PRELIMINARY DESIGN REVIEW

Study of Damping Efficiency of Various Liquids

NASA Student Launch for Middle and High School

Madison West High School | ***New Team*** | **November 3rd of 2017**

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

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Summary of PDR Report

Team

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Launch Vehicle Summary

Size and Mass: 93" x 4", 15.1*lbs* liftoff weight

Motor Choice: Aerotech K1103X, 54mm

Recovery System: 18" drogue at apogee, 84" main at 700*ft AGL*, PerfectFlite Stratologger CF

Flysheet: http://www.westrocketry.com/sli2018/MSRFS_PDR_MadisonWest2018_LiquidVibrations.pdf

Payload Summary

Payload Title: Study of Damping Efficiency of Various Liquids

Summary of Payload Experiment: The payload is designed to investigate damping effects of various liquids on inn-flight vibrations. Six different liquids will be studied, each with different viscosity and properties. An overall effectiveness in damping the vibration as a function of liquid viscosity and its properties will be measured. The payload uses triaxial ADXL-345 accelerometers to measure vibrations and a BlueTooth network of Raspberry-Pi Zero-W computers to record the experimental data. Most of the payload structural system is 3D-printed from PLA.

Changes since Statement of Work

Changes in Document

- Updated document structure from *Statemement of Work* to *Preliminary Designed Review*, as described in NASA Student Launch Handbook for Middle and High Schools
- Removed *Community Engagement* section
- Removed *Rocket Program Sustainability* section
- Removed *section 508 Compliance* section
- Removed team member information (list of team members and their resumes)
- Removed *NAR Safety codes* section
- Removed list of applicable MSDS

Changes in Vehicle Criteria

- Added vehicle component tree
- Added vehicle verification tests
- Added vehicle verification matrix

Changes in Payload Criteria

- Added vehicle component tree
- Added vehicle verification tests
- Added vehicle verification matrix

Changes in Project Plan

- Completed outreach event at Plasma Expo, October 27th (report pending)
- Completed outreach event at Boy Scout Troop #302 (report pending)

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 inaccessible. 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 a 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 their 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:**
  - ***Construction falls behind the schedule:*** a significant amount of 3D printing will be necessary to build the payload. Currently we have three functional 3D printers capable of printing parts of this payload and the printing will commence as soon as the payload design is finalized to provide a sufficient time for the production of all payload parts.

- **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 issued by their range personnel and our mentors.

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 ground 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/sli2018/safety/safety2018h.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 shall be carried out before the rocket 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 shall not be allowed to launch their rocket.

Technical Design

Vehicle

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 damping efficiency of various liquids in suppressing the vibrations induced by the rocket flight.

The rocket will be constructed from fiberglass tubing, using sandwiched 1/8” G10 fiberglass fins. The rocket will be robust enough to endure 35+*g* of acceleration and high power rocket flight and deployment stresses.

To have a successful mission the rocket must reach (but not exceed) altitude of one mile AGL and the payload must record all data necessary for our experiment. The rocket will be 93*in* long, with a 4.0*in* diameter. It has estimated liftoff mass of 15.1*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 K1103X, 54*mm*) with total impulse of 1789*Ns*. The vehicle can launch from a standard size, 8*ft* launch rail.

The rocket will use dual deployment to minimize drift.

Dimensions

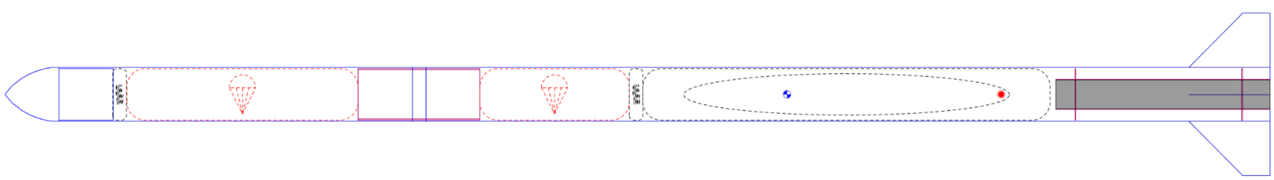

Figure 1: A two dimensional schematic of the entire rocket

Length *[in]*	Mass *[lbs]*	Diameter *[in]*	Motor Selection	Stability Margin *[calibers]*	Thrust to weight ratio
93	15.1	4.0	K1103X	3.94	26.1

Table 1: Vehicle parameters

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 CF altimeters.

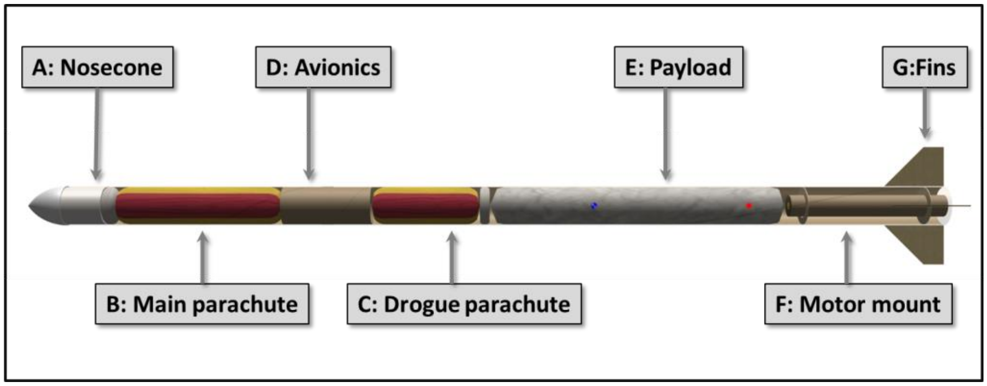

Figure 2: A three dimensional schematic of the entire rocket

	Key
(A)	Nosecone
(B)	Main parachute
(C)	Drogue parachute
(D)	Avionics
(E)	Payload
(F)	Motor mount (54mm)
(G)	1/8" G10 Fiberglass fins

Table 2: Rocket parts and compartments

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

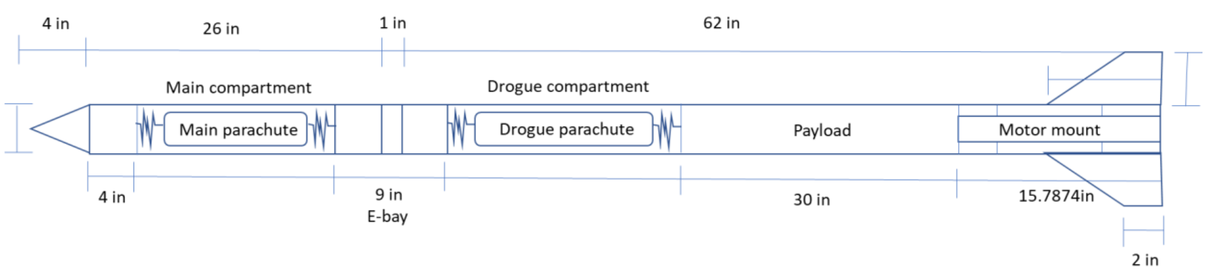

Figure 3: Dimensioned drawing of the vehicle

Material Selection

We have decided to used fiberglass for most of the materials for the rocket. Fiberglass can be precisely machined, has the desired strength to weight ratio and can be easily finished. Because we are using 4" diameter vehicle, we will have sufficient total impulse to deliver the rocket to 1 mile of altitude using a K-class motor.

Rocket Part	Material
Nosecone	3D printed PLA plastic, Von Karman shape
Tubing	Fiberglass tubing, 4” diameter
Fins	1/8” G10 fiberglass
Parachutes	Ripstop Nylon
Couplers	Fiberglass 4” couplers
Motor Mount	Fiberglass 54*mm* tubing
Centering Rings	1/8” fiberglass
Anchors	¼” stainless steel U-bolts
Tie-rods	#10/24 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 rocket will be all-fiberglass construction, including bulkheads and centering rings. 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.

