NASA Student Launch Initiative 2006-2007
Critical Design Review

Post Rocket-Flight Expression of Stress Response Genes in Refrigerated Wild-Type *Arabidopsis thaliana* Compared to that of Agravitropic Mutants

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I) VEHICLE CRITERIA

Design and Verification of the Launch Vehicle

Mission Statement

The goal of this project is to launch a vehicle that carries agravitropic and wild type *Arabidopsis Thaliana,* in both cold and normal temperature compartments, to an altitude of 5280 feet (one mile). The single stage rocket will be powered by either a J-2135NP or J-800T Aerotech RMS motor. G-Wiz accelerometer/altimeter/flight computer will be used in the vehicle, enabling the collection of acceleration values over the course of time. The requirements for the success of this mission include a functioning rocket and its subsystems. A vehicle succeeds under several conditions. The rocket must launch successfully, reach the target altitude, withstand the enormous stresses of high acceleration flight, properly deploy the parachute, and return safely to the ground, keeping the rocket intact and payload undamaged. Furthermore, it's essential that the rocket can be found and recovered within a period of several hours after the launch.

Major Milestone Schedule

January 2007
27th Full Scale Construction (Begin construction of payload and integration modules)
29th Submit Invoice for CDR

February 2007
17th Finish Full Scale Construction
18th Ejection Charges Testing
25th First Full Scale Rocket Flight (no payload)
26th Begin Writing FRR

March 2007
10th Repair Full Scale Rocket/Revise Payload Integration
18th Second Full Scale Rocket Flight (including payload)
19th Flight Readiness Review Presentation Slides Due
24th Rocket Repairs Made
26th Submit Invoice for FRR

April 2007
8th Third Full Scale Flight (including payload)
14th Final Modifications to Rocket
25th Travel to Huntsville

May 2007
25th Final Report Due

Review of Design at System Level

Preliminary Motor Selection

Many simulations have been conducted in RockSim and have led to the preliminary selection of either a J800T or J2153NP motor for the rocket. The J800T meets all of the requirements for the rocket, and therefore is the preliminary motor selection. However, the J2153NP is projected to give the rocket an acceleration force of around 40g, which may produce more drastic results in the onboard experiment. Therefore, the J2153NP is also a possible motor selection for the rocket if it becomes available on manufacturer's schedule.

System Level Design

Required Subsystems

- **Vehicle:** Propulsion System, Structural System, Deployment System, Tracking System, Recovery System
- **Other:** Launch System

Subsystems

- **Propulsion System:** Our rocket will be powered by a J800T motor, which uses a Blue Thunder propellant or the motor is J2135NP motor, Aerotech Warp 9 propellant (if available). The motor will be contained in a motor mount tube and centered in the body tube with three ¼" plywood centering rings. It will be held in with a Lock'N'Load motor retention system.

- **Structural System:** The structural system will consist of 3" fiberglass or carbon fiber tubing. There will be a boat tail on the end of the rocket made from plastic. Three fins made of 0.125" G10 fiberglass will be attached with West epoxy through the wall, to the motor mount at the back of the rocket.

- **Deployment System:** The deployment system will consist of two dual event altimeters connected to ejection charges for both the main and drogue parachutes. These will both fire the same charge at apogee, ejecting the drogue parachute and will both fire another charge at 500 feet, ejecting the main parachute. The drogue parachute will deploy from behind the electronics bay and the main parachute will deploy from the section in front of the electronics bay. If one altimeter fails the other one will still fire the charge. Both altimeters will also be connected to separate batteries for redundancy.

- **Recovery System:** *see Recovery Subsystem section*

- **Tracking System:** The tracking system will consist of a 140dB screamer and Walston radio beacon and receiver.

- **Launch System:** We will be using a standard 12-volt launch control. The launch system will consist of a standard HPR launch pad with an 8-foot rail. Standard sized rail buttons will be used.

Analysis and Test Results

RockSim results show that the rocket will be stable and should be able to reach an altitude of one mile. Test flights of the scale model ensure our confidence in the stability of the design and the suitability of the construction techniques (use of industrial strength epoxy glue, G10 through-the-wall fins, and plywood bulkheads). The rocket was flown on a G64 motor to prove the basic stability and then on a G336 motor for a stress test. Petri dishes with agar were included in the stress test and suffered no damage. The estimated acceleration during G336 flight is 45-60 gees.

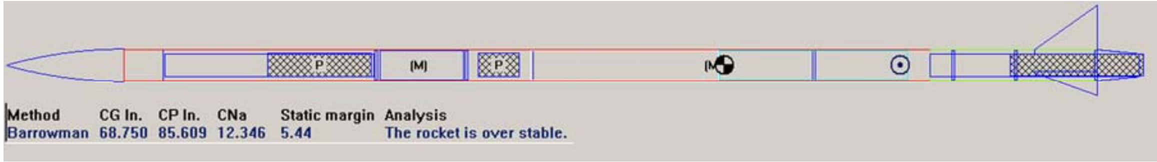
System Level Functional Requirements

1. The rocket must reach an altitude of one mile at apogee --- The rocket has been tested extensively in RockSim and the simulations show that the rocket will reach an altitude of one mile on either a J800T or J2153NP motor. Test flights will also be conducted in order to collect more precise altitude data on the rocket.

2. The rocket must remain intact --- The body tube of the rocket will be constructed of fiberglass tubes which will sufficiently withstand the forces exerted on the rocket during liftoff and flight. The fins will be constructed of 0.125” G10 fiberglass and will be attached through the outer tube of the rocket to a tube of smaller diameter inside with West Epoxy. The nosecone will be a commercially made plastic nosecone, which is made to withstand the forces exerted during flight. The sections of the rocket that need to separate when the ejection charges fire will be fitted tightly and shear pins will be used to prevent early deployment of main parachute.

3. The rocket must return safely and undamaged to the ground and be recovered --- The recovery system used will be a classic dual deployment system which will minimize drift distance of the rocket and allow it to be recovered in a timely fashion. There will be a drogue and main parachute housed near the front of the rocket. The ejection charges for both of the parachutes will both be attached to two altimeters, for the purpose of redundancy. The drogue parachute will be deployed first, at apogee feet, to slow the rocket’s descent to around 60 fps. At 500 feet, the main parachute will be deployed and slow the rocket’s descent to a safe landing speed of 15-20 fps. Parachute diameters have been calculated in order to insure correct descent speed of the rocket (see table in Recovery Subsystem section).

4. The rocket must be stable --- Data from RockSim indicates that the rocket has a stability margin of 5.5 calibers (see 2D model below). Test flights of the 2/3 scale rocket show that the rocket design is stable.



Method	CG In.	CP In.	CNa	Static margin	Analysis
Barrowman	68.750	85.609	12.346	5.44	The rocket is over stable.

Figure 1: Diagram showing the stability of the rocket.

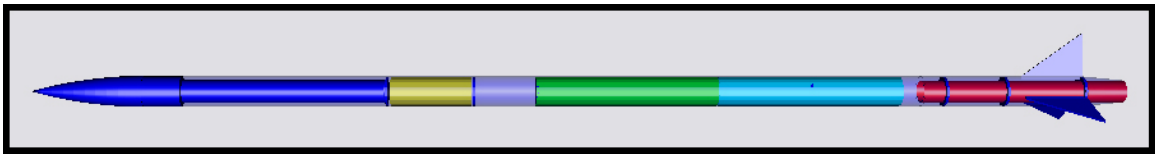


Figure 2: 3D Model. Color code: blue – structural elements, red – propulsion, cyan – cold temperature payload compartment, green – ambient temperature payload compartment, yellow – electronics bay

5. The rocket must be able to withstand winds up to 20 mph during flight --- RockSim simulations show that the rocket will fly well in winds up to 20 mph (see table below). The table also shows, that despite the large stability margin (approximately 6 calibers), the rocket experiences almost no weathercocking, even when launched under 15deg angle. This allows us to eliminate the front fins that were originally included to lower the stability margin and reduce weathercocking.

