MIT Rocket Team
Preliminary Design Review

November 28, 2011

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1 SUMMARY OF PDR REPORT

1.1 TEAM SUMMARY

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1.2 LAUNCH VEHICLE SUMMARY

The purpose of the launch vehicle is to reach an apogee of 1 mile employing two sets of three fins. One set of fins will be uniform and matching and be designed to stabilize the rocket. The second set of fins will be non-uniform and will be used as part of the rocket's scientific payload. The stabilization fins will be designed such that stability will be maintained even with failure of one or more of the test fins. Additionally the launch vehicle will be used to deploy a secondary, educational payload on descent.

The carbon-phenolic airframe will be 9 feet in length, and the inner diameter of the rocket tube is designed to be 6 inches. The semi-span of the stability fins will be 9 inches, and the test fins will have semi-spans ranging from 5-8 inches. The projected mass of the rocket is 42 pounds including all payloads and ballast. The rocket will fly on a commercial CTI L1395, and main deployment will be performed at 700ft.

Additional Vehicle details can be found in the Vehicle Criteria subsection, and the attached Fly Sheet.

1.3 PAYLOAD SUMMARY

The scientific payload for the 2011-2012 year will be a system for quantitatively measuring flutter on secondary set of fins. This system will include a set of high-speed video cameras, and strain-gauges built into test fins. The data and video from the flight will be analyzed and compared to computer models developed prior to flight.

A secondary payload will be flown as part of ongoing educational outreach programs. The secondary payload will be a science experiment developed and built by a local high-school team. The payload will be selected as part of a mini-design competition. Additional information on this may be located in the educational outreach section.

2 CHANGES MADE SINCE PROPOSAL

2.1 CHANGES MADE TO VEHICLE CRITERIA

Only a couple of changes have been made to the vehicle criteria since the proposal. The primary change is the fin attachment method. This method will allow easy removal and replacement of fins between flights. This will allow the liberated fins to be replaced between test flights without rebuilding any portion of the rocket other than installing new test fins. Relatedly, the airframe tube will not be permanently attached to the fin unit, this will allow its removal to replace fins.

2.2 CHANGES MADE TO PAYLOAD CRITERIA

- There will no longer be any video streaming or data telemetry during flight.
- A system of radio controlled relay switches was added to turn on the camera shutters prior to launch.

2.3 CHANGES MADE TO ACTIVITY PLAN

An additional event with the MIT Museum has been scheduled for January 9th

3 VEHICLE CRITERIA

3.1 SELECTION, DESIGN, AND VERIFICATION OF LAUNCH VEHICLE

3.1.1 MISSION STATEMENT, REQUIREMENTS, AND MISSION SUCCESS CRITERIA

Mission Statement

The MIT Rocket Team aims to develop and test methods of analyzing the causes and effects of fin flutter as it pertains to the flight of high powered rockets.

Constraints

Follow all rules of NASA USLI 2011-2012, including but not limited to:

- Rocket apogee shall be closest to but not exceeding 5280ft.
- At no time may a vehicle exceed 5600ft.
- Dual deployment recovery must be used
- Dual altimeters must be used for all electronic flight systems.
- Each altimeter must have its own battery and externally located arming switch.
- Each altimeter must be commercially available and meet the requirements as listed by USLI officials.
- Recovery and payload electronics must be independent from each other.
- At all times the system must remain subsonic.
- Shear pins must be used in the deployment of both the drogue and main parachute.
- All components of the system must land within 2500ft of the launch site in a wind speed of 15 mi/hr.
- Each tethered section, of which there may be no more than 4 of, must land with kinetic energy of less than 75 ft-lbf
- Scientific method must be used in the collection, analysis and reporting of all data.
- Electronic tracking devices must be used to transmit the location of all components after landing.
- Only commercially available, NAR/TRA certified motors may be used.
- Full-scale flight model must be flown prior to FRR.
- Students must do 100% of all work for USLI competition related projects
- $5000 maximum value of rocket and science payload as it sits on the launch pad.

Requirements

The mission requirements are as follows:

1) Launch rocket with 6 fins of different thicknesses, geometry, and materials
    a) Analytically demonstrate rocket stability with 6 fins and additionally only the 3 non-fluttering fins.
    b) Attach strain gauges to fins to measure predicted versus actual strain
    c) Purposely induce flutter or failure in 3 of 6 fins
2) Successfully deliver high school outreach payload
3) Visually identify flutter effects with high speed camera and custom mirror system
    a) Use image post-processing software to accurately track fin movement

Success Criteria

Success will be defined as completing the above requirements within the constraints of the USLI 2011-2012 rules.

3.1.2 MAJOR VEHICLE MILESTONE SCHEDULE

Further details on the system schedule may be located in section 5.2. Key dates are presented below for reference:

- 9/10: Project initiation
- 11/28: PDR materials due
- 12/17: Scaled test launch
- 1/21: First full-scale test launch
- 1/23: CDR materials due
- 2/18: Second full-scale test launch
- 3/10: Optional full-scale test launch
- 3/17: Third full-scale test launch
- 3/26: FRR materials due
- 4/2: Optional full scale test launch
- 4/21: Competition launch

3.1.3 ROCKET DESIGN AND SUBSYSTEMS

The rocket to be used for this project will be propelled by a single Cessaroni L1395 motor in order to induce fin flutter, as seen in Figure 1.

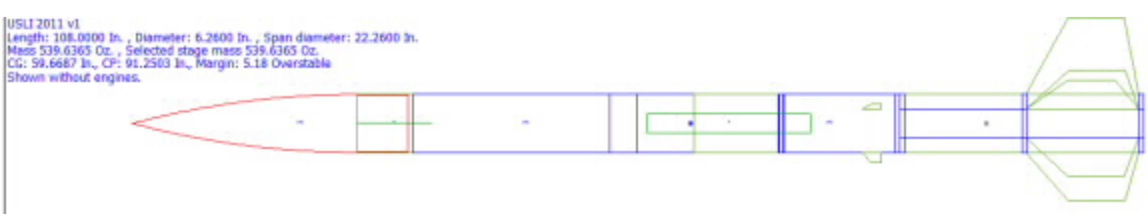

FIGURE 1:ROCKSIM 2D ROCKET MODEL

As can be seen in the figure, the rocket is 9’0” in length, the inner diameter of the rocket tube is 6.10”, and the fin semi-span is 9”. The three fins used to analyze fin flutter have a span of 5”, 6” and 8” respectively. Furthermore, the mass of the rocket is projected to be 42.4 pounds for a payload mass of 8 pounds and ballast in the nose cone as necessary in order to reach an apogee of 1 mile. Current design projections show a 5700’ apogee, which will be left as margin throughout the design process. The exact specifications of payload deployment depend on the experiment chosen, although a 24” long by 5.8” ID tube will remain available for use. The exterior dimensions will remain the same and the payload will be ballasted as necessary to reach the 8 pound design weight. The airframe will be made from Soller-Composites carbon fiber sleeve applied to a 6” diameter PML tube. The fins will be attached with a custom laser cut structure that will allow the easy insertion and removal of fins. This will allow the fin shapes to be varied during testing to meet the requirement that 3 of the fins flutter. The fins will be made of various thicknesses of G10/FR4.

Based on the results of numerical simulations of the rocket trajectory, a CTI L1395 motor has been chosen as it has a thrust profile and total impulse most closely matching that which is required to obtain the target altitude. Additionally, the higher impulse L1115 and the lower impulse L1355 are available should the final rocket mass not match expectations.

The recovery system will consist of the deployment of a 60” diameter surplus, tangle-free, pilot parachute at apogee and a Rocketman R14 at 300’. Deployment will be performed by a Featherweight Raven2, backed up by a Perfectflite Stratologger. Both of these altimeters will fire a black powder charge located in the nose cone at apogee. The nose cone will separate and the rocket will descend on the drogue/pilot parachute at approximately 55 feet/second until 300’. At 300’, the Raven will fire an electric match inside the Tender Descender to allow the payload and main parachute to come free. This event will be backed up by the Stratologger at 250’. The pilot parachute will pull the payload module out of the rocket, followed by the main parachute deployment bag. This deployment system has been flight tested and shown to be 100% successful over 3 flights in the previous USLI iteration. The rocket will land in two tethered pieces, the 13 pound nosecone/payload and the 24 pound rocket body and fin unit. The nose cone/high school payload section will land at approximately 19.16ft/sec for a total energy of 72 ft-lbs (98.2 joules). The lower section will land at approximately 12.89 ft/sec for a total landing energy of 60 ft-lbs (82.3 joules) of energy. These numbers are calculated using an online parachute descent rate calculator that also closely matches the published values for the Rocketman parachute we are using. Each section will contain a BigRedBee 70cm tracker for location after launch. The larger, lower section will also likely contain a BigRedBee 2m GPS tracker as an additional tracker.

The subsystems, which will be described in greater detail below, are:

- Airframe
- Recovery
- Deployment
- Propulsion
- Avionics/Communications

3.1.4 SUBSYSTEM REQUIREMENTS AND DESCRIPTIONS

Airframe

The airframe is comprised of the following components:

- Body Tube
- Nose Cone
- Fins
- Motor Retention System
- Avionics bay tube

Each of these will be described in detail below.

The body tube is a Soller-Composites carbon fiber sleeve applied to a Public Missiles 6" Phenolic airframe tube. Carbon fiber was chosen as the material for the primary structure due to its high strength-to-weight ratio, toughness, and ease of manufacture to customized shapes and dimensions. All layups for the rocket are done in-house using a custom oven in the rocket team lab. PML phenolic tubing was chosen for its size and history of performance in high humidity environments, unlike Blue-Tube. The PML tube, although strong enough for rocket flight, has a history of not surviving transportation and recovery, thus the carbon reinforcement. For fabrication and transportation reasons, it would be difficult to make the entire tube in one segment. As a result, the body tube is split into 2 segments, with a joint just above the avionics bay. The two segment lengths are 48" for the lower tube and 36" for the upper tube. The lower tube will also have fin slots and camera mirror mounting shrouds. The tube coupler will consist of an 18" length of PML phenolic coupler tube with carbon fiber applied to the inside for additional resistance against fracturing.

Additionally, the tube will have 2 pressure relief holes (of 0.25" diameter, unless otherwise specified) in each of the following locations:

- Just above the fins in the propulsion section
- Avionics bay: the hole for the switches will double as a pressure relief hole
- In the middle of the section between the avionics bay and the high school science payload

- In the nose cone

The nose cone is PML 6” diameter fiberglass nose cone. It is 24” long and was chosen as it is designed to interface with the PML 6” phenolic tubes that were chosen as a base airframe material.

The nose cone is mounted to the body tube using 2 nylon 2-56 bolts (MMC 97263A077), which will act as shear pins. Bolts are used because they can be easily threaded into the nose cone shoulder during integration and will fail at low loading.

The three “main” fins will be constructed of ¼” G10/FR4. They will have dimensions as shown in Figure 2.

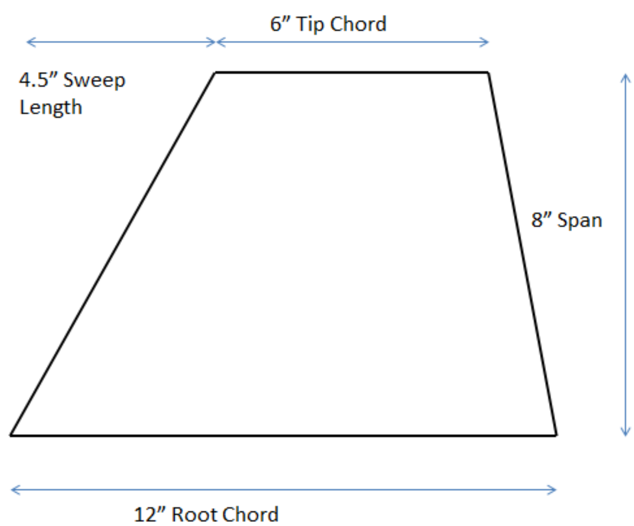

FIGURE 2: FIN

Additionally, the 3 test fins will have dimensions similar to those above, with different thicknesses and spans. The spans of the test fins will 5”, 6” and 8”. The fins will be attached to the rocket by a structure shown in the figure below. This structure will allow for easy removal and replacement of fins after test flights. In order to test a variety of fins with the same rocket without resorting to a total rebuild of the aft section, a custom fin attachment system has been designed for use in this year’s USLI project. Originally fins were to be bolted onto the airframe at the root chord, however because we wish to analyze the bending effects in this region, this would not be a possibility. Instead oversized slots are cut into the aft section of the airframe where the fins are to be located. An inner alignment tube is used to restrain the fins from falling inward, and separate the assembly from the motor mount tube at the center. Two fin holders are then used as shims to restrain the fin within the slit in the airframe. To keep the fin from being pulled out of the opening, tabs are located on the internal section of the fin chord. These tabs extend above the airframe opening and thus prevent the fin from being removed. A lockdown collar is used below the fins to restrain them in the axial direction.

This collar is directly attached to the airframe tube in the areas between fin slots using screws or another suitable fastener. A diagram of this system is included in Figure 3, note that this is for demonstrational use only and does not reflect the flight design. The flight design will be refined and presented at CDR.

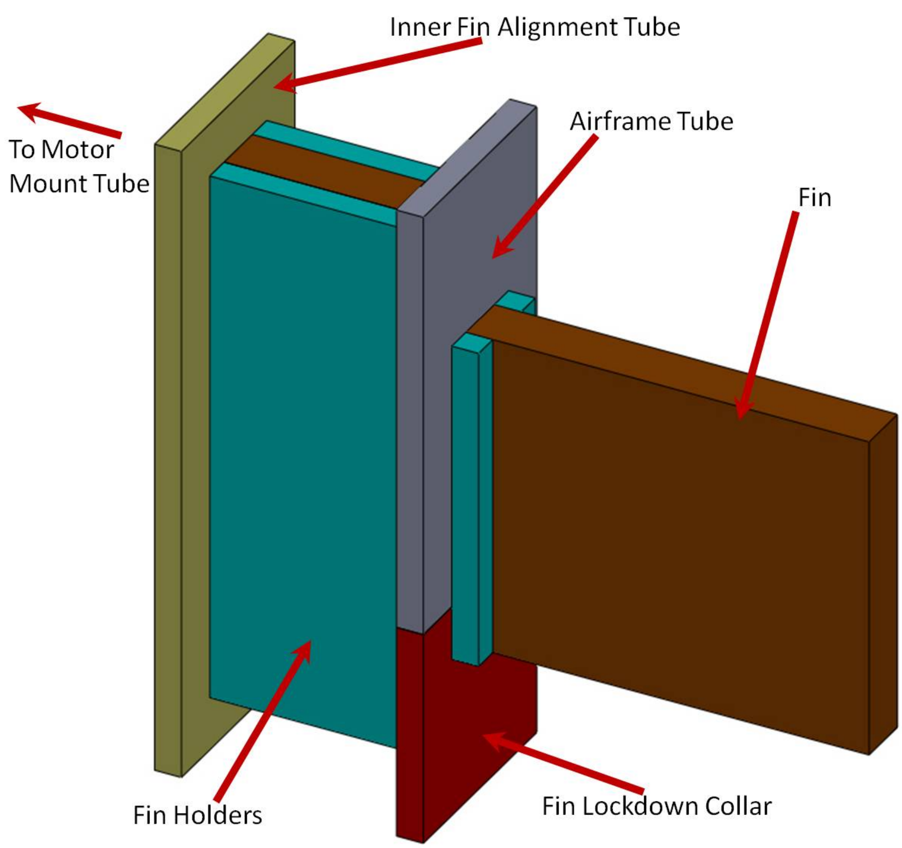

FIGURE 3: FIN ATTACHMENT ASSEMBLY MODEL

The motor mount will consist of a commercial 75mm motor tube and laser-cut, plywood centering rings. There will be three centering rings in total, one located at each end of the motor tube and one at the forward root of the fins. The forward ring will be made from 1/2" plywood. The farthest aft centering ring will be made from two rings of 1/2" plywood sandwiched together; the OD of the forward ring will be the ID of the body tube, and the OD of the aft ring will be the OD of the body tube. This will transfer the thrust load through compression of the aft centering ring. Plywood is chosen because it is relatively cheap, strong, light, and able to withstand the high temperatures of the motor casing without deforming.