Performance Predictions

All performance predictions were made using OpenRocket v15.03.

Altitude Profile

The graph below shows the simulated flight profile for the Aerotech (AT) K1103X motor. The vehicle reaches the apogee of 5,427*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 105*s* and the drift under 15*mph* wind conditions is 1,948*ft.*

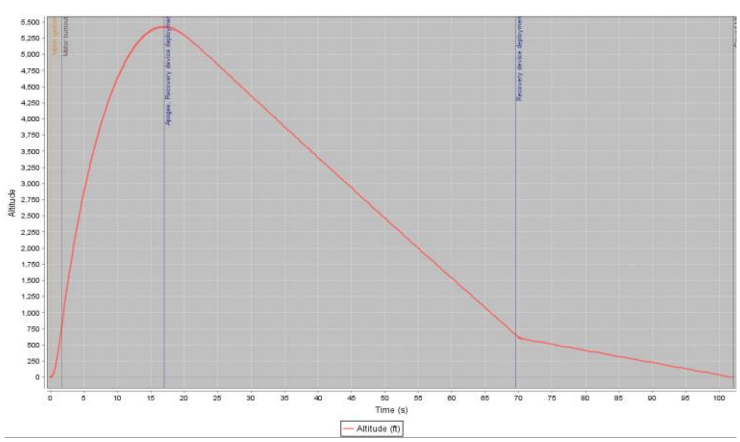

Figure 4: Altitude over Time Graph

The simulations indicate a small (2.8%) overshoot 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 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 1.25% from the apogee reached in windless conditions.

Wind Speed *[mph]*	Altitude *[ft]*	Percent Change In Apogee
0	5427	0.00
5	5420	0.13
10	5406	0.39
15	5387	0.74
20	5361	1.22

Table 4: Apogee vs. wind speed

Thrust Profile

The graph below shows the thrust profile for the AT K1103X motor. The AT K1103X motor reaches its maximum thrust of 1600*N* after 0.02*s* and burns at approximately constant thrust level for about 1.5*s* (the average thrust-to-weight ratio is 16.08, maximum thrust-to-weight-ratio is 26.1). The rocket requires an eight-foot rail for sufficient stability on the pad and leaves the 8*ft* rail at about 103*ft/s* (70.2*mph*).

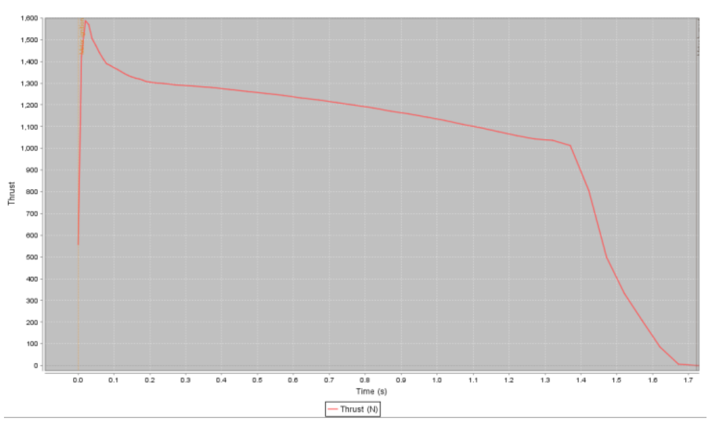

Figure 5: Thrust (N) vs Time.

Velocity Profile

According to the velocity profile (next graph), the rocket will reach maximum velocity of 800*fps* (545*mph*) shortly before the burnout (1.6*s*). The rocket remains subsonic for the entire duration of its flight.

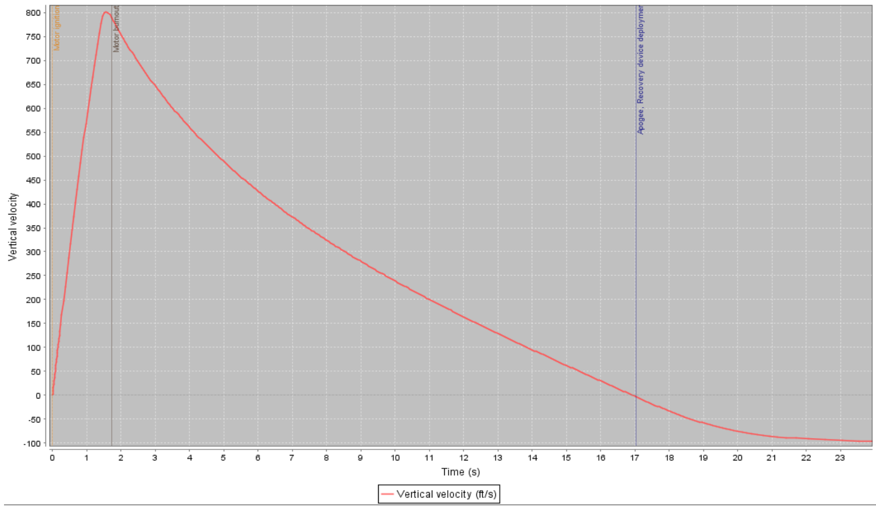

Figure 6: Vertical Velocity (mph) vs Time

Acceleration Profile

The graph below shows that the rocket will experience maximum acceleration of about 23.2*g* (745ft/s^2). Our rocket will be robust enough to endure the 30*g*+ acceleration shocks.

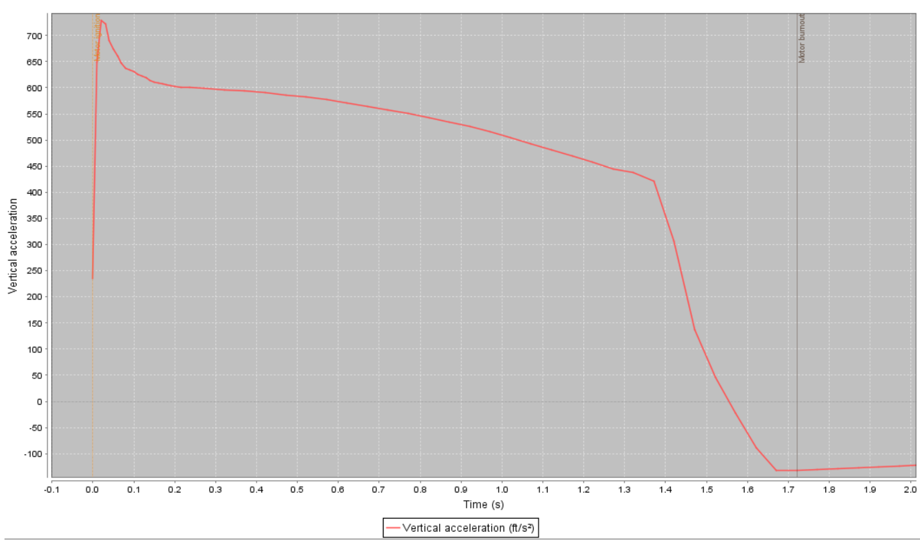

Figure 7: Vertical Acceleration vs Time

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.

