PRELIMINARY DESIGN REVIEW

The Effect of Gravitational Forces on Gene Expression in Arabidopsis Thaliana Plants

NASA Student Launch for Middle and High School

Madison West High School	*New Team*	September 30th 2016

Madison West High School, 30 Ash Street, Madison, WI 53726

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Team Summary

Madison West High School
Team Arabidopsis (new team)

Mailing Address

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

Team Mentor

Dr. Pavel Pinkas
NAR #73307
Level-2 HPR Certification

Launch Vehicle Summary

Length: 84.5 inches
Diameter: 5.5 inches
Liftoff weight: 24.5 lbs
Motor: K1620-Vmax
Flysheet: http://westrocketry.com/sli2017/MSRFS_PDR_MadisonWest2017_Arabidopsis.xls

Project Title and Summary

The Effect of Gravitational Forces on Gene Expression in Arabidopsis Thaliana Plants

Our project is inspired by the growing interest of cultivating plants in space in hopes of being able to sustain human life outside of Earth. Through our experiment, we will obtain information about how the extreme gravitational forces of a launch affect the gene expression of *Arabidopsis Thaliana* seedlings. *Arabidopsis Thaliana* is a member of *Brassicaceae family* and a close relative of broccoli. We will study response to gravitational forces in wild type *Arabidopsis*. Our results will provide valuable insights into the effects the genes of plants will receive from gravitational forces and what precautions need to be implemented to keep healthy plants when exposing them to the stress of a launch. We chose the *Arabidopsis Thaliana* to use as a model plant since the *Arabidopsis Thaliana* has a mapped out genome and a short lifespan. Knowing what genes the gravitational forces from a launch affect will provide us with further insights of how the plants responds to this type of stress.

Changes made since Proposal

Changes made to vehicle criteria

- Added verification plan and status
- Added vehicle risk analysis
- Added vehicle maturity discussion
- Added mass statement
- Updated detailed dimensional drawing of the vehicle
- Updated recovery table to include impact energy for all parts of the rocket
- Added electrical schematic of deployment electronic
- Added mission performance criteria
- Added preliminary checklist for final assembly and launch procedures
- Added description of interfaces
- Added discussion of environmental concerns

Changes made to payload criteria

- Added verification plan and status

Changes made to project plan

- Updated outreach information

Safety

Written Safety Plan

The following risks could endanger the successful completion of our project (listed with proposed mitigations):

- **Facility Risks:**
    - ***Workshop inaccessible:*** we have signed 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. with several choices available should the primary room become inaccssible. 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 individual 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.
  - ***Propellant unavailability:*** all purchasing is conducted as soon as practically possible and motor alternatives are thoroughly investigated during the vehicle design. We are also working with several vendors, trying to maintain propellant availability redundancy as much as possible.
  - ***Final vehicle heavily overweight, unable to reach target altitude:*** 30% of total vehicle weight is added to the initial estimate of vehicle weight and all initial simulations are carried out with coefficient of drag (C_d) set to 0.7 (reasonable estimate for a single diameter, cylindrical vehicle). This prevents overly optimistic estimates of vehicle performance and also simulates the vehicle weight increase accurately.

- **Payload risks:**
  - ***Plants fail to emerge or die early:*** we will practice growing of Arabidopsis Thaliana for the entire duration of project. We will be tutored by Prof. Gilroy from Botany Dept. and Prof. Bednarek from Biochemistry Dept. Aseptic technique will be used to eliminate the possibility of molds taking over the plant colony. Proper germination techniques, such as cold treatment (to simulate winter) will be use to assure high rate of germination.

- **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.
  - ***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

Dr. Pavel Pinkas (L2 certified, NAR and TRA member) is the mentor for the team and designated owner of the rocket for liability purposes. Dr. Pinkas will accompany the team to Huntsville, AL.

All hazardous materials will be purchased, handled, used, and stored by Mr. Lillesand (L3 certified, NAR and TAR member, LEUP holder) or project educators (Dr. Pinkas or Ms. Hager). Dr. Pinkas and Mr. Lillesand will be the only people 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.

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/sli2017/safety/safety2017a.php

Energetics Purchase, Storage, Transport and Use

NAR/TRA mentor, Dr. Pinkas, holds a Level 2 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. Dr. Pinkas and Mr. Lillesand will be the only people 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.

Vehicle Criteria

Mission Statement, Requirements and Mission Success Criteria

We will use a single stage, K-class vehicle to deliver our payload to the target altitude of 5,280*ft*. Our project will investigate changes in gene expression in *Arabidopsis thaliana* plants as a response to plant's exposure to severe gravitational forces.

To have a successful mission the rocket must reach (but not exceed) altitude of one mile AGL and the payload must record all data necessary for our experiment. Vehicle requirements are addressed in detail starting on page (I don't know how to do the automatic page numbering).

System Level Review

Subsystems necessary to accomplish the overall mission are:

- *Structural Subsystem*, description starting on page **Error! Reference source not found.Error! Bookmark not defined.**
- *Propulsion Subsystem* with performance predictions starting on page **Error! Bookmark not defined.**
- *Deployment and Recovery Subsystem*, description starting on page 22

Vehicle Construction

The rocket will be constructed from LOC Precision fiber tubing, using sandwiched 1/32" G10 fiberglass with two cross-grained layers of 1/16" balsa sheets for fins. The fiberglass provides the outer layer and is sandwiched with balsa via vacuum-bagging process. The rocket will be robust enough to endure 25+*g* of acceleration and high power rocket flight and deployment stresses.

The rocket will be 85*in* long, with a 5.5*in* diameter. It has estimated liftoff mass of 25.4*lbs* (including 30% of simulated weight increase). The proposed vehicle and propulsion options are discussed in detail below. The primary propulsion choice is a K-class motor (Aerotech K1999N-P, 98*mm*) with total impulse of 2540*Ns*. The vehicle can launch from a standard size, 10*ft* launch rail.

The rocket will use dual deployment to minimize drift.

Dimensions

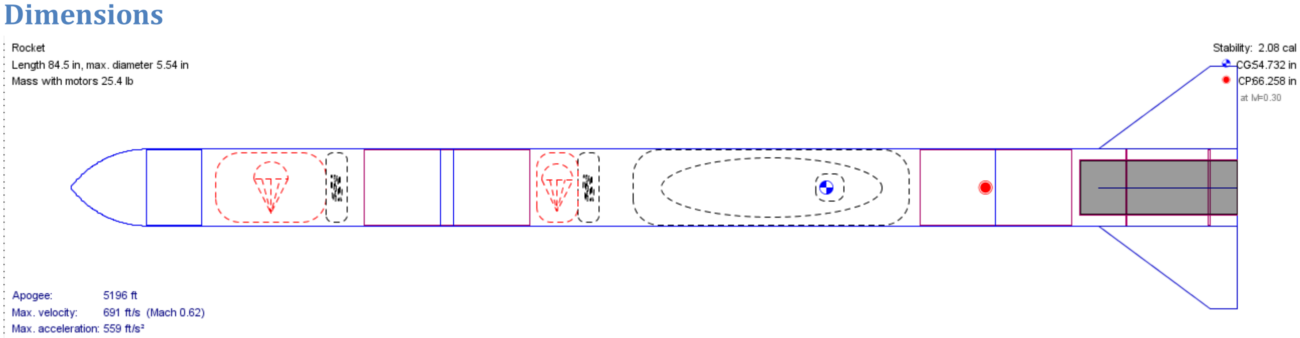
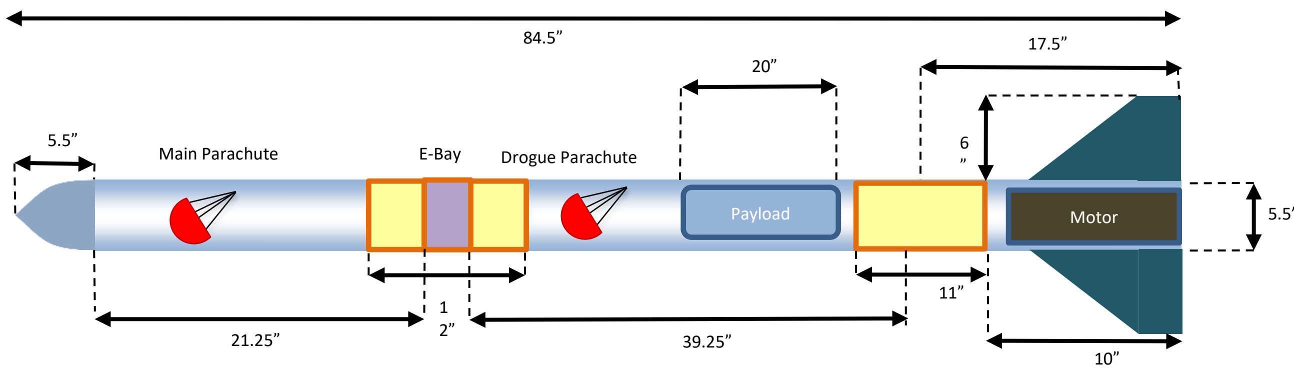


Figure 1: A two dimensional schematic of the entire rocket

Length *[in]*	Mass *[lbs]*	Diameter *[in]*	Motor Selection	Stability Margin *[calibers]*	Thrust to weight ratio
84.5	24.5	5.5	K1620 Vmax	2.08	18.73

Table 1: Vehicle parameters

This diagram below shows the main dimensions of the rocket and its sections



The following figure shows all compartments and sections of our rocket. The rocket separates into **three** tethered parts (nosecone, main parachute bay and booster section). The payload travels in the booster section. We will use standard dual deployment triggered by two fully redundant PerfectFlite StratoLogger altimeters.

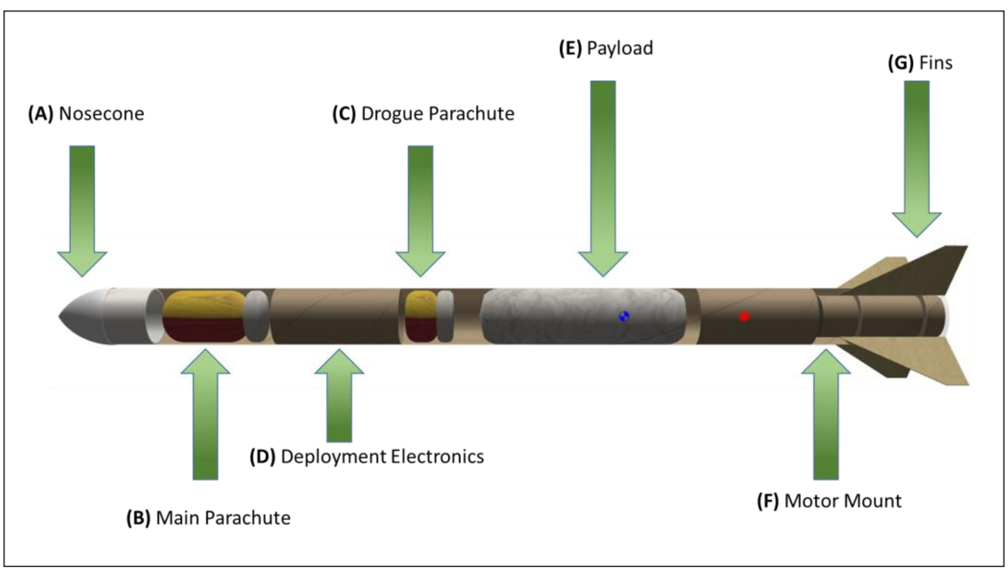


Figure 2: A three dimensional schematic of the entire rocket

	Key

(A)	Nose Cone
(B)	Main Parachute
(C)	Drogue Parachute
(D)	Deployment Electronics
(E)	Payload
(F)	Motor Mount (98mm)
(G)	Sandwiched fins made from Balsa covered in 1/32 inch G10 Fiberglass

Table 2: Rocket parts and compartments

This diagram below shows the main dimensions of the rocket and its sections:

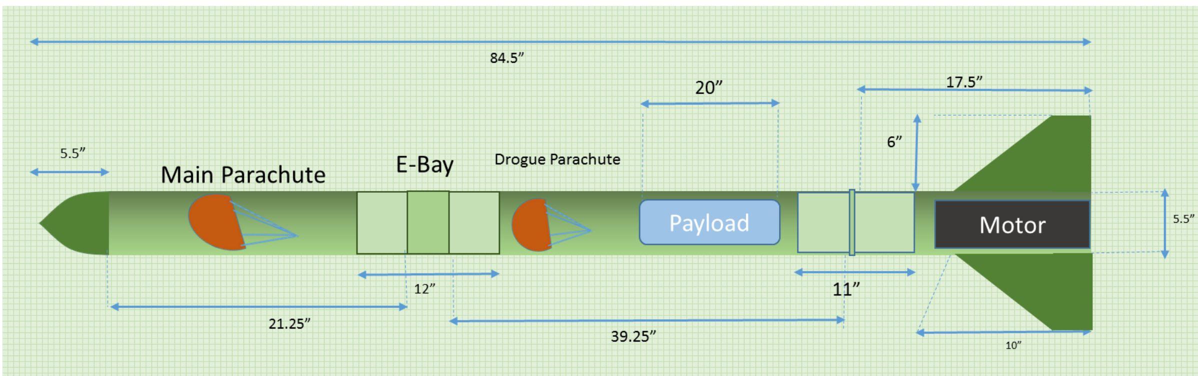


Figure 3: Dimensioned drawing of the vehicle

Interfaces and Integration

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

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

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

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

Material Selection

From previous projects where a similar delivery vehicle was used, we know that given the total impulse limit, the vehicle of this diameter will not be able to reach the target altitude if built from using fiberglass as the main material. For this reason we decided to use LOC Precision fiber tubing for body and sandwich of G10 and balsa for fins. Both materials are capable of withstanding the stresses of the flight and the weight reduction will be sufficient to allow the vehicle to reach its target altitude of 1 mile.