The airframe tube will not be permanently attached to the motor mount tube and fin unit. This will be accomplished by extending the slots for the fins to the back of the airframe and sliding the airframe on. This will allow the replacement and interchange of fins between flights.

Motor retention will be accomplished by a 3/8-16 threaded rod that will extend through the avionics bay into the threaded tap on the forward closure of the motor. The motor will be secured by inserting it into the motor tube and twisting it until all of the threads have engaged. This is shown in Figure 4 below.

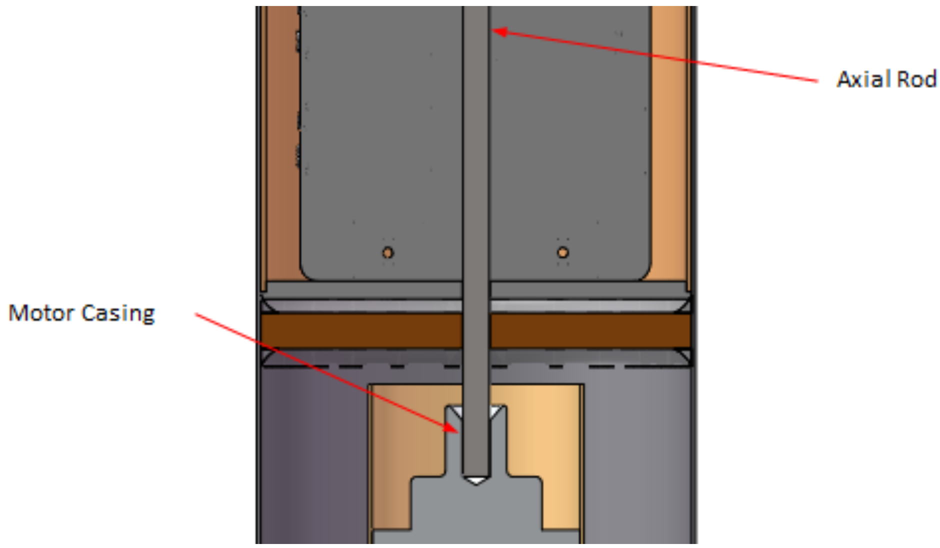

FIGURE 4: MOTOR RETENTION

The avionics bay tube will primarily act as a container for the avionics bay and as a place to attach the eye bolt for the recovery system. The tube will consist of a 12” long segment of PML phenolic coupler tube with a ½” plywood bulkhead on either end. Housed inside will be deployment and payload avionics. A piece of 3/8-16 threaded rod will extend through the bulkhead from the top of the motor to an eye nut that will be installed on the bulkhead. This will serve to provide motor retention and a recovery attachment point. Additionally, the airframe will be secured to the avionics bay bulkhead with 6x 4-40 screws to prevent the motor mount tube assembly and avionics bay from slipping out the back of the rocket after motor burnout.

<u>Recovery</u>

A detailed description of the recovery process can be found in the Section 3.2.

<u>Deployment</u>

Deployment of the high school science payload and parachutes is as follows.

Initially, the stacking of the rocket above upper avionics bay bulkhead is as follows (as seen in the figures below):

- Charge released locking mechanism
- Main parachute
- High School Science Payload
- Drogue parachute quick link
- Drogue parachute
- Nose cone ejection charges

Note: There is a redundant igniter in the charge released locking mechanism and a redundant drogue ejection charge.

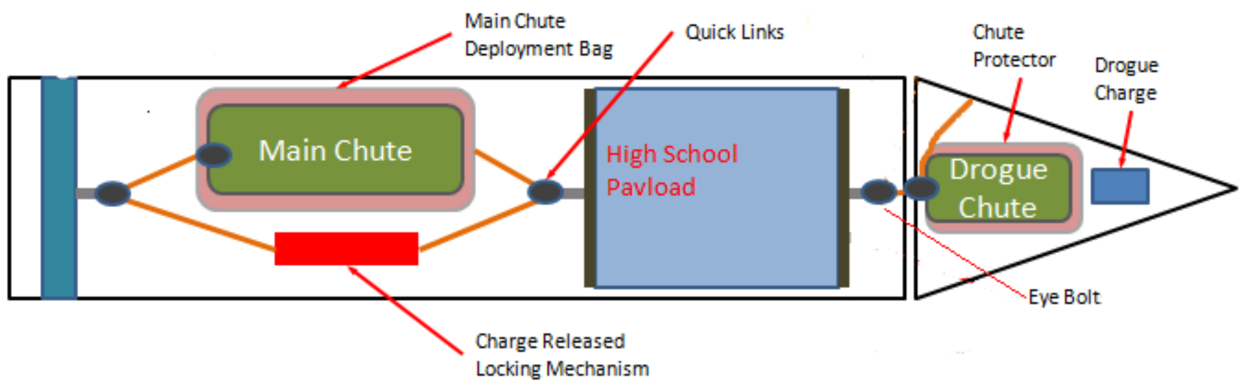

FIGURE 5:RECOVERY COMPONENT STACKING

The deployment then occurs as follows:

- Just after apogee, nose cone ejection charge fires
- Nose cone separates, but remains attached to the drogue parachute
- Drogue parachute deploys
- Rocket descends to 300 feet
- At 300 feet, the charge released locking mechanism fires. Mechanism to be used is the “FruityChutes L2 Tender Descender”
- The drogue parachute pulls the science payload out of the rocket tube
- The science payload pulls the main parachute deployment bag out behind it
- Main parachute deploys and remains attached to the main body tube

After deployment, the rocket will fall to the ground in two sections, as shown in Figure 6:

- High school science payload and nose cone, which are attached to the drogue parachute via a shock cord

- Main body tube, which is attached to the main parachute via eye nut on the avionics bay and a shock cord.

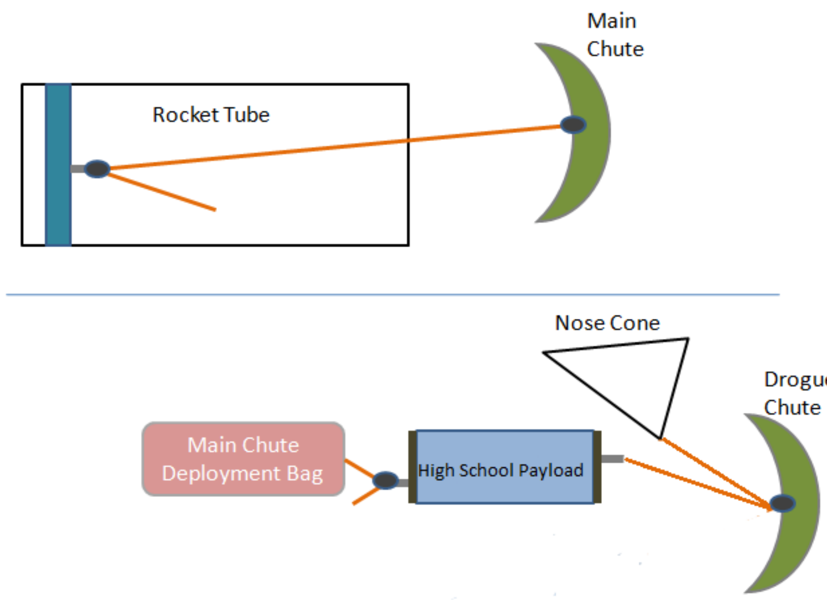

FIGURE 6:DEPLOYED RECOVERY COMPONENTS

Deployment into two pieces (rather than one) is performed in order to minimize the chance of contact between the nose cone and high school science payload and the body tube after separation. This will enable the drogue parachute to pull the high school science payload away from the rocket to allow clean separation and minimize the chances of entanglement.

The high school science payload will consist of a 6” PML coupler tube with bulkheads attached inside either end. 3/8” eye bolts will be attached to these bulkheads to provide an attachment point for the recovery system.

Finally, a Big Red Bee 70cm tracker will be located in the nosecone and attached to the shock cord on the main parachute.

<u>Propulsion</u>

The rocket will be powered by a Cesaroni L1395 solid rocket motor. This motor was chosen because it is commercially available and does not require any modifications in order to reach the flight altitude requirement of 5280 feet based off the mass estimates available this early in the design process. The motor is actually more powerful than required given the current mass estimates, but this will ensure that even with mass creep over multiple design iterations, the rocket mass can be optimized with ballast weight to come as close to 5280 feet as the models can predict.

The Cesaroni L1395 is also reloadable and relatively inexpensive compared to its Aerotech counterparts. The L1395 is 75mm in diameter, 24.5 inches in length, and has a total impulse of 4895.4 Newton-seconds over a 3.5 second burn time.

For the full-scale test launches, the L1395 will also be used. This is due to the availability of fields that will support full altitude test launches, and the requirement that the payload be tested at full scale flight velocities in order to show that the payload works and can be flown safely.

Avionics/Communications

The purpose of the rocket avionics is to control parachute deployment while collecting rocket flight data.

The rocket avionics system is comprised of two flight computers (Raven2 and Stratologger) The Stratologger flight computer serves as a backup altimeter that measures the rockets altitude during launch and stores in on the computer board and will fire a redundant igniter for the recovery charge after the Raven2 is programmed to. This data can be retrieved after rocket recovery where the Stratologger flight computer is connected to the ground station computer via a PC Connect Data Transfer Kit. The Raven2 flight computer handles primary parachute deployment as well as determining the rocket state variables and flight states.

Rocket Flight data includes:

- State Variables:
  - Altitude
  - Maximum Altitude
  - Velocity
  - Acceleration
- Flight State:
  - On Pad
  - Thrust
  - Coast
  - Apogee
  - Descent
  - Drogue parachute Deployment
  - Main parachute Deployment

Power Supply

Two 9 volt batteries will provide power for the flight computers and transmitters. One of the batteries will be dedicated towards powering the Stratologger while the other will power the Raven2 flight computer. They will be located inside the removable rocket avionics section of the rocket, alongside the rest of the avionics system.

Hardware Description

Stratologger (PerfectFlite)

This flight computer measures the rocket's altitude by sampling the surrounding air pressure relative to the ground level pressure. The altitude above the launch platform is calculated every 50 milliseconds. After launch, the device continuously collects data until landing. Altitude readings are stored in nonvolatile memory and can be downloaded to a computer through a serial data I/O connector. The Stratologger has two channels for parachute deployment; one for the main parachute and the other for drogue parachute.

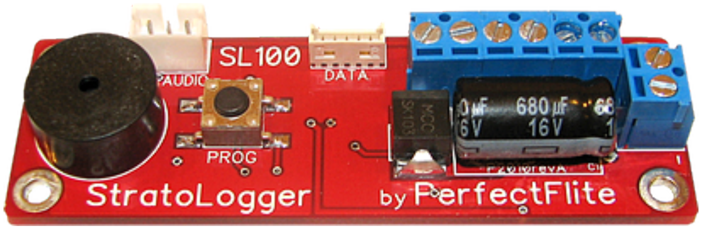

FIGURE 7: STRATOLOGGER ALTIMETER (PERFECTFLITE.COM)

Raven2 (Featherweight Altimeters)

This flight computer calculates the rockets altitude by sampling the surrounding air pressure relative to the ground level pressure and measuring the rockets acceleration. Also the altitude and other flight data are stored in nonvolatile memory to be downloaded to a computer through a serial data I/O connector. The Raven2 has four channels for parachute deployment; one for the main parachute, one for the drogue parachute and two additional channels which will not be used. All 4 channels are fully programmable.

TABLE 1: HARDWARE SEPCIFICATIONS

Hardware	**Operating Voltage**	**Minimum Current**	**Dimensions**	**Weight**	**Altitude Accuracy**	**Operating Temperature**	**Maximum Altitude**
Stratologger	4-16 volts	1.5 milliamps	0.90"W, 2.75"L, 0.5"T	13 grams	+/- .1%	-14C to 85C	100,000 feet
ARTS2	1.3-20 volts		.8"W, 1.8"L, 0.55"T	~8grams			N/A

Switches

A toggle switch that is recessed within the airframe with a horizontal throw will be used for each altimeter to provide power

Parachute Deployment

Both the Raven2 and the Stratologger are programmed to deploy the drogue parachute at apogee, while the main parachute is set to deploy after apogee is reached at an altitude of 300 feet. This creates system redundancy in case one of the flight computers fails.

Mounting/Placement

Placed in the avionics bay, which is in the lower segment of the rocket as described below. The flight computers will be mounted in such as way so that their pressure and acceleration readings are not disturbed. This means that the barometer on both the Raven2 and Stratologger would have to have at least a 1 centimeter clearance from any closest surface parallel to it. Also, the Raven2 will be mounted with its length parallel to the rocket's length in order for the accelerometer to record proper positive values.

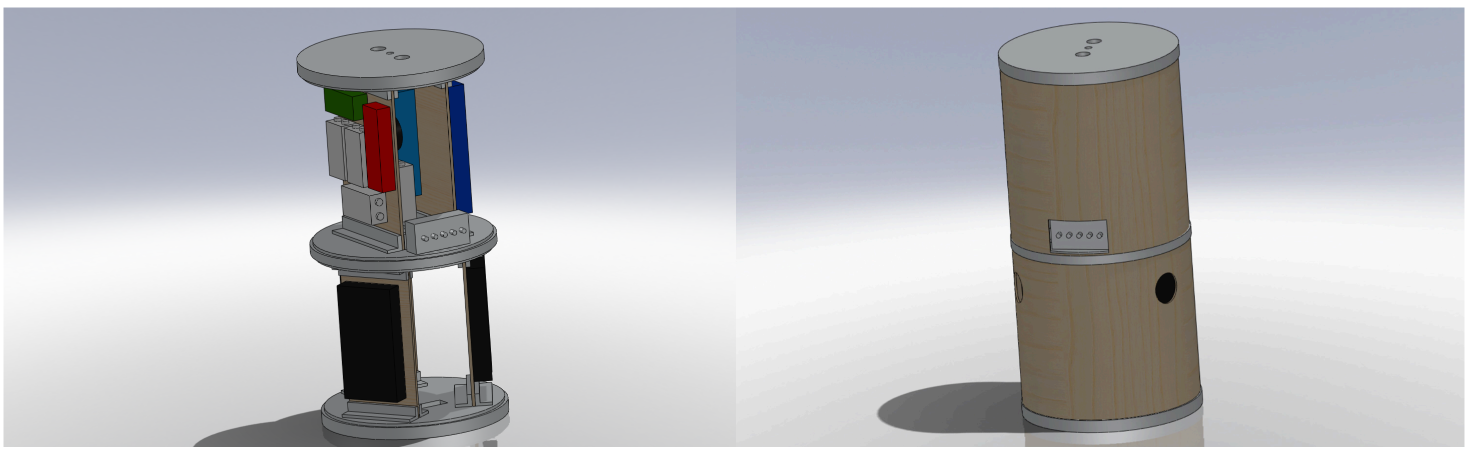

FIGURE 7: AVIONICS PACKAGE

The boards and battery are mounted to a plate, which will be mounted vertically in the avionics bay tube. A framework structure will hold the cameras in place, and the boards will be held in place by tubing glued to the avionics boards and slid over the all thread running through the middle of the avionics bay. This design was chosen to make the avionics assembly as modular as possible, while still maintaining access just before flight and low mass/cost of the assembly.

The following figure shows the wiring diagram for deployment avionics. This diagram shows independence of the redundant systems in place.