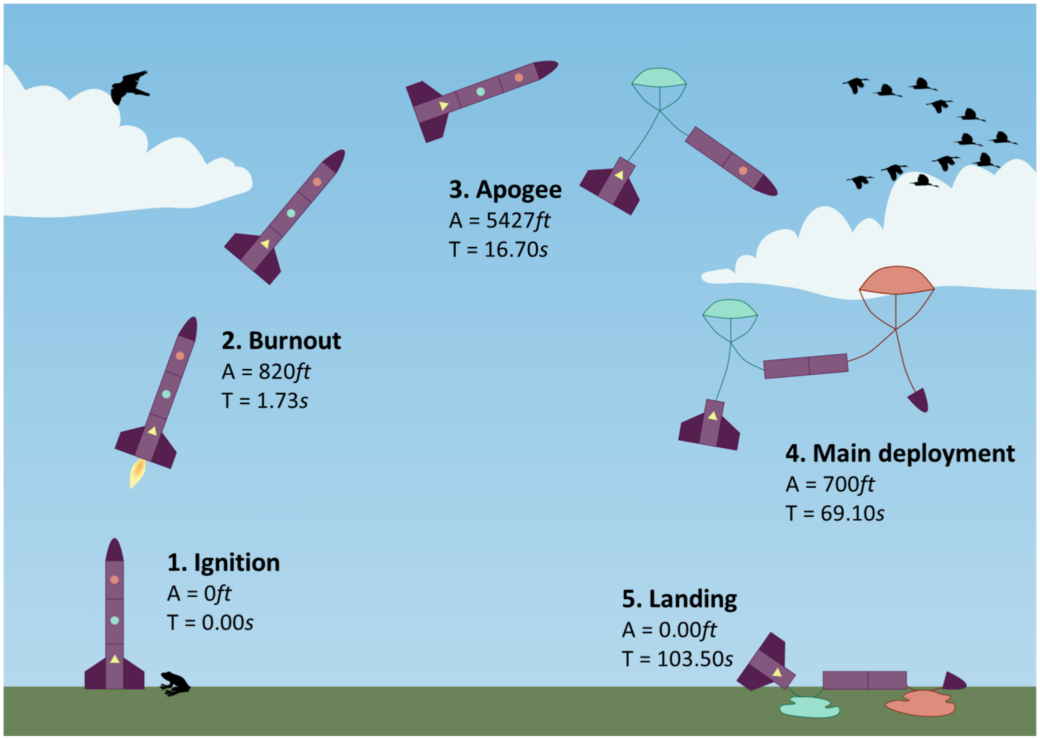

Figure 8: Mission profile chart

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

#	Event	Time [s]	Altitude [ft]	Trigger
1	*Ignition/Boost*	*0.00*	*0*	*Launch Controller*
2	*Burnout*	*1.73*	*820*	
3	*Apogee/Separation*	*16.70*	*5427*	*Altimeter*
4	*Vehicle Drogue Deployment*	*16.70*	*5427*	*Altimeter*
5	*Vehicle Main Deployment*	*69.10*	*700*	*Altimeter*
6	*Vehicle Landing*	*103.50*	*0*	

Table 5: 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).

Parachute System Design

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	18	88.6	1.38	5427	0.33	2.6%	79.05
					2.90	22.8%	353.49
					9.48	74.6%	1119.38
Main	84	19.9	1.89	700	0.33	2.6%	1.99
					2.90	22.8%	17.95
					9.48	74.6%	58.82

Table 6: Parachute parameters: The rocket recovers in three sections, nosecone (2.6% of total weight), upper section (22.8% of total weight) and booster section (74.6% 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 12.71*lbs*.

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 20*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	667	0.126
10	1302	0.247
15	1948	0.371
20	2587	0.490

Table 7: Drift predictions

Propulsion Selection

Based on the results of computer simulations we have selected AT K1103X (54*mm*) motor as our primary propulsion choice. Our backup is CTI K740 54*mm* 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 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 1103X	54	1789	1.6	3.94	26.1
AT K740	54	1874	2.5	3.94	12.9

Table 8: Propulsion alternatives

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.

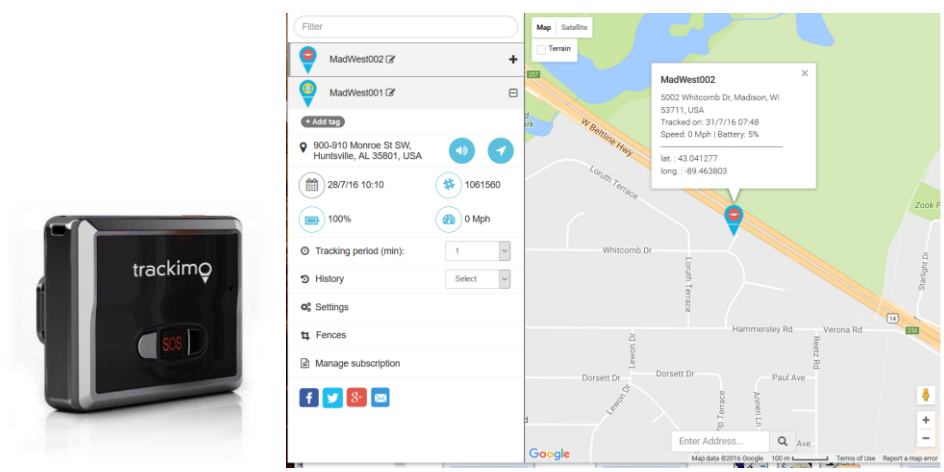

Figure 9: Trackimo tracker and a screenshot from Trackimo app

Vehicle Verification

The following picture shows the hierarchical breakdown of components that our vehicle consists of.

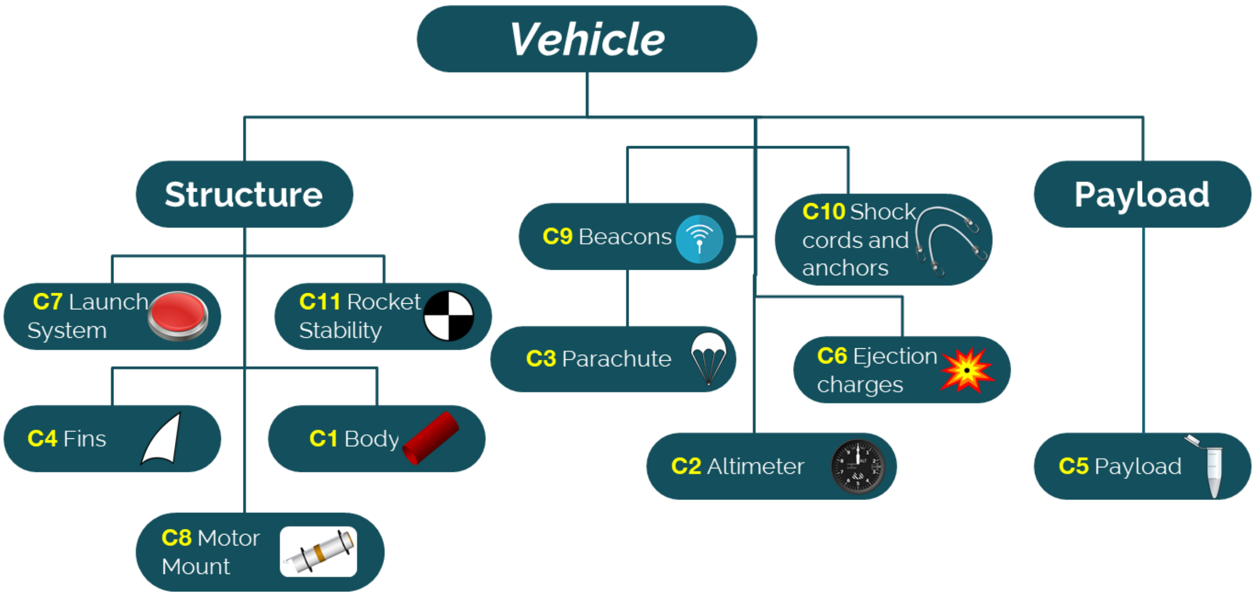

Figure 10: Vehicle component tree

We have selected the following tests that selected vehicle components will be subjected to during vehicle verification process.

- **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:** these that the deployment charges have the right amount of force to cause the 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 snugly into the vehicle, and is robust enough to withstand flight stresses.

Finally, the verification matrix indicates which test will be applied to which vehicle and which project requirement will be satisfied by successful completion of such test.