Most recently similar vehicle was constructed for our SL2016 project and its altitude reach was measured to 4,900*ft*, using the K1620 motor while being 3 pounds heavier than the predicted maximum liftoff weight of our vehicle.

Rocket Part	Material
Nosecone	3D printed ABS plastic, Von Karman shape
Tubing	LOC Precision fiber tubing
Fins	2x 1/32”G10 fiberglass + 2x 1/16”balsa wood
Parachutes	Ripstop Nylon
Couplers	LOC Precision fiber tubing & Stiffy™
Motor Mount	Blue Tube 98*mm* tubing
Centering Rings	Aircraft plywood
Anchors	¼” stainless steel U-bolts
Tie-rods	#8 stainless steel threaded rods with
Motor retention	Aeropack aluminum flange mounted retainer

Table 3: Materials for rocket construction

Construction Methods

We will work under the supervision and advice of our mentors, Dr. Pavel Pinkas and Mr. Brent Lillesand, to make sure that the rocket is built correctly and fitting its mission. We plan to use West System epoxy with appropriate fillers for rocket assembly. The fins will be made out of two outer layers of 1/32” G10 with two 1/16” inner layers of balsa, laid cross-grained for maximum strength. The sandwich will be sealed with epoxy, using vacuum bagging method. The rocket construction will be done in our workshop, which is fully equipped for high power rocketry projects. Mr. Jim Guither is our advisor and production manager for 3D printed parts.

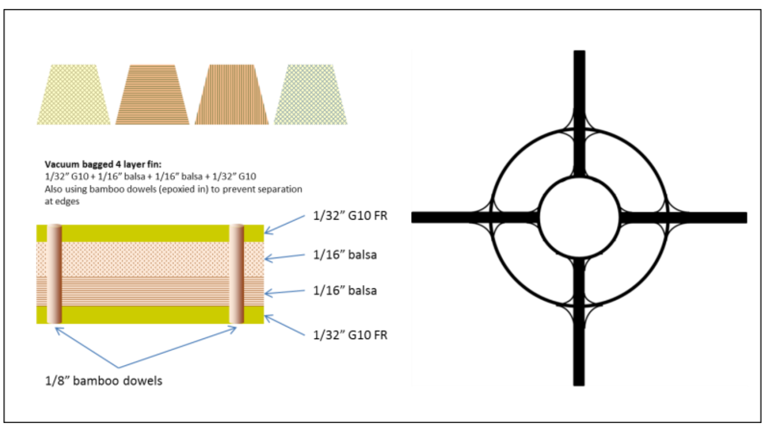


Figure 4: Fin construction and mounting

The fin construction and mounting are illustrated on Figure 4. The sandwiched fins will be mounted through the body tube wall and anchored on the motor mount tube. Epoxy filets will be formed between i) motor tube and fins root edge; ii) inner wall of body tube and fins and iii) outer wall of body tube and fins. All surfaces wetted with epoxy will roughen up by sanding to increase the penetration of the glue and strength of the bond.

Mass Statement

- Our rocket has a mass of 25.4 *lbs*, which includes the 6.85*lbs* AeroTech k1999n motor. This estimate of the mass comes from the OpenRocket application where our rocket is being designed.
- If the rockets gains 5*lbs* of weight it will only reach altitude of 4,184 *ft* which we consider unacceptable performance.
- The rocket would have to weigh more than 111*lbs* for the thrust to weight ratio to drop under 5 (underpowered rocket).

Performance Predictions

All performance predictions were made using OpenRocket v15.03.

Propulsion Selection

Based on the results of computer simulations we have selected AT K1999N-P (98*mm*) motor as our primary propulsion choice. Our backup is CTI K1620-VMax 98mm motor. Characteristic parameters for each motor are shown in the table below. While CTI motors are normally our first choice, we have downgraded the CTI K1620VMax motor to a backup alternative because of its extremely limited availability due to the recent fire in Cesaroni factory.

Motor	Diameter *[mm]*	Total Impulse *[Ns]*	Burn Time *[s]*	Stability Margin *[calibers]*	Thrust to Weight ratio
AT K1999N-6	98	2540	1.4	2.08	28.55
CTI K1620-Vmax	98	2433	1.5	2.06	24.47

Table 4: Propulsion alternatives

Altitude Profile

The graph below shows the simulated flight profile for the Aerotech (AT) K1999N-P motor. The vehicle reaches the apogee of 5,146*ft* in seventeen seconds (17*s*) after the ignition. For the purpose of this preliminary simulation the average coefficient of drag is C_D = 0.7 (we have flown this type of vehicle during our prior SLI projects and the collected flight data indicate that C_D = 0.7 is a reasonable estimate of overall drag coefficient for a single diameter vehicle). The entire flight duration is estimated at 95*s* and the drift under 15*mph* wind conditions is 2,092*ft.*

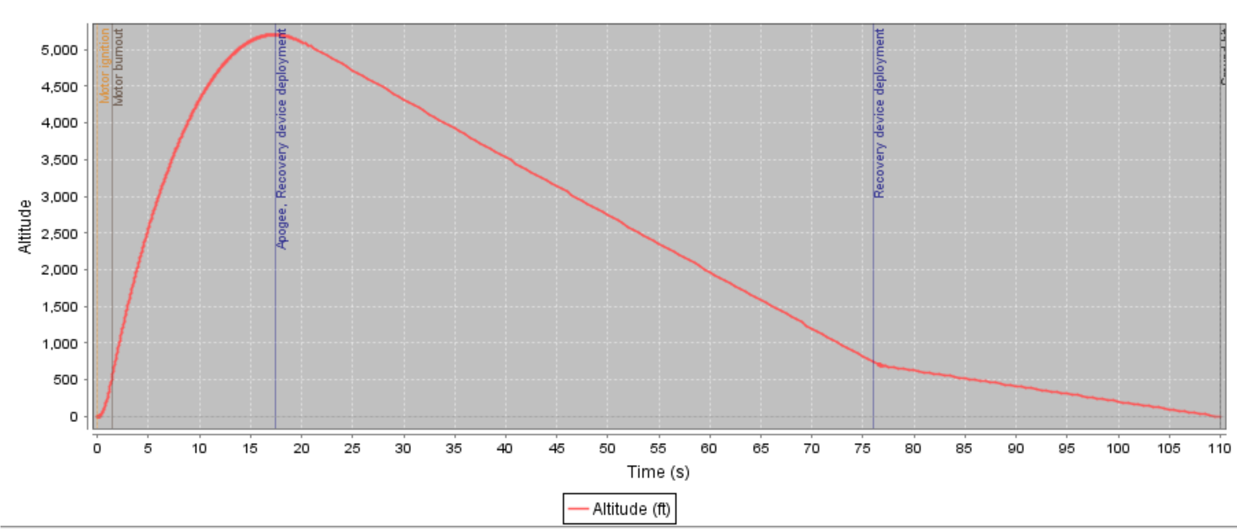


Figure 5: Altitude over Time Graph

The simulations indicate a small (2.5%) 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 just a simulation artifact (we have accounted for possible 30% liftoff weight increase in our simulations and used coefficient of drag 0.7). 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 SLI launch will use the same motor as we will use for our flight in Hunstsville 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 1.5% from the apogee reached in windless conditions.

Wind Speed *[mph]*	Altitude *[ft]*	Percent Change In Apogee
0	5146	0.0
5	5140	0.12
10	5133	0.25
15	5113	0.64
20	5086	1.17

Table 5: Apogee vs. wind speed

Thrust Profile

The graph below shows the thrust profile for the AT K1999N-P motor. The AT K1999N-P motor reaches its maximum thrust of 2000*N* after 0.16*s* and burns at approximately constant thrust level for about 1.05*s* (the average thrust-to-weight ratio is 17.98). The rocket requires a ten-foot rail for sufficient stability on the pad and leaves the 10*ft* rail at about 102*fps* (69.6*mph*).

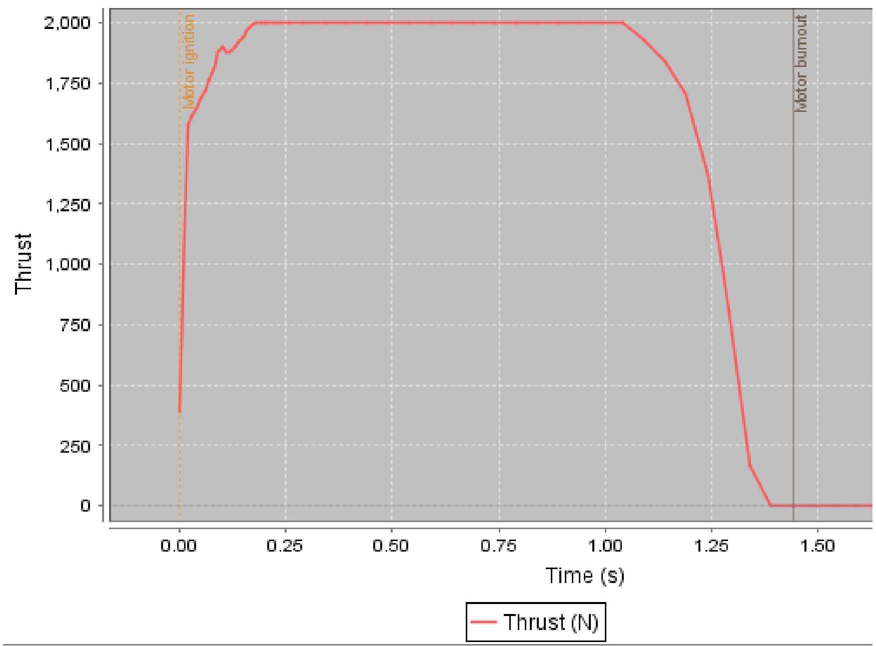


Figure 6: Thrust (N) vs Time.

Velocity Profile

According to the velocity profile (next graph), the rocket will reach maximum velocity of 470*mph* shortly before the burnout (1.3*s*). The rocket remains subsonic for the entire duration of its flight.

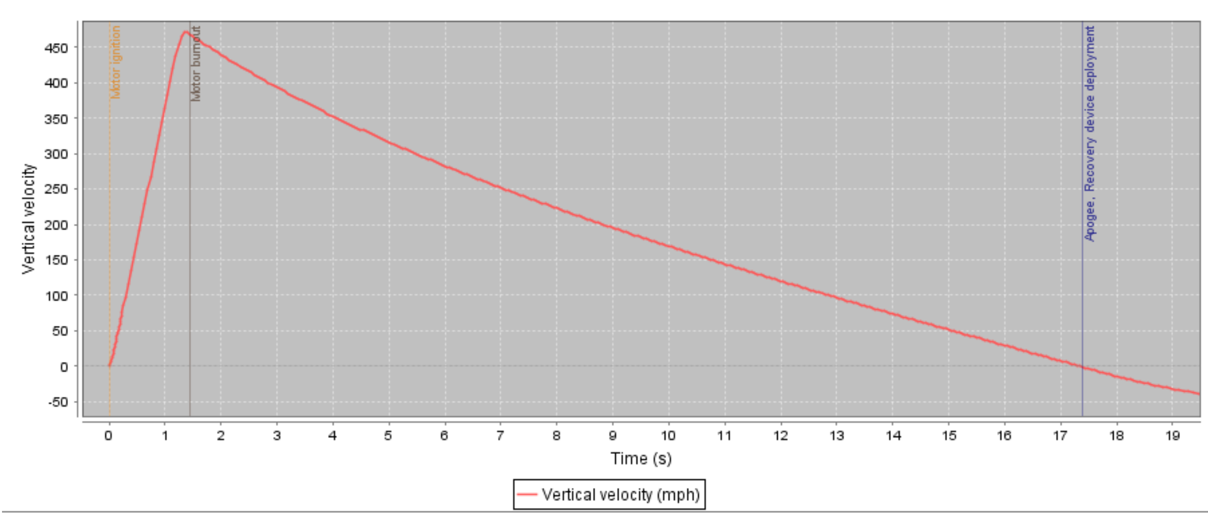


Figure 7: Vertical Velocity (mph) vs Time

Acceleration Profile

The graph below shows that the rocket will experience maximum acceleration of about 18*g* for 1.3*s*. Our rocket will be robust enough to endure the 30*g*+ acceleration shocks.