Motor	Wind Speed (MPH)	Launch Angle (deg.)	Max. Altitude (ft)	Max.Gee's
J2135NP	0	0	6000	43.74
J2135NP	20	0	5976	43.74
J2135NP	0	15	5607	43.74
J2135NP	20	15	5738	43.74
J800T	0	0	5856	22.98
J800T	20	0	5794	22.98
J800T	0	15	5439	22.98
J800T	20	15	5652	22.98

6. The rocket must be able to house the payload and return it safely to the ground --- The payload requires a 2 foot section of the rocket. The payload bay of the rocket is 3 feet in length, which is sufficient space.

Workmanship

Essential to the success in rocketry, precision and careful workmanship is a key factor to determining mission success. Working in properly lighted areas, using appropriate measurement devices and tools and progressing in a focused manner the team is able to ensure a successful launch and project completion.

Project Status

Construction Status

Construction of the 2/3 scale model has currently been completed and three test flights have been conducted with the scale model. The results seen in our test flights indicate that the design is suitable for our experimental purpose and this design will be used for the full sized model. Construction on the full size rocket will begin after the CDR video conference.

Verification Plan, Status, and Matrix

Because our scale model is 2/3 model of the final vehicle, we can predict that many of the tests that we performed for the scale model will yield similar, favorable results for the full size vehicle.

Verification Tests

V_1: Integrity Test: applying force to verify durability.
V_2: Parachute Drop Test: testing parachute functionality.
V_3: Tension Test: applying force to the parachute shock cords to test durability
V_4: Prototype Flight: testing the feasibility of the vehicle with a scale model.
V_5: Functionality Test: test of basis functionality of a device on the ground
V_6: 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 (Estes igniters or low resistance bulbs can be used for verification).
V_7: Electronic Deployment Test: testing if the electronics can ignite the deployment charges.
V_8: Ejection Test: test that the deployment charges have the right amount of force to cause parachute deployment.
V_9: Computer Simulation: use RockSim to predict the behavior of the launch vehicle.
V_{10}: Integration Test: ensure that the payload fits smoothly and snuggly into the vehicle, and is robust enough to withstand flight stresses.

Tested Components

C_1: Body (including construction techniques)
C_2: Altimeter
C_3: G-Wiz
C_4: Parachutes
C_5: Fins
C_6: Payload
C_7: Ejection charges
C_8: Launch system
C_9: Motor mount
C_{10}: Screamers, beacons
C_{11}: Shock chords and anchors
C_{12}: Rocket stability

Matrix Legend
P: Planned Tests
F: Finished Tests

	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}
C_1	P			F						
C_2				F	P	P	P			
C_3				P	F		P			
C_4		F		F						
C_5	P			F						
C_6				F						P
C_7				F			P	P		
C_8				F	F					
C_9	P			F						
C_{10}				P	P					
C_{11}			P	F						
C_{12}				F					F	

Verification Matrix

Integrity of Design

The rocket is long and slender which allows for greater acceleration. There is also a boat-tail on the back end of the rocket, which further lowers the drag coefficient. The fins on the rocket are a simple shape, which allows for easiness of construction and they were proven to provide sufficient stability in flight. After much research, it has been determined that the front six fins on the rocket will not be necessary, and they will not be included in the final design. The fins on the full scale rocket will be attached through the outer tube of the rocket to an inner tube of smaller diameter. They will be attached to the outer and inner tubes with West Epoxy, with both inner and outer fillets, and the empty space between the outer and inner tube will be filled with foam. This system of fin attachment has already been proven to be sturdy during the scale model launch and past SLI projects. An added bonus to the design of the fins is that it is simple, which allows for ease of construction.

After a test flight on the scale model, we found the CD to be 1.2. This is an unusually high CD for a rocket of this shape. This may be due to the unprofessionally done paintjob and the high winds on the day of the launch. We shall conduct more test flights on the scale model to re-determine the CD of the rocket. Our full scale rocket will have a professionally done paintjob and for now we will assume, from previous experience, we will have a CD between 0.5 and 0.6.

Proper Materials

Fins	
G10 Fiberglass	Durable under high stress.
Bulkheads	
0.25 inch Plywood	Withstands stress through 40g; supports weight of components inside rocket.
Tubes	
Fiberglass Tubes	Pre-manufactured fiberglass tubes will be used for exterior body tube to withstand 40g and will lower the overall drag because of their smooth surface
Fiberglass couplers	Fiberglass tubing will be also used for interior components of rocket, such as electronic bay and tube couplers.
Nosecone	
Plastic Nosecone	Pre-manufactured plastic nosecone suitable for high power rockets.

Proper Assembly Procedures

We will use U-bolts and solid bulkheads for shock-cord attachments. Metal tie rods will be used to hold the electronics bay together and bear the pull-load delivered by the shock chords. We will always use metal bolts when attaching shock cord, and use quick links to attach the shock chord to the metal bolts. West epoxy will be used wherever adhesive is needed.

Motor Retention

The motor will be harbored in the motor tube extending all the way through the boat tail. A motor mount tube couple boat tail with vehicle and a lock-and-load retention system will be attached to the end of the boat tail. The boat tail will be permanently attached to the end of the rocket.

Safety and Failure Analysis

Subjecting the rocket to acceleration in excess of 40-gees, it is possible that the rocket could disintegrate or experience electrical failure, by the disconnection of electrical circuits. The team will use standard methods recommended for high power rocketry construction, avionics connectivity and ensure the firm attachment of all electrical devices. See launch operations for proposed steps.

Activation of Remote Control Devices

Preventing the inadvertent activation of any remote control devices, the team will terminate any radio signals emitting from cellular devices, walkie-talkies, or other devices operating transmitting radio waves. This is crucial to the safety of anyone involved in rocketry experiences and the team will take great care to ensure its fulfillment.

Safety and Failure Analysis

Risk Mitigation Chart for Rocket

Risk	Repercussion	Resolution
Faulty design-unstable rocket	Unsuccessful flight. Possible injury/death of rocket team personnel. Possible property damage.	We will use prototype flights, computer simulations, and low altitude flights to make sure that the rocket is stable.
Failed structure	Rocket disintegrates.	We are using materials such as Kevlar, fiberglass, epoxy, etc. that are sturdy and can sustain the pressure and stresses of the flight.
Ignition failure	No lift-off.	We will properly use the motors and the igniters.
Launch failure-launch rail malfunctioned	Rocket leaves launch pad at an undesired angle. Possible injury/death and property damage.	The launch rail will be leveled, lubricated, and firmly secured to a stable surface. Rail buttons will be repeatedly checked for secure attachment to the rocket body.
Transportation-rocket is damaged during transportation	Possible deviation of flight, launch, or recovery.	The rocket will be properly packaged for the transportation and carefully inspected prior to launch.
Miscellaneous failure - G-Wiz failure	Acceleration data won't be recorded	G-Wiz will be tested during test flights and prior to the launch to ensure that it is properly functioning before it is inserted into the rocket. Fresh batteries will be inserted prior to launch.