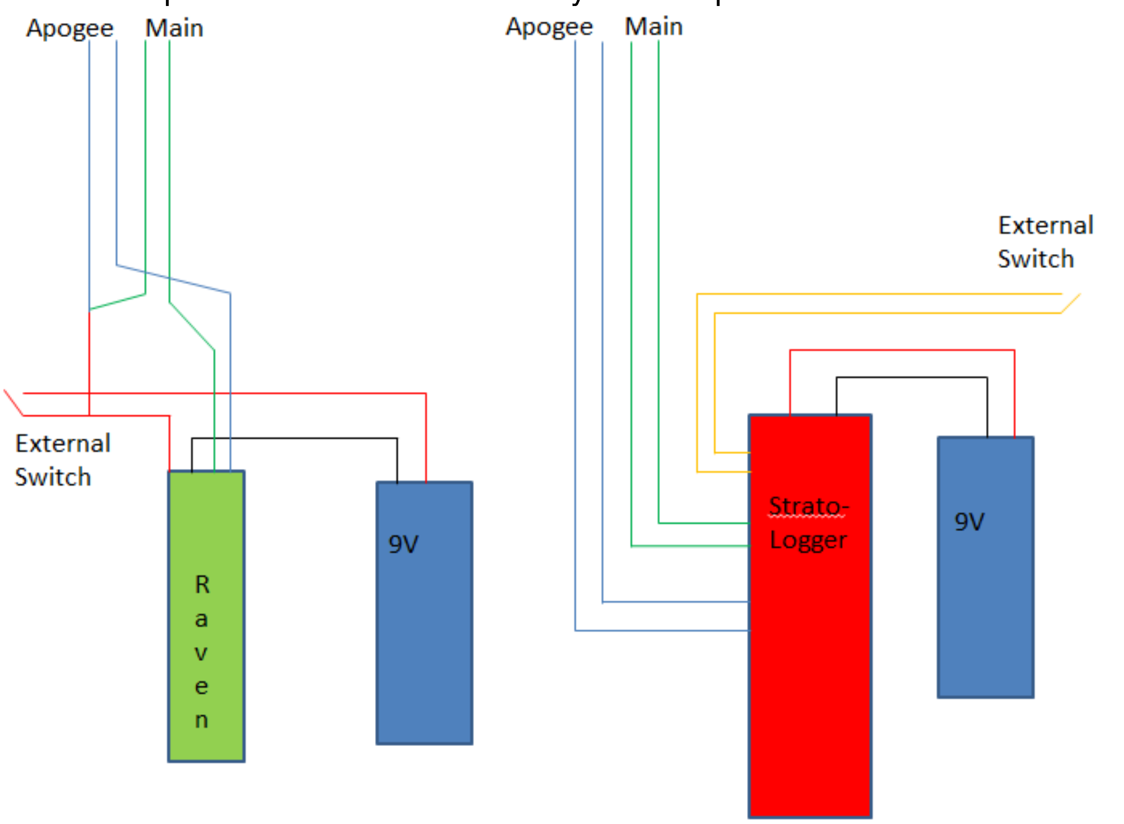

FIGURE 8: AVIONICS WIRING DIAGRAM

3.1.5 VEHICLE MASS

The total estimated mass of the vehicle is currently 42 pounds. The high school science payload is being allotted 8 pounds, with the rest of the vehicle, minus the motor, weighing approximately 28 pounds. The mass is estimated based off previous experience and a detailed Rocksim model with realistic component weights. In previous projects, Rocksim component weights have been used in addition to mass objects to obtain a final mass. These final masses have been accurate to within 2% during the design phase. Additionally, these mass estimates match the final mass of the rocket that was flown in last year's USLI project, assuming modifications are made to make them similar. The vehicle has approximately 2 pounds of mass margin before the L1395 in no longer able to deliver it to 5280'. In this event, margin can be taken from the high school payload as needed. This is possible due to the scheduling of a full scale test flight before their construction begins. Additionally, the CTI L1115 could be used and would provide an additional 3 pounds, leaving 5 pounds of margin at this point. Although a 25% margin is not currently being held, previous experience has shown that the 12% being held currently will be more than sufficient. Additionally, if more than 12% is needed, mass can be cut from the high school science payload to make up the required margin.

3.1.6 SYSTEM AND SUBSYSTEM PERFORMANCE CHARACTERISTICS

The following section describes the system and subsystem performance characteristics and validation metrics.

Airframe

The airframe is required to maintain the structural soundness of the rocket and provide stability. This will be verified post-launch by a visual inspection upon recovery. After recovering all sections, the system will be dis-integrated and a thorough inspection for damage, including holes, breaks, tears, zippers and soft spots will be conducted before deeming the system safe for further flights.

Recovery

The recovery system must perform in a matter that allows for the safe recovery of the overall system as planned. Failures in the recovery system will be investigated and further flights will be postponed until all underlying causes are identified and remedied.

Deployment

As the deployment and recovery system are coupled, all performance and verification metrics will match that of the Recovery subsystem.

Propulsion

Only the use of motors certified by TRA/NAR will be allowed. By doing such there is an understanding that manufacturers will be providing a safe and reliable product. If for some reason there is a failure, all pertinent information will be gathered for an independent investigation. Furthermore, the manufacturer and certifying authority will be contacted such that they may also carry out a similar investigation.

Avionics/Communications

The avionics are required to deploy the parachutes and allow the finding of the rocket upon landing. As they are designed for their specific purpose, verification beyond functional ground testing described below is not required. If problems arise during test flights, they will be investigated to determine a root cause. If such a cause cannot be determined, the unit will be replaced.

3.1.7 VERIFICATION PLAN

The team's first priority will be to perform qualification testing on the structural components of the rocket. The tests to be performed are as follows:

- The body tube will be tested using a crush test in the axial direction and bending test in the lateral direction. It will be tested with a variable mass, such as sand, to determine the stiffness and failure force.
- A crush test will also be performed between two tubes to verify the strength of the tube coupler.
- The fins will also be tested using a series of pull/push tests (also using a variable mass and gravity) in order to test the fin strength in each of the 3 orthogonal directions.

In addition to structural testing, several deployment and recovery tests will need to be performed:

- Deployment altitude will be verified using barometric testing. The team has constructed a small vacuum chamber, which is capable of roughly simulating ambient pressure. As a result, the avionics package will be placed into the vacuum chamber to ensure that it sends charge ignition commands at the right times.
- In order to verify the failure force of the shear pins, a representative tube will be used with a representative nose cone, with the open side of the tube covered. The shear pins are mounted into the relevant brackets in flight orientation. The black powder charge will be ignited at the closed end to validate the mass of black powder to be used.

Finally, these tests will culminate in a representative scaled test launch, which will verify functionality of all systems.

In additional, verification of the compliance with NASA 2011-2012 USLI handbook requirements will be completed as follows.

TABLE 2: REQIREMENTS

Requirement	Design Features that meet this requirement	Verification of compliance
The vehicle must carry a science payload of the	Fin flutter analysis experiment	Inspection

team's choosing		
The vehicle shall target 5280' and not exceed 5600'	Rocksim modeling	Altimeter readings from flight tests
The vehicle shall carry an official altimeter and be returned to NASA by 5:00pm on launch day	A Featherweight altimeters Raven2 will be flown, along with trackers to allow the rocket to be found quickly	Inspection (altimeters are flown) and flight testing (rocket can be found)
The recovery system shall be armed on the launch pad	The altimeters will have externally accessible switches, the check lists will including arming the altimeters on the launch pad	Inspection
The recovery system electronics shall be independent of payload electronics	The Raven2 and Stratologger are not used for the payload	Inspection
The recovery system shall contain redundant altimeters	A Raven2 and Stratologger will be used	Inspection
Each altimeter shall have a dedicated arming switch	2 switches will be used, one for each altimeter	Inspection
Each altimeter shall have a dedicated battery	2 batteries will be used, one for each altimeter	Inspection
Each arming switch shall be accessible from the exterior of the airframe	A hole in the side of the airframe will allow switch access	Inspection
Each switch shall be capable of being locked in the on position	The switches will not be of the momentary type. They will also be mounted horizontally to prevent g-forces from changing their state	Inspection
Each switch shall be less than 6' above the base of the rocket	The switches will be 26" from the base of the rocket	Inspection
The recovery system shall be shielded from all onboard transmitting devices	The upper avionics bay will be coated in aluminum foil tape, shielding it from the transmitters well above it.	Inspection and testing. The altimeters will be turned on with electric matches attached to ensure there is no interference
The vehicle shall remain subsonic at all times	Rocksim simulations place the vehicle maximum	Altimeter data from flight testing will provide an

	velocity at 700 feet/sec	actual velocity
The vehicle shall be reusable	The parts that need replacing on each flight are as follows: Ejection charges Electric Matches Motor Test fins (if they fail)	A series of 3 flight tests with the same vehicle will confirm this
The vehicle shall employ dual deployment recovery techniques	The vehicle is designed to have a drogue at apogee and a main at 300'	Previous experience and flight tests will show that this works
The vehicle shall employ removable shear pins	2x 2-56 nylon screws will be used on the inflight separation joint	Inspection
The vehicle shall land in no more than 4 pieces	The vehicle will land in at most 4 pieces: -The main body -The nose cone/high school payload -0 to 2 fins	The third test fin will be designed not to fail
Each piece shall land with a K.E. of less than 75ft-lbf	The K.E. of the nose cone/payload is 72 ft-lbf, the main body is 60ft-lbf. The K.E. of the fins is TBD, however, mitigation strategies to keep it below 75ft-lbf exist	Flight data from the altimeters and drop tests of the fins
Each piece shall be designed to recover within 2,500' of the launch pad in 15mph winds	This requires a recovery time of 114 seconds. 90.5 of those will be under drogue, with the remaining 23.5 available after main deployment.	Verification of descent rates through simulation and confirmation of these after test flights are performed
The launch vehicle shall be able to be prepped at the launch site in 2 hours	A more complex design took 1.5 hours to prep after the waiver was open in 2011.	Realistic use of check lists and pre-flight procedures during flight tests
The vehicle shall be able to remain in launch ready configuration at the pad for at least 1 hour without losing functionality of any onboard component	Altimeter and payload batteries have a life time on the order of at least 6 hours. Cameras will be turned on remotely via a wireless connection just	Bench tests of electronics

	before launch	
The launch vehicle shall using a standard 10 second countdown	The series of numbers 10-n where n = [0:9] will be announced by the LCO before launch	Listening
The launch vehicle shall require no external circuitry or special ground support equipment other than that provided by the range	The vehicle only requires the pair of alligator clips from the launch system	Inspection
Data shall be analyzed using the scientific method	Data will be acquired and analyzed	Scientists will be consulted to confirm we are using scientific method
Radio trackers must be used in each section	A Big Red Bee 70cm tracker will be located in the nosecone, on the main parachute shock cord and either on the tips of the fins that will fail or on the streamer attached to said fins	Inspection
TRA/NAR/CAR Certified motors must be used	The Cessaroni L1395 is certified	Inspection
The total impulse must not exceed 5120N-s	The Cessaroni L1395 has 4895N-S	Inspection
The rocket must be successfully launched prior to FRR	3 test flights on 3 separate dates are planned with 2 contingency dates	Inspection
The rocket must not use flashbulbs	Quest Q2G2 igniters will be used for all charges	Inspection
The rocket must not use forward canards	The rocket does not have forward canards	Inspection
The rocket must not use forward firing motors	The rocket only has 1 motor and it is pointing aft	The motor will only go in the rocket in the correct orientation
The rocket must not use rear ejection parachute designs	The rocket ejects the drogue out the nose. The main is pulled out the same end of the tube. If streamers are used on fins, they will not be ejected, and they are not parachutes.	Inspection
The rocket must not use	The L1395 uses APCP and	Inspection

hybrid motors	APCP only	
The rocket must not use sparky motors	The L1395 is not a sparky motor	Inspection
The team shall have and use safety checklist	Safety checklists are being developed and will be revised as needed.	Checklists are included in this document.
Student team members must do 100% of the work on the project	All work will be completed by full time student team members	Verification of this by an outside person would be a violation of this rule
The rocketry mentor must have had 15 L class dual deploy flights prior to PDR	Robert DeHate has over a decade of HPR experience and has flown some of the most complex and high altitude flights in amateur rocketry.	Questioning
The rocket must cost less than $5,000 on the launch pad.	A budget summary is provided in this document. The total cost is well under $5,000	Calculation

3.1.8 RISK MITIGATION AND FAILURE MODES

TABLE 3: RISK ANALYSIS

Risk	Likelihood	Effect on Project	Risk Reduction Plan
Scale test model flight failure	Medium	Low	Ensure model is stable and meets safety codes.
Full-Scale Test Flight Failure	Medium-High	Low	Ensure appropriate simulations and testing are done before flight. Do not fly with any outstanding technical or safety issues. The possibility for 5 test flight dates exist
Team member suffering major accident or illness	Medium	Low	Ensure team members and mentors can suitably make up for the unavailability of a team member due to illness.

Loss of support by any critical personnel, sponsors or organizations	Medium	Medium	Ensure all supporting organizations understand their importance to the project and plan ahead incase problems arise. Cross train team members to be able to step in for others.
Vehicle Damage from transportation or other causes prior to launch	Medium	High	Ensure vehicle is packed securely and packaging and vehicle are rugged enough to handle transportation. Carry spares for parts that are known to be easily breakable.
Unforeseen regulatory problems	Low	Medium	Ensure that knowledge of regulations is kept up to date to know of any impending problems.
Late delivery of vehicle components	Medium	Medium	Ensure components are available and ordered early enough to ensure proper arrival time
Payload components are not ready in time	High	High	Plan ahead and keep on schedule to ensure delivery of tested data acquisition system and strain gauges in time
Vehicle components are not ready in time	Medium	High	Plan ahead and keep on schedule. Make simplifications if necessary.

3.1.9 PLANNING

As can be seen in our schedule in section 5.2, most of the manufacturing, verification and integration plans take place in January. MIT does not hold classes during January, however, most team members are on campus. This provides a great opportunity to perform a large part of the work on the project.

A summary of these plans is as follows:

- 9/10: Project initiation

- 11/28: PDR materials due
- 12/3: Construct Scale rocket
- 12/17: Scaled test launch
- 12/19: Initiate materials acquisition for full scale rocket
- 1/6: Return from winter break
- 1/6: Initiate construction of fin unit
- 1/7: Initiate construction of test body tubes
- 1/9: Perform tests on body tubes (crush, bending, etc).
- 1/9: Perform ejection charge tests
- 1/10: Cut out fins
- 1/11: Perform fin unit tests
- 1/13: Initiate construction of flight body tubes
- 1/15: Initiate construction of mirror system and avionics mounting system
- 1/16: Start integrating vehicle components
- 1/19: Prepare for full scale launch (pack parachutes, build motor, etc)
- 1/21: First full-scale test launch
- 1/23: CDR materials due
- 2/18: Second full-scale test launch
- 3/10: Optional full-scale test launch
- 3/17: Third full-scale test launch
- 3/26: FRR materials due
- 4/2: Optional full scale test launch
- 4/21: Competition launch

As can be seen, by taking advantage of the month of January, we are able to complete the majority of the work over a short time period well ahead of the required deadlines. This will give us ample time to re-design or rebuild the rocket in the event of a failure, and still perform a large number of full scale flight tests to work out any other issues with the rocket prior to the Huntsville flight. This will also give us a number of opportunities to show that the fin flutter payload can be flown safely.

3.1.10 DESIGN MATURITY

The design as-is is likely to only see a couple of changes. These are mostly related to the payload. As a very similar rocket structure has been flown in the past, the confidence level in that area is very high. The following areas may see changes depending on further development and testing:

-Fin attachment design

The need to be able to remove and replace fins is a unique design requirement that has not yet been fully explored. The option presented in the rocket design section is likely to work, however, other options exist

-Fin recovery design

One of the following options needs to be chosen for liberated fin recovery

a) Tumble recovery with tracker embedded in fin tip
b) Streamer recovery with tracker attached to streamer and streamer attached by a Kevlar cord. Streamer would be housed in tube in the base of the rocket and cord would be attached to fin tip
c) Streamer recovery as above with the tracker in the fin tip
d) Attachment of fin tip to main rocket body by a small Kevlar cord

-Parachute sizing

This will depend on the results of test flights to ensure the landing energy is below 75ft-lbf.

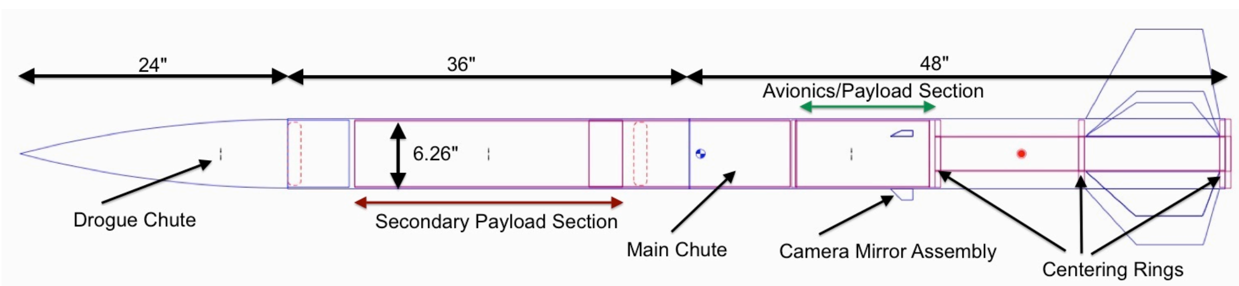

FIGURE 9: VEHICLE DESIGN

3.2 RECOVERY SUBSYSTEM

When the drogue parachute is deployed at apogee, it will need to support a total system mass of 16 kg. A 5ft diameter parachute will be used to achieve a descent rate of 55ft/s.