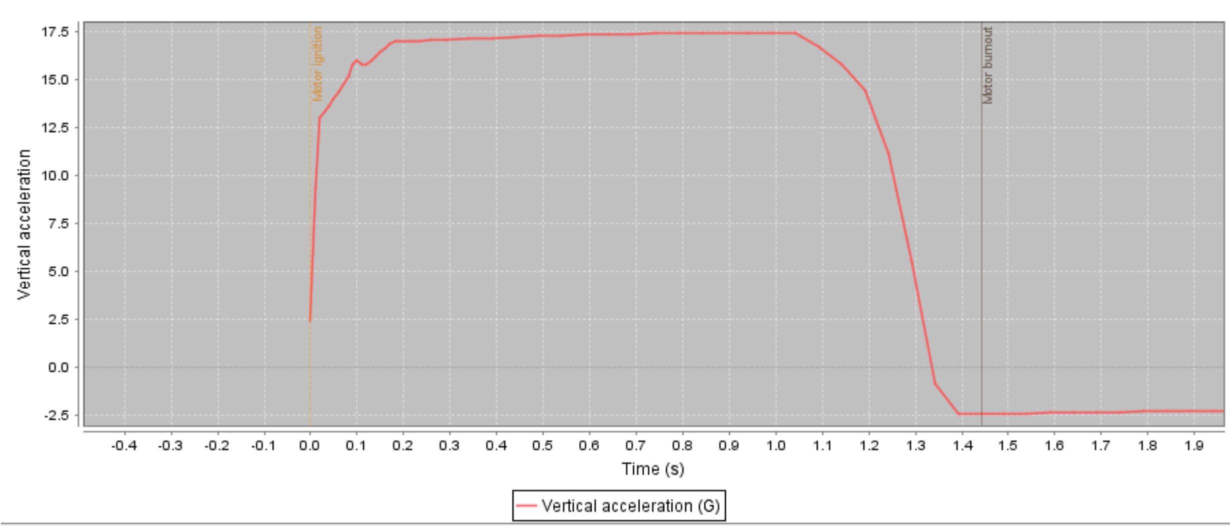


Figure 8: Vertical Acceleration vs Time

Vehicle Flight Sequence

The vehicle flight sequence is shown on the figure below. The rocket is a standard dual deployment rocket, with deployment e-bay between drogue and main parachute compartments. The rocket is recovering as three tethered sections. The drogue parachute is deployed at apogee and the main parachute at preset altitude (currently set to 700*ft* AGL). The payload does not separate from the rocket.

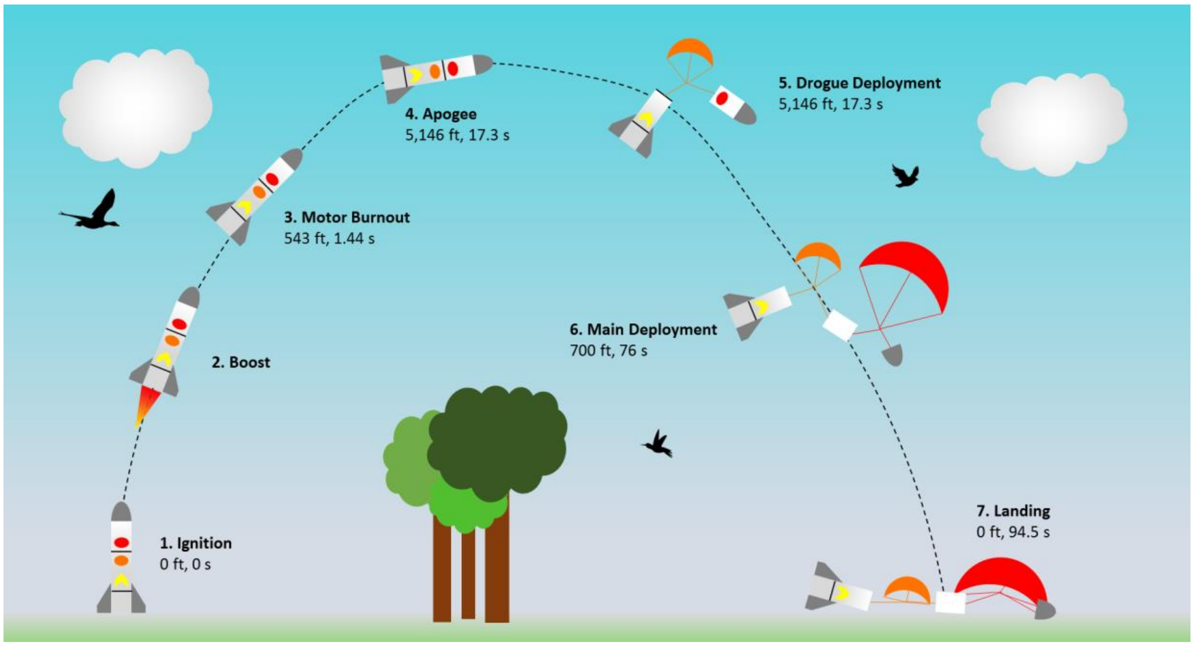


Figure 9: Mission profile chart

The table below summarizes the flight events for the entire mission.

#	Event	Time [s]	Altitude [ft]	Trigger
1	*Ignition/Boost*	*0*	*0*	*Launch Controller*
2	*Burnout*	*1.44*	*543*	
3	*Apogee/Separation*	*17.3*	*5146*	*Altimeter*
4	*Vehicle Drogue Deployment*	*17.3*	*5146*	*Altimeter*
5	*Vehicle Main Deployment*	*76*	*700*	*Altimeter*
6	*Vehicle Landing*	*95*	*0*	

Table 6: Flight Events

The mission is configured to satisfy all applicable performance targets. The payload requires the main parachute to function. The payload will be kept upright during payload drogue descent. Both the vehicle and the payload will remain within the confines of the launch site (2,640*ft* from the launch pad) even under 15*mph* wind speed conditions (estimated drift is 1386*ft* at 15*mph* winds).

Vehicle Design Maturity

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

Target altitude: We have carried out flight simulations in OpenRocket software, with coefficient of drag set to 0.7, a typical value for single diameter, cylindrical rockets and the simulated apogee is very close to desired altitude target (target is 5280*ft,* and our simulations show predicted apogee of 5146*ft*).

Flight safety parameters: the following table shows the flight safety parameters. Thrust to weight ratio is significantly above the minimal required of 5, rocket has stability of 2.08*calibers* (stable) and the exit velocity of the 10*ft* rail is 102ft/s (above the minimum required value of 44ft/s).

Parameter	Value
Flight Stability Static Margin	2.08 *calibers*
Thrust to Weight Ratio	18.73
Velocity at Launch Guide Departure (10ft launch rail)	102 ft/s

Table 7: Vehicle flight safety parameters

High wind performance: the rocket will lose about 2% of altitude when flying under 20*mph* wind conditions.

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

Recovery Subsystem

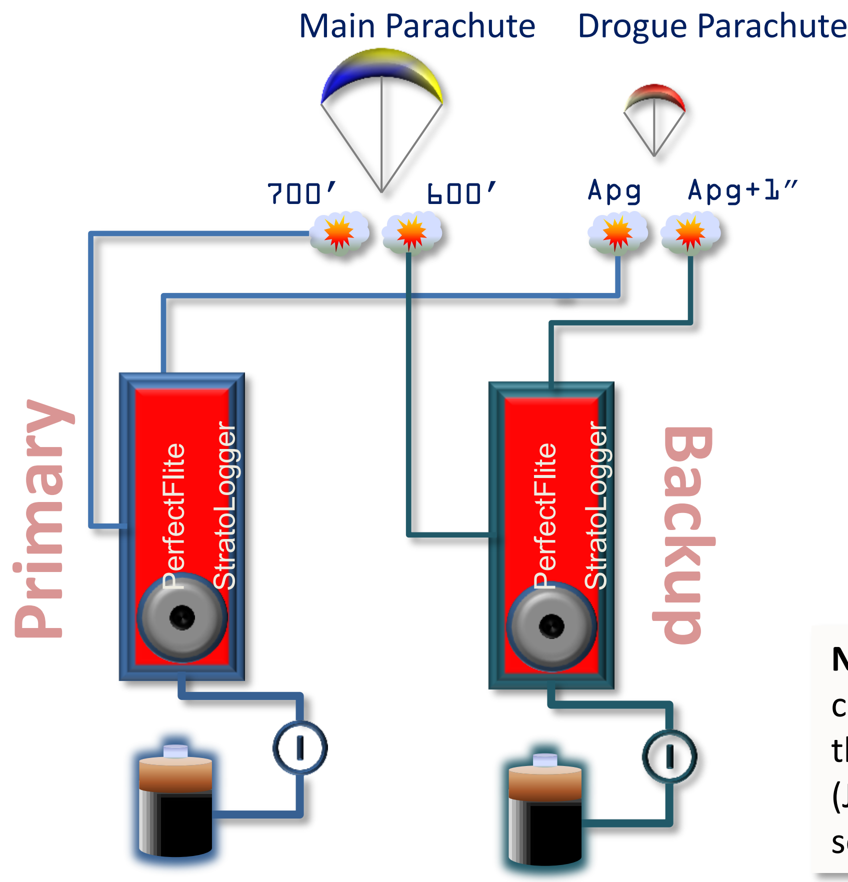
The table below shows the estimated parachute sizes, descent rates and landing impact energy. As required, the rocket separates in no more than four tethered/independent sections (three tethered sections and a payload in our case) and the impact energy is no more than 75 *ft.lb-f* for any of the parts. The total descent weight of the rocket is 22*lbs*, divided into three sections: i) nosecone, 5%, 1.1*lbs*; ii) upper section, 38%, 8.4*lbs*; iii) booster section, 57%, 12.2*lbs*.

Parachute	Diameter *[in]*	Descent Rate *[fps]*	Ejection Charge *[g]*	Deployment Altitude *[ft]*	Descent Weight *[lbs, %]*		Impact Energy *[ft-lbf]*
Drogue	28	75.9	1.49	5146	1.1	5%	98.5
					8.4	38%	748.4
					12.2	57%	1122.7
Main	108	19.2	2.15	700	1.1	5%	5.9
					8.4	38%	44.7
					12.5	57%	67.0

Table 8: Parachute parameters: The rocket recovers in three sections, nosecone (5% of total weight), upper section (38% of total weight) and booster section (57% of total weight). The descent weights and kinetic energies of impact are show for each section, in this order of sections: nosecone, upper section, booster section. The total descent weight of the rocket is 22*lbs*.

Parachutes are made out of rip-stop nylon, shock-cords are ½" tubular Kevlar and all anchors are ¼" stainless steel U-bolts. Bulkheads are made from ½" aircraft plywood. We have successfully used these materials and parts (upon recommendation from our mentor, Mr. Brent Lillesand) in our previous Student Launch projects.

Fully Redundant Recovery Electronics



NOTE: Backup ejection charges are 25% larger than primary charges (Jeffries' redundancy scheme)

Drift

The following table shows the estimated drift of the rocket considering the descent rates in the table above. We can fly in up to 15*mph* wind and both the vehicle and the payload will still remain within the allowed ½ mile radius.

Wind speed *[mph]*	**Drift** *[ft]*	**Drift** *[mi]*
0	0	0
5	523	0.099
10	1046	0.198
15	1569	0.298
20	2092	0.397

Table 9: Drift predictions

Tracking and Recovery

The rocket will be tracked using a Trackimo tracker. Trackimo is a CAT (Cloud Aided Telemetry) device that utilizes GPS sensor and cellular network to report its location in regular intervals. The device uploads its current coordinates to a data cloud. Trackimo smartphone app then retrieves the tracker’s coordinates from the cloud and displays its location on a map. We have extensively tested the reliability and accuracy of Trackimo trackers last year and decided to adopt them as our primary tracking devices for this year. The device is dependent on a presence of a cellular network at the launch site, which is satisfied at all our primary launch sites (Bong, WI; Princeton, IL and Huntsville, AL). Trackimo is a USB rechargeable device, taking about 2-3 hours to fully charge for 24 hours of operation. The tracker is about 1.5” x 1.5” in size, making it suitable even 54*mm* diameter rockets.

We also use Walston radio beacons and 140dB sonic beacons as secondary and tertiary tracking devices.

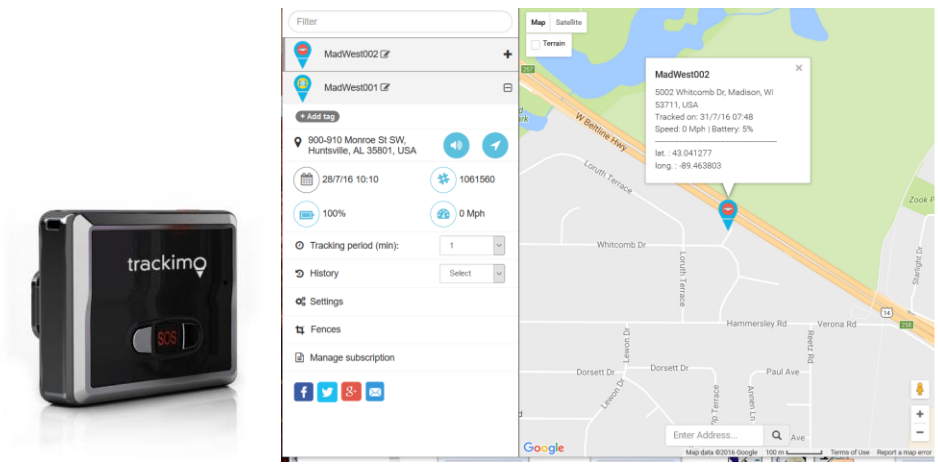


Figure 10: Trackimo tracker and a screenshot from Trackimo app (showing that our tracker #2 has last transmitted from near Dr. Pinkas’ home and is almost out of battery).