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
C1	2.16			3.5				3.2		2.6
C2				3.5	2.9	2.2				
C3	2.16	2.16	3.2	3.5				3.2		
C4	2.16			3.5						
C5	2.16				2.9					2.6
C6				3.5	2.9		3.1	3.2		
C7	2.16			3.5						
C8	2.16			3.5						
C9	2.16			3.5	2.9					
C10				3.5				3.2		
C11				3.5	2.9			3.2	2.1	

Legend
Planned
Completed

Table 9: Vehicle verification matrix

The red entries indicate test planned but not yet carried out, while the completed test will be indicated by green color. As of now the verification process has not begun.

Payload

Motivation

Vibrations produced by thrust oscillations are a serious issue during the initial phase of a space flight. These vibrations are capable of damaging parts of the vehicle, endangering both the crew and the cargo. There are already several established methods used to damp the vibrations, one of the methods is the use of liquids dampers. Our project will examine how different liquids affect vibrations an aerospace vehicle experiences during flight. We have selected six different liquids, each with different viscosity and behavioral characteristics.

Objective

The objective of this project is to analyze how different liquids dampen the vibrations produced by a rocket in flight. Six different liquids, each representing a different class of liquid response to stress were chosen for this study.

Hypothesis

Viscosity is the resistance of fluid against flow. It is established as the property of fluid quantifying friction between molecular layers in a body of fluid. More viscous liquids need more force to flow or change shape and thus may be better vibration dampers. Based on their properties (in addition to viscosity), we have selected six (6) different types of liquids to study:

Symbol	Liquid/Viscosity	Type	Behavior
	HONEY η = 10,000 [cP]	***Thixotropic***	*The longer the stress, the lower the viscosity*
	CREAM η = 21 [cP]	***Rheopectic***	*The longer the stress, the higher the viscosity*
	KETCHUP η = 50,000 [cP]	***Shear thinning***	*The higher the stress, the lower the viscosity*
	OOBLECK η = 20,000 [cP]	***Shear thickening***	*The higher the stress, the higher the viscosity*
	WATER η = 1 [cP]	***Newtonian***	*Neither the duration or the intensity of the stress changes viscosity*
	MAYONNAISE η = 2,000 [cP]	***Bingham plastic***	*Acts as a solid under low stress, as a liquid under high stress*

Table 10: Liquids selected for the study

The behavioral traits and expected response to vibrations for each liquid are summarized in the illustrations bellow:

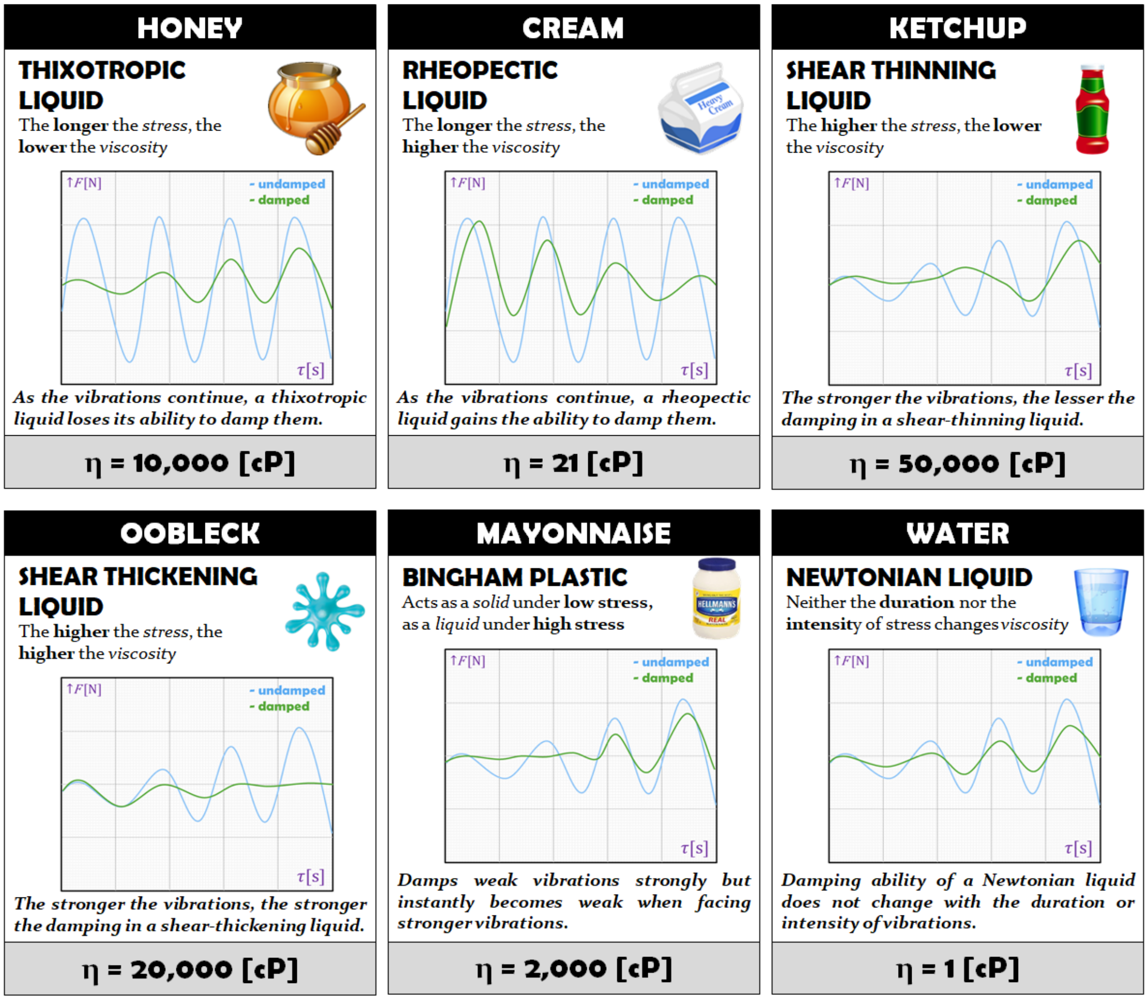

Figure 11: Behavioral traits and expected response to vibrations, for each of the selected liquids. The blue line in each graph shows undamped vibrations and the green depicts the expected dampening of the vibrations.

Since viscosity is the measure of liquid's resistance to deformation, we hypothesize that the higher viscosity liquids will absorb more energy from vibrations, thereby increasing damping effectiveness. Further, the properties of each liquid will determine how the damping of vibrations will change with intensity and duration of vibrations as shown in the following table:

Liquid	Viscosity	Expected Response to different vibrations types			
Type	*[cP]*	*Weak*	*Strong*	*Initial*	*Lasting*
Water *Newtonian*	1	POOR	POOR	POOR	POOR
Honey *Thixotropic*	10,000	GOOD	GOOD	GOOD	DECLINING
Cream *Rheopectic*	21	SOME	SOME	SOME	IMPROVING
Ketchup *Shear thinning*	50,000	GOOD	POOR	*Will depend on vibration strength*	*Will depend on vibration strength*
Oobleck *Shear thickening*	20,000	POOR	GOOD	*Will depend on vibration strength*	*Will depend on vibration strength*
Mayonnaise *Bingham plastic*	2,000	GOOD	POOR	*Will depend on vibration strength*	*Will depend on vibration strength*

Table 11: Tabulated hypothesis summary

- **Water** with its low viscosity is expected to dampen vibrations poorly. Furthermore, due to its Newtonian properties, neither duration nor intensity of the vibrations will change its viscosity. Therefore this liquid is expected to dampen the same amount of vibrations regardless of the type and strength of vibration.
- **Honey**, with its high viscosity and thixotropic nature is expected to dampen weak, strong, and short lasting vibrations well. However, the damping effectiveness of honey is expected to decline during lasting vibrations due to its decrease in viscosity under prolonged stress.
- **Cream** is expected to perform as a mediocre damper because of its somewhat low viscosity. However, due to its rheopectic nature, it is expected to improve its damping effectiveness during lasting vibrations.
- **Ketchup**, with its high viscosity and shear thinning properties is expected to do well with weak vibrations. However, as the vibrations become stronger, the viscosity is expected to decrease and the damping effectiveness will deteriorate.
- **Oobleck** is expected to do the opposite of ketchup; do poorly in weak vibrations and become more viscous and better at damping during strong vibrations.
- **Mayonnaise** is expected to perform similarly to ketchup. Weak vibrations will be damped well but strong vibrations will see a decrease in damping effectiveness. However, since Bingham plastics act as a solid under low stresses the damping effectiveness is expected to be significantly different from its shear thinning counterpart.