Risk Mitigation Chart for Recovery Subsystem

Risk	Repercussion	Resolution
Recovery Failure-parachute get stuck in tube / ejection charge is not big enough	Ballistic fall of rocket and/or payload.	Parachute will be properly prepared and installed before the launch. Size of ejection charges will be computed and charges will be tested during static tests.
Ejection charge fails to	Parachute doesn't deploy	Redundancy will be

fire	– ballistic fall of rocket	employed – 2 altimeters will be used.
Rocket is Carried off by Strong Wind	Rocket is lost. Mission failure.	A tracking system will be used to locate the rocket. Radio beacon and screamers provide help in finding the rocket.
Parachute is Tangled	Unsafe landing of rocket.	Parachute shock cords will be carefully folded and inserted to prevent entanglement.

Recovery Subsystem

Parachute sizes

This rocket will use a dual deployment recovery system. Both the drogue and main parachute will be commercially available rip-stop nylon parachutes with nylon shroud-lines. To determine the proper parachute size for our vehicle, we used an online calculator. We wanted the drogue to return at 45-90 feet per second, and the main parachute to return at 15-20 feet per second. These goals yielded the following measurements:

	Parachute Diameter (in)	**Vent Diameter (in)**	**Descent Rate (fps)**
Main	60	9.5	17.59
Drogue	24	0	43.37

Ejection charges

The ejection charges for the final vehicle will be calculated using the formula

$$E\ [g] = 0.06 \times \text{length}\ [in] \times \text{diameter}^2\ [in]$$

Attachment scheme

The Kevlar shockcords will be attached using QuickLinks to the U-bolts in plywood bulkheads or electronics bay caps.The electronics bay caps will be connected by two 0.25“ threaded metal rods. A standard dual deployment scheme with the drogue parachute under the electronics bay and the main parachute above the electronics bay will be used. The electronics bay serves as a tube coupler between the booster and upper part of the rocket.

Safety analysis

The risks and mitigations for the recovery subsystem are discussed in the table in Safety and Failure Analysis section.

Mission Performance Predictions

Mission Performance Criteria

The goal of this project is to launch a vehicle that contains agravitropic and wild type *Arabidopsis Thaliana,* in both cold and normal temperature compartments, to an altitude of 5280 feet (one mile). The single stage rocket will be powered by either a J-2153NP or J-800T motor. G-Wiz accelerometer/altimeter/flight computer will be used in the vehicle, enabling the collection of acceleration values over the course of time. The requirements for the success of this mission include a functioning rocket and its subsystems. A vehicle succeeds under several conditions. The rocket must launch successfully, reach the target altitude, withstand the enormous stresses of high acceleration flight, properly deploy the parachute, and return safely to the ground, keeping the rocket intact and payload undamaged. Furthermore, it's essential that the rocket can be found and recovered within a period of several hours after the launch.

Flight Profile Simulations

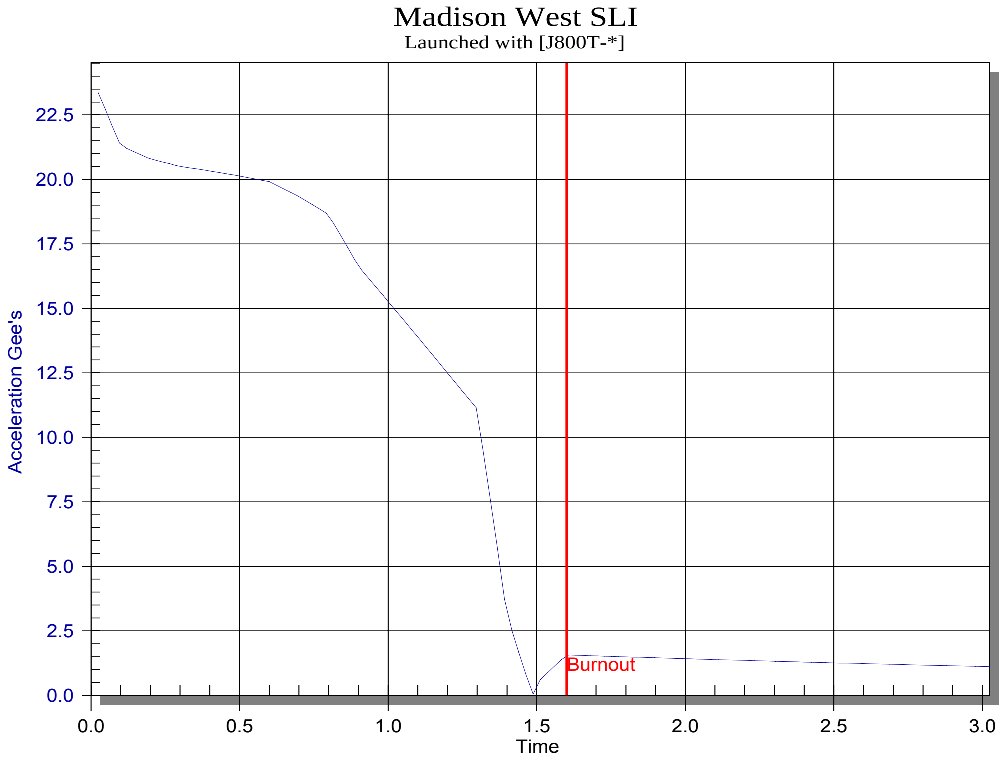


Figure 3: Acceleration profile using a J800 motor (acceleration vs. time)