Verification Plan and Status

The following components are included in our verification plan:

- **C1:** Body (including construction techniques)
- **C2:** Altimeter
- **C3:** Parachutes
- **C4:** Fins
- **C5:** Payload
- **C6:** Ejection charges
- **C7:** Launch system
- **C8:** Motor mount
- **C9:** GPS
- **C10:** Shock cords and anchors
- **C11:** Rocket stability

The following tests will be applied to the components listed above:

- **V1 Integrity Test:** applying force to verify durability.
- **V2 Parachute Drop Test:** testing parachute functionality.
- **V3 Tension Test:** applying force to the parachute shock cords to test durability
- **V4 Prototype Flight:** testing the feasibility of the vehicle with a scale model.
- **V5 Functionality Test:** test of basic functionality of a device on the ground
- **V6 Altimeter Ground Test:** place the altimeter in a closed container and decrease air pressure to simulate altitude changes. Verify that both the apogee and preset altitude events fire.
- **V7 Electronic Deployment Test:** test to determine if the electronics can ignite the deployment charges.
- **V8 Ejection Test:** test that the deployment charges have the right amount of force to cause parachute deployment and/or planned component separation.
- **V9 Computer Simulation:** use RockSim to predict the behavior of the launch vehicle.
- **V10 Integration Test:** ensure that the payload fits smoothly and snuggly into the vehicle, and is robust enough to withstand flight stresses.

Verification matrix below shows which test will be applied to which component:

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
C1	1.14			1.13				2.2		1.4
C2				1.13	1.7	1.2				
C3	1.14	1.14	1.14a	1.13				2.2		
C4	1.14			1.13						
C5	1.14				1.7					1.4
C6				1.13	1.7		2.1	2.2		
C7	1.14			1.13						
C8	1.14			1.13						
C9	1.14			1.13	1.7					
C10			1.13	1.13				2.2		
C11				1.13	1.7			2.2	1.1	

Table 10: Vehicle verification matrix

The number inside a cell denotes which project requirement will be satisfied by subjecting a given component (row) to a given test (column).

Currently, no tests have been completed. The verification process will start upon successful completion of Preliminary Design Review milestone.

All vehicle requirements are in detail addressed in Project Requirements section, with Vehicle Requirements starting on page (I still don't know how to do automatic page numbering).

Vehicle Risks and Safety

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

Risk and Hazard Analysis

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

	needed.		
Team member injury	All team members, mentor and educators will utilize personal protective equipment for all activities. All safety related documentation is kept on hand for quick access. The team members are supervised by the mentor and educators at all times. The first aid kit is kept on-hand during all activities.	**HIGH**	**LOW**
Personnel (not being available)	We have several workshop supervisors that can work with the students and our workshop is accessible 24 hours, 7 days of week. Two or more students are assigned to each task to ensure that no task will stall because of personnel shortage. The school exam periods and break are accounted for in our schedule.	**MEDIUM**	**LOW**
Rocket Construction (the ability of the team to build a rocket that will be suitable for the mission)	The team is supervised by highly experienced mentor with previous Student Launch experience to ensure that the vehicle is constructed using proper construction techniques and materials and that sufficient time is allocated to each of the construction tasks.	**HIGH**	**LOW**
Rocket Performance	The team will perform several test flights to make sure that the rocket will reach but not exceed the target altitude. This will include computer simulations, half-scale model flights and full scale vehicle test flights. After each flight the collected data will be analyzed to evaluate the overall performance of the launch vehicle.	**MEDIUM**	**LOW**
Deployment Failure (damage to rocket, possible rocket loss)	Static ejection tests will be performed to make sure that the ejection charges are of correct size and the coupling surfaces are smooth enough. Fully redundant ejection electronics will be used to increase the probability of successful deployment of both the main and drogue parachute. The rocket flight preparations will be observed by the mentor	**HIGH**	**LOW**

	and checklists will be used to prevent step omissions.		
Rocket Loss	The team is aware of possibility of losing the rocket during any of the test flights. A sufficient surplus of parts will be kept to allow for construction of the new vehicle. All test flights will be scheduled in sufficient advance of the final launch to allow team to recover from the rocket loss. The team mentor will supervise the team during all test flights to ensure the highest possible probability of favorable flight outcome. The weather situation will be critically evaluated before every test flight to balance the risk of rocket loss with the consequences of not making the test flight.	**HIGH**	**LOW**
Parts/Supplies Availability	We work with several vendors and use materials with normalized dimensions to avoid situations when the only vendor carrying a critical item runs out or the item is discontinued.	**HIGH**	**LOW**

Table 11: Project risks related to the vehicle

Hazard	Mitigation	Likelihood	Severity
Workshop tools and machinery hazards	Personal Protective Equipment (PPE) will be used at all times in the workshop. All students will be periodically briefed on workshop safety procedures and supervised by adults at all times. First aid kit is on-hand.	**LOW**	**MEDIUM**
Dangerous substance hazards	MSD sheets are required for all chemicals use during the project. Appropriate protective equipment must be used when working with hazardous substances. Students will be supervised by adults at all times.	**LOW**	**HIGH**
Payload integration failure	Team will verify before every launch that the payload fits into payload compartment and that the payload door closes without any misalignment.	**LOW**	**HIGH**
Vehicle assembly failure	The day before every launch the team will run through complete vehicle assembly procedure,	**LOW**	**HIGH**

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

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

Table 12: Hazard analysis

Preliminary Assembly and Launch Procedures

Final Assembly

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

- ☑ Fold the main parachute, wrap in Nomex sheet and insert on the top part of the shockcord
- ☑ Neatly coil the remainin shockcord and insert above the main parachute
- ☑ Install nosecone
- ☑ Install top shear pins

Launch Procedure

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

Environmental Concerns

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

Payload

Motivation

Our project is inspired by the growing interest in cultivating plants in space in hopes of being able to sustain human life outside of Earth. Our experiment will analyze how mechanical and gravitational stress caused by rocket flight affect gene expression and development throughout the life cycle of *Arabidopsis thaliana* plants. *Arabidopsis thaliana* is a member of the *Brassicaceae* family and a close relative of broccoli. We chose this plant because the entire genome of *Arabidopsis thaliana* has been mapped and it has a short life cycle, so we can look at how specific genes respond to the stresses of rocket flight and how they are affected over the plant's entire life cycle. We will be fixating (terminating) plants at different stages in the experiment in order to compare their initial response with any long-term effects. Fixation is necessary to freeze the short term changes of gene expression levels in plants.

This project draws inspiration from and continues our SLI 2007 study of gene expression in *Arabidopsis thaliana*, which addressed how gravitational forces affect it. We are revisiting the project from 2007 after a decade of technological improvement. This project will be supported by Gilroy lab at UW Madison, Dept. of Botany and UW Astrobotanical Society.

This project is also an extension of our 2016 project, but focuses on a different aspect of the plants' response to rocket flight. Last year's project studied several *Arabidopsis thaliana* mutants' responses to gravity by taking images to observe plant health and development (macroscale), while this year's project will study the gene expression of the *Arabidopsis thaliana* wild type through the gene analysis method PCR (Polymerase Chain Reaction), a nanoscale study. The macroscale methods developed last year will be also part of our experiment, complementing our findings from nanoscale study (gene expression measurements via PCR method).

Objective

The objective of our project is to analyze how mechanical and gravitational stresses caused by rocket flight affect the expression of genes in *Arabidopsis thaliana.*

Payload Design and Experimental Setup

The overall block scheme of the payload is shown below. The plants are grown on a phytogel base in Petri dishes. Hygrometer, thermometer and light sensor measure environmental conditions and periodically report measurements to the payload computer. Payload computer writes all measurement to EEPROM non-volatile memory. Accelerometer is used to measure the amount of gravitational forces experienced by the payload. The payload computer also controls lighting inside the payload and should the temperature exceeds predetermined limit, the payload computers will switch on a cooling fan. The data sampling frequencies and memory consumption are summarized in Table 13.

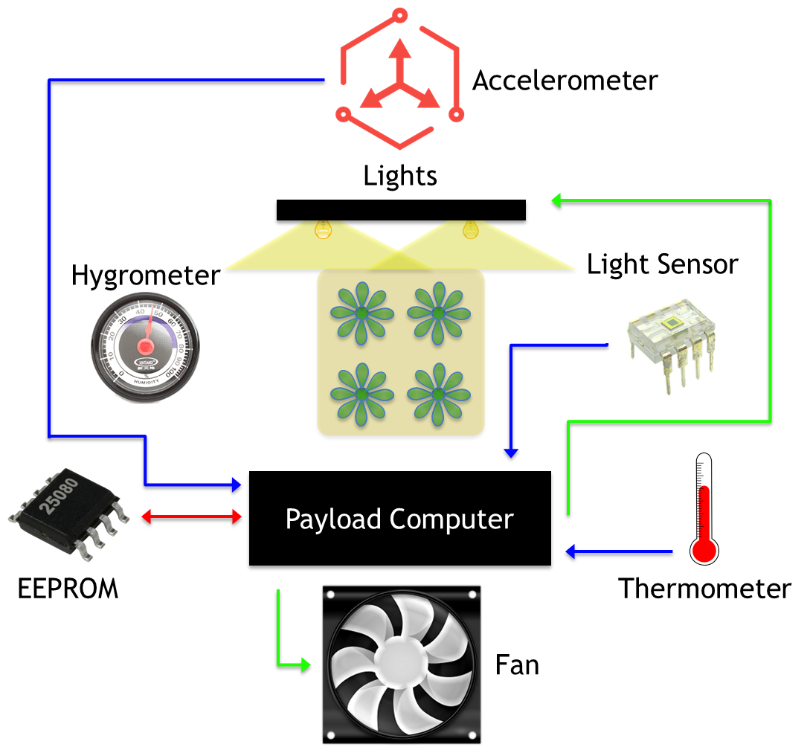


Figure 11: Payload block scheme

Data	Data Record Size	Sampling Frequency	Total Memory (120*s* flight, apogee at 20*s*)
Temperature	2 bytes	1 Hz	240 bytes
Humidity	2 bytes	1 Hz	240 bytes
Acceleration	X: 2 bytes Y: 2 bytes Z: 2 bytes Total: 6 bytes	Before apogee: 200Hz After apogee: 100 Hz	24000 bytes + 60000 bytes = 84000 bytes
Illumination	4 bytes	1 Hz	480 bytes

Table 13: Data sampling frequency and memory consumption

Payload Units and Assembly

The entire payload is composed from stackable payload units. Each payload unit houses a single Petri dish, its lighting and necessary wiring. An expanded view of a payload unit is shown in Figure 12.

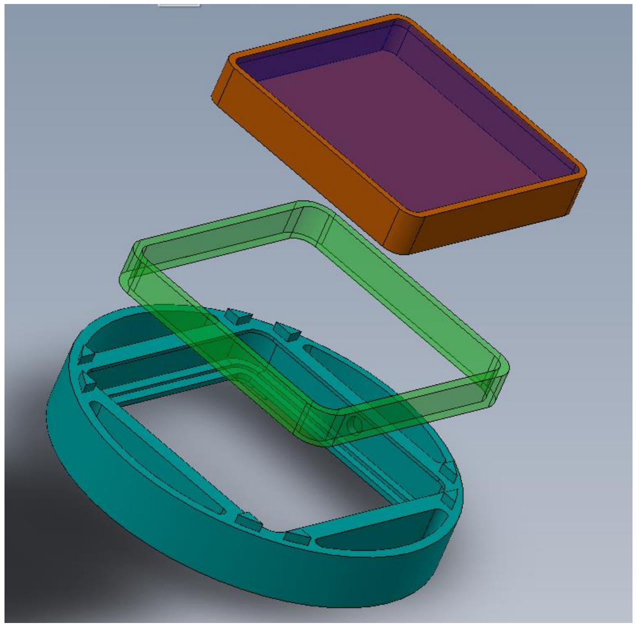


Figure 12: Payload unit, expanded view. Top to bottom: Petri dish, lighting (LED strip), stackable holder.

Each payload unit is a home for four Arabidopsis thaliana plants. A sketch showing the plants and lighting inside each payload unit is shown in Figure 13.

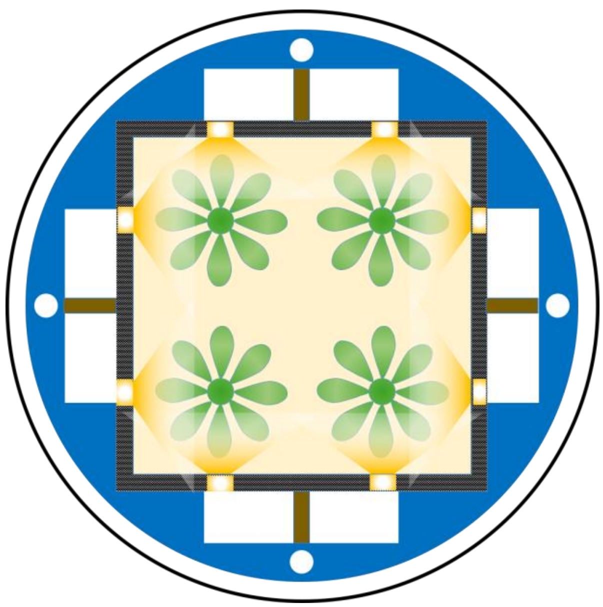


Figure 13: Plants and lights inside a payload unit

Payload units can be arbitrarily stacked and their rotation is prevented by notches and inserts near the Petri dish corners. The entire stack of payload units is held together by #8 tie rods. The fan sits on the top of all units, while the electronics and batteries are on the bottom. The expanded stack of 20 payload units is shown on Figure 14 and the drawing of assembled stack is shown on Figure 15.