Once an altitude of 300 ft AGL is reached, the tether securing the high school payload inside the rocket will release, allowing the drogue parachute to pull the payload section and the main parachute out of the rocket. At this point, the rocket body will separate from the payload/nose/drogue section and free fall as the main parachute deploys. This will allow for a considerable gap between the rocket body and the nosecone, decreasing the risk of the rocket's main parachute becoming tangled with the nose cone, drogue or deployment back.

With the payload deployed and separated from the rocket body, the remaining structure has a mass of 10.6 kg. With a 14ft diameter parachute, a final descent rate of 12.9 ft/s can be achieved. Under the 5ft parachute, the nose cone and payload will have a final descent rate of 19.1 ft/s.

TABLE 4: DESCENT RATES

Final Descent Rate & Energy		
System Under Drogue	55 ft/s	1670ft-lbf
Nose/Payload Final Descent Rate	19.1 ft/s	72ft-lbf
Rocket Body Under Main	13 ft/s	60ft-lbf
Liberated Fin	<40 ft/s	<25 ft-lbf

The following table shows the drift calculations for the various sections on the rocket. These are based on a vertical ascent and a constant wind speed. Assuming the rocket weathercocks, these calculations are overestimates.

TABLE 5: SECTION DRIFT CALCULATIONS

Section Drift	Main Body	Nose cone and payload	Fin	Fin with streamer
Descent Time	113 seconds	106 seconds	~33 seconds	~60 seconds
Drift at 0mph	0	0	0	0
5mph	828'	777'	242'	440'
10mph	1656'	1554'	484'	880'
15mph	2484'	2331'	968'	1760'
20mph	3312'	3108'	1936'	1760'

The drogue parachute and nose cone are directly connected to the high school science payload. This assembly is initially connected to the upper avionics bay bulkhead via the explosive tether. The main parachute is also secured directly to the recovery system bulkhead (not by the tether). Its deployment is constrained by the payload.

The calculations for the amount of black powder required to successfully separate the nose cone from the body tube can be found below.

The charge release mechanism will contain 0.2 grams of black powder. This number is recommended by the manufacturer.[1]

The drogue deployment charge must provide ample force to break the shear pins, accelerate the nose cone away from the rocket body, and accelerate the drogue parachute out of the nose cone. Two 2-56 nylon screws (MMC 94735A177) will be used a shear pins to retain the nose cone. Nylon 6/6 has a shear strength of 10ksi.[2] With this, the maximum shear force can then be calculated by the following equation:

$$F = A \cdot \tau,$$

where A is the cross-sectional area of the bolt, and τ is the shear strength. For a 2-56 screw, the minimum pitch diameter is 0.0717 in.3 This leads to a shear force of 40 lbf. With two pins, the charge will have to provide a minimum force of 60 lbf. Adding 25% margin, the charge will need to provide a total force of 75 lbf. This leads to a required black powder mass of 1.05 g.4

Previous testing with a nearly identical setup has shown that 4 grams of black powder is required to shear the shear pins and deploy the drogue.

3.3 MISSION PERFORMANCE PREDICTIONS

3.3.1 MISSION PERFORMANCE CRITERIA

In order for this mission to be considered a success, the following events must occur:

- Achieve an altitude as close to 5280 feet (1 mile) as possible. (It is preferable to undershoot the target, as the flight score penalty for overshooting is twice as great.)
- Eject nose cone and deploy drogue parachute at apogee
- Deploy high school science payload and main parachute at 300'.
- Land safely (intact and reusable with no necessary repairs) on the ground.
- Successfully collect high speed video and strain gauge and/or other data from the fluttering fins.

[1] Tender Descender User's Guide, http://fruitychutes.com/Recovery_Tether_manual.pdf
[2] http://www.aptllc.net/datasheets/Nylon66.pdf
[3] http://www.engineersedge.com/screw_threads_chart.htm
[4] Black Powder Pressure-Force Calculator: http://www.info-central.org/files/303-Pressure_Force_Calculator_Ver2.xls

3.3.2 FLIGHT PROFILE SIMULATION

For the Preliminary Design Review flight profile simulations, RockSim was used. A model of the rocket was built in RockSim. A battery of simulations was run, taking into account the approximate location and altitude of the launch site and average temperature, pressure, and humidity conditions. It was known that the Cesaroni L395 would be more powerful than necessary and propel the rocket higher than the target altitude. With no added ballast or winds, the rocket flew over 600 feet above the target altitude. This was expected and desired, especially considering the mass margin of the payload and other components, the masses of which have only been measured up to this point.

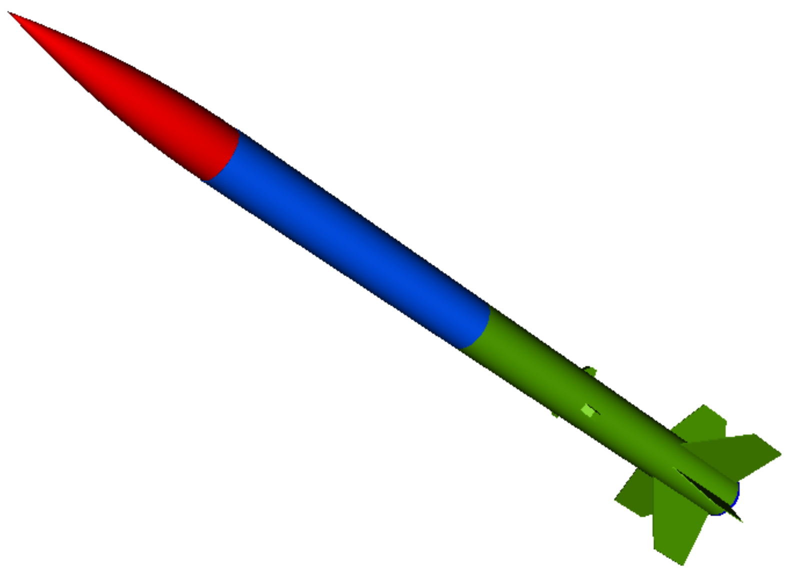

FIGURE 10: 3D ROCKET MODEL

At t = 0, the Cesaroni L1395 is ignited. Burnout occurs at 3.5s, and apogee occurs at approximately 19 seconds. At this time, the first charge is ignited to eject the nosecone and deploy the drogue chute. At 300’, the Tender Descender releases the main parachute, which is pulled out of the body by the high school science payload and drogue parachute.

Figure 11 shows the acceleration and velocity of the rocket during the first 30 seconds of flight (the remaining flight time was omitted for clarity). The maximum speed occurs near burnout, and does not exceed Mach 0.5. The maximum predicted acceleration, although not shown, occurs at the parachute deployment, as expected.

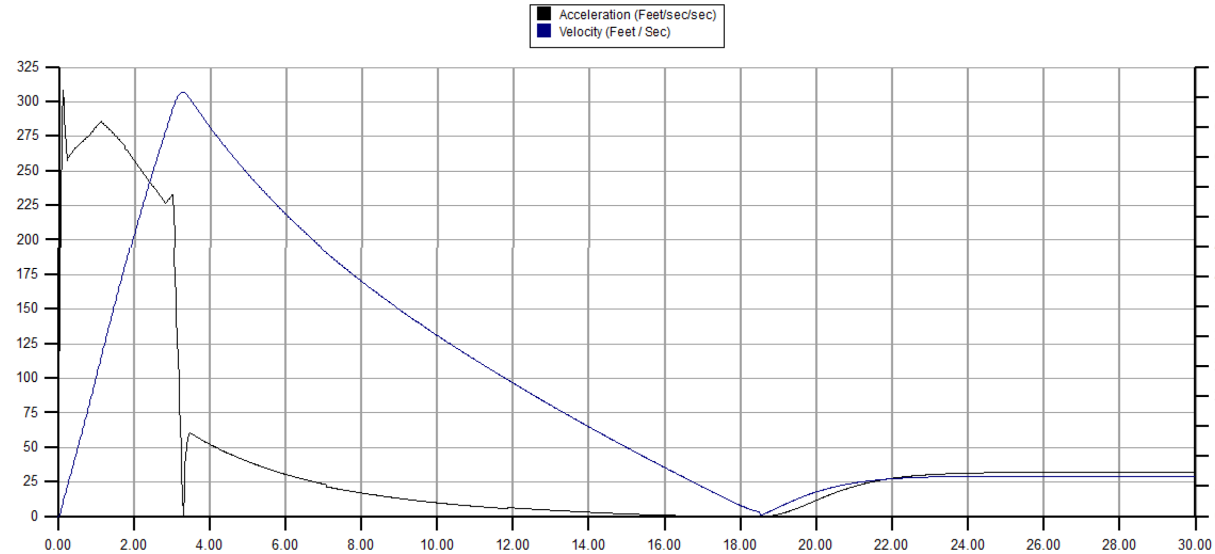

FIGURE 11:VELOCITY AND ACCELERATION DURING FIRST 30SEC OF FLIGHT

Figure 12 shows the simulated altitude profile of the rocket. Burnout and apogee are shown with red and blue dotted lines, respectively, and the main parachute deployment can be seen as the kink in the altitude line near 105 s. Note that the descent time is not exactly representative of the actual descent time used for drift calculations as the parachutes used in Rocksim simulations are not exactly what will be used in flight.

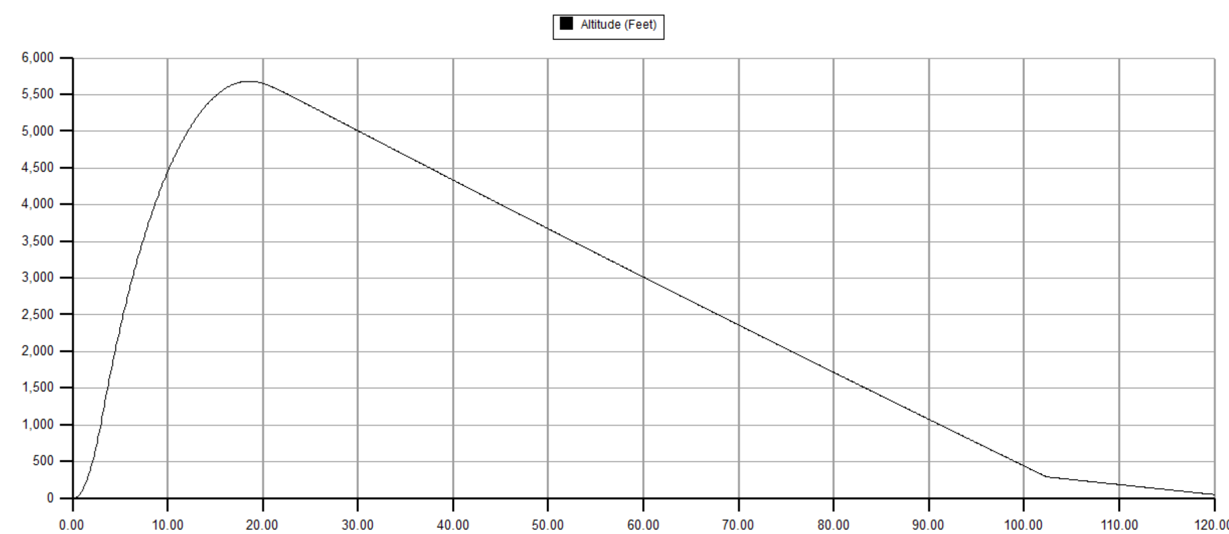

FIGURE 12: ALTITUDE VS TIME

Finally, Figure 13 shows the thrust curve for the L1395

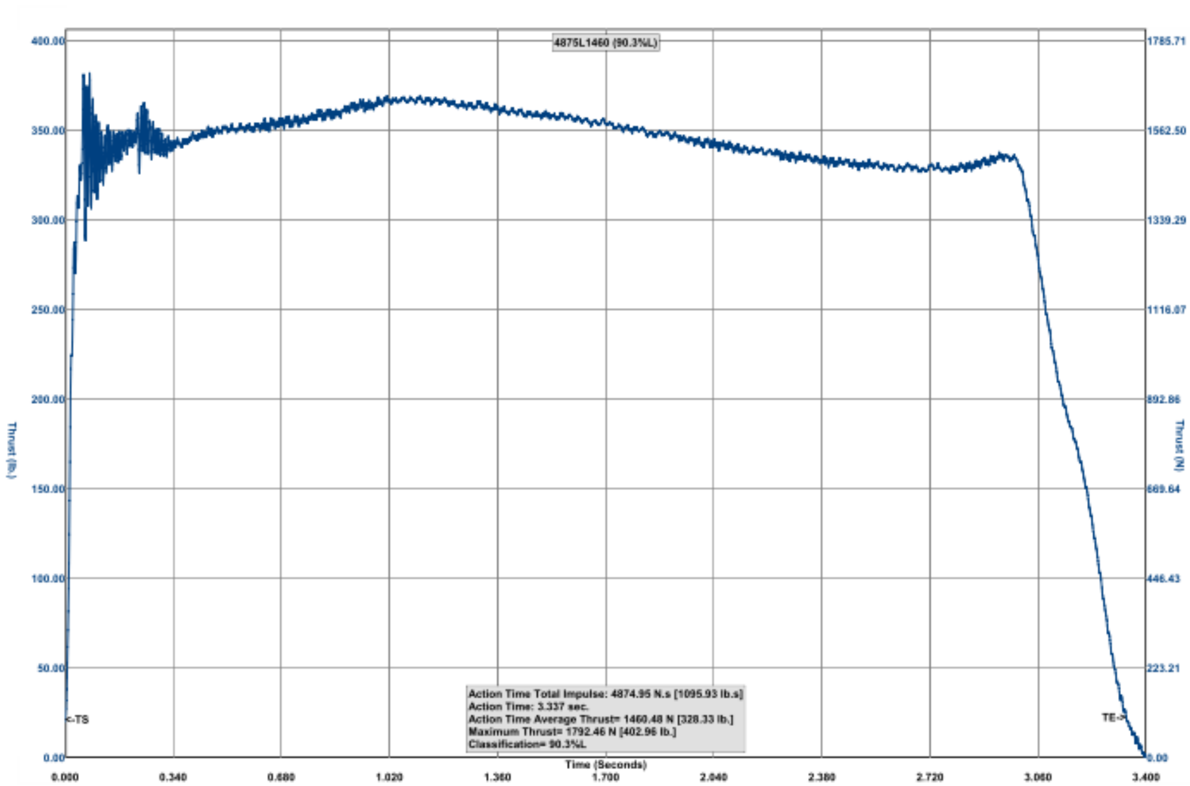

FIGURE 13:L1395 THRUST PROFILE

Future flight profile modeling will more accurately define the launch conditions, including launch pad altitude, predicted weather conditions (relative humidity, average wind speed, etc.), and competition settings. Immediately before the flight, these conditions will be taken into account and the mass of the ballast will be adjusted according to on-site simulations to achieve the predicted altitude given the very best initial conditions simulations the team can generate.

3.3.3 STABILITY PREDICTIONS

Initial modeling shows that the CP will be at 91.25” from the nose tip, and the CG at 67.2” from the nose tip at launch and 63” at burnout. This provides 3.9 calibers of stability at launch, which is slightly over the 1.8 calibers needed given the length to diameter ratio of the rocket. This extra stability is being kept due to the unknowns that are involved with liberating fluttering fins during flight. With only the 3 primary fins, the static stability margin is 3.3 calibers. After the first test flight, it is likely that the stability margin will be reduced in order to reduce weathercocking in high winds. This will be followed by more test flights ensuring that the performance during fin failure is acceptable.

