle School (2010-2013)
Madison West High School (2013-present)

Languages
English (native), Spanish (5 years)

Rocketry
Madison West Rocketry (2013-present)
Team America Rocketry Challenge 2014
HPR Level 1 Certification, 2015
NASA SL2015 Participant - Madison West High School - Project Land Imaging

Music
Cello (2009-2010)
Saxophone (2010-present)
Jazz Band (2010-2013)
Pep Band (2013-present)

Sports
Soccer (2002-2006)
Bicycling (2013-present)

Other
Book Bowl (2010)
Boy Scouts of America (2011-2015)
Future Problem Solvers (2008-2009)

Volunteering
Bell Ringing for the Salvation Army (2011-2013)
Serving pancakes after Sunday Church Service (2011-2015)
Menominee Animal Shelter (2006)
Community Service with Rocketry Club (2013-present)

Honors Classes
Pre-algebra Honors (2011-2012)
Algebra 1 Honors (2012-2013)
Geometry Honors (2013-2014)
Algebra 2/Trigonometry Honors (2014-present)
Biology Honors (2013-2014)
Western Civilization Embedded Honors (2014-2015)

Interests
Rocketry, traveling, reading, foreign languages

Resume for Jeff

Academic Experience
Leopold Elementary School (2005-2007)
Randall Elementary School (2007-2009)
Hamilton Middle School (2009-2013)
West High School (2013-present)

Languages
Mandarin (fluent), English (fluent), French (4 years)

Clubs
Madison West Rocketry (2013-present)
Future Problem Solving (2008-present)
Plant Propagation Club (2013-present)
French Honor Society (2015-present)

Music
Piano (8 years)
Alto Saxophone (3 years)

Sports
Basketball (7 years)
Track (1 year)
Cross Country (1 year)

Work/Volunteering
Volunteering at Madison Children's Museum (70+ hours)
Volunteering at Fitchburg Public Library (60+ hours)
High School Summer Research Internship at UW-Madison Pike Laboratory
Utility Clerk at Copps

Awards and Achievements
TARC 2015 (Nationals, 7th place)
FPS State Bowl Senior Division Global Issues Problem Solving 2nd Place
FPS State Bowl Middle Division Global Issues Problem Solving 3rd Place
FPS International Conference (2014)
Honor/ AP Classes
Algebra 1 and Geometry Honors
Algebra 2/Trigonometry Honors
AP Calculus AB
Biology Honors
English 1 and 2 Honors
U.S. History 1 Honors
Western Civilization Honors

Interests
Engineering, Baking, Gardening, Running, Photography

Resume for Mathilda

Academic Experience
Midvale Elementary School (2003-2006)
Lincoln Elementary School (2006-2009)
Velma Hamilton Middle School (2009-2012)
Madison West High School (2012-Present)

Languages
English, Latin (4th year)

Rocketry
Madison West Rocket Club (2013-Present)
TARC Finals (2014)
NASA SL (2015)

Latin
West Latin Club (2012-Present)
2013 Wisconsin Junior Classical League Convention
 Latin Derivatives 1st, Latin Literature 1st, Mottoes 4th, Mythology 2nd, Pentathlon 3rd, Roman History 2nd, Roman Life 3rd, Vocabulary 4th, Team Sight Reading 4th, Certamen 2nd, Individual Sweepstakes 3rd
2013 National Junior Classical League Convention
 Greek Life and Literature 4th, Greek Derivatives 4th, Greek Language 8th, Certamen 5th
2014 Wisconsin Junior Classical League Convention
 Roman History 4th, Private Life 5th, Grammar, 4th, Latin Literature 2nd, Mythology 5th, Reading Comprehension 7th, Certamen 2nd, Individual Sweepstakes 9th
2014 National Junior Classical League
 Greek Derivatives 4th, Greek Life and Literature 7th, Certamen 9th
Silver on the National Latin Exam (2013 and 2014)
Silver on the Medusa Mythology Exam (2013 and 2014)
West Latin Club First Vice-President (2016)