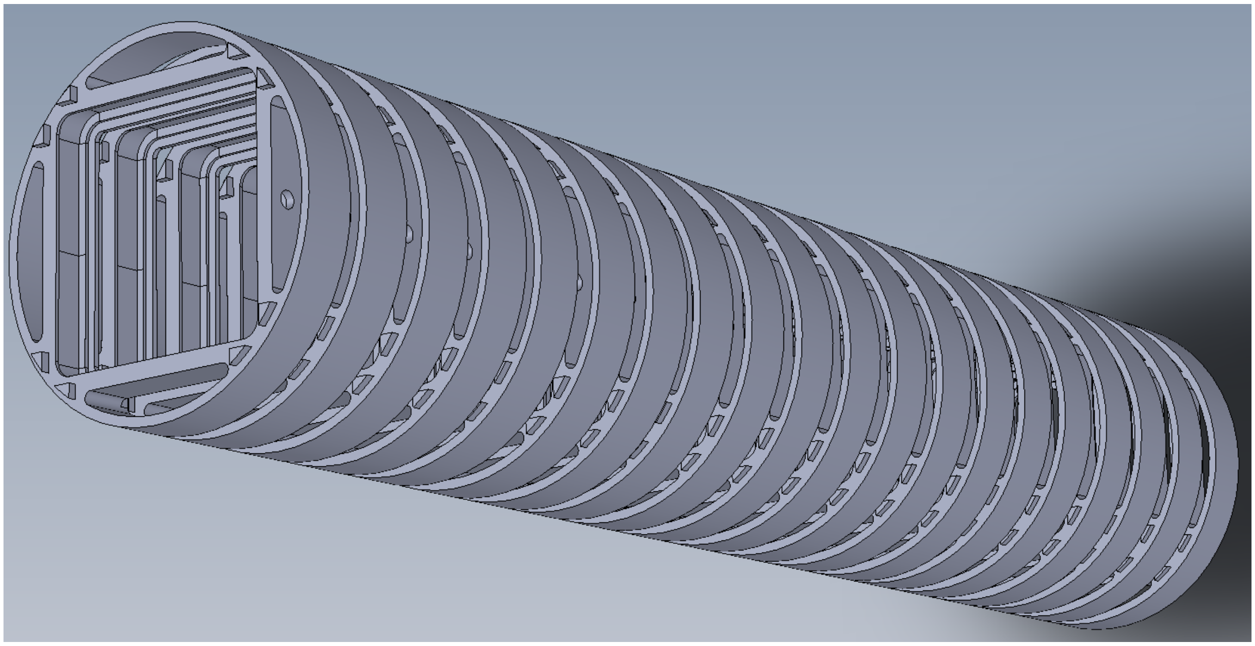


Figure 14: Expanded view of stack of 20 payload units

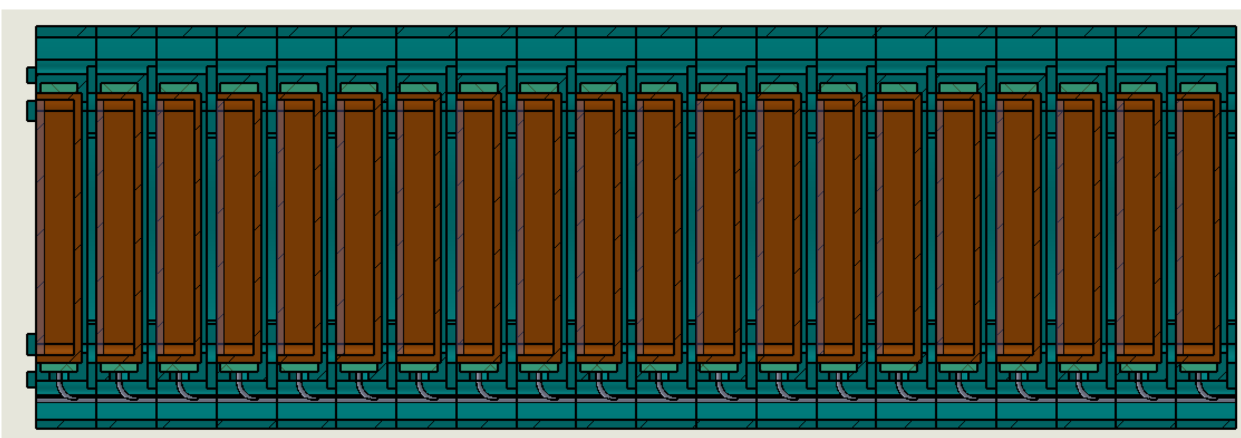


Figure 15: A drawing of a stack of 20 payload units

Experimental Groups of Plants

The following figures show the experimental groups we will use. The groups are divided by the type and amount of stress they will experience, and each group is made up of 6 subgroups (2 Petri dishes each) divided by the time they will be fixated (terminated), plus an extra 7^{th} larger group (8 Petri dishes) that will be grown to adulthood instead of being fixated.

The groups are as follows:

- **Group F, flight group:** this group undergoes both the transportation and flight stresses
- **Group B, backup group:** this group undergoes the transportation stresses and only flies if the flight group suffers unexpected damage or loss (not pictured in Figure 16).
- **Group T, transportation only group:** this group undergoes only transportation stresses
- **Group Z, zero stress group:** this group undergoes neither transportation nor flight stresses

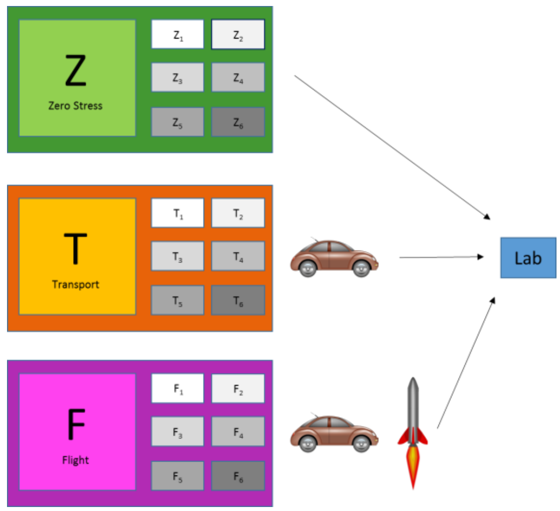


Figure 16: Experimental groups: Z - zero stress, T - transportation stress, F - flight and transportation stress

The schedule of experimental events (gene expression level samplings) is summarized in the figure and table below. Selected plants from each of the group (**F**, **B**, **T**, **Z**) are fixated (terminated) at predetermined intervals and after certain events, to preserve the levels of gene expressions. Each group consists of 20 plants, 12 of each are fixated at 6 time points and 8 are let to grow to maturity while being images at 30 minutes intervals. The fixated plants will undergo measurement of gene expression levels using PCR method while the plants grown to maturity will be periodically imaged.

The following comparisons will be made at teach time point (fixation):

- **F** versus **T:** differences in plant development are assumed to be caused by the stresses of rocket flight.

- **T** versus **Z:** differences in plant development are assumed to be caused by the stresses of transportation.

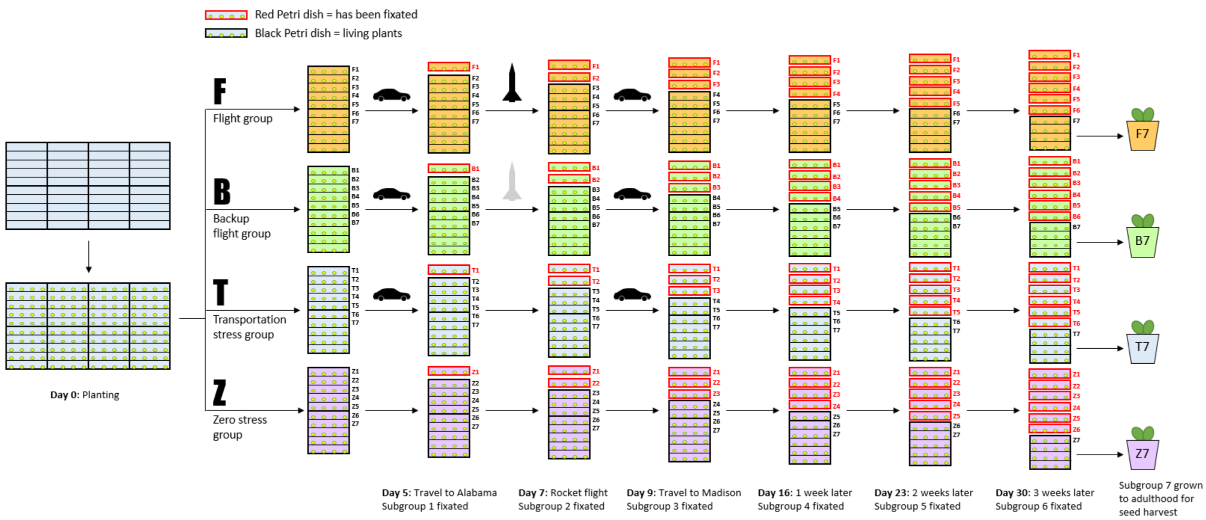


Figure 17: Schedule of experimental events (gene expression level sampling)

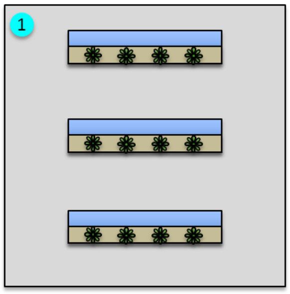
	Flight Group	Transport Group	Zero Stress Group
Fixation* 1 – Arrival in Alabama	Fixate 2 dishes (F1)	Fixate 2 dishes (T1)	Fixate 2 dishes (Z1)
Fixation 2 – After Flight	Fixate 2 dishes (F2)	Fixate 2 dishes (T2)	Fixate 2 dishes (Z2)
Fixation 3 – Return to Madison	Fixate 2 dishes (F3)	Fixate 2 dishes (T3)	Fixate 2 dishes (Z3)
Fixation 4 – 1 week after fixation 3	Fixate 2 dishes (F4)	Fixate 2 dishes (T4)	Fixate 2 dishes (Z4)
Fixation 5 – 1 week after fixation 4	Fixate 2 dishes (F5)	Fixate 2 dishes (T5)	Fixate 2 dishes (Z5)
Fixation 6 – 1 week after fixation 5	Fixate 2 dishes (F6)	Fixate 2 dishes (T6)	Fixate 2 dishes (Z6)
Group 7 Grown to maturity	Replant 8 dishes to soil and grow to maturity	Replant 8 dishes to soil and grow to maturity	Replant 8 dishes and grow to maturity

*Fixation- Terminating plants, preserving ("freezing") their gene expression so it can be studied later.

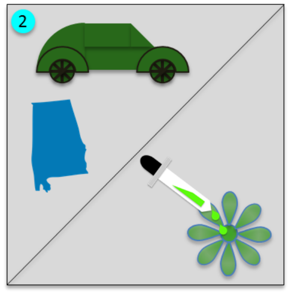
Table 14: Schedule of gene expression level samplings

Experimental Sequence

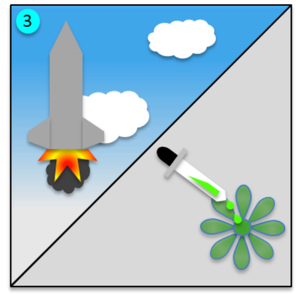
The overall experimental sequence is shown on the figure below:



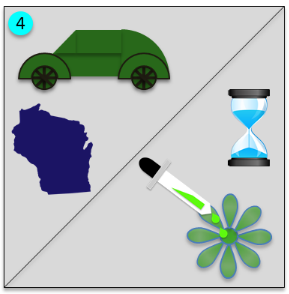
Planting Plants



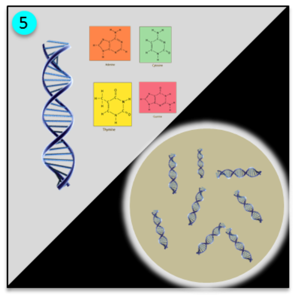
Travel to AL & 1st Fixation



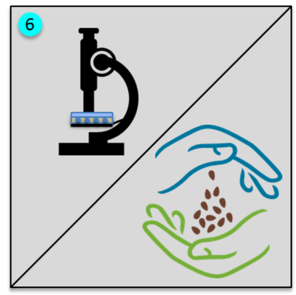
Rocket Flight & 2nd Fixation



Return to WI & Weekly Fixations



PCR & Gene Analysis



Observe Plants & Harvest Seeds

1. We will plant *Arabidopsis thaliana* in agar using aseptic technique.
2. The plants will travel to Huntsville, Alabama by ground support vehicle and the first set of plants will be fixated upon arrival.
3. At one week of age, the flight experimental group will be launched in our rocket, and fixated immediately following the flight.
4. The plants will return to Madison, Wisconsin by ground support vehicle and the next set of plants will be fixated upon return. Following return to Madison, sets of plants will be fixated at weekly intervals for several weeks.
5. The plants that have been fixated will be analyzed using the gene analysis method of PCR (polymerase chain reactions) and data will be collected to create a report on the expression of selected genes.
6. We will allow some plants to continue grow to maturity. Throughout their life cycle, we will observe and image them in the lab, and at the end of their life cycle we will harvest their seeds in order to determine if there are any effects on the second generation.