3.4 PAYLOAD INTEGRATION

3.4.1 PROCEDURE

The payload will be integrated as follows:

- The fins, which will have pre-installed strain gauges will be mounted to the fin attachment unit
- The strain gauge wiring will be run up the side of the motor tube
- The cameras and recording electronics will be installed in the avionics bay
- The avionics bay will be placed on top of the fin assembly
- The strain gauge wires will be plugged into the corresponding plugs on the avionics bay
- The lower tube will be slid over the avionics bay/fin unit
- The lower tube and avionics bay will be screwed into the fin unit
- The rest of the rocket assembly will continue with integration of the drogue parachute and high school payload. The two body tubes will be joined together, the internal quick link connected and the door in the side of the airframe closed.
- Finally, the machined mirror mounts, outlined in section 4.1, will be screwed into their proper position on the rocket body tube.

3.4.2 INTERNAL PAYLOAD INTERFACES

The interfaces between the structural components of the vehicle are described in the vehicle section. All of these interfaces will use components that are designed to fit said interfaces, either commercially provided components or CNC cut components. These interfaces include bulkheads, avionics bay boards, the fin unit, tubes, the recovery system and nose cone.

3.4.3 LAUNCH VEHICLE AND GROUND INTERFACES

Beyond the launch pad, which is discussed in 3.4.5, a wireless transmitting interface will be used to activate the cameras shortly before launch. This transmitter will turn on the cameras and at the same time turn on a loud buzzer that will be audible at the LCO table.

3.4.4 LAUNCH VEHICLE AND LAUNCH SYSTEM INTERFACES

The launch vehicle will interface with the ground launch system in 2 areas:

- The launch pad. This will be accomplished with a pair of Delrin 1515 rail buttons, one into the base of the rocket and located just below the avionics bay
- The alligator clips from the launch controller will be connected to the rocket motor igniter

3.5 LAUNCH OPERATION PROCEDURES

3.5.1 LAUNCH SYSTEM AND PLATFORM

Launch Pad

We will be using a custom build launch pad that is constructed from 1.5" aluminum extrusion. It has a 7' square footprint and will have an 8' long 1515 rail attached.

Launch Controller

We will be using the controller provided by the clubs we will be doing test flights with and the controller provided by the NASA range

3.5.2 CHECKLISTS AND STANDARD OPERATING PROCEDURES

Caution Statement

Recall the Hazards Recognition Briefing. Always wear proper clothing and safety gear. Always review procedures and relevant MSDS before commencing potentially hazardous work. Always ask a knowledgeable member of the team if unsure about equipment, tools, procedures, material handling, and/or other concerns. Be cognizant of your and others' actions. Keep work station as clutter-free as possible.

Equipment Packing Checklist:

1. Support Equipment and Tools
    a. Safety Gear
        i. Goggles
        ii. Rubber Gloves
        iii. Leather/Work Gloves
        iv. Face Masks
        v. All Safety Documents and References

b. Furniture
    i. Tent (1x)
    ii. Tables (2x)
    iii. Chairs (6x)
    iv. Rocket assembly benches
c. Generator
    i. Gas
    ii. Power Strip(s) (3x)
    iii. Extension Cord(s) (3x)
d. Tools
    i. Corded Drill
    ii. Cordless Drill
        1. Cordless Drill Batteries
        2. Charger
    iii. Drill Bit Index(s)
    iv. Wrench Set
    v. Pliers
    vi. Screwdriver Set
    vii. Hex Keys Set
    viii. Files
    ix. Sandpaper
    x. Knives
    xi. Flashlight
    xii. Soldering Iron
        1. Solder
        2. Solder Wick
        3. Sponge
    xiii. Wire Cutter/Stripper(s)
    xiv. Extra Wire (Black and Red)
    xv. Pocket Scale
e. Adhesive
    i. 5-minute Epoxy (2 part)
    ii. CA and Accelerant
    iii. Aeropoxy (2 part)
    iv. Epoxy Mixing Cups
    v. Popsicle Sticks
    vi. Foam (2-part)
    vii. Foam (solid)
f. Other supplies
    i. Tape

            1. Duct Tape
            2. Scotch Tape
            3. Vacuum Tape
            4. Electrical Tape
            5. Masking Tape
            6. Gaffer’s Tape
        ii. Trash Bags
        iii. Isopropyl Alcohol (general clean up)
        iv. Water Bottle
        v. Camera Lens Cleaning Supplies
        vi. Paper Towels
        vii. Wipes
        viii. Spare Hardware
        ix. Lithium/Silicon Grease (for building reload; other)
        x. Zip-ties
        xi. Talcum Powder (for parachutes)
2. Ground Support
    a. Yaesu VX-8GR and Arrow Antennas 7 element Yagi Antenna
    b. Miniature Weather Station (wind speed/direction, temperature)
    c. Camera remote control
3. Launching Equipment
    a. Launch Pad
    b. Launch Rail
    c. Angle Measuring Tool
4. Rocket
    a. Body
        i. Lower Tube Section
        ii. Upper Tube Section
        iii. Nose Cone
        iv. Ballast
        v. Shear Pins (10x)
    b. Recovery
        i. Parachutes
            1. Drogue (2x)
            2. Main (2x)
            3. Nomex Parachute Protectors (3x)
            4. Deployment Bag
        ii. Shock Cord (40’)
        iii. Ejection Charges
            1. Black Powder

        2. Igniters (4x)
    iv. Charge Released Locking Mechanism (2x)
    v. Quick links (10x)
  c. Motor
    i. Casing
    ii. Reload (2x)
  d. Avionics
    i. Avionics Bay
    ii. Altimeters
        1. Raven2 (2x)
        2. Stratologger (2x)
    iii. 9V Batteries (10x)
    iv. Beeline 70cm Trackers (4x)
    v. Hardware
        1. 4-40x1” bolts (10x)
        2. 4-40 locknuts (6x)
5. Miscellaneous
  a. Digital Camera
  b. Video Camera
  c. Extra Batteries
  d. Binoculars
  e. Two-Way Radios
  f. Two-Way Radio Chargers

Pre-Flight Checklists:

1) Integrate Avionics Bay
  a) Integrate the altimeters and tracker
  b) Integrate 2 New Batteries
  c) Test electronics (turn on and off)
  d) Wire ejection charge wires through upper avionics plate
  e) Insert threaded rod and eye nut through avionics bay
  f) Slide assembly into tube
  g) Check all connections
  h) Check pressure holes
  i) Install motor into motor mount tube and screw into threaded rod to hold avionics bay in
2) Make Black Powder Ejection Charges and assemble Tender Descender
   (Safety Officer will oversee this step)
3) Integrate rocket body with high school payload assembly by sliding the payload into the upper tube, ensuring the proper end is up
4) Recovery*

a) Attach Tender Descender to ejection charge wires from avionics bay
b) Attach Tender Descender shock cord to the upper Tender Descender quick link
c) Attach the lower Tender Descender quick link to the avionics bay eye-nut
d) Attach main parachute shock cord to avionics bay eye-nut
e) Place main parachute deployment bag in lower tube
f) Attach deployment bag line to Tender Descender shock cord

5) Nose Cone
   a) Turn on and install tracker
   b) Attach parachute to shock cord with a Girth Hitch
   c) Attach shock cord to nose cone with bowline knot
   d) Attach shock cord to the top of the sabot hardpoints with water knot
   e) Attach ejection charges to wires on sabot
   f) Place ejection charges in nose
   g) Fold and pack parachute in nose
   h) Install nose on upper tube
   i) Install shear pins
6) Tube integration
   a) Install Tracker
   b) Ensure that the quick link and ejection charge wires in the lower tube are easily accessible
   c) Slide upper tube on to lower tube
   d) Install alignment bolts
   e) Connect the two (2) ejection charge wires to the high school payload unit
   f) Connect the quick link to the Tender Descender and the deployment bag to the lower side of the high school payload unit.
   g) Install detachable door with screws

Launch Checklist:

1. Get approval from event administration to set up pad, ELS, and rocket
2. Set up pad
3. Tip pad over and install rail
4. Check all tube interfaces
5. Slide rocket onto rail down to stop
6. Tip up launch pad
7. Stake pad to ground
8. Arm Electronics
   a. Listen for proper beeps
9. Put igniter into motor and secure it
10. Connect launch clips
11. Clear launch area/back up appropriate distance
12. Get approval from event administration for launch

The following depend on procedures outlined by event administration:

13. Check to see if range and skies are clear
14. Insert key into the launch system to check continuity
15. Countdown from 5
16. Launch
17. Remove key from launch system
18. Disconnect launch system from battery
19. Recover Rocket

3.6 SAFETY AND ENVIRONMENT

3.6.1 IDENTIFICATION OF SAFETY OFFICERS

Andrew Wimmer will be the primary rocket safety officer for the team. Ben Corbin is the team's MIT EHS representative and is the assistant safety officer and is in charge of safety issues not directly related to the rocket. Both team members have considerable experience in their respective areas.

3.6.2 ANALYSIS OF FAILURE MODES AND MITIGATIONS

The following table provides a preliminary analysis of the failure modes of the proposed vehicle design, integration and launch operations.

TABLE 6: POTENTIAL FAILURE MODES

Failure Mode	Effects	Precautions to prevent result	Precautions to prevent event
Motor Failure	Property Damage, Injury	Stand up, follow path of rocket visually, move if needed. Follow proper launch safety distances	Store and assemble motor in accordance with manufacture's instructions
Recovery System Entanglement	Property Damage, Injury	Follow rocket's descent path visually, move if needed	Design and rigorously test recovery system in accordance with accepted HPR standards
Recovery System Structural	Property Damage, Injury	Follow rocket's descent path visually, move if needed	Perform pull tests on unrated components to ensure their strength.

Failure (bulkheads, shockcords, etc)			Components to be tested to 50g shock loads
Recovery System failure to deploy	Property Damage, Injury	Follow rocket's descent path visually, move if needed	Ensure rigorous testing of black powder charges, Tether release mechanisms and deployment altimeters and power supplies. Don't forget to arm altimeters
Recovery Device deployment on ground	Property Damage, Injury (especially eye)	Avoid placing body in path of parts if electronics are armed. Wear safety glasses if necessary.	Shunt charges until they are attached to recovery electronics. Do not move the rocket with armed electronics.
Unstable Vehicle	Property Damage, Injury	Stand up, follow rocket's path visually, move if needed. Confirm vehicle stability before launch.	Ensure actual CG position is acceptable relative to calculated CP
Brush Fire	Fire damage, injury	Have fire protection equipment and personnel trained in its use onsite	Follow NFPA table for dry brush around pad area.
Mid-flight vehicle destruction (excessive forces on vehicle)	Loss of vehicle, Injury, Property damage	Follow rocket's path visually and move if needed if vehicle does come apart	Design, construct and test vehicle to assure successful flight. Use standard construction procedures for LII-LIII rockets, including sufficient bulkheads, fins, motor retention and couplers.
Fin liberation mid flight	Small fin falling from rocket at reasonable speed	Visually track fin and move if needed	Rigorously test fin recovery system to ensure adequate visibility and reliability of aerodynamic breaking

			method

3.6.3 PERSONNEL HAZARDS

A listing of personnel hazards and evidence of understanding of safety hazards is provided in the sections below.

Safety Checklist

In order to assure a safe and successful flight, a checklist must be followed during prep activities and launch. In order to reduce personnel hazards during the prep of the vehicle before taking it to the pad, the following precautions must be taken.

- Always wear safety glasses when dealing with rocket parts containing small hardware or pyrotechnic charges.
- Never look down a tube with live pyrotechnic charges in it.
- Always point rocket and pyrotechnic charges away from body and other people
- Avoid carrying devices that have live electrical contacts (radios, cell phones, etc.) while prepping live pyrotechnic charges.
- Never arm electronics when rocket isn’t on pad unless the area has been cleared and everyone knows that pyrotechnic continuity checks are being done.
- Always follow the NAR/TRA safety codes.
- Always follow all applicable local, state and national laws and regulations
- Do not allow smoking or open flames within 25 feet of the motor or pyrotechnics.
- Make sure the checklist is followed and all steps are completed properly in a thorough, workmanlike manner to assure mission success.

To further ensure mission success, considerations must be taken while at the launch prepping and flying the vehicle to keep all the people around and the vehicle itself safe. Important safety related considerations are found in the following list:

- Always follow the NAR/TRA safety code.
- Adhere to local, state and federal regulations.
- Never arm electronics unless rocket is vertical and the criterion for testing continuity listed above is met.

- Never proceed with launch if there are any outstanding technical issues that may reduce the chances of a safe flight without first consulting both safety officers and NASA officials if needed.
- No smoking or open flames within 25 feet of the vehicle.
- Do not put self or others in path of body tube in case of early ejection on the ground; always be aware of the possibility of ejection charges firing at any time.
- Verify that ignition leads are not live before connecting igniter to ground control. (A simple test is to touch the leads together in the shade and listen and watch for sparks, or place against tongue)
- Verify rocket will exit launching device vertically with almost no friction from the launch guides
- Verify that ground around launch pad is cleared of flammable materials.

TABLE 7: TOOL INJURY POTENTIALS AND MITIGATION

Tool:	Injury Potential:	Risk mitigation procedure:
Electric Handheld Sander	Burns, cuts, skin abrasion	Avoid loose clothing
Soldering Iron	Burns	Exhibit care not to come in contact with hot element
Table Saw	Cuts, Limb/appendage removal	Avoid loose clothing, follow safety procedures found in instruction manual.
Wood Lathe	Cuts, broken appendages	Avoid loose clothing, use proper tools and safety equipment
Table Router	Cuts, Limb/appendage removal	Use proper protective gear.
Drill Press	Cuts, abrasion, loss of limbs/ appendages	Use proper protective gear, hold down work with clamps
Miter Saw	Cuts, Limb/appendage removal	Avoid loose clothing, follow safety procedures found in instruction manual.
Band Saw	Cuts, loss of limbs/appendages	Use proper protective gear.
Belt Sander	Burns, skin abrasion	No loose clothes, wear proper protective gear (gloves)

CNC Water cutter	Cuts, loss of limbs/appendages	Only trained personnel use this tool (machine shop employees)

Safety Codes

The Tripoli Rocketry Association and the National Association of Rocketry have adopted NFPA 1127 as their safety code for all rocket operations. A general knowledge of these codes is needed and will be required by all team members. These codes are found in Appendix 2.

Hazards Recognition

The Hazards Recognition Briefing PowerPoint Presentation will be given prior to commencing rocket construction. It will cover accident avoidance and hazard recognition techniques, as well as general safety.

1) General
   a) Always ask a knowledgeable member of the team if unsure about:
      i) Equipment
      ii) Tools
      iii) Procedures
      iv) Materials Handling
      v) Other concerns
   b) Be cognizant of your own actions and those of others
      i) Point out risks and mitigate them
      ii) Review procedures and relevant MSDS before commencing potentially hazardous actions
   c) Safety Equipment
      i) Only close-toed shoes may be worn in lab
      ii) Always wear goggles where applicable
      iii) Always use breathing equipment, i.e. face masks, respirators, etc, where applicable
      iv) Always wear gloves where applicable, e.g. when handling epoxy and other chemicals
2) Chemicals
   a) The following are risks of chemical handling:
      i) Irritation of skin, eyes, and respiratory system from contact and/or inhalation of hazardous fumes.
      ii) Secondary exposure from chemical spills
      iii) Destruction of lab space
   b) Ways to mitigate these risks:
      i) Whenever using chemicals, refer to MSDS sheets for proper handling

    ii) Always wear appropriate safety gear
    iii) Keep work stations clean
    iv) Keep ventilation pathways clear
    v) Always wear appropriate clothing

3) Equipment and Tools
    a) The following are risks of equipment and tool handling:
        i) Cuts
        ii) Burning
        iii) General injury
    b) Ways to mitigate these risks:
        i) Always wear appropriate clothing, e.g. closed-toed shoes.
        ii) Always wear appropriate safety equipment
        iii) Always ask if unsure
        iv) Err on the side of caution
4) Composites Safety
    a) Carbon fiber, fiberglass, epoxy, and other composite materials require special care when handling.
    b) The following are risks composites handling:
        i) Respiratory irritation
        ii) Skin irritation
        iii) Eye irritation
        iv) Splinters
        v) Secondary exposure
    c) Ways to mitigate these risks:
        i) Always wear face masks/respirators when sanding, cutting, grinding, etc., lay-ups.
        ii) Always wear gloves when handling pre-cured composites
        iii) Always wear puncture-resistant gloves when handling potentially sharp composites
        iv) A dust-room has been constructed, as per MIT EHS guidelines, specifically for the handling of composite materials.
    d) No team member will handle carbon fiber until properly trained

3.6.4 ENVIRONMENTAL CONCERNS

- All waste materials will be disposed of using proper trash receptacles
- Biodegradable and flame resistant recovery wadding will be used
- Solid rocket motor manufacturers’ instructions will be followed when disposing of any rocket motor parts
- Consideration of environmental ramifications will be made regarding applicable activities

- Proper blast shields on the launch pad will be used to prevent direct infringement of rocket motor exhaust on the ground
- Waste receptacles (trash bags) will be available for use around the prep area to encourage proper disposal of waste from rocket prep activities
- The following list of materials have been identified as potentially hazardous:
    a. Aeropoxy 2032 Epoxy Resin
    b. Aeropoxy 3660 Hardener
    c. Ammonium Perchlorate Composite Propellant
    d. Black Powder

See Appendix 1 for complete MSDS specifications on these materials.