Payload Design and Experimental Setup

To measure the vibrations, a three-axis accelerometer (LIS331) submerged in a body of liquid will be used. To protect the accelerometers from malfunction, a sealed dry container will be used to house each of the accelerometers. In order to capture both low frequency and high frequency vibrations, acceleration in all three directions will be sampled at least 200 times per second. The data from each accelerometer are transferred to the collecting computer via insulated wires.

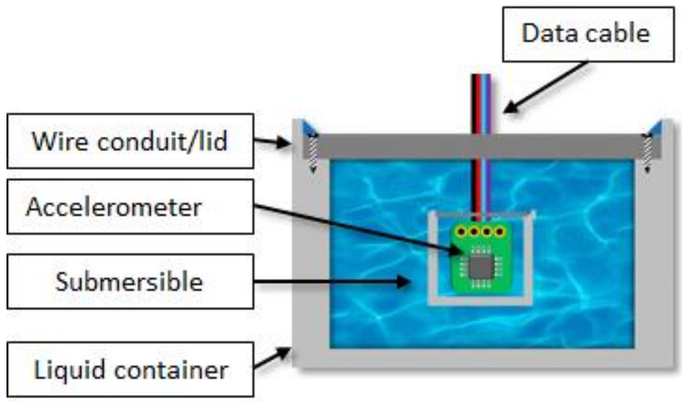

Figure 12: Payload module for measuring vibrations in a liquid

Data	Data Record Size	Sampling Frequency	Total Memory (120*s* flight, apogee at 20*s*)
Acceleration	X: 2 bytes Y: 2 bytes Z: 2 bytes Total: 6 bytes	200*Hz*	144*KB*

Table 12: Data sampling frequency and memory consumption

The following table lists the electronic instruments that we will use to build our payload.

Instrument	Quantity	Measurement	Unit	Sampling Frequency
LIS331 triaxial accelerometer	6	X-acceleration Y-acceleration Z-acceleration	*g* *g* *g*	200*Hz* min. 200*Hz* min. 200*Hz* min
Raspberry Pi ZeroW	3	Data collection	N/A	N/A

Table 13: Payload instrument and their roles

Payload Units and Assembly

A 3D model of a single payload unit (design to house one liquid sample) is shown on the following figure.

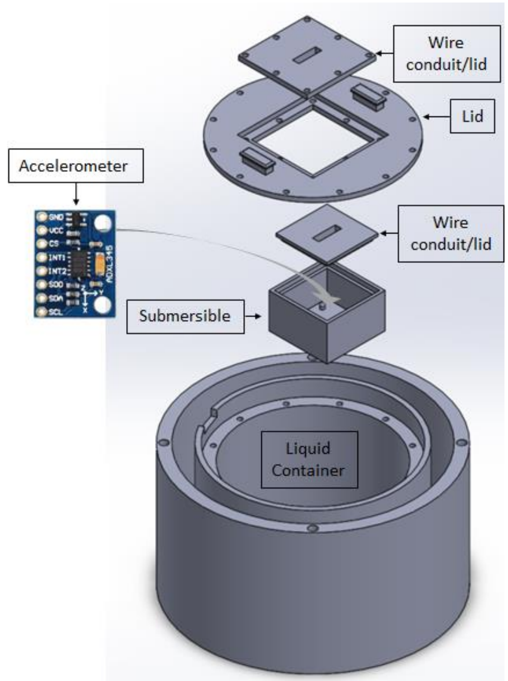

Figure 13: 3D model of a single payload unit. The payload unit consists from a container to hold the studied and liquid and submersible module to hold the accelerometer. The entire unit must completely leak-proof.

The data from each of the accelerometers are collected using Raspberry Pi Zero-W computer. Each Raspberry Pi can service two payload modules (collect data from two accelerometers). We have selected Raspberry Pi Zero-W as our data collecting computer for its wireless and Blue-tooth capabilities, which will be used to synchronize the operation of all payload modules and to make the data extraction after the flight easier.

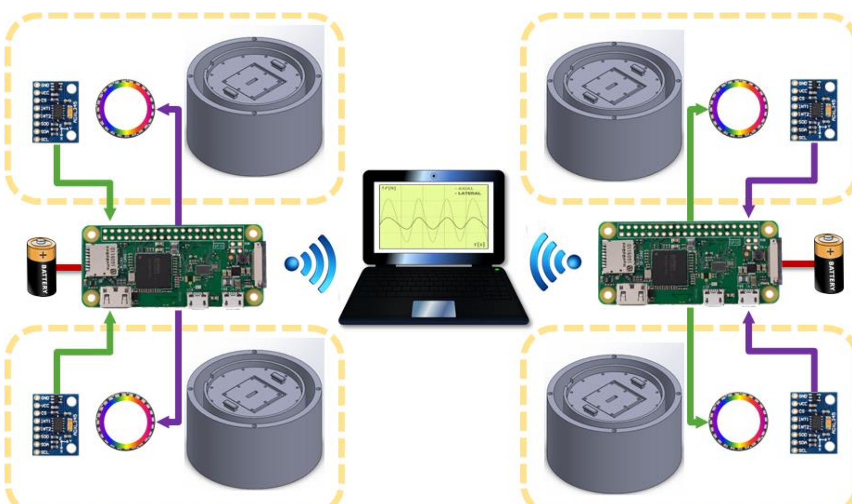

Figure 14: Data collection and payload modules synchronization (only 4 of 6 planned payload modules are shown)

Experimental Sequence

The following illustration shows our experimental sequence:

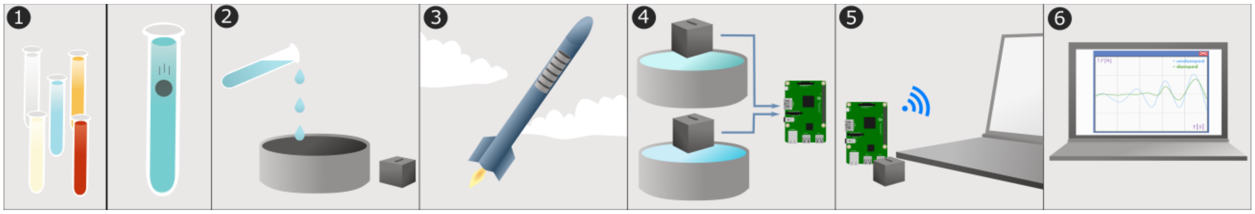

Figure 15: Experimental sequence

1. Viscosity of the liquids is measured in the lab using a *viscometer*.
2. The payload modules are filled with the liquids and the submersible accelerometer modules are inserted and connected. The payload is fully assembled and tested for leaks.
3. The payload is launched inside a rocket, travelling to an altitude of 1 mile.
4. During the entire flight, the accelerometers measure acceleration in all three directions, sampling at 200*Hz*.
5. After the flight the data from the payload are downloaded over the Bluetooth link.
6. The data are analyzed as described in the following section.

Data Analysis

The data analysis is outlined in the chart below. For each liquid we will compute the total amount of vibrations observed, using the data collected by the accelerometers. We expect that the water will have the poorest vibration damping efficiency and we will compare all other liquids using water as a baseline.

For the purpose of our experiment, we define damping factor Φ as the total amount of vibrations observed in each of the studied liquids, normalized by the amount of vibrations observed in the water. Φ values under 1.00 mean that a given liquid is a better vibration damper than water, values over 1.00 mean that a given liquid is worse at vibration damping than water. The liquid with smallest Φ value is the best vibration damper.