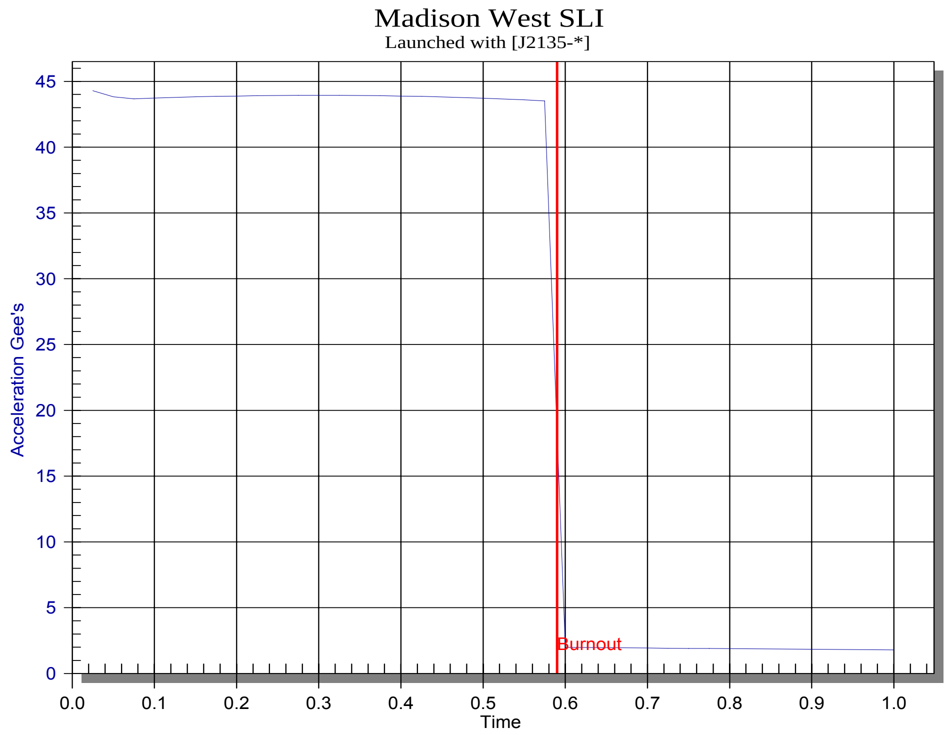


Figure 4: Acceleration profile using a J2135 motor

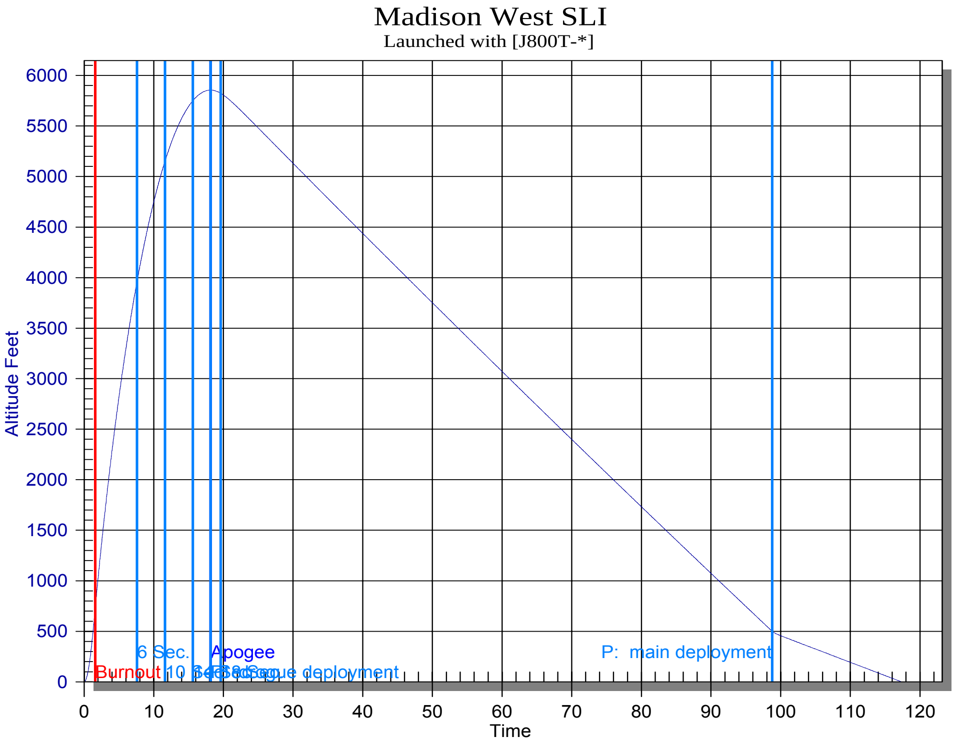


Figure 5: Altitude profile using a J800 motor

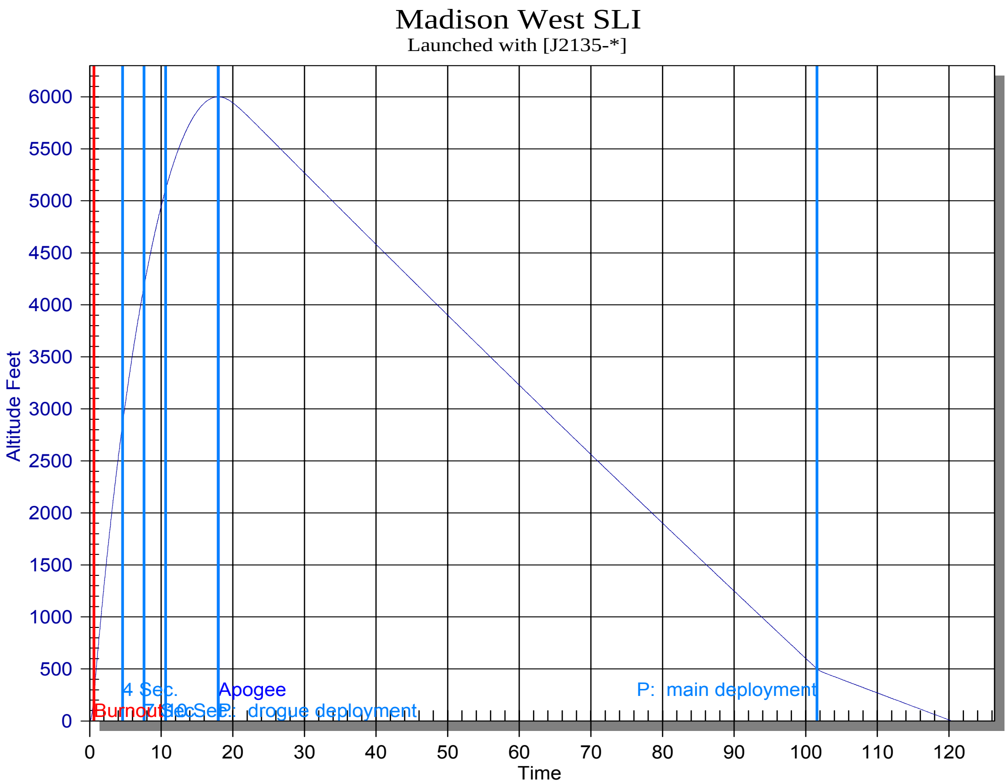


Figure 6: Altitude profile using a J2135 motor

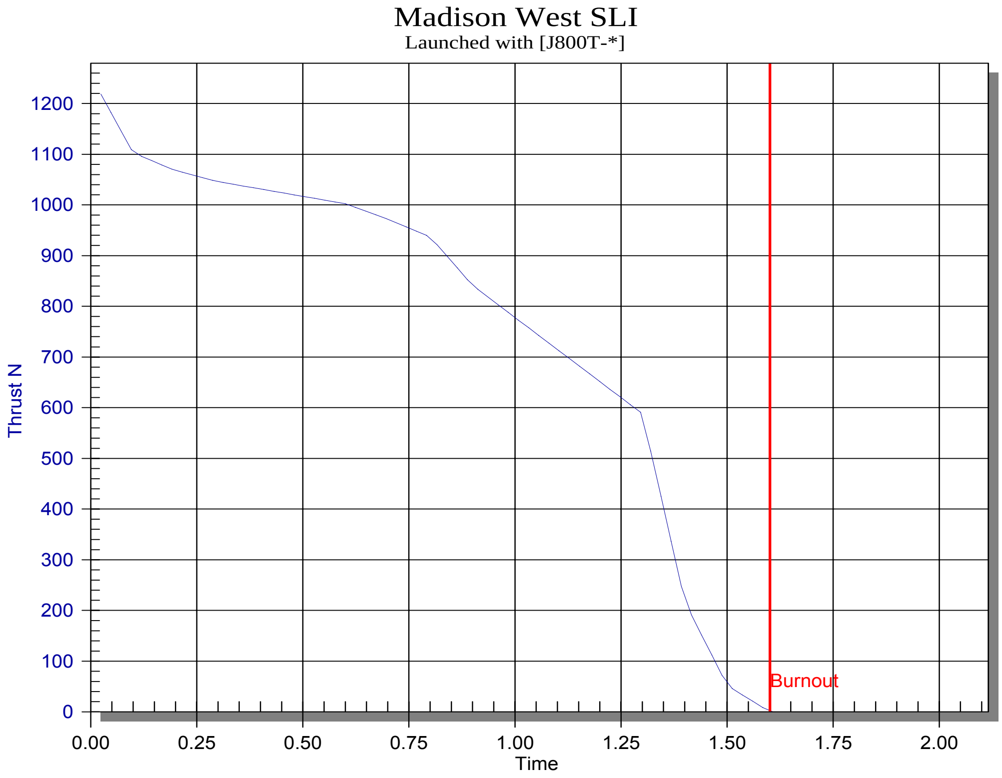


Figure 7: Thrust curve using a J800 motor

Figure 8: Thrust curve using a J2135 motor

Payload Integration

The payload section will be divided into two independent sections: one for cold-treated plants and the other for ambient temperature plants. Each individual section will be built into a coupler tube and have multiple layers. The layers (in order from exterior to interior) will consist of the coupler tube; a layer of thermal insulation, followed by a fixed inner tube. These three components will be permanently attached to each other. Inside the interior tube will be a removable tube that will harbor the Petri dishes with seedlings of Arabidopsis thaliana growing on a nutrient agar. The removable tube will be slightly greater than the diameter of the Petri dishes (40mm) so that they may snugly fit into the tube. The inner tube separating the insulation from the removable tube will either be slightly greater in diameter to allow a snug fit, or will have custom made rings (made from bulkheads) to hold the removable tube in place if we are unable to procure a tube of the appropriate diameter.

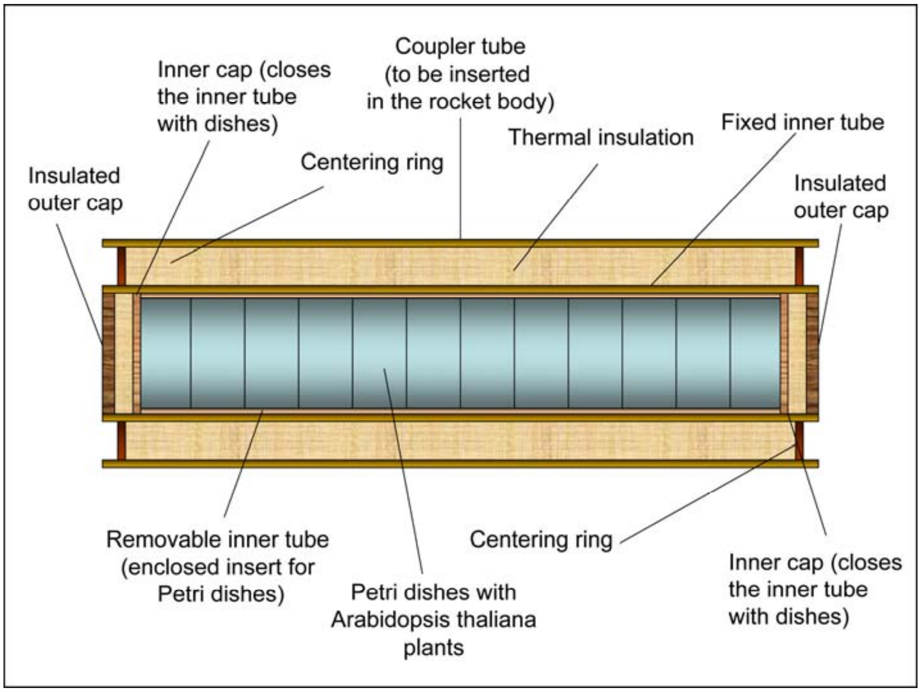


Figure 9: Payload integration scheme

By constructing the payload compartments from a coupler tube, we will be able to slide the compartments into the outer body tube. Because the two payload compartments (cold and ambient temperature compartments) are independent, we will be able to store them in appropriate environments until the rocket is ready for launch.

Launch Concerns and Operations Procedures

Assembly Procedure

1. Apply talcum powder to the parachute to assist with deployment.
2. Fold the parachute in an accordion then "Z" fold.
3. Cover parachute in a fire retardant cloth (Nomex).
4. Tie Kevlar cord to nose-cone (length of Kevlar cord = 2x rocket length).
5. Tie knot around midpoint of the Kevlar cord and attach the main parachute to the resulting loop.
6. Attach shock cord to the U-bolt on electronic bay.
1. Attach the drogue parachute (folded using same method as the other parachute) using the drogue shock cord to the U-bolt above the motor. The other end of the drogue shock-cord attaches to the U-bolt in the bottom cap of the electronics bay.
7. Check amperage on batteries to ensure electronic functionality (at least 3 amps required for ejection charge firing).
8. Verify wire terminals in electronics.
9. Prepare black powder charges, making sure to wear safety goggles and stay away from any electronic devices or other triggering materials.
10. Place black powder in a small square of plastic, folding the four corners together and taping together with electrical tape.
11. Tape electrical match to the side of the black powder charge.