4 PAYLOAD CRITERIA

4.1 SELECTION, DESIGN, AND VERIFICATION OF PAYLOAD EXPERIMENT

4.1.1 SYSTEM LEVEL DESIGN

The payload will meet the following objective:

Determine the accuracy of existing fin flutter simulators and equations by successfully comparing experimental fin flutter data to theoretical predictions. The predicted time and velocity at which the fins flutter as well as the predicted fin deflections versus velocity will be compared to actual values derived from testing.

The main payload of the rocket will be a fin flutter measurement system to quantitatively analyze the fin flutter induced modes in the three extra test fins. This measurement system will consist of high speed cameras, mirrors, strain gauges, an on-board computer, and solid state memory. Together, these systems will allow the rocket to collect reliable fin flutter data during flight to be analyzed after rocket recovery. Using the data to find test fin stress, strain, defection as a function of time and position, a first mode fin flutter model will be created and compared to expected models and stress behavior as dictated by fundamental fin flutter equations.

4.1.2 SUBSYSTEMS

1. FIN DESIGN

The three test fins, used to measure fin flutter, will be located at the same distance from the nose cone as the main rocket stabilization fins, in order to meet the USLI regulation concerning the prohibition of forward canards on rockets, with a single fin placed evenly in between two main fins. The test fins will be machined from 0.318cm thick sheets of G-10 fiberglass. The dimensions of the fin were chosen, using a fin flutter estimator provided by Rocketry Online (R.O.), to display 1st mode fin flutter at a velocity expected to be achieved by the rocket and as to not interfere with the overall stability of the rocket. The fins will be attached to the rocket body as dictated by the rocket section of the document. Once we have the information from R.O, we can start writing a MATLAB simulation of the fin flutter equations for 1^{st} modes (Note this will use the fin flutter equations found from R.O. and other sources). The parameters of the simulation will be the fin shape, material properties, and rocket velocity (apparent wind velocity). The results of this simulation will be compared to the R.O. simulation, specifically the velocity need to “induce flutter”. Two types of fin geometries are presented, trapezoidal and rectangular. Currently, trapezoidal fins will be flown for the spring launch, however this may change prior to CDR. The results from R.O. shows that for the given fin geometries at least one fin will not flutter off (shred) at velocities less than or equal to the predicted maximum rocket velocity of 409 m/s.

TABLE 8: FIN TRAPEZOIDAL DIMENSIONS

	1	2	3
Root Chord	30.480 cm	30.480 cm	30.480 cm
Tip Chord	15.240 cm	12.700 cm	15.240 cm
Span(Height)	20.320 cm	15.240 cm	12.700 cm
Sweep length	11.609 cm	11.574 cm	11.574 cm
Sweep angle	29.74	37.2	42.35

TABLE 9: FIN RECTANGULAR DIMENSIONS

	1	2	3
Root Chord	9 in	9 in	8.5 in
Tip Chord	9 in	9 in	8.5 in
Span(Height)	8 in	6 in	5 in

TABLE 10: G-10 FIBERGLASS MATERIAL PROPERTIES

Density	1.91 g/cm^3
Shear Modulus	7.69 Gpa
Modulus of Elasticity	20 Gpa
Poisson's Ratio	0.3

TABLE 11: ROCKETRY ONLINE RESULTS-SWEPT TRAPEZODIAL

V_{max} Simulated (mph)	V_{max} Simulated (m/s)	Flutter Velocity (mph)	Flutter Velocity (m/s)	Predicted Outcome	Velocity Ratio
469.75	209.99704	162	72	Shred	191
469.75	209.99704	212	95	Shred	122
469.75	209.99704	299	134	Flutter	57

TABLE 12: ROCKETRY ONLINE RESULTS-RECTANGULAR

V_{max} Simulated (mph)	V_{max} Simulated (m/s)	Flutter Velocity (mph)	Flutter Velocity (m/s)	Predicted Outcome	Velocity Ratio
469.75	209.99704	176	78	Shred	168
469.75	209.99704	254	113	Flutter	85
469.75	209.99704	326	146	Flutter	44

2. STRAIN GAUGE DESIGN

Each fin will be fitted with at least 4 Omega 1-Axis Precision Strain Gauges, arranged in a 'C' shape, to record strain data for each fin during flight. The size and type are noted in section 4.1.7. The gauges are simply glued to the fin as the method of attachment and the lead wires will be integrated into the rocket body tube such that gauges can be connected to a male wire terminal which plugs into a female wire terminals located on the bottom of the avionics and cameras bay, located near the top of the bottom rocket body tube. The terminals are arranged in a Wheatstone bridge circuit which is connected to the on-board computer, an Arduino Mega, which will be programmed to read and save amplified voltages of the connected gauges. The time of flight between launch and peak velocity is approximately 3 seconds. This results in very little time for data collection; hence, in order to gain a reasonable amount of reliable data the computational time of the Arduino Mega has to be as fast as possible. To decrease computation time on the Arduino Mega calculations to find the resulting deflections versus time and velocity will take place in a post flight MATLAB script. An accelerometer is also connected to the Arduino Mega. This not only provides an optional way to measure rocket velocity, but it also allows the Arduino to record the strain gauge data versus velocity during flight without having to rely on the flight computers used for rocket recovery. This data is then saved to a 2 GB SanDisk Flash memory card with is then compared to the expected stress strain response as documented by fin flutter equations and simulations for a given test fin. See section 4.1.5 for the Arduino Mega wiring diagram.

4.1.2.1.1 OUTLINE OF THE STRAIN GAUGE ARDUINO CODE

Strain Gauge Arduino Code Outline:

Time_Interval = 30000;

System_Time_Check = getSystemTime;

main{

//Data will be stored in an array of matrices

Strain_Gauge_Array = [Strain_Gauge_Matrix_1; Strain_Gauge_Matrix_2; Strain_Gauge_Matrix_3;];

//Data will be stored in a matrix for each strain gauge

Strain_Gauge_Matrix_1 = [Measured_Resistance; System_Time; Rocket_Acceleration;];

Strain_Gauge_Matrix_2 = [Measured_Resistance; System_Time; Rocket_Acceleration;];

Strain_Gauge_Matrix_3 = [Measured_Resistance; System_Time; Rocket_Acceleration;];

//Read resistances from strain gauges

Number_of_Gauges = length(Strain_Gauge_Array);

for i = 1:Number_of_Gauges{

Pin_Start = 0

Strain_Gauge_Array[i] = [read(PinOut(i+Pin_Start)); getSystemTime; getRocketAcceleration;];

}

//Save data to SD card

//Data is written to SD card every 30 seconds. This insures that data is not being saved during rocket assent, reducing //computation time.

If (getSystemTime >= System_Time_Check + Time_Interval){

writeSDcard(println(Strain_ Gauge_Array));

System_Time_Check = getSystemTime;

}

```
}
readPinOut{
//Obtains the measured analog voltage/resistance for a give pin on the Arduino
}
getSystemTime{
//Obtains the current arduino's internal time
}
getRocketAcceleration{
//Obtains the current rocket acceleration from accelerometer wired to the Arduino
}
```

3. HIGH SPEED CAMERA DESIGN

The avionics and cameras tube also contains the rocket altimeters and flight computers (Featherweight Raven2 and Perfectflite Stratologger) needed for payload and parachute deployment and rocket recovery in addition to the three Casio Exilim EX-FC150 high speed digital cameras used for fin flutter measurement. Using a specially design mounting system, to reduce excess vibrations during flight, the cameras will be placed in the avionics and cameras bay with each camera positioned 120 degrees apart from its neighbor with the lens facing outward in the radial direction of the body tube. Also, the power switch for each camera will be wired together, and connected to a physical switch which is accessible during rocket integration. To prevent the cameras from running out of power or memory before launch, the shutter switch for each camera will be wired together in a remote switch circuit. This circuit contains a receiver, two radio relay switches wired in parallel and a piezo buzzer.The basic concept is that, just before launch, a radio transmitter will signal the receiver to complete the remote switch circuit thereby starting recording. There are multiple switches in parallel for redundancy, and the buzzer lets the ground team know that camera shutters have been turned on. See section 4.1.5 for the Avionics and Camera Bay CAD model. Also see section 4.1.5 for the remote switch wiring diagram.

4. MIRROR DESIGN

The avionics and camera bay, and the bottom rocket body tube will have three 1.35 inch diameter holes integrated into them to allow each camera to view the outside of the rocket while being aligned to a test fin. Each hole will have a 1.35 x 1.35 inch mirror angled at 30-35 degrees from the body tube so that each camera can have a head on view of its respective test fin. The mirror size and position is calculated by a team written MATLAB script to obtain the smallest mirror drag profile for a given set of rocket and fin parameters and camera variables. Each mirror is placed on a machined angled mount that is integrated into the rocket body tube. See section 4.1.5 for a more detailed view of the machined mirror mount CAD model.

5. MIRROR MOUNT CAD MODEL

The mirror is comprised of two major parts, the angled mirror holder and the crescent shaped mount that the mirror holder screws into. The crescent mount will be integrated with the rocket body tube during body tube fabrication. It will be glued to the body tube before the final layer of carbon fiber is laid. The final layer of carbon fiber will be applied over the mount with sections cut out in order to expose the screw terminals for the mirror holder. The mirror holder is then attached to the crescent mount during rocket integration. This process enables a safe and quick rocket integration as well as ensuring that the mirrors will remain secure to the body tube during flight.

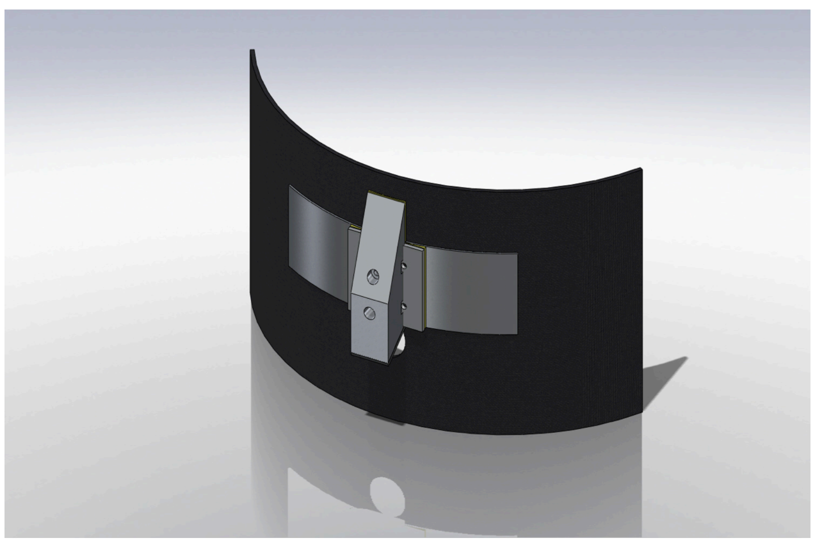

FIGURE 14: MIRROR ASSEMBLY

6. DATA RETRIEVAL AND PROCESSING

MATLAB Fin flutter Simulator

The team will write its own fin flutter simulator script using a set equations that are different from the ones used on the R.O. simulator. The results of this MATLAB script will also serve as another theoretical model to compare the experimental results to.

Strain Gauge Data

The team will write a MATLAB script to covert the strain data saved on the SD card to deflection using the fundamental equations of strain-displacement relationships for 2-D bodies.

Video Data

During flight each camera will record test fin movement at approximately 480 frames per second and store this video data on a Transcend 8 GB HC SecureDigital Class 6 (SDHC) Card. The maximum recording time we can achieve with the memory card and extended battery will be tested. If it is found that the recording time is one of the limiting factors, either the memory or the battery capacity will have to be increased, however the factory estimated battery life exceeds USLI requirements as outlined in section 4.1.7. Video data will also be transmitted to the ground station using three 2.4GHz Aerial Video Systems transmitters, one for each camera. Video frames will be analyzed by the ground station during and after flight using OpenCV, a C based open source computer vision programming language. To get the OpenCV code to know that the rocket has launched, a small led is placed at the top of the test fin, on the rocket body tube. Once the rocket fires, the accelerometer that is wired to the Arduino lights the led blink for 10 milliseconds. The OpenCV algorithms will count the video frames starting from when it notices the blue led; hence, the time before rocket launch is ignored and the video data is then synchronized with the strain gauges and the flight time. Using the OpenCV algorithms of shape and color recognition, the team will write executables to track leading and trailing edge fin deflection by calculating how a certain location on a fin appears in each video frame. These locations will be denoted by rectangle or circular markings spaced evenly along the width of the fin. The basic idea is to use the markings to obtain pixel locations over time. How these points move over time can be converted into functions of position and time and these equations can be compared to the expected 1st mode fin flutter functions for a given test fin.

7. OPENCV CODE PART A OUTLINE

Small red squares will be placed on the leading edge of the fin. The first square is placed at the point where the leading edge meets the rocket body tube; the rest of the squares are substantially placed at even intervals of 0.5 inches. Small yellow circles will be placed on both sides of the fin face near the trailing edge. Like the red squares, these also start at the rocket body tube and fin contact point and are placed every 0.5 inches. The OpenCV code will estimate the location of points on the fin and store these points in an array. Both shape and color tracking are used for redundancy, as point tracking for both the leading and trailing edges of the fin will return two arrays each, one from color tracking, and the other from shape tracking. For example, if the camera or code fails to recognize the shape of a point the position of that point can still be derived from color recognition. Similarity, if the camera or code fails to recognize the color of a point the position of that point can still be derived from shape recognition. The output of Part A of this code is a matrix were each row contains the video frame number and the generalized x and y pixel positions of each point.

8. OPENCV CODE PART B OUTLINE

Part B takes the matrix from Part A and converts its values into more physical and usable units. First, since the speed at which the camera is taking pictures is known, 420 frames per second, the time since launch for each frame can easily be deduced. The x and y pixel positions are converted to distances from the current position to initial position. These distances which are in pixels are then converted into meters using an empirically found meter to pixel ratio. The final output of Part B is a matrix were each row contains the time and the generalized displacement of each point from their initial value (just before launch) in meters. With this matrix one can plot the displacements/deflections and determine how warped a fin is at any given time.

Equation for Finding Image Frame Time:
Time [seconds]= (Frame Number [frames])/(Video Capture Rate [frames per second])

Equation for Finding Distance:
Distance [pixels] = sqrt((x_current - x_initial)^2+ (y_current - y_initial)^2)

> Positive displacement for x_current >= x_initial:
> Displacement [pixels] = Distance [pixels]
> Negative displacement for x_current < x_initial:
> Displacement [pixels] = -1*Distance [pixels]

Equation for Converting Pixels to Meters:
Displacement [meters] = (Displacement [pixels]) * (Meter to Pixel Ratio)

9. EXPECTED FINAL DATA

- Results from inputting rocket and fin parameters into theoretical fin flutter equations:
    - Theoretical calculations from Rocketry Online
        - Predicted time and velocity at which the fins experience flutter
    - Theoretical calculations from Matlab Fin Flutter Simulator

        - Predicted time and velocity at which the fins experience flutter
        - Predicted fin deflections versus time and velocity

- Results from inputting actual rocket flight data, strain gauge data, and camera data:
    - Calculations from Matlab Fin Flutter Simulator
        - Predicted time and velocity at which the fins experience flutter
    - Calculations from OpenCV
        - Actual time and velocity at which the fins experience flutter
        - Actual fin deflections versus time and velocity
    - Calculations from Matlab Strains to Deflection Converter
        - Actual time and velocity at which the fins experience flutter
        - Actual fin deflections versus time and velocity

- Computed errors between the resulting theoretical and experimental values.