Sports
Soccer (2003-2008)
Basketball (2012-Present)
Lacrosse (2013-Present)
Cross-Country (2014-Present)

Music
Viola
 Elementary School Orchestra (2008-2009)
 Middle School Orchestra (2009-2012)
First United Society of Madison Teen Choir (2012)
Guitar (2012-2013)

Other
Teacher's Assistant for a Latin 1 class (4 semesters, 2013-2015)
Member of Friends of Hoyt Park

Honor Classes
Algebra 1 Honors (9th Grade)
Geometry Honors (10th Grade)
Algebra 2/Trigonometry Honors (11th Grade)
US History Honors (1st Semester 9th Grade)
Western Civilizations Honors (10th Grade)
Advanced Writing Workshop (11th Grade)
AP U.S. Government and Politics (12th Grade)
AP Physics 2 (12th Grade)
AP Computer Science A (12th Grade)

Interests
Management
Linguistics
History
Education

Resume for Ramya

Academic Experience
Van Hise Elementary School (2008 - 2010)
Velma Hamilton MIddle School (2010 - 2013)
West High School (2013 - present)

Languages
Telugu (native)
Hindi
English
Spanish (4 years)

Honors and AP classes
Algebra I Honors
Biology I Honors
US History Honors
Geometry Honors
English II Honors
Algebra II / Trigonometry Honors
AP Chemistry (current)
AP Statistics (current)

Clubs
Madison West Rocketry (2013-present)
Madison West Math Team (2013-present)

Music
Violin (2010-2011)
Choir (2011-2013)

Sports
JV Tennis (present)

Volunteering
Madison Sequoya public library (2011 - present)
Madison Red Cross (2012 - present)
Wisconsin Science Festival (2013 - present)

Awards and Achievements
Rockets For Schools team 2014 - 1st place
Team America Rocketry Challenge (TARC 2014) - 20th place
Hawk Pride recipient (2012-2013)
National Spanish Exam – bronze award (2013)
"Valuable member" of the Junior Varsity Math Team (2013 – 2015)
Honor Roll (2013-2015)
Spanish Honor Society (present)

Experience
TARC 2014
R4S 2014
SL 2015

Interests
Rocketry
Biology
Neurology
Math
Law
Drawing
Badminton
Tennis

Resume for Sebastian

Education
Madison West High School, cumulative GPA: 3.57 (2013-Present)

Work **Experience**
Carpentry *Aid*
Gained knowledge of the trade by working with an experienced carpenter

Achievements and Awards
Placed Nationally in Team America Rocketry Challenge (May 2013)
6th place nationally in the Team America Rocketry Challenge (May 2014)
"PEOPLE Elite" student (July 2015)
Honor Roll (2013- Present)

Extracurricular Activities
Team America Rocketry Challenge (2013, 2014)

- Designed, fabricated and troubleshot an airbrake system to control a rocket's altitude based on realtime flight data

NASA Student Launch 2015

- Established a study of Muon flux in relation to altitude
- Fabricated and troubleshot a rocket to carry Muon detection instruments to high altitudes
- Developed skills presenting research in a professional & interesting manner

RepRap 3d printer Club (2014-present)

- Discussed limitations of 3d printers & possible solutions
- Used *SolidWorks* CAD software to design components
- Constructed functioning, water-cooled 3d printer

People Program *(*2011-2015)

- Attended tutoring services multiple times a week during the school years
- Participated in a six week residential engineering internship
- Partook in vigorous residency programs to heighten college readiness

Volunteer Work
Homeroom Leader Madison West Senior Citizens (2015)

- Overseeing the introduction of incoming freshman to high school
- Attended Leadership Workshops

Outreach events at various science fairs (2012-2015)

- Explained scientific payloads to attendees
- Oversaw the creation and launch of pneumatic rockets to help interest children in science

Camp Woodbrooke (2013-2015)

- Worked as part of a ground crew clearing trails
- Determined problems with and replaced rototiller engine

Skills
Woodworking, soldering (surface-mount & through hole), *Solidworks* & *Autodesk Inventor* CAD software, Microsoft PowerPoint, small engine repair, bike repair