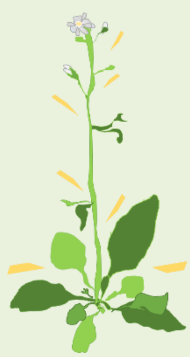
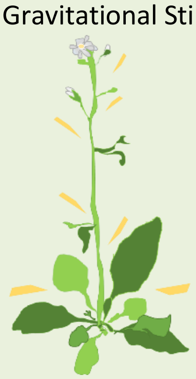
Hypothesis

In our experiment we will be studying the effects of rocket stress in the expression of certain genes in *Arabidopsis thaliana*. We will be studying gene expression in the wild type of *Arabidopsis thaliana*.

We have selected genes in four different categories:

- **Touch and Mechanical Stress:** genes that get expressed in a response to touch or mechanical stress on the plants (CAM2, CML24, CML12, XTH4) – we expect increased expression in the flight group because all plants will be subjected to mechanical stresses during flight.
- **Gravitational Stimulation:** genes expressed when plants experience normal or increased gravitational forces (ARG1, ROSY1) – we expected increased expression in the flight group because all plants in the flight group will experience increased gravitational forces during flight.
- **Mechanical Wounding:** genes expressed when the plant is wounded due to mechanical forces (JAZ4, JAZ10, LOX2) – changes in expression of these genes will help us evaluate the extent of wounds that the plants accrue during flight.
- **Oxidative Stress:** genes expressed when the plant is severely wounded – changes in expression of these genes will provide further insight into magnitude and type of wounds that the plants suffer during rocket flight.

The following table summarizes the different types of genes selected for this experiment, and their expected responses:

Gene Category	**Gene Names and Expected Response**			
Sensitive to Touch/Mechanical Stress 	***CAM2*** Highly expressed	***CML24*** Highly expressed	***CML12*** Highly expressed	***XTH4*** Highly expressed
Sensitive to Gravitational Stimulation 	***ARG1*** Highly expressed		***ROSY1*** Highly expressed	

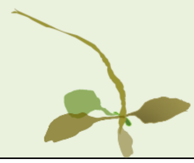
Sensitive to Mechanical Wounding 	***JAZ4*** Moderately Expressed	***JAZ10*** Moderately Expressed	***LOX2*** Moderately Expressed
Sensitive to Oxidative Stress 	***ZAT12*** Mildly Expressed	***RBOHD*** Mildly Expressed	

Table 15: Genes selected for the study and the expected changes in their level of expression

We hypothesize that the genes sensitive to mechanical stress and touch will be highly expressed after rocket flight because they are the selected the genes that are involved in sensing strains related to vibrations, which will most certainly be caused by rocket flight. Wild type plants sense gravity through the use of *amyoplasts,* which are dense starch granules. Due to the effective use of *amyoplasts* in the wild type plants we hypothesize that their genes relating to gravitational stimulations will be highly expressed after rocket flight.

The genes that respond to mechanical wounding are hypothesized to be moderately expressed because of their ability to sense if the plants have experienced low level damage, which is a likely result of rocket flight.

The genes related to the response of oxidative stress are hypothesized to be expressed only mildly because they will be mainly expressed when high level damage to the plants has occurred, which is a less likely result of rocket flight.

The expectations for the expression of the genes related to mechanical wounding and oxidative stress are uncertain because we do not know the full extent of the damage that rocket flight will inflict on *Arabidopsis thaliana.* Studying the expression of genes related to mechanical wounding and oxidative stress will allow us a greater understanding of the full extent of the long term stress caused by rocket flight.

Analytical Methods

We will use several analytical methods to evaluate and quantify the effect of gravitational forces and flight stresses on the Arabidopsis thaliana plants.

Parameter	Method of Measurement
Gene expression	We will use PCR method to measure changes in expression of selected genes. Measured changes will be summarized in “heat table” which is a graphical overview of gene expression levels, displayed using a color scale. The heatmap is a quick way of identifying groups of genes that react to a given stimuli. Cf. Figure 18.
Agravitropic assay	Agravitropic measures changes in plants response to gravity by measuring the change in root growth after the plant has been rotated by 90 degrees. Plants capable sensing gravity will alter their roots growth direction. Cf. Figure 19.
Plant Health	Image analysis of times lapse sequence of infrared and visible spectrum of the images of plants. Plant health issues are easily detected in infrared spectrum long before they become apparent in visible light. NDVI (Normalized Difference Vegetation Index) simplex is used to combine data both from the visible (red) and infrared channels into a single quantity. See Figure 20 for time-lapse example and Figure 21 for NDVI example.

Table 16: Table of analytical methods in the experiment

A heatmap (e. g. Figure 18) shows the changes in gene expression using a color scale (sometimes also called “not-or-hot” scale). The rows in the heatmap table represent genes (one gene per row). The columns then represent condition or sampling points. If the gene is expressed more than under baseline conditions (overexpressed), the color of the cell gravitates toward the “hot” (usually red) end of the scale. If the gene is expressed less than under baseline conditions (underexpressed), the cell color leans toward the “not” end of the scale (traditionally a blue color). Finally, if the gene shows level of expression similar to the baseline conditions, the cell in the table remain black (neutral).

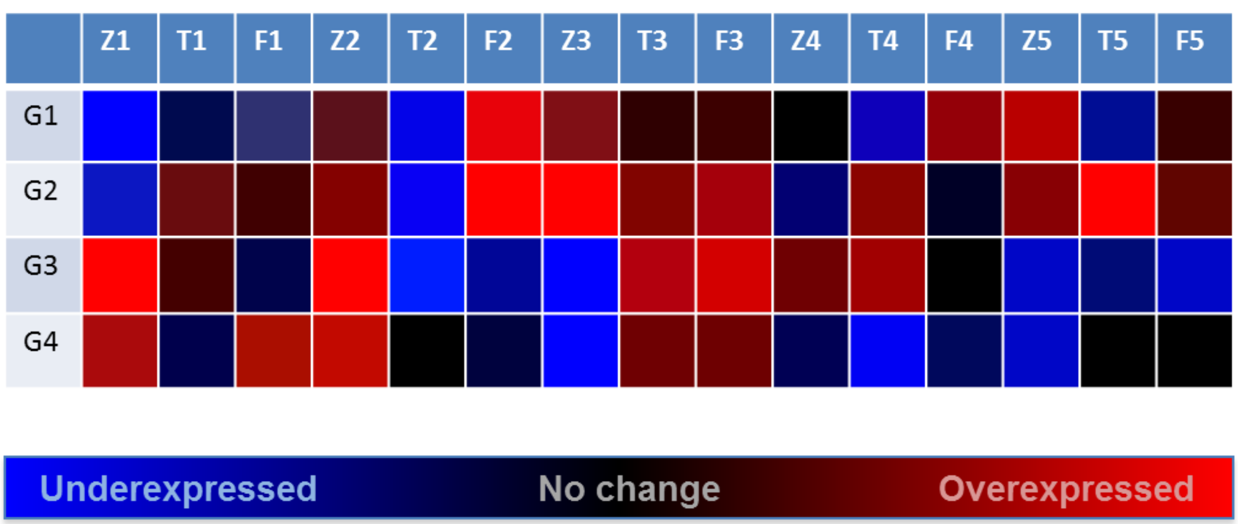


Figure 18: A heatmap representation of gene expression changes

Agravitropic assay measure plant's ability to respond to changes in gravitational field. Plants are rotated by 90 degrees and then imaged for 24 hours to observe the change in the direction of their roots. Plants that can sense gravity will rapidly alter the direction of their root growth, while the plants with altered or absent sense of gravity will show weaker of no reaction. The imaging of the plants is usually done by a flatbed scanner. More detailed analysis of the root growth change can be obtained by using a dedicated analytical software, such as RootNav.

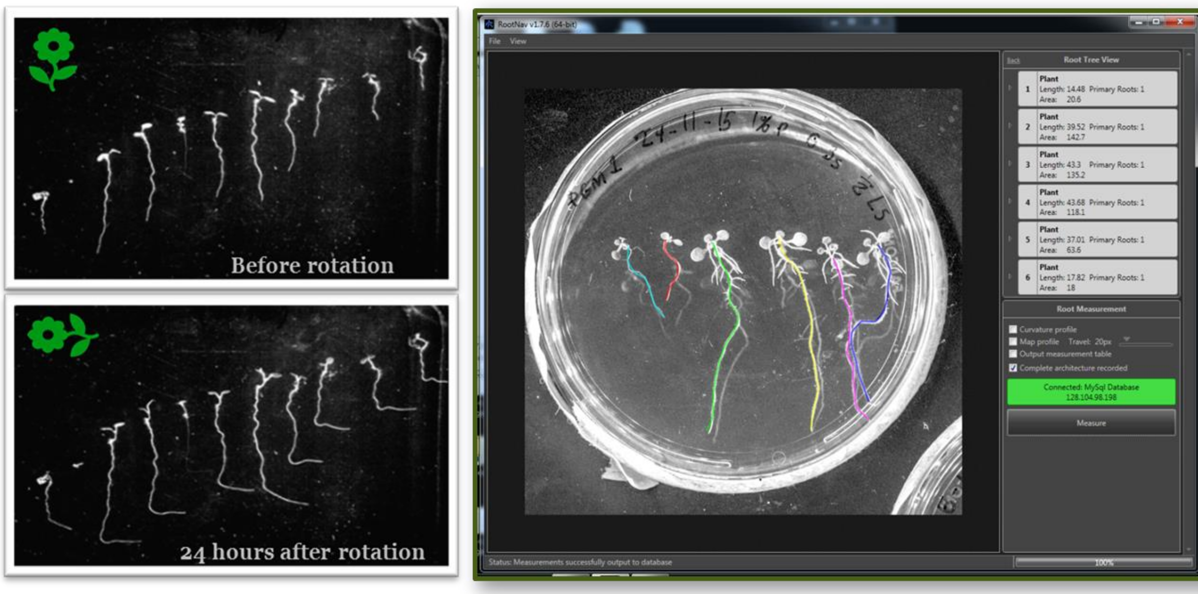


Figure 19: Response to gravity: left - agravitropic assay; right - RootNav software

Time lapse imaging simply takes an image of plants at regular intervals. These images can then be used to evaluate the development of the plant and observe any irregularities that may have occur. The example of time-lapse imaging is on Figure 20.

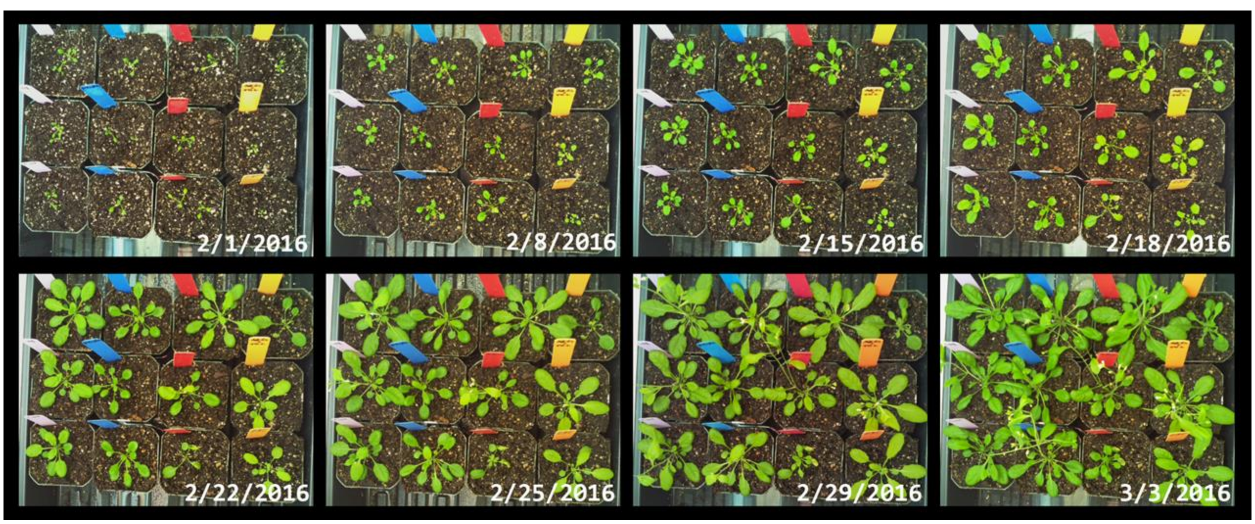


Figure 20: Example of time-lapse imaging of Arabidopsis thaliana plants in visible spectrum

NDVI (Normalized Difference Vegetation Index) is a simplex that combines information from red (visible) and infrared channel. NDVI simplex is a long recognized indicator of the plant's health. The simplex is calculated as follows:

$$NDVI = \frac{infrared - red}{infrared + red}$$

The two pictures below show the difference between NDVI image for a healthy plant (left) and the plant with declining health (right). NDVI imaging can discover the changes in plant's health long before they become apparent to unaided human eye.