4.1.3 VERIFICATION PLAN

Qualification testing on the electrical and structural components and software of the payload will performed as follows:

- The rigidity of the mirror mount will be testing using a wind tunnel to simulate predicted rocket conditions.
- All circuits, electric components, and the avionics bay will be tested and inspected with a voltage meter to check for potential safety hazards from shorts or open circuits.
- Software will be complied debugged before every ground and flight test were it is being used.
- The stability of the mounted components will be tested though vibration testing in order to simulate rocket conditions.

4.1.4 INTEGRATION PLAN

As the majority of the payload is inside the rocket avionics bay or on the rocket body, the payload integration procedure follows the plan that is outlined in section 3.4.

4.1.5 INSTRUMENTATION PRECISION

Strain gauge precision plays a large role in the payload mission, as they must be about to detect both large and small strains in the fin material over small period of time. For this reason industry standard strain gauges that meet are specific needs were carefully chosen. Also, the strain gauges will be rigorously tested and calibrated in order to get consistent and accurate measurements. A high speed camera was chosen to as a way to visibly display rapidly changing fin flections over a short period of time. The computer vision program openCV was chosen to analyze the collected video frames, as it could be programmed to quickly calculate minute distances in the images. Furthermore, the precision and sensitivity of the payload components is, when applicable, individually outlined in section 4.1.7.

4.1.6 DRAWINGS AND SCHEMATICS

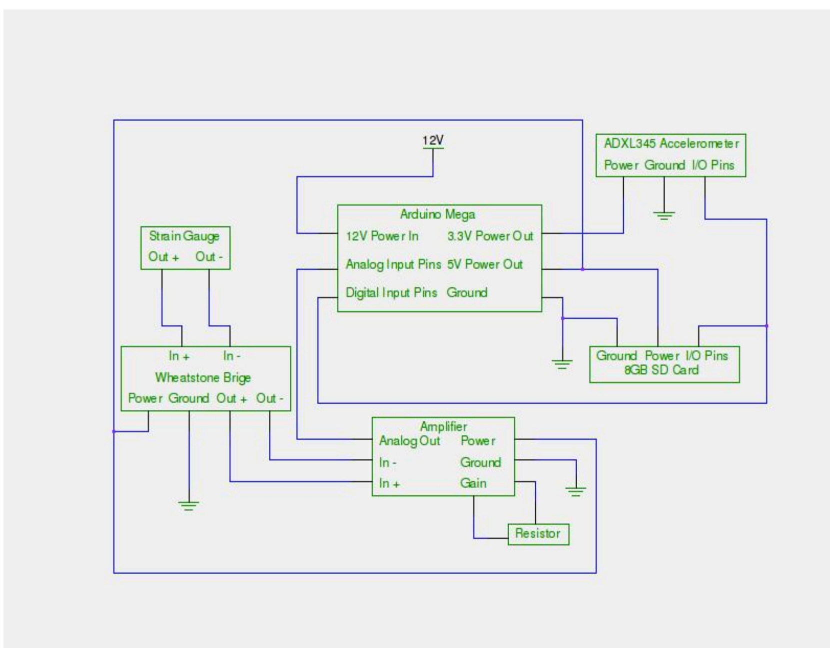

FIGURE 15: ARUINO WIRING DIAGRAM

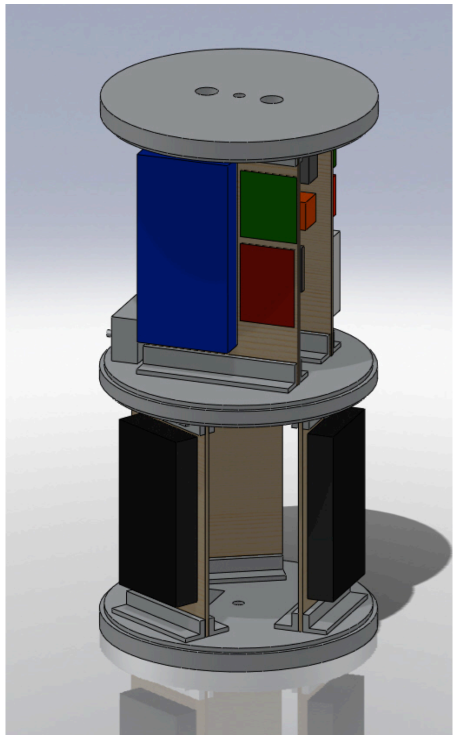

FIGURE 16: AVIONICS AND CAMERA BAY CAD MODEL VIEW 1

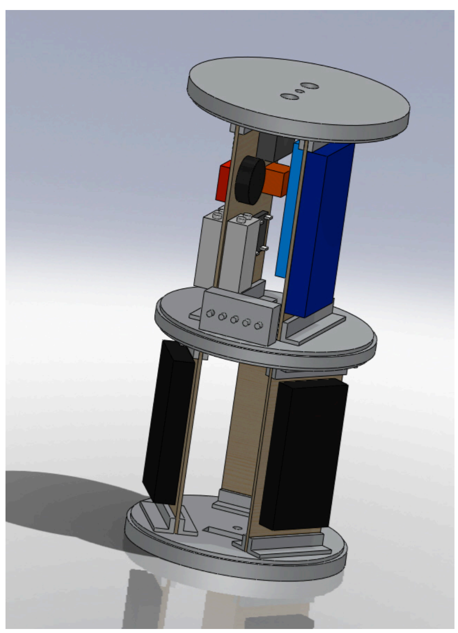

FIGURE 17: AVIONICS AND CAMERA BAY CAD MODEL VIEW 2

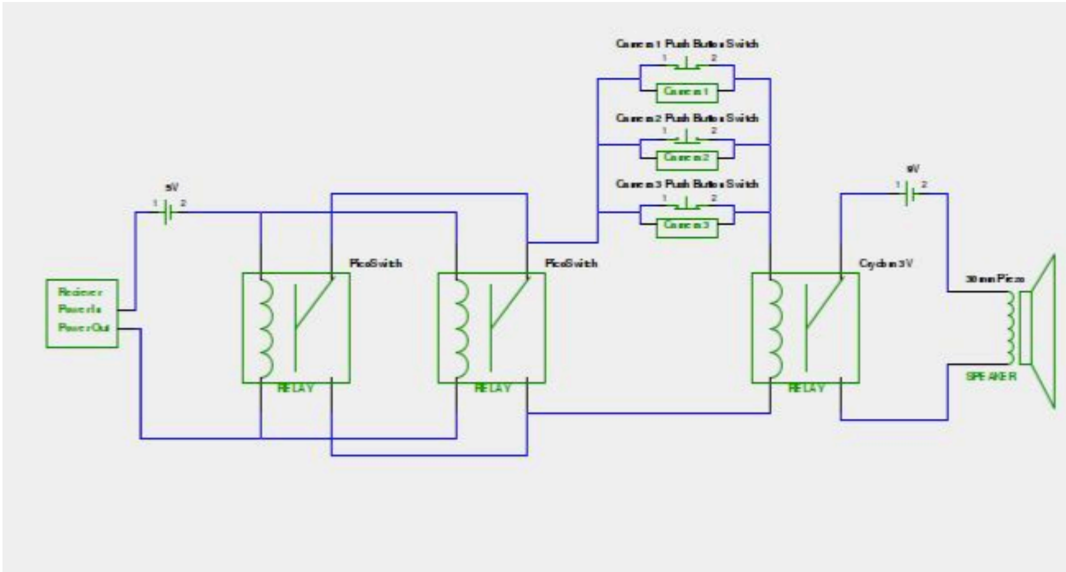

FIGURE 18: REMOTE SWITCH CIRCUIT DIAGRAM

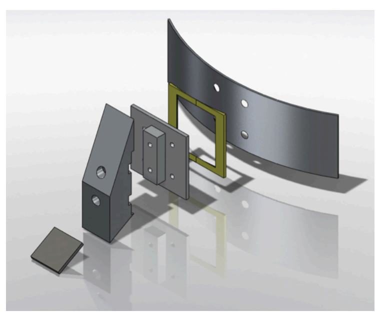

FIGURE 19: MIRROR MOUNT CAD MODEL FRONT VIEW

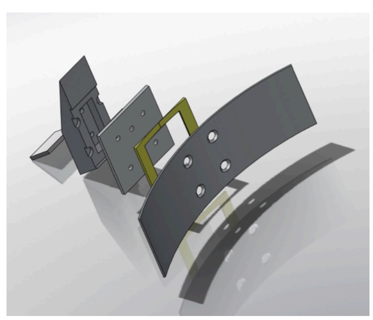

FIGURE 20: MIRROR MOUNT CAD MODEL BACK VIEW

4.1.7 KEY COMPONENTS

Arduino Mega

This micro-controller is used to obtain data from the strain gauges and accelerometer and write it to the SD card. It also controls the signaling leds on the outside of the rocket.

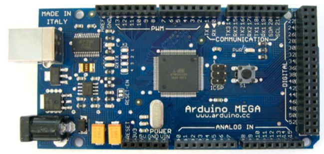

FIGURE 21: ARDUINO MEGA

TABLE 13: ARUINO MEGA SPECIFICATIONS

Recommended Input Voltage	7-12 V
Digital I/O Pins	54
Analog Input Pins	16
Flash Memory	128 KB
Clock Speed	16 MHz
Power Input Pin	6-20 V
Power Output Pins	5 V and 3.3 V
Temperature Range	-40 to +85 degrees Celsius
Dimensions (WxHxD)	108 x 53 x 15 mm
Weight	40 g

Casio Exilim EX-ZR100 High Speed Digital Camera:

The Casio Exilim EX-ZR100 is a store bought speed digital camera that will record fin movement at 480 frames per second during flight. The average lifetime of camera's battery is much greater than the estimated amount of time we will be using it (60 minutes of standby time plus 20 seconds of high speed recording time).

FIGURE 22: CASIO EXILIM

TABLE 14: CASIO EXILIM SPECIFICATIONS

Total Pixels	12.75 Megapixels
Sensor Size	1/2.3 in
Movie Frame Size	224 x 160 @ 480fps
Lens Type	EFL: 4.24-53mm (35mm equivalent: 24-300mm)
Focus Range	2 in (5.08 cm) – infinity
Aperture Range	f/3.0 (W) - f/5.9 (T)
Power Source	NB-130L Rechargeable Lithium-Ion Battery Pack
Continuous Movie Recording Time (High Speed)	2 hours 50 minutes
Dimensions (WxHxD)	4.13 x 2.33 x 1.13" / 10.49 x 5.92 x 2.87cm
Weight	7.2 oz (204 g)

Omega 1-Axis Precision Strain Gauges (Omega SGD-2/350-LY11):
Used to measure strains for static and dynamic applications with a high degree of accuracy.

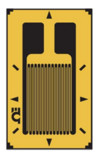

FIGURE 23: STRAIN GAUGE

TABLE 15: STRAIN GAUGE SPECIFICATIONS

Grid Dimensions	0.079 x 0.098in
Carrier Dimensions	0.299 x 0.228in
Pattern Type	linear
Resistance	350
Maximum Voltage	7.5

SD Card Breakout Board:
This breakout board serves as a holder to the SD card which will contain the strain gauge and accelerometer data. It also allows easy wiring of the solid state memory drive to the Arduino Mega. A SD card was used as the preferred memory device due to its small size, weight, ease of reading and writing on personal computers and microcontrollers.

FIGURE 24: BREAKOUT BOARD

TABLE 16: BREAKOUT BOARD SPECIFICATIONS

Dimensions	1.3x1.5in

Triple Axis Accelerometer Breakout – ADXL345

This accelerometer is used to synchronize the initial rocket launch between the strain gauges and the cameras. It does this by allowing the Arduino Mega to detect a large change in acceleration in the vertical direction, ie launch; the Arduino Mega can then set the time that this event occurred as the initial value for launch time and can send a visual signal to the cameras so that during video payback the estimated time of liftoff can be exactly the same as the estimated time of liftoff for the strain gauges. The accelerometer helps to reduced potential errors, as without it there would be no way to confirm the exact time at which a certain piece of data was recorded.

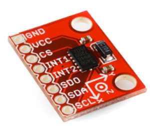

FIGURE 25: ADXL345 BREAKOUT BOARD

TABLE 17: ACCELEROMTER SPECIFICATIONS

Operating Voltage Range	2.0-3.6V
Measurement Rate	6.25-3200Hz
Turn-On Time	1.4 ms
Operating Temperature Range	-40 to +85 degrees Celsius
Sensitivity	29-36 LSB/mg
Dimensions	1.75x1.25in
Weight	20mg

30mm Piezo Buzzer: 1-30V

The piezo buzzer is used as a simple way for the ground team to know that the receiver that controls the camera shutter switches has successfully received a signal. This is useful in preventing the accidental transmission of multiple signals that could result in the cameras being on standby instead of filming during launch.

FIGURE 26: 30MM BUZZER

TABLE 18: BUZZER SPECIFICATIONS

Operating Voltage Range	1-30V
Maximum Current	5mA
Minimum Sound Output at 10cm	90dB
Resonant Frequency	2500Hz
Operating Temperature Range	-40 to +85 degrees Celsius
Dimensions(RxD)	3.7x14mm
Weight	5g

Hobby King GT-2 2.4Ghz Receiver 3Ch

Receiver that sends power to the PicoSwitch relay after receiving a signal transmitted by the ground team just before launch.

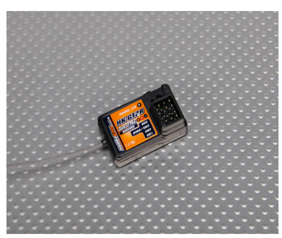

FIGURE 27: RECEIVER

TABLE 19: RECEIVER SPECIFICATIONS

Channels	3ch
Frequency Band	2.4Ghz
Modulation	GFSK
Sensitivity	1024
Power	4.5-6V
Antenna length	26mm
Dimensions	37.6x22.3x13mm
Weight	19g

PicoSwitch radio controlled relay

These relays act as push button switches as a replacement for the cameras shutter button. This system of radio controlled relays reduces the amount of irrelevant data recorded by the cameras while the rocket is sitting on the launch pad.

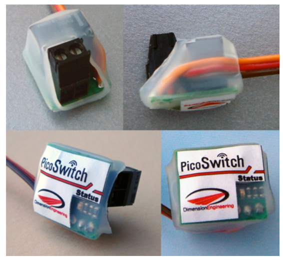

FIGURE 28: PICOSWITCH

TABLE 20: PICOSWITCH SPECIFICATIONS

Operating Voltage Range	3.5-5.5V
Max Relay Voltage	60V
Dimensions	20x16x16mm
Weight	7.6g

4.2 PAYLOAD CREATIVITY AND ORIGINALITY

The idea of experimentally field testing rocket fin flutter is a fairly recent idea. Some rocket enthusiasts have tested this phenomena and even a few large companies have begun to explore this area of research. However it is obvious that this is a fairly unexplored field and the experimental data acquired those fair as not been able to create of confirm a mathematical model of fin flutter with a low margin of error. The fin flutter measurement system that the MIT Rocket Team is developing aims to provide a simple, quick, and cost effective method of measuring and recording fin flutter attributes in rocket fins. As such a simple mechanism for holding test fins is being developed to easily test multiple fin geometries and materials, and since the rocket is designed to be launched multiple time and succession, this reduces the number of rockets that have to be built. This means that more resources can be put into to data collecting and processing, instead of costly and lengthy rocket fabrication. Furthermore, by choosing a quick rocket deployment and keeping a relatively low budget, it allows for the for this technology to be applied to situations were cheap and rapid scientific data gathering is necessary.

4.3 SCIENCE VALUE

4.3.1 SCIENCE PAYLOAD OBJECTIVES

The payload objectives are to record video using high-speed cameras of the fins expected to experience flutter and to measure the strains in the fins from attached strain gauges throughout the entire duration of the flight.

4.3.2 PAYLOAD SUCCESS CRITERIA

The video recording and data logging shall be deemed successful if the payload captures video frames for all three cameras of a clear and unobstructed head-on view of all three test fins. This video recording should save stills at 480 frames per second for the entire ascent of the rocket flight. In addition to this requirement, the payload will be deemed a success if the payload obtains and logs strain gauge data for all three fins at no more than 0.5 second intervals.