Resume for Siyi

Academic Experience
Shorewood Hills Elementary School (2006-2009)
Velma Hamilton Middle School (2009- 2012)
Madison West High School (2012-2016)

Languages
English
Mandarin
Spanish (4 years)

Honors and AP classes
Geometry Honors
Algebra 2 Trig Honors
Biology Honors
Western Civilization Honors
US history Honors
English 2 Honors
Trends in 20th Century Literature Honors
English Lit Honor
AP Computer Science
AP Chemistry

Clubs
Madison West Rocketry (2012 - present)
Madison West Math Team (2012- present)
Science Olympiad (2012- present)

Music
Piano (2006 - 2012)
Violin (2008 - present)
Wisconsin Youth Symphony Orchestra (2009 - present)

Sports
JV Tennis (2012 - Present)

Volunteering
Children's museum (2012- present)
ICE camp (2014 - present)
Wisconsin Science Festival (2012- present)
Peer Tutoring (2013- present)

Awards and Achievements
Rockets For Schools 2013 - 2nd Place
Rockets For Schools 2014 - 1st Place
Team America Rocketry Challenge 2013- 29th Place
Team America Rocketry Challenge 2014 - 11th Place
Spanish Honor Society

National Honor Society

Work Experience
Summer Science Internship- Loeb Lab in Wisconsin Institutes for Medical Research (2015)
Playthings (2015 - present)

Experience
TARC (2012 - 2015)
R4S (2012 - present)

Interests
Sketching, Painting, Music, tennis, photography

Resume for William

Academic Experience
Tsinghua Elementary School (2004-2006)
Stoner Prairie Elementary School (2006-2008)
Core Knowledge Charter School (2008-2012)
Madison West High School (2012-Present)

Languages
Chinese (Fluent)
English (Fluent)
Spanish (Level 5)

Rocketry
Madison West Rocket Club (2012-Present)
TARC Finals 2012
TARC Finals 2013
Top 25 (11th Place)
Student Launch 2015 - Best Payload Display Award

Music
Piano (2004-Present)
Clarinet (2010-2013)
Middle School Orchestra (2010-2012)
High School Symphony Orchestra (2013)

Sports
Figure Skating (2008-2010)
Karate (2010-Present)
Free-running (2013-Present)

Other
Forensics (2012)
Science Olympiad (2013-Present)
Student Council (2012-2013)
NHS (2014-Present)

Achievements
Madison West Honor Roll (2012-2014)
1st Place at Diamond Nationals Karate Competition (2012-2013)
1st Place at AKA Grand Nationals Karate Competition (2013)
Student Launch Best Payload Display Award
TARC Top 25

Volunteer Experience
MACCO – Madison Area Chinese Community Organization (10+ Hours)
Chinese Culture Festival
Sino Language (80 Hours)
Total English Immersion
VAIS – Verona Area International School (3 Hours)
Chinese Book Reading
St. Mary's Hospital (100+ Hours)
Hospital Volunteering
Student Council (10+ Hours)
Food Drive Coordination

Work Experience
Einstein Chinese School (2014-Present)
 Teacher
Kumon Learning Center (2012-2014)
 Assistant Teacher
McArdle Lab at Wisconsin Institutes for Medical Research (2014)
 Intern

Honors Classes
Geometry Honors (9th Grade)
English 1 Honors (9th Grade)
US History 1 Honors (9th Grade)
Biology Honors (9th Grade)
Pre-Calculus Honors (10th Grade)
English 2 Honors (10th Grade)
Advanced Writing Workshop (11th Grade)
English Literature Honors (11th Grade)