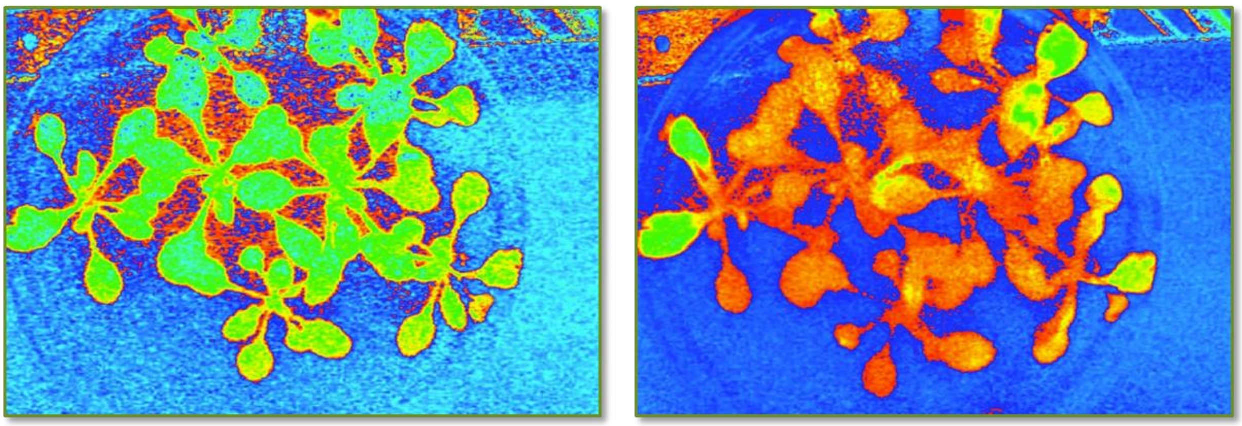


Figure 21: NDVI map for healthy (left) and declining (right) plant

Verification Plan and Status

The following components are included in our verification plan:

- **C1:** Cameras
- **C2:** LED Array
- **C3:** Batteries
- **C4:** Petri Dishes
- **C5:** Thermometer
- **C6:** Hygrometer
- **C7:** Accelerometer
- **C8:** Raspberry Pi Computer
- **C9:** Payload Controller

The following tests will be applied to the components listed above:

- **V1** Functionality Test: Test of basic functionality of a device on the ground
- **V2** Robustness Test: Test of structural integrity when exposed to forces equal to those of flight
- **V3** Battery Capacity Test: Test of power capacity
- **V4** Coding Capacity Test: Test of coding capacity
- **V5** Memory Capacity Test : Test of memory capacity

- **V6** Connection Test: Test of the connection between components
- **V7** Calibration Test: Test of accuracy and precision (includes camera focus)

Verification matrix below shows which test will be applied to which component and which project requirement will be satisfied:

	V1	V2	V3	V4	V5	V6	V7
C1	3.2	3.5,3.2	3.5	3.2		3.5	3.5
C2	3.2	3.2,3.5	3.2			3.2	3.2
C3	3.2	3.2,3.5	3.2		3.2	3.2	3.2
C4	3.2	3.2,3.5					
C5	3.2,	3.2,3.5	3.2		3.2	3.2	3.2
C6	3.2	3.2,3.5	3.2		3.2	3.2	3.2
C7	3.2	3.2,3.5	3.2		3.2	3.2	3.2
C8	3.2	3.2,3.5	3.2	3.2	3.2	3.2	3.2
C9	3.2	3.2,3.5	3.2		3.2	3.2	3.2

Table 17: Verification matrix for payload

Requirements

Vehicle

All vehicle requirements are in detail addressed in **Error! Reference source not found.Error! Reference source not found.**Project Requirements section, with Vehicle Requirements starting on page 60. The vehicle itself is described in the Technical Design section, starting on page 13.

Recovery System

All recovery system requirements are in detail addressed in **Error! Reference source not found.Error! Reference source not found.**Project Requirements section, with Recovery System Requirements starting on page 64. The detailed description of the recovery system starts on page 22.

Payload

All payload requirements are in detail addressed in Project Requirements section, with Payload Requirements starting on page 67. The detailed description of the proposed payload starts on page 27.

Major Technical Challenges and Solutions

Major Technical Challenges and Solutions for Vehicle

1. **Performance:** We need a 5.5” diameter vehicle to house our payload and our total impulse is limited to 2,560*Ns*. Simulations indicate that our rocket needs to have an excellent performance to reach the target altitude of 5,280ft. We will have to construct the vehicle cleanly and watch for all weight savings possibilities. We have chosen 98mm motor to decrease the overall length of the vehicle (we have saved 18” by using 98mm motor instead of 54mm one). We will give the vehicle glossy finish to further decrease its drag coefficients and will carefully evaluate all test flight data to ensure that the vehicle performs as necessary.
2. **Launch Site Dimensions:** the launch site in Huntsville allows for only 2,500*ft* drift during recovery. We will have to carefully select the drogue and main parachute sizes to ensure that the vehicle will not drift outside the launch site yet it will have enough time to deploy main parachute and land safely with no section of the vehicle exceeding the maximum impact energy of 75*ft-lbf*. We will closely monitor the descent rates during our test flights and make adjustments to parachutes and deployment schedule as necessary.
3. **Motor selection:** using 98mm motor in K-class severely limits our motor selection. Our primary motor choice will deliver over 15*g* of acceleration and we will have to build our vehicle so it is robust enough to sustain the forces while remaining light enough to reach the target altitude. We will use LOC Precision fiber tubing.
4. **Heavy loads on anchors**: successful construction and operation of a 5.5" vehicle is a drastically different task from the more traditional and manageable 4" vehicle. Special attention needs to be paid to all anchor points, coupler stiffeners and positive lock-in must be used on all load-bearing parts.
5. **Coupling surfaces:** coupling of 5.5" tubing is generally unforgiving to minor issues that would present no problem with 4" tubing. We will pay attention to perfect alignment and cleanliness of our coupling surfaces, using talcum powder to lubricate all separation points. Static ejection tests will be carried out prior each launch to ensure that the separation and ejection events will occur as expected.

Major Technical Challenges and Solutions for Payload

1. **Transportation:** We will need to move our rocket, flight payload, and control payload to both our local launch sites and the launch site in Alabama, which could cause extra stress to our plants and has the possibility of damaging our rocket. We will take extreme care when handling our rocket to prevent any damage. We will also have two control payloads, one we leave at our workshop and one that we take to launch sites, in order to see if the transportation of our payloads had any effects on our experiment.
2. **Vehicle Performance:** We need a large diameter rocket to house our payload and we know that we have just enough total impulse to fulfill the requirements of vehicle mission. Our payload will need to be both space and weight conscious without compromising its own scientific value. Careful and thorough design will be needed to balance the constraints of the vehicle with the needs of the payload.

3. **Data Analysis:** We will have to be able to correctly analyze the data from our experiment to be able to acquire accurate conclusions. We will be using reliable software like RootNav with the aid of experienced workers at the Department of Botany at UW-Madison to ensure we obtain valid results from our experiment by minimizing the risks of human error. We will also be looking at the health of our various Arabidopsis Thaliana plants in various ways, including time-lapse photos, infrared cameras, and the leaf area index in order to measure the effects of our experiment in multiple aspects of the plants. We will consult with experts in image analysis and gene expression disciplines to determine the optimal tools and methods for our goals.
4. **Cultivation of Plants:** In order for our experiment to be valid, we will have to ensure that the plants will be grown in the proper conditions, and that we make sure that the plants are at the proper stage of growth at the time of the launch. We have spoken with Dr. Simon Gilroy, a professor of Botany at UW-Madison to ascertain the correct methods of growing our Arabidopsis Thaliana plants, and we will practice growing the plants before our launches in order to maintain proper timing and ensure that we can grow healthy plants under our conditions.
5. **Aseptic Technique:** We must be able to use aseptic technique during our experiment in order to avoid contamination of our plants and thus invalidate our results. We will be using sterile petri dishes, sterilizing other equipment we use with 70% ethanol alcohol, and using proper aseptic procedure with the aid of the experienced professionals at the Department of Botany at UW-Madison to avoid any contamination of our plants.
6. **PCR Analysis of Gene Expression Levels:** in total we will collect 198 samples (11 genes, 3 experimental groups, 6 samplings) that will be analyzed using PCR method (DNA/RNA multiplication). This translates to significant workload in lab and entire team will need to contribute time and efforts (including vehicle team members).

Second Year Project

This project is a continuation of the project that we undertook last year. We have a time limited opportunity to work with researchers at Dept. of Botany with significant chances of being able to contribute to the payloads sent to the International Space Station. We have presented our work at Astrobotanical Society meeting, attracting interests of researchers working on similar projects.

The project proposed for this year builds on our experience and work done for SL2016 project. In addition to we are dramatically increasing the number of samples (from 4 Petri dishes in each experimental group to 20 dishes). We will be periodically sampling gene expression levels in all experimental groups (the 2016 project was limited only to imaging the plants). The payload structural subsystem will be rebuilt to include built-in lights (as opposed to add-ons from last year) and to incorporate higher number of Petri dishes.

The evaluation of the effects of gravitational forces on the plants is now divided to 4 distinct categories (while it was bundled into a single category last year). We will be evaluating changes in gravity sensing, response to mechanical stimuli, mechanical wounding and oxidative stress response. In total, 11 genes will be sampled in three experimental groups on six different occasions, to obtain 198 samples for PCR analysis in lab. Additionally visual observation and imaging of the plants will be performed, same as last year.

Project Plan

Development Schedule

Timeline

	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 18: Color code for timeline

	August 2016
15	Request for Proposal (RFP) goes out to all teams
20	Organizational Meeting
27	SOW writing session
	September 2016
3	SOW writing session
10	SOW writing session
18	SOW writing session
30	SLI Proposal due to NASA at 5p.m. (electronic copy)
	October 2016
2	Raking
5	Boy Scouts Outreach
5	Organizational meeting
7	West High School Homecoming parade
9	Raking
12	Awarded Proposals Announced
12	Organizational meeting

14	Kickoff and PDR Q&A
15	PDR writing session
16	Raking
20-23	Wisconsin Science Festival Outreach
22	PDR writing session
23	Raking
29	PDR writing session
30	PDR writing session
31	Team web presence established
31	Preliminary Design Review (PDR) reports, presentation slides, and flysheet posted on the team website by 8:00 a.m. Central Time.
	November 2016
2-18	PDR video teleconferences
6	Raking
7	Organizational meeting
13	Raking
14	Organizational meeting
18	Workshop – scale model construction begins
19	CDR writing session
20	Raking
21	Organizational meeting
24-25	Thanksgiving
26	CDR writing session
27	Raking
28	Organizational meeting
30	CDR Q&A

	December 2016
2	Workshop
3	CDR writing session
4	Raking
5	Organizational meeting
9	Workshop
10	CDR writing session
12	Organizational meeting
16	Workshop - scale model complete
17	Scale Model test flight
18	Scale model data analysis
19	Organizational meeting
22-Jan 3	Winter Break
23	Workshop – full scale vehicle construction beings
	January 2017
6	Workshop
7	Scale Model test flight backup date
8	Scale model data analysis, CDR writing session
9	Organizational meeting
13	Critical Design Review (CDR) reports, presentation slides, and flysheet posted on the team Website by 8:00 a.m. Central Time.
13	Workshop
14	CDR teleconference practice
16	Martin Luther King Jr. Day
17-31	CDR video teleconferences
23	Organizational meeting

27	Workshop
28	FRR writing session
30	Organizational Meeting
	February 2017
3	Workshop
6	Organizational Meeting
8	FRR Q&A
10	Workshop
11	FRR writing session
13	Organizational meeting
17	Workshop – full scale vehicle completed
TBD	Physics Open House
18	FRR writing session
19	Full scale vehicle half-impulse flight
20	Organizational meeting
24	Workshop
25	Full scale vehicle half-impulse flight data analysis
27	Organizational Meeting
	March 2017
3	Workshop
5	FRR Teleconference Practice
6	Flight Readiness Review (FRR) reports, presentation slides, and flysheet posted to team Website by 8:00 a.m. Central Time.
6	Organizational Meeting
8-24	FRR video teleconference
TBD	Randall-Franklin Super Science Saturday

10	Workshop
14	Organizational meeting
17	Workshop – payload completed
TBD	O'Keeffe Middle School Super Science Saturday
20	Organizational meeting
25-26	Full scale vehicle full impulse flight, data analysis
27	Organizational meeting
31	Workshop- final vehicle payload adjustments
	April 2017
TBD	Kids Express Outreach
3	Organizational meeting
5	Team travel to Huntsville, AL
5	Launch Readiness Review (LRR)
6	LRR's and safety briefing
7	Rocket Fair and Tours of MSFC
8	Launch Day
8	Banquet
9	Backup launch day
10-14	Spring Break
15	PLAR writing session
17	Organizational meeting
22	PLAR writing session
24	PLAR posted on the team Website by 8:00 a.m. Central Time

Table 19: 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.