Independent Variables:

- η __________ viscosity
- T __________ liquid type
- τ __________ time

Dependent Variables:

- a_A __________ axial acceleration
- a_L __________ lateral acceleration

Total Impulse from Vibrations:
(total amount of energy measured in vibrations from ignition to apogee)

$$\theta = \int_{\tau=0}^{\tau=\tau_{apogee}} m \cdot (a_A + a_L) \cdot d\tau$$

Damping Factor:
(total vibration impulse measured in liquid of type T compared to reference liquid (H_2O))

$$\Phi = \frac{\theta_T}{\theta_{H_2O}}$$

Correlation Measured:

- $\Phi = f(T)$ __________ damping factor as function of liquid type

Figure 16: Summary chart of data analysis

Payload Verification

The following picture shows the hierarchical breakdown of components that our vehicle consists of.

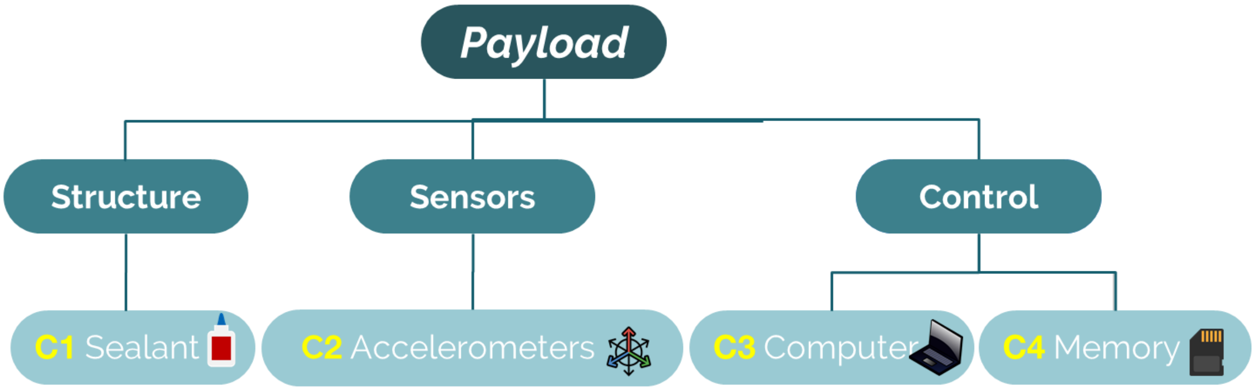

Figure 17: Payload component tree

We have selected the following tests that selected vehicle components will be subjected to during vehicle verification process.

- **V1** ***Functionality test:*** of basic functionality of a device on the ground
- **V2** ***Robustness test:*** test of structural integrity when exposed to forces equal to those in 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

Finally, the verification matrix indicates which test will be applied to which vehicle and which project requirement will be satisfied by successful completion of such test.

	V1	V2	V3	V4	V5	V6	V7	V8
C1 sealent	4.2	4.2, 4.5						
C2 accelerometers	4.2	4.2, 4.5	4.2		4.2	4.2	4.2	4.2
C3 computer	4.2	4.2, 4.5	4.2	4.2	4.2	4.2	4.2	4.2
C4 memory	4.2	4.2, 4.5	4.2		4.2	4.2	4.2	4.2

Planned tests
Completed tests

Table 14: Payload verification matrix

The red entries indicate test planned but not yet carried out, while the completed test will be indicated by green color. As of now the verification process has not begun.

Project Requirements

1. General Requirements

1.1. Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done bythe team's mentor). Students will do 100% of work on the project, write the documentation and presentations and present the project during teleconferences. Dr. Pavel Pinkas is the Level 2 mentors for the team and he will handle all motor and ejection charge assembly.

1.2. The team will 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.

1.3. Foreign National (FN) team members must be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during launch week due to security restrictions. In addition, FN's may be separated from their team during these activities. The list of foreign nationals will be provided to NASA by PDR teleconference.

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

1.4.1. Students actively engaged in the project throughout the entire year. All ten team members are identified in the Student Participants section near the beginning of this document.

1.4.2. One mentor (see requirement 1.14). Dr. Pavel Pinkas is the mentor for the team.

1.4.3. No more than two adult educators. Ms. Christine Hager and Dr. Rob Williamson are the team's educators.

1.5. The team will engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics (STEM) activities, as defined in the Educational Engagement Activity Report, by FRR. An educational engagement activity report will be completed and submitted within two weeks after completion of an event. A sample of the educational engagement activity report can be found on page 30 of the handbook. To satisfy this requirement, all events must occur between project acceptance and the FRR due date. Our education engagements plan includes 10000 students from local elementary and middle schools and members of general public. 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.

1.6. **The team will develop and host a Web site for project documentation.** The WEB presence for the team will be developed on schedule and updated throughout the entire project.

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

1.8. **All deliverables must be in PDF format.** All deliverables will be in PDF format.

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

1.10. **In every report, the team will include the page number at the bottom of the page.** Page numbers will be included at the bottom of each page in all reports.

1.11. **The team will provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and a broadband Internet connection. Cellular phones can be used for speakerphone capability only as a last resort.** We will be using fully equipped teleconference rooms in Engineering Hall at UW Madison.

1.12. **All teams will be required to use the launch pads provided by Student Launch's launch service provider. No custom pads will be permitted on the launch field. Launch services will have 8 ft. 1010 rails, and 8 and 12 ft. 1515 rails available for use.** We will use the launch pads provided by Student Launch's launch service provider. We will need an 8*ft*, 1010 rail for this project.

1.13. **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 the required paragraphs of Section 508, details of our compliance are described earlier in this document.

1.14. Each team must identify a "mentor." A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with the school, institution, or organization. The mentor must maintain a current certification, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle and must 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 launch week. One travel stipend will be provided per mentor regardless of the number of teams he or she supports. The stipend will only be provided if the team passes FRR and the team and mentor 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.

2. Vehicle Requirements

2.1. The vehicle will deliver the payload to an apogee altitude of 5,280 feet above ground level (AGL). The current simulation predicts that the rocket will reach 5,146*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.

2.2. The vehicle will 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 5280 feet AGL. The team will lose one point for every foot above or below the required altitude. 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.

2.3. Each altimeter will 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.

2.4. **Each altimeter will 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.

2.5. **Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).** 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.

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

2.7. **The launch vehicle will 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).

2.8. **The launch vehicle will be limited to a single stage.** The launch vehicle is a single stage rocket.

2.9. **The launch vehicle will be capable of being prepared for flight at the launch site within 3 hours of 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.

2.10. **The launch vehicle will 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 components.** 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.

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

2.12. The launch vehicle will 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.

2.13. The launch vehicle will 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 K1103X 54*mm* motor is the primary propulsion choice.

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

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

2.14. Pressure vessels on the vehicle will be approved by the RSO and will meet the following criteria: Not applicable.

2.14.1. The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews. Not applicable.

2.14.2. Each pressure vessel will include a pressure relief valve that sees the full pressure of the valve that is capable of withstanding the maximum pressure and flow rate of the tank. Not applicable.

2.14.3. Full pedigree of the tank will be described, including the application for which the tank was designed, and the history of the tank, including the number of pressure cycles put on the tank, by whom, and when. Not applicable.

2.15. The total impulse provided by a Middle and/or High School launch vehicle will 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 1789*Ns*.

2.16. The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail. The vehicle stability margin is predicted as 3.94 calibers at liftoff.

2.17. The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit. The predicted rail exit velocity is 102*fps*.

2.18. All teams will successfully launch and recover a subscale model of their rocket prior to CDR. Subscales are not required to be high power rockets. 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.

2.18.1. The subscale model should resemble and perform as similarly as possible to the full-scale model, however, the full-scale will not be used as the subscale model. The subscale model will half-size model of the full scale vehicle. The stability margin will be same and the same deployment scheme will be used.