4.3.3 EXPERIMENTAL LOGIC, APPROACH, AND METHOD OF INVESTIGATION

By using a science payload consisting of strain gauges and high speed cameras in an ascending rocket, fin flutter measurements, as presented in section 4.2, will be collected. The science payload will be contained inside built-in compartments in the avionics bay of the rocket body tube, preventing thrashing of instruments from launch initiation to recovery. To obtain the necessary data, all the sensors and components will be turned on just prior to launch and measurements will be recorded at regular intervals and at consistent frame rates during flight. Using a rocket that is easily configured for different fins and can be used more than once to carry the science payload of multiple sensors will provide a more efficient means for obtaining fin flutter phenomenon data.

4.3.4 TEST MEASUREMENTS, VARIABLES, AND CONTROLS

Testing and verification of the avionics occurs in two distinct phases: ground testing and flight testing.

4.3.5 RELEVANCE OF EXPECTED DATA

The data collected is vital for the analysis of the rocket systems as in high-powered rocketry many failed flights have been attributed to be the effects of fin flutter. The data collected by this payload will provide real data, to contrast to theoretical data in order to being to provide more accurate models of fin flutter effects.

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4.3.6 ACCURACY AND ERROR ANALYSIS

Accurate data provides information about fin flutter conditions to people who need realistic data for the analysis of different potential rocket designs. Such data will also allow for scientific groups to consider the possible threats to the safety of people or payloads due to fin failure caused by induced flutter. Electronic measuring devices, computing components, and cameras can be greatly affected by variables such as pressure, temperature, and vibrations; appropriate knowledge of such variables can allow for proper preparation for objects entering such conditions.

4.3.7 PRELIMINARY EXPERIMENT PROCESS PROCEDURES

- Individually test all strain gauges, cameras, accelerometers, and radio controlled switches
    - Strain gauges can be tested by applying a know strain to the gauges and measuring the resulting value using a laboratory strain gauge reader
    - Camera endurance testing be done in lab
    - The accelerometer can be tested by comparing its results to that of a verified accelerometer. This can be done by placing both on a accelerating mass and recording their values.
- Determine mass of all instruments, avionics, and power devices
- Identify a suitable battery for device powering
- Using computational software, Excel and MATLAB, verify calculations for expected
  parameters and requirements of the payload.
- Using CAD and circuit simulation software, model payload with appropriate dimensions, parts, and correct wiring.
- Ensure rocket, electric components, and other equipment are reusable after each mission

4.4 SAFETY AND ENVIRONMENT (PAYLOAD)

4.4.1 SAFETY OFFICER

The safety officer is Andrew Wimmer, as stated in section1.1, and will oversee payload integration as outlined in section 4.1.4.

4.4.2 FAILURE MODES

Risk	Likelihood	Effect on Project	Risk Reduction Plan
Cameras do not record video	low	Loss of science value	Test the remote relay switch circuit and make sure that there are redundancies in the system.

Video is blurry or is obstructed in some way	medium	Accurate models of fin deflections cannot be deduced	Securely mount the cameras in the avionics bay and use vibration testing to determine and improve stability.
Video and/or strain gauge data is not synchronized with the rocket launch	medium	Collected data is less reliable and useful when making comparisons to theoretical models	Test the system on a full scale test to ensure that the system works properly.
Strain gauges fails to send usable data to Arduino	high	Loss of science value	Rigorously test strain gauge circuits in ground and flight testing.
Arduino fails to log data to SD card	low	Loss of science value	Ensure rigorous testing of all electronics and software prior to launch.

4.4.3 PERSONNEL HAZARDS

A listing of personnel hazards and evidence of understanding of safety hazards of the payload is provided in the sections below.

Safety Precautions

In order to assure safe and successful operations concerning the payload, a checklist must be followed. In order to reduce personnel hazards the following precautions must be taken:

- Make sure all relevant testing (reference checklist) has been completed prior to attempting a flight test.
- Make sure the checklist is followed and all steps are completed properly in a thorough, workmanlike manner to assure mission success.

Lithium Polymer Battery Hazards and Procedures:

- Always charge lithium polymer batteries with a balancer. Out of balance packs can explode.
- Never over-discharge a lithium polymer battery (below 2.7V per series cell).
- Never attempt to charge a lithium polymer battery if it looks bloated, damaged, over discharged (below 2.7V per series cell). Damaged packs can explode.
- Never leave a lithium polymer battery unattended while charging.
- Always charge lithium polymer batteries on a non-flammable surface and away from flammables.

• Never discharge a lithium polymer battery at more than the published discharge rate. The pack may explode if discharged too quickly.

4.4.4 FIN LIBERATION

The liberation of fins may cause concern due to the potential safety issues involved and the possibility of safety code violates. In order to remove these concerns, we have developed 4 options to deal with liberated fins. Experimental testing will determine which option is ultimately chosen, however, at no point will the fins be landing at greater than 40ft/s or 25ft-lbf of energy. Additionally, each fin will have a radio tracker installed to help locate it post flight. A series of at least 3 flight tests and many fin drop tests will help us show that the vehicle is safe to fly and in compliance with requirements and regulations. The options for fin braking are listed below:

- Tracker in tip of fin, no streamer
  ☐Only acceptable if energy and velocity are low enough, as shown through extensive drop tests
  ☐Fins must be painted vibrant color

- Fin tethered to rocket body
  ☐Tethered by a Kevlar cord from the tip of the fin to the base of the rocket
  ☐Likely not possible due to motor burning

- Streamer attached to fin, tracker attached to streamer
  ☐Streamer stored in small tube in base of rocket
  ☐Attached by a Kevlar cord tied to the tip of the fin
  ☐Kevlar cord taped to bottom of fin for aerodynamic reasons

- Fins not liberated
  ☐If we are not able to come up with an acceptable solution to keep the fins falling at safe speeds and energies, the experiment will be modified to ensure the fins stay attached. It is still possible to induce flutter and not fail fins. This point will only be reached after unsuccessful testing of the other options.

4.4.5 ENVIRONMENTAL CONCERNS

- All waste materials will be disposed of using proper trash receptacles
- Consideration of environmental ramifications will be made regarding applicable
- activities
- The following list of materials have been identified as potentially hazardous:
  - Aeropoxy 2032 Epoxy Resin

- Aeropoxy 3660 Hardener
- Lithium Polymer Batteries

5 ACTIVITY PLAN

5.1 BUDGET PLAN

To meet the budget needs set forth in the initial proposal, the MIT Rocket Team has reached out to four main sponsors. The largest percentage of funding will be provided by the Massachusetts Institute of Technology department of Aeronautics and Astronautics, in their support of undergraduate projects. The Massachusetts Institute of Technology Edgerton Center, and the MIT Gordon Engineering Leadership Program are also expected to donate heavily to the team. Finally this year the MIT Rocket Team has secured funding from its first industry sponsor, Lockheed Martin. As the year moves forward the MIT Rocket Team looks forward to reaching out to other sponsors to invest in this and other projects. A breakdown of financial contribution can be seen in Table 21, and a budget summary is shown in Table 22.

TABLE 21: FUNDING SOURCES

Source	Contribution
MIT Aero-Astro	$7,000
MIT Edgerton Center	$5,000
MIT Gordon Engineering Leadership Program	$4,000
Lockheed Martin	$1,000
Total	$17,000

TABLE 22: SYSTEM COST BREAKDOWN

System	Item	Cost
Rocket	Propulsion	563
	Airframe	400
	Avionics	700
	Payload Support Equipment	150
	Recovery	450
Payload	Cameras	720
	Strain Gauges	230
	Data loggers	40

	Accelerometer	50
	Radio Receiver and Relay Switches	90
	Micro-controller	100
Support	Testing	2500
	Spares	4000
	Team Support	5500
	Outreach	1000
Total		**$16,4473**

5.2 TIMELINE

As previously discussed the majority of tasks for this years project will take place during the month of January. This is due to the fact that during this month most members of the team will be on campus, without normal class. This allows for a larger percentage of time to be devoted to work on the rocket than during the normal semester.

A timeline taking into account the key events listed previously can be seen here in Table 23.

TABLE 23: PROJECT TIME LINE

Month	Date	Task
September	10	Project initiation
November	28	PDR materials due
December	3	Construct Scale rocket
	17	Scaled test launch
	19	Initiate materials acquisition for full scale rocket
January	6	Return from winter break
	6	Test MATLAB and openCV software
	6	Initiate construction of fin unit
	7	Initiate construction of test body tubes
	7	Begin machining mirror mounts
	7	Initiate construction of payload circuits
	9	Perform tests on body tubes (crush, bending, etc).
	9	Perform ejection charge tests
	9	Perform tests on camera placement and mirror positions
	10	Cut out fins
	11	Perform fin unit tests

	13	Initiate construction of flight body tubes
	13	Initiate construction of avionics bay
	15	Initiate construction of mirror system and avionics mounting system
	15	Perform tests on electrical subsystems
	16	Start integrating vehicle components
	19	Prepare for full scale launch (pack parachutes, build motor, etc)
	21	First full-scale test launch
	23	CDR materials due
February	18	Second full-scale test launch
March	10	Optional full-scale test launch
	17	Third full-scale test launch
	26	FRR materials due
April	2	Optional full scale test launch
	21	Competition launch

5.3 OUTREACH PLAN

5.3.1 PURPOSE OF COMNUNITY OUTREACH

The team plans to hold four community outreach events and a competition over the next few months to inspire and educate the general public about space and space-related technologies in a hands-on fashion. The plan is to reach audiences ranging from classrooms of high school students, to auditoriums of both children and adults. Through a combination of presentations, demonstrations, and hands-on activities, our goal is to share our enthusiasm for science and engineering: in particular, rocketry.

The following table lays out these activities:

TABLE 24: OUTREACH EVENTS

EVENT	DATE
MIT Splash Weekend	20 November (Complete)
Rocket Day at MIT Museum (Zoom)	January 9
Rocket Day at the Boston Museum of Science	Mid-January
MIT Spark Weekend	March (Tentative)
USLI Payload Competition	December -> January

10. BOSTON MUSEUM OF SCIENCE

The MIT Rocket Team is a subset of a larger student group, which is focused on expanding space-related undergraduate student groups. In the past, this group has organized highly successful community workshops and presentation at the Boston Museum of Science where undergraduates and graduate students conduct hands-on activities for the purpose of increasing public interest in math, science and higher education. With these resources available to us, we are securing a date at the museum designated for exploring all aspects of rocketry. Our curriculum calls for a series of presentations on the history of rocketry, each followed by a fun hands-on activity or demonstration. Our target audience for this activity will be middle school to high school students and anyone interested to listen from the museums regular audience. To promote this event, we have access to several student websites, public radio, and the Museum's public relations personnel. Posters and flyers would also be created and distributed around the museum. The duration and exact date of the presentation will be determined at a later time in collaboration with the museum. The current target is for a mid-January event.

The details on each of the activities are contingent on review by museum staff but our proposed list includes:

1) Film canister rockets

2) Parachute construction

3) Shortwave radio communications (emulate mission control with delay)

4) Bottle rocket demonstration

5) Full-scale hobby rockets and scaled down models of famous rockets

6) Demonstrations to demonstrate the scales of larger rockets

The learning objectives for this activity will be the following:

1) Ensure a basic understanding of the history of rocketry. To understand rocketry and its development, we believe in the importance of explaining the history of rocketry through the ages and the key people and organizations that have advanced this field. Topics will include Wernher von Braun, Robert Goddard, NASA, the Space Race, and current commercial rockets such as SpaceX's Falcon 9.

2) How does a rocket work? The main premise for this activity is to explain how rockets work and prime our target audience with an interest in math and science through the amazing technology that are rockets. This portion of the presentation will introduce the importance of math and science in developing rockets by explaining the basics principles that allow us to send rockets into space. Hands-on activities will be used to ensure a rich understanding of the basics of projectile motion.

3) The social impact that low-Earth orbit rocketry has brought to our everyday lives. This portion of our presentation will explore the invaluable contributions that rockets have brought to our society from advancing our telecommunication capability to allowing accurate weather forecasts to creating a paradigm shift into our technology embedded world.

To evaluate the success of our engagement, we plan to include a session of questions to the audience and rate their responses on accuracy with relationship to our presentations and activities. Ideally, we would use entrance and exit surveys to quantitatively measure the success of our public outreach in meeting our educational goals. However due to the large range of ages expected, an interactive conversation is more practical.

11. ROCKET DAY AT THE MIT MUSEUM

We plan to run a nearly identical event at the MIT Museum, which is an administrative department of the Institute. The nature of the audience will allow us to be slightly more technical in our presentation, and will expand the range of people we reach through our efforts.

As with the Museum of Science, SEDS members have had successful experiences with presenting at the MIT Museum in the past. This year the Museum has invited us to present at their 'Zoom' event on January 9th.

12. MIT SPLASH AND SPARK WEEKENDS

MIT's Educational Studies Program is a student group that offers services to student and community members alike. As part of its community outreach it offers student-taught classes all weekend long during the months of November (called Splash) and March (called Spark) on campus to a target group of 7th-12th graders. Registration to teach a class is simple and we intend to offer one class at each event. Our plan for Spark is to use a presentation similar to that given at Splash. Splitting up the curriculum into each of the three learning objectives and the activities related with each would be ideal. We want them to understand that the field of engineering is not intimidating, but rather it offers an exciting, fast-paced, and very innovative work environment. We aim to get the students enthusiastic about pursuing math and science beyond high school. Since these classes would be smaller and engaging, we plan to use entrance and exit surveys to quantitatively gauge the learning that occurred. This will be useful to know if we need any changes to the curriculum before presenting at the museum (which will occur after Splash).

13. ROCKET PAYLOAD COMPETITION

In the past, the MIT Rocket Team has sent mentors to many Boston and Cambridge area rocket clubs and after-school programs. This year we intend to continue our partnership with these local organizations by hosting a ‘payload competition’. We plan to invite these younger rocket teams to submit ideas for a small scientific payload that can also be flown aboard our USLI rocket. These proposed payloads will need to fit within certain constraints (i.e., 8lbs, 5.5” diameter by 24” long). In early 2012 we will select the best idea, and will then assist the ‘winning’ team in constructing their scientific payload. The final payload will be brought to Huntsville with us and flown aboard our USLI rocket in its official launch. We hope this competition will spark an interest in competitions like TARC and SLI among the schools and science clubs in our area.

The rocket team is now advertising this competition to local schools and science clubs. We will begin accepting proposals in December, and will have a hard deadline for all proposals in the first week of January. Proposal selection and payload construction will occur throughout January and February.

6 CONCLUSION

As a returning team to NASA’s USLI competition the MIT Rocket Team has elected to take on a new, and ambitious challenge: to measure the effects of flutter on fins used in amateur high-power rocketry. In recent years as hobbyists have been pushing the limits of the sport many failures have been attributed to fin flutter. However, this phenomenon is only loosely understood, and very little research has specifically examined the effects on rocket fins. It has recently come to our attention that even industry leaders such as Lockheed Martin are actively investigating this topic as they push the limits of current technology. In this way the MIT Rocket Team will be on the leading edge of this field as we continue this year’s project.

To study this event, the Team has designed a custom airframe that with two key features. First the tail-end of the rocket will house a custom build fin-can that allows for the simple changing of test fins. In this way the team will be able to test a wider number of fin variations without the need to rebuild a launch vehicle. Secondly, the payload section of this vehicle will house three consumer grade high-speed video cameras. Coupled with a custom mirror assembly, the cameras will allow for high frame rate video of the fins throughout the entire flight. When this source of information is coupled with data from strain gauges embedded into the test fins the team will have access to a large depth of information to correlate with existing models of fin flutter. In this way the team will be able to then validate the existing models, or help develop a new model for fin flutter.

Along with this exciting science project, the team has elected to take on an aggressive community outreach program, through a mini-design competition aimed at high school students. In this competition high schools in the area will be encouraged to develop and submit science experiments for flight in the secondary payload section of our launch vehicle. A winning submission will then be selected and a portion of allocated funds will be donated to the high school team to develop the science experiment. When completed the experiment will then be transported to the USLI Launch and flown at the time of our flight. Through this outreach program we will reach over a hundred students encouraging them to become active in STEM.

Building upon the success of our rookie year, the MIT Rocket Team is eager to return to USLI with another successful year. With the acceptance of our proposed project the team has started on its journey to success and we all look forward to the launch this coming April.