12. Attach each ejection charge to one of the electrical terminals on electronics bay.
13. Install ejection charges in the rocket.
14. Insert parachutes and shock cords into rocket.
15. Fit electronics bay into upper section and secure using screws.
16. Insert electronics bay into lower section of the rocket.
17. Insert the nose-cone shear-pin.

Launch Procedure

1. Place assembled rocket on the launch rail.
2. Raise the launch rail to vertical position.
3. Verify functionality of altimeter and G-Wiz accelerometer.
4. Insert igniter into motor.
5. Arm all electronics.
6. Attach ignition clips to the igniter.
7. Verify igniter continuity.
8. Everybody moves to the safe launch distance (100ft for J-class motors).
9. Countdown.
10. Launch.

Misfire Procedure

1. Wait at least one minute after the misfire before approaching the rocket.
2. Disconnect ignition system.
3. Remove the igniter.
4. Approach the rocket and disarm all electronics.
5. Lower the launch rail.
6. Remove rocket from the launch rail for repairs, igniter replacement or other adjustments.

Recovery Preparation

In order to successfully recover the rocket there will be a Walston radio beacon inside the rocket, as well as a screamer. On ground there will be specific teammates with walkie-talkies designated to locate the rocket upon landing.

Motor Preparation

The primary motor used will be either a J2135NP or a J800T. The motor will be placed in a motor casing and then inserted into the boat-tail of the rocket. The motor preparation will be carried by a properly certified mentor.

Igniter Installation

Insert the igniter into the nozzle. It may take several pushes to make sure it is all the way inside. Place the red cap over the end of the nozzle so that the igniter doesn't fall out.

Setup on Launcher

Two rail buttons will be attached to the rocket body. The launch rail will be lowered and the rocket will be slid into place using the rail buttons. The launch rail will be raised again so it is perpendicular to the ground. We will use a buble level to ensure that the launch rail is properly leveled.

Post-Flight Inspection

Inspect rocket for cracks in the body tube and fins. Confirm that the electronics are still intact and properly functioning. Check payload for explanation. See payload section.

Frequencies of Remote Control Devices

We will not be using any devices that require remote controls.

Troubleshooting

The entire disarming procedure must be executed prior any troubleshooting.

Safety and Environment

Safety Officer

The safety officer for the team will be Corinne Hay.

Remote Control Devices

We are not using any remote control devices. Flight electronics will be activated only after the rocket is in launch position. Flight electronics will be deactivated after each misfire to allow the crew to work with the rocket without the hazard of accidental activation of ejection charges. Cell phones and personal radios will not be allowed in the vicinity of the rocket.