2.18.2. The subscale model will carry an altimeter capable of reporting the model's apogee altitude. The subscale model will be equipped by the same altimeter brand as the full scale vehicle (PerfectFlite StratoLogger CF).

2.19. All teams will successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown at FRR must be the same rocket to be flown on launch day. The purpose of the full-scale demonstration flight is to demonstrate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at a lower altitude, functioning tracking devices, etc.). The following criteria must be met during the full-scale demonstration flight:

2.19.1. The vehicle and recovery system will have functioned as designed. The vehicle recovery system will be operated in full configuration on all planned test flight.

2.19.2. 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.

2.19.2.1. If the payload is not flown, mass simulators will be used to simulate the payload mass. Before the payload is ready for flight, payload will be simulated by mass simulators during test flights.

2.19.2.1.1. **The mass simulators will 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.

2.19.3. **If the payload changes the external surfaces of the rocket (such as with camera housings or external probes) or manages the total energy of the vehicle, those systems will 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.

2.19.4. **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 simulates, as closely as possible, the predicted maximum velocity and maximum acceleration of the launch day 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.

2.19.5. **The vehicle must 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. Additional ballast may not be added without a re-flight of the full-scale launch vehicle.** The vehicle will be fully ballasted (if ballast is necessary) for the final full scale test flight.

2.19.6. **After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components will 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.

2.19.7. **Full scale flights must be completed by the start of FRRs (March 6th, 2018). If the Student Launch office determines that a re-flight is necessary, then an extension to March 28th, 2018 will be granted. This extension is only valid for re-flights; not first-time flights.** The full scale flight tests will be complete by March 6th of 2018.

2.20. **Any structural protuberance on the rocket will be located aft of the burnout center of gravity.** There are no structural protuberances on the rocket.

2.21. **Vehicle Prohibitions**

2.21.1. The launch vehicle will not utilize forward canards. The vehicle does not have forward canards.

2.21.2. The launch vehicle will not utilize forward firing motors. The vehicle does not utilize forward firing motors.

2.21.3. The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.) The vehicle does not utilize motors expelling titanium sponges.

2.21.4. The launch vehicle will not utilize hybrid motors. Hybrid motors are not used.

2.21.5. The launch vehicle will not utilize a cluster of motors. Clustered motors are not used.

2.21.6. The launch vehicle will not utilize friction fitting for motors. A flange mounted, thread secured motor retention system is used.

2.21.7. The launch vehicle will not exceed Mach 1 at any point during flight. The vehicle remains subsonic during entire flight. The maximum predicted velocity is 545*mph*.

2.21.8. Vehicle ballast will not exceed 10% of the total weight of the rocket. The ballast (if used) will not exceed 10% of the vehicle weight.

3. Recovery System Requirements

3.1. The launch vehicle will stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a lower altitude. Tumble 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 RSO. 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.

3.2. 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.

3.3. At landing, each independent sections of the launch vehicle will 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*.

3.4. The recovery system electrical circuits will be completely independent of any payload electrical circuits. This performance target is a standard requirement for all Madison West projects and will be satisfied.

3.5. **All recovery electronics will be powered by commercially available batteries.** All recovery electronics will be powered by 9V Duracell batteries. Batteries are installed fresh and only used for one flight.

3.6. **The recovery system will 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.

3.7. **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.

3.8. **Removable shear pins will 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.

3.9. **Recovery area will be limited to a 2500 ft. radius from the launch pads.** The rocket will remain within the confines of the launch area even under 20*mph* wind-speed conditions.

3.10. **An electronic tracking device will be installed in the launch vehicle and will 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.

3.10.1. **Any rocket section, or payload component, which lands untethered to the launch vehicle, will also carry an active electronic tracking device.** Target satisfied with 3.10.

3.10.2. **The electronic tracking device will 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.

3.11. **The recovery system electronics will 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.

3.11.1. **The recovery system altimeters will 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.

3.11.2. **The recovery system electronics will 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.

3.11.3. **The recovery system electronics will 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.

3.11.4. **The recovery system electronics will 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.

4. Experiment Requirements

4.1. **The launch vehicle will carry a science or engineering payload. The payload may be of the team's discretion, but must 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 designed to investigate the efficiency of various liquid in damping vibrations. Our payload is described in detail earlier in this document. We will comply with all NASA requests for changes (if applicable).

4.2. **Data from the science or engineering payload will 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.

4.3. **Unmanned aerial vehicle (UAV) payloads of any type will 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.

4.4. Any payload element that is jettisoned during the recovery phase, or after the launch vehicle lands, will receive real-time RSO permission prior to initiating the jettison event. Not applicable.

4.5. The payload must 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 4 hours).

5. Safety Requirements

5.1. Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any 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.

5.2. Each team must identify a student safety officer who will be responsible for all items in section 5.3. Joshua is the team's safety officer.

5.3. The role and responsibilities of each safety officer will include, but not limited to:

5.3.1. Monitor team activities with an emphasis on Safety during:
5.3.1.1. Design of vehicle and payload
5.3.1.2. Construction of vehicle and payload
5.3.1.3. Assembly of vehicle and payload
5.3.1.4. Ground testing of vehicle and payload
5.3.1.5. Sub-scale launch test(s)
5.3.1.6. Full-scale launch test(s)
5.3.1.7. Launch day
5.3.1.8. Recovery activities
5.3.1.9. Educational Engagement Activities

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

5.3.2. **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.

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

5.3.4. **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.

5.4. **During test flights, teams will 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 Student Launch Initiative does not give explicit or implicit authority for teams to fly those certain vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.** The team's intentions are communicated to the host organization prior each launch. The team will abide by the launch rules set by the host organization.

5.5. Teams will abide by all rules set forth by the FAA. All FAA rules are strictly followed during all our activities.

Project Plan

Development Schedule

Timeline

	School
	SLI writing sessions
	Organizational meeting
	Workshop
	Fundraising
	Test launch
	Outreach
	SLI Event Dates

Table 15: Color code for timeline

AUGUST	
Saturday 26	SLI writing session
SEPTEMBER	
Saturday 2	SLI writing session
Wednesday 6	School starts
Friday 8	Workshop
Saturday 9	SLI writing session
Monday 11	Organizational meeting
Friday 15	Workshop
Saturday 16	SLI writing session
Monday 18	Organizational meeting
Wednesday 20	SOW due by 5:00 p.m.
Friday 22	Workshop
Saturday 23	SLI writing session
Monday 25	Organizational meeting
Friday 29	Workshop
Saturday 30	SLI writing session
OCTOBER	
Monday 2	Organizational meeting
Thursday 5	Outreach with Boyscouts
Friday 6	Workshop
Friday 6	Accepted Proposals Announced
Saturday 7	SLI writing session
Monday 9	Organizational meeting
Thursday 12	Kickoff and Preliminary Design Review (PDR) Q&A
Friday 13	Randall Elementary Outreach
Friday 13	Workshop
Saturday 14	SLI writing session
Sunday 15	Fundraising
Monday 16	Organizational meeting
Friday 20	Workshop