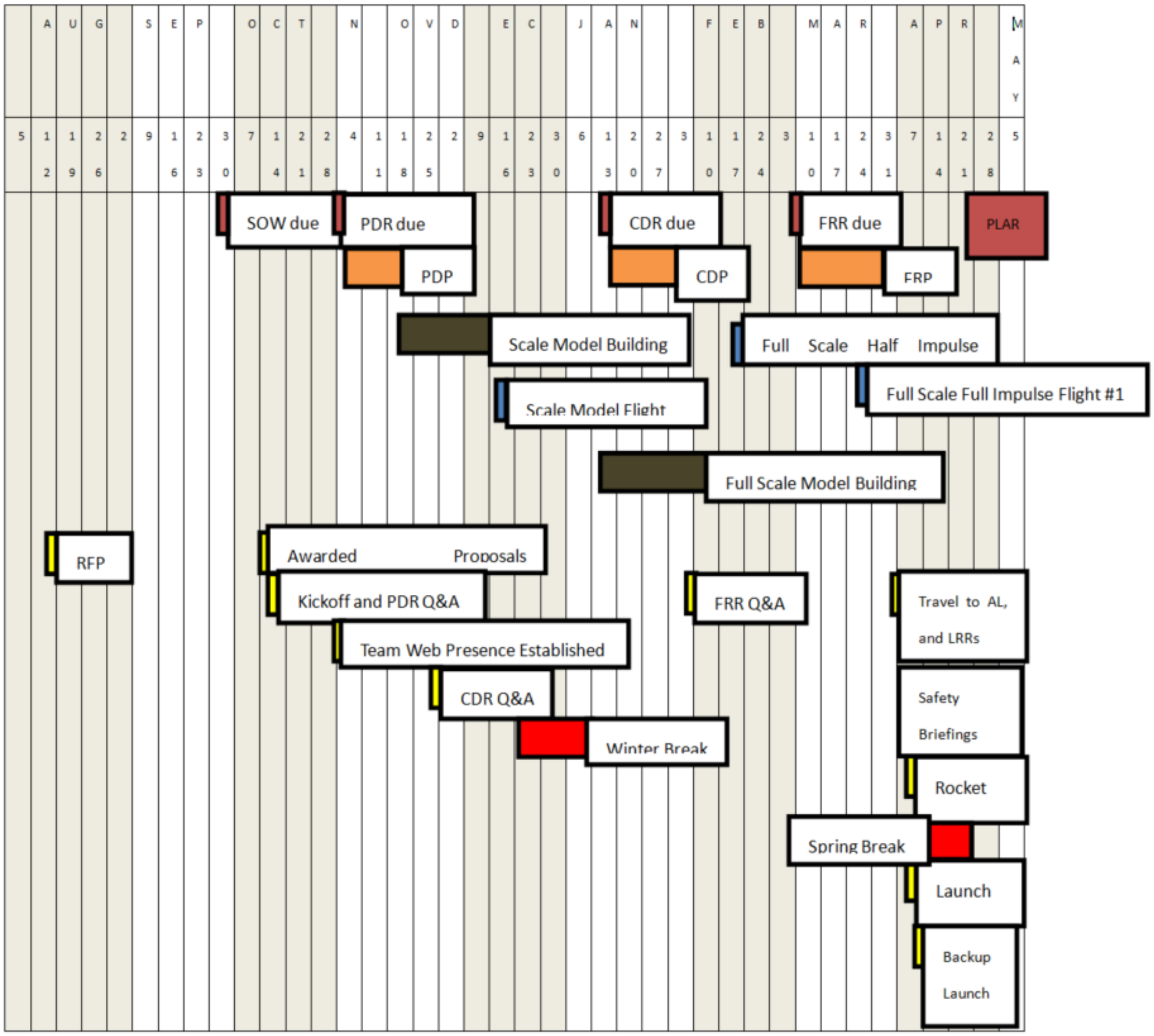


Figure 22: GANTT chart for SL2017 project

Project and Travel Budgets

Project Budget	
Full-Scale Vehicle	
Tubing, nosecone, bulkheads, rings	$300.00
Fin Material (G10 Fiberglass)	$100.00
Paint and Primer	$100.00
PerfectFlite Stratologger Altimeter (x2)	$150.00
Motor Retention	$100.00
Motor Casing*	$0.00
Parachutes, Shock Cords, Nomex	$200.00
Epoxy, Fillers	$200.00
CAT Enabled Smart Phones (x1)	$40.00
Walston Beacon*	$0.00
Miscellaneous Supplies (tools, batteries, wires, hardware)	$300.00
Scale Model	
Tubing	$100.00
Parachutes and Shock Cord	$50.00
Fin Material (G10 Fiberglass)	$50.00
Motors	
Scale Model Motors	$200.00
Full Scale Test Flight Motors	$400.00
Payload	
Controller (Custom PCB)	$200.00
Raspberry Pi (6)	$210.00
Raspberry Pi Cameras (x12)	$300.00
Arabidopsis Seeds/Growing Media**	$0.00
PLA (for 3D Printing)	$400.00
Total	**$3,400.00**

Table 20: 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 21: 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.

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

Expenses		
Project cost	$3,400.00	
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	***$15,164.00***	
Funds		
Raking fundraiser	$3,000.00	
Donations from families	$2,500.00	
Material support from companies	$1,000.00	
Travel funds	$9,864.00	Students pay the travel expenses associated with SL launch
Total Funds	***$16,364.00***	

Table 22: Breakdown of expected expenses and available funds

Project Requirements

1. Vehicle Requirements

1.1. The vehicle shall deliver the science or engineering payload to, but not exceeding, an apogee altitude of 5,280 feet above ground level (AGL).

The current simulation predicts that the rocket will reach 5,146*ft*. The coefficient of drag is set to C_D = 0.7. We have obtained this experimentally measured value from our previous experiments using a similar constant diameter K-class delivery vehicle. The performance predictions will be updated as data from scale model flight and half-impulse flight become available. If necessary, the rocket will be ballasted to prevent it from exceeding altitude of 1 mile. The amount of ballast will not exceed 10% of rocket liftoff weight.

1.2. The vehicle shall carry one commercially available, barometric altimeter for recording the official altitude used in determining the altitude award winner. 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. Any team is eligible for the award as long as their rocket remains below an altitude of 5,600 feet AGL.

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.

1.3. The launch vehicle 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.

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.

The vehicle is a single stage rocket.

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 and the payload can remain in wait-state for 8 hours. 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 Range Services Provider.
The vehicle is using Aerotech 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 require no external circuitry or special ground support equipment to initiate launch (other than what is provided by Range Services).
No external circuitry other than the standard 12V launch system is required to launch the vehicle.

1.10. 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, Aerotech K1999N-P motor is the primary propulsion choice.

1.10.1. Final motor choices must be made by Critical Design Review (CDR).
We will finalize our propulsion choice by Critical Design Review.

1.10.2. Any motor changes CDR must be approved by the NASA Range Safety Officer (RSO), and will only be approved if the change is for sole purpose of increasing the safety margin.
We will comply with all instructions provided by NASA should this situation arise.

1.11. Pressure vessels on the vehicle must 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 milestone reviews.
Not applicable.

1.11.2. The low-cycle fatigue life shall be a minimum of 4:1
Not applicable.

1.11.3. Each pressure vessel shall include a solenoid pressure relief valve that sees the full pressure of the tank.

Not applicable.

1.11.4. Full pedigree of the tank shall be described, including 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. The total impulse provided by a Middle and/or High School launch vehicle shall not exceed 2,560 Newton-seconds (K-class).
None of the three motor alternatives considered for this project exceeds 2,560*Ns* impulse limit. The primary motor choice has total impulse of 2540*Ns*.

1.13. All teams shall successfully launch and recover a subscale model of their rocket prior to CDR. The subscale model should resemble and perform as similarly as possible to the full-scale model, however the full-scale model shall not be used as the subscale model.
We are planning to launch the subscale model prior the Critical Design Review due date. This is a standard step in our project development cycle.

1.14. 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 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 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.

1.14.1. 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.

1.14.2. The payload does not have to be flown during the full-scale test flight. The following requirements still apply:
We intend to have the payload fully functional for our final test flight.

1.14.2.1. 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.

1.14.2.1.1. 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.

1.14.2.2. 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.

1.14.3. 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.

1.14.4. 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 launch day flight.

The vehicle will be fully ballasted (if ballast is necessary) for the final full scale test flight. Requirement 1.14 will be observed.

1.14.5. 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.

1.15. 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.

1.15.6 The launch vehicle shall not use motor ejection as a primary or secondary means of deployment.

All ejection charges are triggered electronically by two fully redundant barometric altimeters. Motor ejection charge is neither used nor present.

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*.

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 supply 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 cellular network (Trackimo trackers). Additionally, 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. Payload Requirements

3.1. The launch vehicle shall carry a science or engineering. The payload may be of the team's discretion, but shall be approved by NASA. NASA reserves the authority to require a team to modify or change a payload, as deemed necessary by the Review Panel, even after a proposal has been awarded.

We have selected to use a payload investigated the effect of gravitational force on gene expression levels in Arabidopsis Thaliana plants. Our payload is described in detail earlier in this document. We will comply with all NASA requests for changes (if applicable).

3.2. Data from the science or engineering payload shall be collected, analyzed, and reported by the team following the scientific method.

We will thoroughly analyze and document all data collected by our payload. Post Launch Assessment Report will be sent to NASA after our final launch in Huntsville. The hypothesis and analytical methods are described earlier in this document.

3.3. Unmanned aerial vehicle (UAV) payloads of any type shall be tethered to the vehicle with a remotely controlled release mechanism until the RSO has given the authority to release the UAV.

The payload does not separate from the vehicle. No UAV is used.

3.4. Any payload element which is jettisoned during the recovery phase, or after the launch vehicle lands, shall receive real-time RSO permission prior to initiating the jettison event.

The payload does not separate from the vehicle.

3.5. The science or engineering 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.

The payload has its own tracking capabilities (to facilitate recovery) and can be flown several times a day (the maximum payload preparation time is 2 hours).

4. Safety Requirements

4.1. Each team shall use a launch and safety checklist. The final checklist shall be included in the FRR report and used during the Launch Readiness Review and launch day operations.
We will use a launch and safety checklist for each launch. The checklists will be checked and improved during each test launch. All checklists will be included in our Flight Readiness Review.

4.2. Each team must identify a student safety officer who shall be responsible for all items in section 4.3.
Ian Shi is the team's safety officer.

The role and responsibilities of each safety officer shall include, but not limited to:

4.2.1. Monitor team activities with an emphasis on Safety during:

4.2.1.1. Design vehicle and launcher
4.2.1.2. Construction of vehicle and launcher
4.2.1.3. Assembly of vehicle and launcher
4.2.1.4. Ground testing of vehicle and launcher
4.2.1.5. Sub-scale launch test(s)
4.2.1.6. Full scale launch test(s)
4.2.1.7. Launch day
4.2.1.8. Recovery activities
4.2.1.9. Educational Engagement Activities

All items are acknowledged and part of our standard set of procedures.

4.2.2. Implement procedures developed by the team for construction, assembly, launch and recovery activities.
All items are acknowledged and part of our standard set of procedures.

4.2.3. Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures and MSDS/chemical data inventory data.
All items are acknowledged and part of our standard set of procedures.

4.2.4. Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.
All items are acknowledged and part of our standard set of procedures.

4.3. Each team shall identify a "mentor" which 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 have been 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 in Huntsville, AL. 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 attends launch week in April.

Dr. Pavel Pinkas is the mentor for the team. He is Level 2 certified and satisfies all requirements listed above. He will accompany team to the Huntsville launch.

4.4. 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 SLP launch does not give explicit or implicit authority for teams to fly those certain vehicle configurations and/or payloads at local club launches. Teams should communicate their intentions to the local club's Prefect and RSO before attending any NAR or TRA launch.

We will cooperate with local sections (Tripoli Wisconsin and NAR Section #558) during our test launches. We have been attending their launches for 8 years and most of our test flights were launched there.

4.5. Teams shall abide by all rules set forth by the FAA.
All FAA rules are followed during our activities.

5. General Requirements

5.1. Students on the team shall do 100% on the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder charges (to be done by the team's mentor).
Students will do 100% of work on the project, write the documentation and presentations and present the project during teleconferences. Mr. Brent Lillesand is the Level 3 mentors for the team and he will handle all motor and ejection charge assembly.

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.
A project plan will be maintained and update as project progresses. Mr. Jim Guither is the workshop supervisor and will help students to schedule workshop time and tools usage.

5.3. 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 additions, FN''s may be separated from their team during these activities.
The list of foreign nationals will be provided to NASA by PDR teleconference.

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

5.4.1. Students actively engaged in the project throughout the entire year and currently enrolled in the proposing institution.
All ten team members are identified in the Student Participants section near the beginning of this document.

5.4.2. One mentor (see requirement 4.4).
Dr. Pavel Pinkas is the mentor for the team.

5.4.3. No more than two adult educators.
Ms. Christine Hager and Dr. Pavel Pinkas are the team's educators.

5.5. The team shall engage a minimum of 200 participants (at least 100 of those shall be middle school students or educators) 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 an event. A sample of the educational engagement form can be found in this handbook.

Our education engagements plan includes over 7500 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.

5.6. The team shall develop and host a Web site for documentation of all project components.
The WEB presence for the team will be developed on schedule and updated throughout the entire project.

5.7. Teams shall post, and make available for download, the required deliverables to the Web site by the due dates specified in the project timeline
All deliverables will be posted online as required by the project schedule.

5.8. All deliverables must be in PDF format.
All deliverables will be in PDF format.

5.9. In every report, teams shall provide a table of contents including major sections and their respective sub-sections.
The aforementioned format of each report will be followed.

5.10. In every report, the team shall include the page number at the bottom of the page.
Page numbers will include at the bottom of each page at each of the reports.

5.11. The team shall provide any computer equipment necessary to perform a video teleconference with the review board. This includes, but not limited to, a 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.

5.12. Teams must implement the Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standards (36 CFR Part 1194)

Subpart B-Technical Standards (http://www.section508.gov):

- **1194.21 Software applications and operating systems**
- **1194.22 Web-based intranet and Internet information and applications**

We are fully compliant with section 508, details of our compliance are described earlier in this document.