Environmental Concerns

With any activity such as rocketry, one can cause damage to the environment. Fumes emitted from the engine of the rocket during the launch can possibly cause air pollution, rockets that aren't recovered could cause physical harm to animals, and any non-biodegradable material will remain for years. To try to minimize the potential environmental hazards associated with rocketry, we will strictly comply with all state and federal environmental regulations. We will keep track of everything we use to launch our rockets and the rockets themselves to ensure that all parts are recovered.

Personal Hazards

Possible hazards may result in working with high powered rocketry material such as:

- personal damage and health hazards from epoxy fumes
- personal injury from black power charges
- personal damage or injury from power tools in use
- health hazards from fiberglass dust
- health hazards from spray paint fumes
- burn injuries from soldering iron

However, many injuries can be avoided by wearing safety goggles, facial masks, and following the safety steps listed in the instructions to the power tools. All operations involving loose black powder, Pyrodex, motor igniters and motor propellant will be delegated to mentors with appropriate level of HPR certification.

Safety Documents

All safety related documents (such as MSDS sheets for all used supplies and materials, instruction manuals for power tools, NAR Safety Codes, rocket motor instructions, assembly and launch procedures) are kept together in a three ring binder and present at every team activity (such as a worksession, lab session or a launch).

II) PAYLOAD CRITERIA

Testing and Design of the Payload Experiment

Review of the Design at a System Level

A. Plates

Twenty four 40mm diameter Petri dishes will enclose the seedlings for launch. We chose this size of Petri dish—as opposed to a larger, 60mm dish—to leave room for the required thermal insulation. In our work with Prof. Sara Patterson, and our first experiments with RNA extraction, we determined that the baseline biomass necessary for extraction (100mg) required fewer plants than we initially postulated. However, the smaller size of the dishes limits the amount of seedlings which can be plated per dish. Therefore, we will plate only 7 seedlings per dish. Each experimental group will consist of six plates, four of which will be used for RNA extraction and two of which will be used for further growth analysis.

Cold Treatment		**Ambient Temp.**	
Wild-type	*Agravitropic*	*Wild-type*	*Agravitropic*
6 Plates	6 Plates	6 Plates	6 Plates
4 RNA, 2 Growth	4 RNA, 2 Growth	4 RNA, 2 Growth	4 RNA, 2 Growth

Figure 10: The projected experimental flight groups. The control group will be a replica of these groups.

B. Integration Modules

Differences in temperature between the two main experimental groups necessitate a complex integration plan. See vehicle section for detailed description of payload integration plan.

C. G-Wiz (accelerometer and flight computer)

Located within the electronics bay, separate from the payload integration modules, the self-contained chip will measure and record an acceleration profile during flight.

Plates Must:
- Withstand g-forces of launch.
- Fit within integration modules.
- Ensure that seeds remain fixed to the base of the dish.
- Provide continuous hydration to seedlings.
- Ensure that seeds are not damaged or harmed by any part of the housing.
- Maintain sterile conditions.

Integration Modules Must:
- Secure plates during flight.
- Accommodate both temperature groups.
- Minimize unnecessary motion that could dislodge seeds.
- Be quickly and easily installable and removable.
- Minimize environmental effects.

G-Wiz Must:
- Record accurate and consistent acceleration data.
- Operate on the 9V battery pack for the duration of flight.
- Endure the stresses of launch without losing function.
- Remain firmly attached to the mounting board.

Analysis and Test Results

We prepared Petri dishes for the scale model flight to test the integrity of the agar. The media was stained to allow us to scan for changes in color concentration, indicating compression of the agar. The test flight also allowed us to observe the structural integrity of the agar and/or petri dishes. Results indicated that both the agar and the Petri dishes are able to withstand over 40g.

We have had the opportunity to practice RNA extraction at Sara Patterson's lab and were successful. We plan on further practice to hone our skills. From this experience, we found that we don't need as many plants as previously predicted to obtain the amount of plant tissue necessary for RNA extraction. Instead of 120 plants, as we estimated earlier, we only need 20 to 30 per group. This will dramatically reduce preparation time. This reduction allows us to use our optimal payload design, including a layer of insulation

We have determined our genes of interest, which include, but are not limited to:
- **ARG-1 (At1g68370):** A gene up-regulated by gravistimulation. Our agravitropic trait in our mutant plants is caused by the mutation of this gene.
- **SGR-2 (At1g31480):** A second gene up-regulated by gravistimulation to be used as a control for gravistimulation.
- **TCH3 (At2g41100):** A gene up-regulated by mechanostimulation.
- **RC13 (At1g05260):** A gene up-regulated by in response to cold.

The **final gene of interest** will be one up-regulated by both mechanostimulation and gravistimulation.

System Level Functional Requirements

To ensure our data is a direct result of experimental flight stresses, and not the result of other external variables, all flight systems and subsystems must perform their functional requirements to a satisfactory level.

The *Petri dishes* must not, and did not, sustain structural damage under the influence of strong acceleratory forces, so as not to dislodge or harm the seedlings. The *agar* must be able, and was able, to nourish and maintain approximately seven seedlings while simultaneously maintaining its integrity throughout the flight. The *seed lines* we plan to use replicate the previous year's experiment: we plan to use the agravitropic mutant ARG-1 as well as conventional wild-type line. The *cold housing* must maintain the temperature of the dishes (about 5°C). The temperature will be maintained as we intend to include thermal insulation around the payload bay, as well as keep the cold section on ice prior to the flight.

The *integration module* must hold all housings fixed and stable, eliminating unnecessary motion during the flight. All *housings* will be properly affixed to their section of tubing, and held steady within the large tube.

The *G-Wiz accelerometer*, located in the electronics bay, must record, and has recorded, the acceleration profile of the rocket during flight, so that the actual gravitational stresses on the seeds can be determined post-flight.

Integration Plan

Please refer to the vehicle section for further information on the integration of our payload.

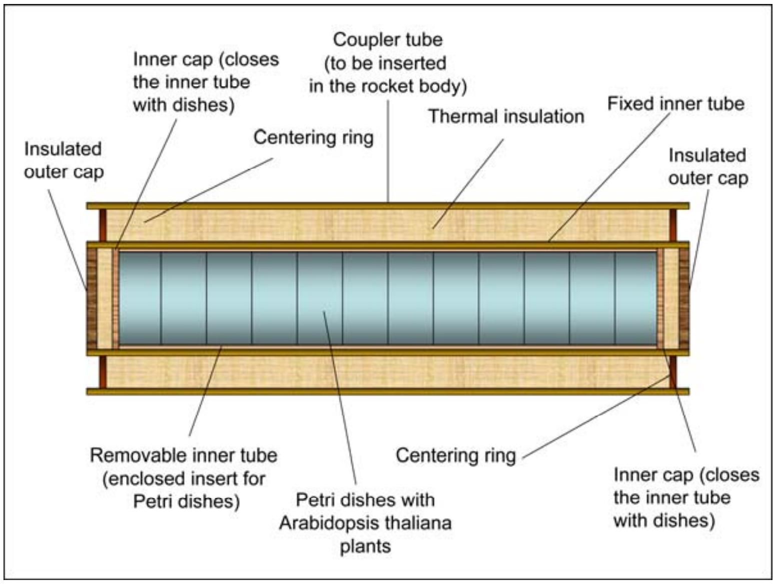


Figure 11: Payload integration scheme

Precision of Instrumentation, Repeatability of Measurement

To measure the acceleration forces in the rocket, we intend to use the on board G-Wiz. The G-Wiz that we will be using can measure forces ranging up to 100g. These specifications were provided by Aerocon electronics, the G-Wiz distributor, and are sufficient for our purposes. In each experimental group, we intend to include at least 42 *Arabidopsis* seedlings (approximately 7 per dish), resulting in a sample size that is large enough to be statistically significant, and addressing our need for 100mg of plant tissue for RNA extraction. In each section (cold, untreated, control cold, and control untreated for each seed line) we will have 6 plates. This will result in a total of 48 plates, or 336 seedlings (per flight.)