Saturday21-22	Wisconsin science festival
Saturday 21	SLI writing session
Sunday 22	Fundraising
Monday 23	Organizational meeting
Friday 27	NO SCHOOL
Friday 27	Workshop
Saturday 28	SLI writing session
Sunday 29	Fundraising
Monday 30	Organizational meeting
NOVEMBER	
Friday 3	Workshop
Friday 3	PDR Due by 8:00 a.m.
Saturday 4	SLI writing session
Saturday 4	The stars above
Saturday 4	SAT TESTING
Sunday 5	Fundraising
Monday 6	Organizational meeting
Monday 6-Wednesday 29	PDR Video Teleconferences
Friday 10	Workshop
Saturday 11	SLI writing session
Sunday 12	Fundraising
Monday 13	Organizational meeting
Tuesday 14	Mt. Horeb Girl scouts
Friday 17	Workshop
Saturday 18	SLI writing session
Sunday 19	Fundraising
Monday 20	Organizational meeting
Wednesday 22- Friday 24	NO SCHOOL
Saturday 25	SLI writing session
Sunday 26	Fundraising
Monday 27	Organizational meeting
DECEMBER	
Friday 1	Workshop
Saturday 2	SLI writing session
Sunday 3	Fundraising
Monday 4	Organizational meeting
Wednesday 6	Critical Design Review (CDR) Q&A
Friday 8	NO SCHOOL
Friday 8	Workshop
Saturday 9	SLI writing session
Monday 11	Organizational meeting
Friday 15	Workshop
Saturday 16	SLI writing session
Monday 18	Organizational meeting
Friday 22- Tuesday, Jan 2nd	WINTER BREAK
JANUARY	

Friday 5	Workshop
Saturday 6	SLI writing session
Monday 8	Organizational meeting
Friday 12	Workshop
Friday 12	CDR due by 8:00 a.m.
Saturday 13	SLI writing session
Sunday 14	Scale model flight
Monday 15	No school
Tuesday 16 - Wednesday 31	CDR Video Teleconferences
Friday 19	Workshop
Saturday 20	SLI writing session
Monday 22	Organizational meeting
Friday 27	Workshop
Saturday 27	SLI writing session
Monday 29	Organizational meeting
FEBRUARY	
Friday 2	Workshop
Saturday 3	SLI writing session
Monday 5	Organizational meeting
Wednesday 7	Flight Readiness Review (FRR) Q&A
Friday 9	Workshop
Saturday 10	SLI writing session
Sunday 11	Full scale half impulse test flight
Monday 12	Organizational meeting
Friday 16	Workshop
Saturday 17	SLI writing session
Saturday 17	Physics open house
Monday 19	Organizational meeting
Friday 23	Workshop
Saturday 24	SLI writing session
Monday 26	Organizational meeting
MARCH	
Friday 2	Workshop
Saturday 3	SLI writing session
Monday 5	Organizational meeting
Monday 5	FRR due by 8:00 a.m.
Tuesday 6 – Thursday 22	FRR Video Teleconferences
Friday 9	Workshop
Saturday 10	SLI writing session
Saturday 10	Super Science Saturday
Monday 12	Organizational meeting
Friday 16	No school
Friday 16	Workshop
Saturday 17	SLI writing session
Sunday 18	Full scale full impulse test flight
Monday 19	Organizational meeting

Wednesday 21	Wingra Science Night
Friday 23	Workshop
Saturday 24	SLI writing session
Monday 26-30	No school
Saturday 31	SLI writing session
APRIL	
Wednesday 4	Travel to Hunsville, AL
Wednesday 4	Launch Readiness Reviews (LRR)
Friday 6	Launch Week Activites
Saturday 7	Launch Day
Sunday 8	Backup Launch Day
Monday 9	Organizational meeting
Friday 13	Workshop
Saturday 14	SLI writing session
Monday 16	Organizational meeting
Friday 20	Workshop
Friday 20	MSCR k12 Showcase
Saturday 21	SLI writing session
Monday 23	Organizational meeting
Friday 27	No school
Friday 27	Workshop
Friday 27	Shorewood elementary
Friday 27	Post-Launch Assessment Review due at 8:00 a.m.
Saturday 28	SLI writing session
Monday 30	Organizational meeting

Table 16: 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.

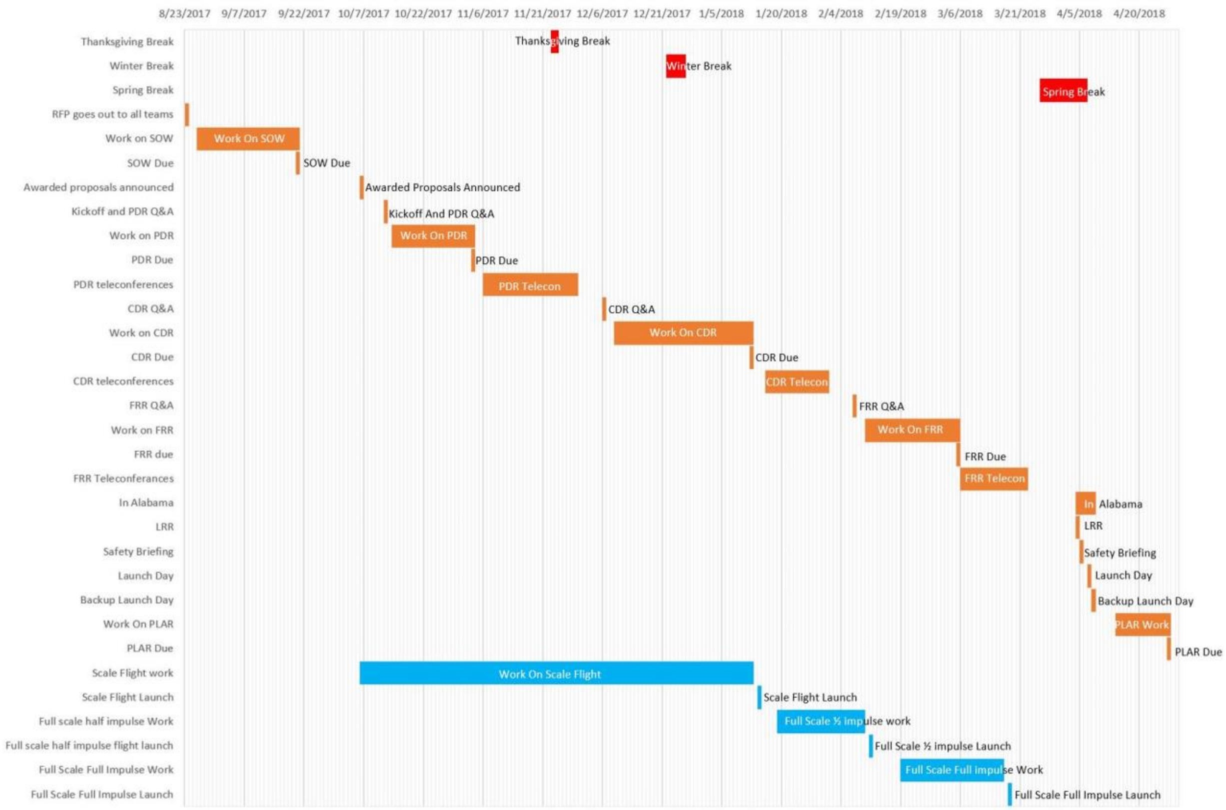

Figure 18: GANTT chart for SL2017 project

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	$100.00
GPS Tracker	$140.00
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	
Raspberry Pi Zero-W (3)	$150.00
LIS331 accelerometers (6)	$180.00
PLA (for 3D Printing)	$100.00
Liquid Samples	$100.00
Total	**$2,820.00**

Table 17: Project budget

Travel Budget	
Flight	
$345/Person * 11 People	$3,795.00
Rooms	
$119/Room * 7 Rooms * 5 Nights	$4,165.00
Car Rental (Ground Support Vehicle)	
$500 rental+ $627 gas	$1,127.00
Total	$9,087.00
Cost per Team Member	**$ 826.09**

Table 18: 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	$2,820.00	
Workshop rental	$2,400.00	
Workshop insurance	$500.00	
Teleconferencing fees	$0.00	Venue and equipment provided at no cost by Chemical Engineering Dept.
Outreach costs	$500.00	
Travel expenses	$9,087.00	
Total Expenses	***$15,307.00***	
Funds		
Raking fundraiser	$6,000.00	
Donations from families	$2,500.00	
Travel funds	$9,864.00	Students pay the travel expenses associated with SL launch
Total Funds	***$18,364.00***	

Table 19: Breakdown of expected expenses and available funds