Interests
Reading, writing, free-running, karate, drawing,

NAR Model Rocketry Safety Code

1. **Materials.** I will use only lightweight, non-metal parts for the nose, body, and fins of my rocket.
2. **Motors.** I will use only certified, commercially-made model rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer.
3. **Ignition System.** I will launch my rockets with an electrical launch system and electrical motor igniters. My launch system will have a safety interlock in series with the launch switch, and will use a launch switch that returns to the "off" position when released.
4. **Misfires.** If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.
5. **Launch Safety.** I will use a countdown before launch, and will ensure that everyone is paying attention and is a safe distance of at least 15 feet away when I launch rockets with D motors or smaller, and 30 feet when I launch larger rockets. If I am uncertain about the safety or stability of an untested rocket, I will check the stability before flight and will fly it only after warning spectators and clearing them away to a safe distance.
6. **Launcher.** I will launch my rocket from a launch rod, tower, or rail that is pointed to within 30 degrees of the vertical to ensure that the rocket flies nearly straight up, and I will use a blast deflector to prevent the motor's exhaust from hitting the ground. To prevent accidental eye injury, I will place launchers so that the end of the launch rod is above eye level or will cap the end of the rod when it is not in use.
7. **Size.** My model rocket will not weigh more than 1,500 grams (53 ounces) at liftoff and will not contain more than 125 grams (4.4 ounces) of propellant or 320 N-sec (71.9 pound-seconds) of total impulse. If my model rocket weighs more than one pound (453 grams) at liftoff or has more than four ounces (113 grams) of propellant, I will check and comply with Federal Aviation Administration regulations before flying.
8. **Flight Safety.** I will not launch my rocket at targets, into clouds, or near airplanes, and will not put any flammable or explosive payload in my rocket.
9. **Launch Site.** I will launch my rocket outdoors, in an open area at least as large as shown in the accompanying table, and in safe weather conditions with wind speeds no greater than 20 miles per hour. I will ensure that there is no dry grass close to the launch pad, and that the launch site does not present risk of grass fires.
10. **Recovery System.** I will use a recovery system such as a streamer or parachute in my rocket so that it returns safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.
11. **Recovery Safety.** I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places.

LAUNCH SITE DIMENSIONS		
Installed Total Impulse (N-sec)	Equivalent Motor Type	Minimum Site Dimensions (ft.)
0.00--1.25	1/4A, 1/2A	50
1.26--2.50	A	100
2.51--5.00	B	200
5.01--10.00	C	400
10.01--20.00	D	500
20.01--40.00	E	1,000
40.01--80.00	F	1,000
80.01--160.00	G	1,000
160.01--320.00	Two Gs	1,500

Table 19: Minimum launch site dimensions

NAR High Power Rocketry Safety Code

Certification. I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.

1. **Materials.** I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.
2. **Motors**. I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.
3. **Ignition System.** I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the "off" position when released. If my rocket has onboard ignition systems for motors or recovery devices, these will have safety interlocks that interrupt the current path until the rocket is at the launch pad.
4. **Misfires.** If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.
5. **Launch Safety.** I will use a 5-second countdown before launch. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table, and that a means is available to warn participants and spectators in the event of a problem. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable.
6. **Launcher.** I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 if the rocket motor being launched uses titanium sponge in the propellant.
7. **Size.** My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.
8. **Flight Safety.** I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.
9. **Launch Site.** I will launch my rocket outdoors, in an open area where trees, power lines, buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater.
10. **Launcher Location.** My launcher will be at least one half the minimum launch site dimension, or

1500 feet (whichever is greater) from any inhabited building, or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.

11. **Recovery System.** I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.
12. **Recovery Safety.** I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.

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

Table 20: Minimum launch site dimensions

Section 508

§ 1194.21 Software applications and operating systems.

(a) When software is designed to run on a system that has a keyboard, product functions shall be executable from a keyboard where the function itself or the result of performing a function can be discerned textually.

(b) Applications shall not disrupt or disable activated features of other products that are identified as accessibility features, where those features are developed and documented according to industry standards. Applications also shall not disrupt or disable activated features of any operating system that are identified as accessibility features where the application programming interface for those accessibility features has been documented by the manufacturer of the operating system and is available to the product developer.

(c) A well-defined on-screen indication of the current focus shall be provided that moves among interactive interface elements as the input focus changes. The focus shall be programmatically exposed so that assistive technology can track focus and focus changes.