Our rocket employs a thoroughly tested recovery method. We will use dual deployment to minimize drift distance; the rocket will return the payload to earth undamaged. The seed lines that will be used are easily attainable and uniform. Furthermore, all other materials are standard. This ensures the experiment can be reproduced assuming the same attention to detail.

Safety Analysis

Because of the biological nature of our payload, there are few environmental and personnel hazards to be addressed. However, RNA extraction does involve the use of phenol, a dangerous chemical which can cause severe burns if mishandled. All RNA extraction will be done under the close supervision of experienced mentors to prevent any injuries. The analysis of our payload also calls for a fixative to be used immediately after the launch to prepare the plants for RNA extraction at a later date. We will also be using dry ice to freeze the plants until we can extract the RNA. The fixative and the dry ice will be kept in a well sealed and labeled container to prevent harm to anyone or to the environment. The safety officer will ensure that all MSDS sheets are kept on hand at all times. Mentors will also be monitoring our use of all hazardous chemicals.

Failure Analysis

Risk	Resolution
Cold compartment does not maintain temperature	Insert Petri dishes full of ice into Payload bay
Plants do not stay frozen post-flight	Periodically check the dry ice for sublimation and procure a replacement source.
Degradation of RNA on site by RNases	Keep plants on dry ice post-flight
Low germination prior to flight	Ensure proper technique and materials used in plating
Contamination of samples	Ensure proper labeling technique is used

Approach to Workmanship

When plating the seeds we will use aseptic technique. We will also use proper technique in the RNA extraction process, which includes keeping the work area free of RNases, keeping the tissue sample cold before the Trizol step, and minimizing tissue loss during the transfer process.

Verification Metrics and Plan

Verification key (checkmark indicates succesful completion of test)

X **V1 :** Full Scale flight test
✓ **V2 :** 2/3 scale model flight test
✓ **V3:** Weight test: to simulate forces of 40 g. Determine the mass of the object to be tested. Place a mass 40 times greater on top of this object.
✓ **V4:** Accelerometer test: Fly G-Wiz inside of expendable rocket to test functionality of G-Wiz component.
✓ **V5:** Drop test: Release component from increasing heights to evaluate the structural integrity of the component
✓ **V6:** Lifespan test: Plate wild type *Arabidopsis thaliana* in simulated experimental conditions.
X **V7:** Cold test: Using thermometer, monitor the temperature of the insulated compartments before and after flight a ten-minute flight simulation.
✓ **V8:** Sterility test: Visually track the agar for signs of bacterial contamination during a two week period.

Verification Metrics for Tested Components

	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8
Cold Treatment Integration Module	♦	♦			♦		♦	
Ambient Integration Module	♦	♦			♦			
Petri Dishes	♦	♦	♦		♦	♦	♦	♦
Nutrient media	♦	♦			♦	♦	♦	♦
RDAS Chip	♦	♦		♦	♦			
Mounting Board	♦	♦		♦	♦			
Battery Pack	♦	♦		♦	♦			
Seeds	♦	♦				♦	♦	♦

Status and Plans of Remaining Manufacturing and Assembly

The payload bay of our scale model was a simplified version of the designs to be implemented in the final model: there was no separation between cold and hot chambers, and no insulation. Construction of a complete payload bay is underway. Please refer to the Integration Plan in the Vehicle section for details and dimensions.

Through practice sessions, team members have gained confidence in their plating technique. This experience will improve the efficiency of plate preparation.

Payload Concept Features and Definition

Creativity, Originality, Uniqueness, and Significance

Last year's experiment showed a surprising resilience of ARG-1 Arabidopsis mutants to acute acceleratory forces. Though this result is intriguing, agravitropic plants are undesirable for cultivation purposes—with no perception of gravity, they grow abnormally. This year's experiment follows logically from the previous year's project: we seek to mimic the protection provided by the ARG-1 trait in wild-type plants by refrigeration, thus slowing the metabolism and hopefully diminishing stress response. Conventional studies on plant gravitropism involve small changes in orientation whereas the key part of our experiment involves hypergravitational forces associated with rocket flight.

Suitable Level of Challenge

Previously, our post flight analysis of the plants was limited to qualitative, visual observations; this year's plan, however, incorporates quantitative as well as qualitative observation. In terms of quantitative analysis, we will test the expression of stress response genes through RT-PCR.

Science Value

Science Payload Objectives

The protection provided by the agravitropic trait is desirable because it allows successful transport of plants in rockets (or other vehicles) undergoing substantial acceleratory forces. However, agravitropism is an undesirable trait in that the plants do not grow normally- they are unaffected by gravity, ergo they grow in abnormal directions. Therefore, we wish to mimic this protection in wild-type seedlings. Research shows that lowering the temperature of plants decreases the metabolic rate, preventing further growth and possibly protecting the plants from outside stresses. We hypothesize that if we apply cold treatment to wildtype plants shortly prior to and during rocket flight, we can replicate the protection provided by the agravitropism trait.

On another level, our experiment involves testing our logical postulation that the gene ARG-1 is responsible for the stunted growth and eventual death of the plants as exhibited last year—the agravitropic mutant cannot express ARG-1, and therefore—we believe—did not undergo an extreme stress response to GS. The difference in their growth led us to hypothesize that ARG-1 is *the* cause of the extreme stress response. The RT-PCR (Reverse Transcriptase Polymerase Chain Reaction) method will be effective in comparing the expression of both ARG-1 and other genes possibly up-regulated in the stress response (such as mechanostimulatory genes), between experimental groups—cold and ambient, agravitropic and wild-type. We hypothesize that ARG-1 is *the* cause of the extreme stress response of the wild-type plants observed last year; therefore, we believe that if cold-treatment can succesfuly diminish the expression of ARG-1, then the plants will not undergo an extreme stress-response as was recorded previously.

In short, our goal is to manipulate, via cold treatment, the wild-type plants with ARG-1 expression (which is essential to normal plant growth) to respond to GS with *less than normal* levels of ARG-1 expression (i.e. without an extreme stress-response).

Payload Success Criteria

- Seeds will need to be plated so that there is a high enough germination rate to produce sufficient tissue to use for RNA extraction.
- Before flight, the plants in the cold-treated sections must be cooled and then insulated in the payload bay so that they stay at a cool temperature throughout the duration of the experiment.
- During the flight, agar must not separate from the plates—separation damages plants' roots.
- After flight, the payload bay will have to be located so that we can terminate the seedlings and place them on dry ice as quickly as possible.
- We must successfully perform RNA extraction and RT-PCR to get credible results.

Relevance of Expected Data, Accuracy/Error Analysis

RT-PCR is an established method of determining gene expression and therefore we expect that the data will be statistically significant. Trizol, the commercial version of phenol, is a well-tested reagent for RNA extraction. The expected yield of RNA for 100mg tissue ranges from 1 to 15µg.