(d) Sufficient information about a user interface element including the identity, operation and state of the element shall be available to assistive technology. When an image represents a program element, the information conveyed by the image must also be available in text.

(e) When bitmap images are used to identify controls, status indicators, or other programmatic elements, the meaning assigned to those images shall be consistent throughout an application's performance.

(f) Textual information shall be provided through operating system functions for displaying text. The minimum information that shall be made available is text content, text input caret location, and text attributes.

(g) Applications shall not override user selected contrast and color selections and other individual display attributes.

(h) When animation is displayed, the information shall be displayable in at least one non-animated presentation mode at the option of the user.

(i) Color coding shall not be used as the only means of conveying information, indicating an action, prompting a response, or distinguishing a visual element.

(j) When a product permits a user to adjust color and contrast settings, a variety of color selections capable of producing a range of contrast levels shall be provided.

(k) Software shall not use flashing or blinking text, objects, or other elements having a flash or blink frequency greater than 2 Hz and lower than 55 Hz.

(l) When electronic forms are used, the form shall allow people using assistive technology to access the information, field elements, and functionality required for completion and submission of the form, including all directions and cues.

§ 1194.22 Web-based intranet and internet information and applications.

(a) A text equivalent for every non-text element shall be provided (e.g., via "alt", "longdesc", or in element content).

(b) Equivalent alternatives for any multimedia presentation shall be synchronized with the presentation.

(c) Web pages shall be designed so that all information conveyed with color is also available without color, for example from context or markup.

(d) Documents shall be organized so they are readable without requiring an associated style sheet.

(e) Redundant text links shall be provided for each active region of a server-side image map.

(f) Client-side image maps shall be provided instead of server-side image maps except where the regions cannot be defined with an available geometric shape.

(g) Row and column headers shall be identified for data tables.

(h) Markup shall be used to associate data cells and header cells for data tables that have two or more logical levels of row or column headers.

(i) Frames shall be titled with text that facilitates frame identification and navigation.

(j) Pages shall be designed to avoid causing the screen to flicker with a frequency greater than 2 Hz and lower than 55 Hz.

(k) A text-only page, with equivalent information or functionality, shall be provided to make a web site comply with the provisions of this part, when compliance cannot be accomplished in any other way. The content of the text-only page shall be updated whenever the primary page changes.

(l) When pages utilize scripting languages to display content, or to create interface elements, the information provided by the script shall be identified with functional text that can be read by assistive technology.

(m) When a web page requires that an applet, plug-in or other application be present on the client system to interpret page content, the page must provide a link to a plug-in or applet that complies with §1194.21(a) through (l).

(n) When electronic forms are designed to be completed on-line, the form shall allow people using assistive technology to access the information, field elements, and functionality required for completion and submission of the form, including all directions and cues.

(o) A method shall be provided that permits users to skip repetitive navigation links.

(p) When a timed response is required, the user shall be alerted and given sufficient time to indicate more time is required.

Note to §1194.22:

1. The Board interprets paragraphs (a) through (k) of this section as consistent with the following priority 1 Checkpoints of the Web Content Accessibility Guidelines 1.0 (WCAG 1.0) (May 5, 1999) published by the Web Accessibility Initiative of the World Wide Web Consortium:

Section 1194.22 Paragraph	WCAG 1.0 Checkpoint
(a)	1.1
(b)	1.4
(c)	2.1
(d)	6.1
(e)	1.2
(f)	9.1
(g)	5.1
(h)	5.2
(i)	12.1
(j)	7.1
(k)	11.4

Table 21: Checkpoint consistent with the Web Content Accessibility Guidelines

2. Paragraphs (l), (m), (n), (o), and (p) of this section are different from WCAG 1.0. Web pages that conform to WCAG 1.0, level A (i.e., all priority 1 checkpoints) must also meet paragraphs (l), (m), (n), (o), and (p) of this section to comply with this section. WCAG 1.0 is available at http://www.w3.org/TR/1999/WAI-WEBCONTENT-19990505.

§ 1194.23 Telecommunications products.

(a) Telecommunications products or systems which provide a function allowing voice communication and which do not themselves provide a TTY functionality shall provide a standard non-acoustic connection point for TTYs. Microphones shall be capable of being turned on and off to allow the user to intermix speech with TTY use.

(b) Telecommunications products which include voice communication functionality shall support all commonly used cross-manufacturer non-proprietary standard TTY signal protocols.

(c) Voice mail, auto-attendant, and interactive voice response telecommunications systems shall be usable by TTY users with their TTYs.

(d) Voice mail, messaging, auto-attendant, and interactive voice response telecommunications systems that require a response from a user within a time interval, shall give an alert when the time interval is about to run out, and shall provide sufficient time for the user to indicate more time is required.

(e) Where provided, caller identification and similar telecommunications functions shall also be available for users of TTYs, and for users who cannot see displays.

(f) For transmitted voice signals, telecommunications products shall provide a gain adjustable up to a minimum of 20 dB. For incremental volume control, at least one intermediate step of 12 dB of gain shall be provided.

(g) If the telecommunications product allows a user to adjust the receive volume, a function shall be provided to automatically reset the volume to the default level after every use.

(h) Where a telecommunications product delivers output by an audio transducer which is normally held up to the ear, a means for effective magnetic wireless coupling to hearing technologies shall be provided.

(i) Interference to hearing technologies (including hearing aids, cochlear implants, and assistive listening devices) shall be reduced to the lowest possible level that allows a user of hearing technologies to utilize the telecommunications product.

(j) Products that transmit or conduct information or communication, shall pass through cross-manufacturer, non-proprietary, industry-standard codes, translation protocols, formats or other information necessary to provide the information or communication in a usable format. Technologies which use encoding, signal compression, format transformation, or similar techniques shall not remove information needed for access or shall restore it upon delivery.

(k) Products which have mechanically operated controls or keys, shall comply with the following:

(1) Controls and keys shall be tactilely discernible without activating the controls or keys.

(2) Controls and keys shall be operable with one hand and shall not require tight grasping, pinching, or twisting of the wrist. The force required to activate controls and keys shall be 5 lbs. (22.2 N) maximum.

(3) If key repeat is supported, the delay before repeat shall be adjustable to at least 2 seconds. Key repeat rate shall be adjustable to 2 seconds per character.

(4) The status of all locking or toggle controls or keys shall be visually discernible, and discernible either through touch or sound.

§ 1194.26 Desktop and portable computers.

(a) All mechanically operated controls and keys shall comply with §1194.23 (k) (1) through (4).

(b) If a product utilizes touch screens or touch-operated controls, an input method shall be provided that complies with §1194.23 (k) (1) through (4).

(c) When biometric forms of user identification or control are used, an alternative form of identification or activation, which does not require the user to possess particular biological characteristics, shall also be provided.

(d) Where provided, at least one of each type of expansion slots, ports and connectors shall comply with publicly available industry standards.

List of Applicable Material Safety Data Sheets

All MSDS sheets are available on our website

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

Propulsion and Deployment Ammonium Perchlorate Aerotech Reloadable Motors Aerotech Igniters M-Tek E-matches Pyrodex Pellets Black Powder Nomex (thermal protector)	**Glues** Elmer's White Glue Two Ton Epoxy Resin Two Ton Epoxy Hardener Bob Smith Cyanoacrylate Glue (superglue) Superglue Accelerator (kicker) Superglue Debonder Norland 63 Loctite 220, 242, 271, 290 3M DP420 Dow 734 Black Max Black CA JB Weld
Soldering Flux Solder	**Painting and Finishing** Automotive Primer Automotive Spray Paint Clear Coat
Construction Supplies Carbon Fiber Kevlar Fiberglass Cloth Fiberglass Resin Fiberglass Hardener Self-expanding Foam Electrical tape	**Solvents** Ethyl Alcohol 70% Isopropyl Alcohol Acetone Flux-off no clean
Payload Materials Aluminum Acrylic Polycarbonate NdFeB magnets Lithium batteries	