Experimental Logic, Approach, and Method of Investigation

The results from last year's experiment showed an interesting and compelling resiliency of *A. thaliana* agravitropic mutants to brief and violent acceleratory forces. Our wild-type plants, on the other hand, showed all signs of an extreme stress response to these forces, such as stunted growth and plant death. As is the nature of scientific inquiry, the results of last year's experiment brought to light new questions, the most intriguing of which is the resiliency of agravitropic mutants to flight stresses. It is our hope, therefore, to gain more insight into the mechanisms by which agravitropic mutants protect themselves from the stresses of rocket flight. In order to do this, we will compare the expression of several stress-response genes in these two seed-lines through Reverse-Transcriptase Polymerase Chain Reactions (RT-PCR).

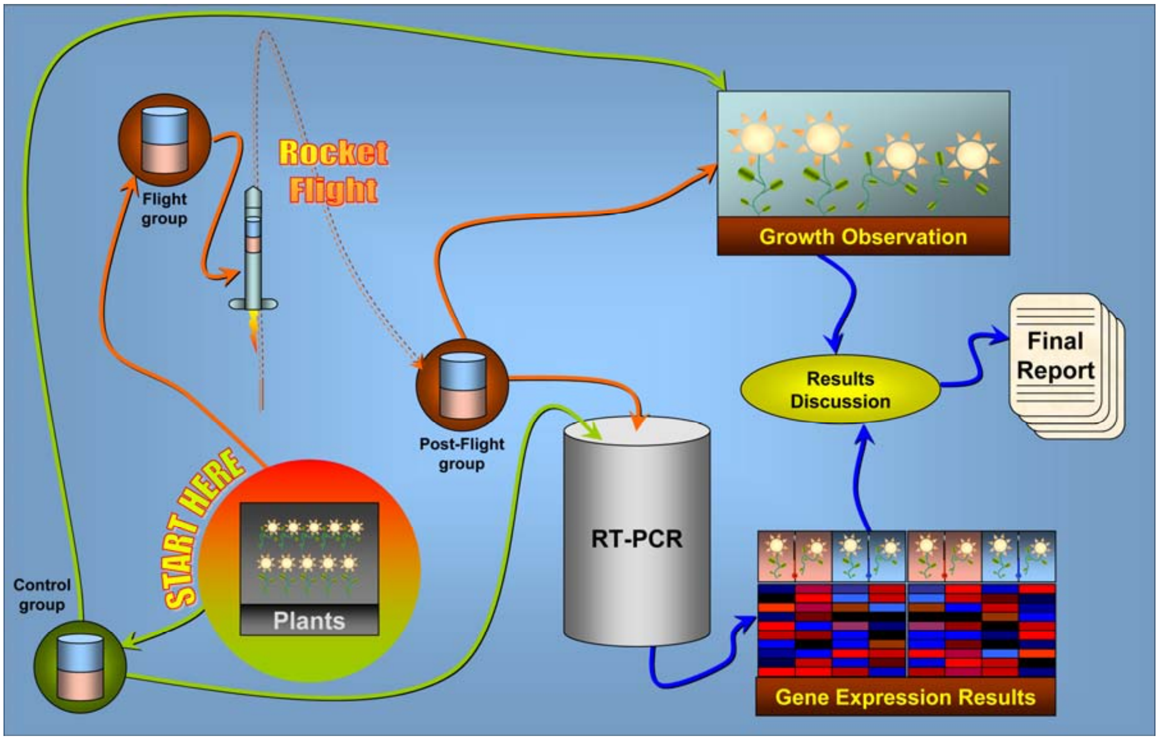


Figure 12: Experimental procedure.

Test and Measurement

1. Gene expression of plants after undergoing hypergravity conditions.
    i. The gene expression of the plants will be measured by RTPCR.
2. Further growth analysis of the plants post-flight.
    i. Comparison analysis of growth between control and experiment plants will be tracked visually.

Variables

1. Independent Variables:
    A. Seed lines
    B. Temperature
    C. Acceleratory Forces
2. Dependent Variables:
    A. Plant Response
        i. Gene expression
        ii. Growth

Controls

1. Plants that remain on the ground: used to compare the gene expression
2. Our mutant plants act as a control for the response to gravistimulation because agravitropic plants do not have any expression of ARG-1.
3. The analysis of the expression of RC13 will verify the cold treatment.
4. The final gene (up-regulated by both mechanostimulation (MS) and gravistimulation (GS)) will determine if the reaction of our plants to flight stresses is a result of the combination of MS and GS, rather than each stress separately.
5. SGR2 is our control to confirm gravistimulation in all launched plants.

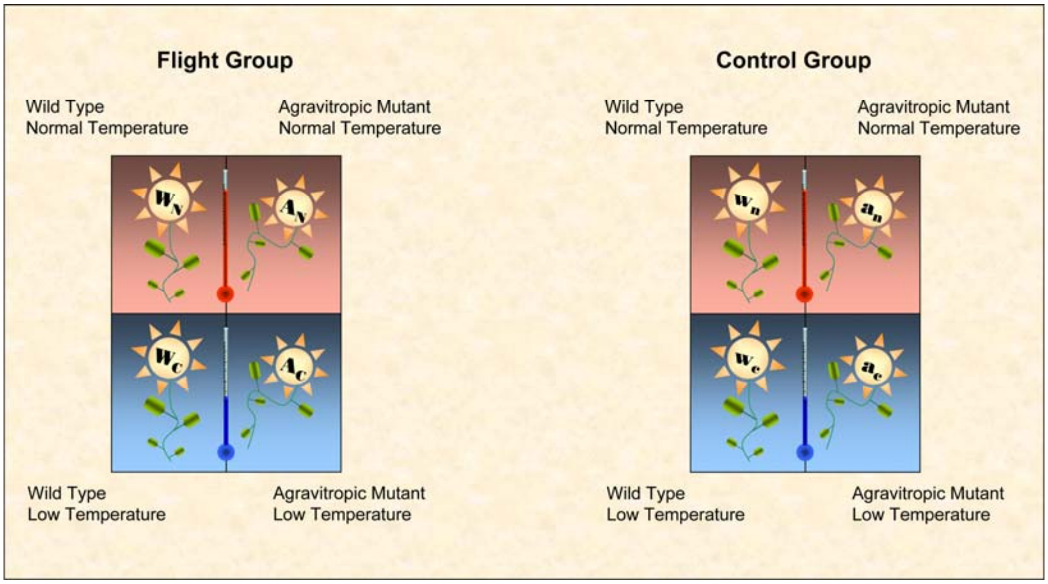


Figure 13: Experimental and control groups: Our experiment rests mainly on comparing cold-treated wild-type plants (data set W_C) and ambient agravitropic plants (data set A_N).

Process Procedures

- Plate plants using aseptic technique two weeks prior to launch.
- Refrigerate plants in the cold-treated group one day before the launch.
- At launch site, plants will be integrated into the payload bay, as described
- in our integration plan.
- Rocket will be launched and plants will be subjected to acute acceleratory
- forces up to 40g.
- Immediately after launch, all plants to be used for RNA extraction will be
- terminated by being placed on dry ice.
- Upon our arrival in Madison, data analysis will begin.
  - We will perform RNA extraction and use RT-PCR to analyze our selected genes.
  - The plants from one plate in each group will be transferred to soil and compared to our control plants to detect any abnormal growth.

- We will use semiquantitative data analysis to display and summarize the RT-PCR results.

Safety and Environment

Safety Officer

Liz Sinclair will act as Safety Officer for the payload team.

Failure Modes

See updated risk/mitigation table in vehicle safety section.