MIT Rocket Team
Critical Design Review

January 25, 2012

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1 SUMMARY OF CDR 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 8 inches, and the test fins will have semi-spans ranging from 6-9 inches. The projected mass of the rocket is 43.1 pounds including all payloads and ballast. The rocket will fly on a commercial CTI L1395, and main deployment will be performed at 300ft.

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 PDR

2.1 CHANGES MADE TO VEHICLE CRITERIA

The following changes have been made to the vehicle criteria:

- Launch mass has increased from 42 to 43.1 pounds following a successful test flight. This places predicted altitudes at 5,350'.
- A Rocketman R16 parachute has replaced the R14 originally planned to keep the K.E. within NASA's required limits
- The upper airframe tube has been split in 2 to facilitate a "zipperless" design

2.2 CHANGES MADE TO PAYLOAD CRITERIA

The planned Arduino Mega DAQ board has been changed to a set of three Arduino Uno boards.

2.3 CHANGES MADE TO ACTIVITY PLAN

The following changes have been made to the Activity Plan:

- An additional event has been planned at the MIT Museum
- High School payload has been reduced to 4lbs to meet altitude goals.

3 VEHICLE CRITERIA

3.1 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. Occurred on 12/28.~~
- ~~1/21: First full-scale test launch. Occurred on 1/15.~~
- ~~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

3.2 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.

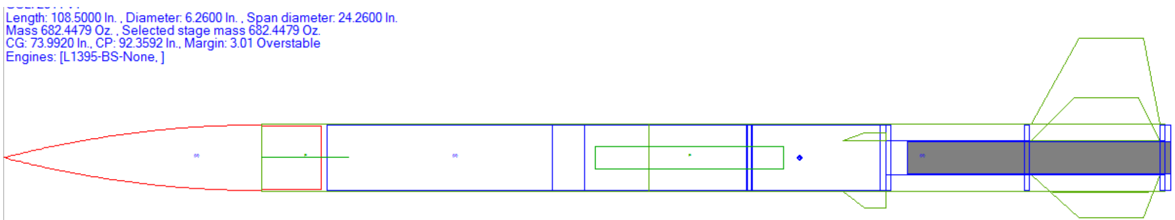


FIGURE 1:ROCKSIM 2D ROCKET MODEL

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 8". The fins used to analyze fin flutter will have spans of 6", 8" and 9" for the 1/32", 1/8" and 1/16" fins, respectively. Furthermore, the mass of the rocket is projected to be 43.1 pounds for a payload mass of 4 pounds and ballast in the high school payload area as necessary in order to reach an apogee of 1 mile. Current design projections show a 5400' apogee, which will be left as margin throughout the design process. The exact specifications of payload deployment depend on the experiment chosen, although a 21" long by 5.3" 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 4 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. Through test flights, it has been determined that the L1395 will remain a viable option and that the other options of the larger L1115 and smaller L1355 will not need to be employed.

The recovery system will consist of the deployment of a 60" diameter surplus, tangle-free, pilot parachute at apogee and a Rocketman R16 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 4 flights in previous rockets with very similar recovery system designs. The rocket will land in two tethered pieces, the 13 pound nosecone/payload and the 24.9 pound rocket body and fin unit. The nose cone/high school payload section will land at approximately

19.1ft/sec for a total energy of 72 ft-lbs (98.2 joules). The lower section will land at approximately 13 ft/sec for a total landing energy of 65 ft-lbs (82.3 joules) of energy. Each section will contain a BigRedBee 70cm tracker for location after launch. The nose cone section will also likely contain a BigRedBee 2m GPS tracker as an additional tracker. The fins will either be tracked with a 70cm tracker or a custom tracker built into the tip of the fin.

3.2.2 DESIGN REVIEW AT SYSTEM LEVEL

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

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

3.2.3 SYSTEM SPECIFICATIONS

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 3 segments, with a joint just above the avionics bay and just below the nose cone. The segment lengths are 48" for the lower tube, 24" for the middle tube and 12" 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. The upper tube joint will be held together during flight by the high school science payload tube, which will rest on the lower joint's coupler and act as a coupler tube itself to join the middle section to the upper section. The upper section will be semi-permanently attached to the nose cone shoulder

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
    - A series of 4 holes will be used in the avionics bay: 3x ¼" holes and 1x ½" hole to access switches
- In the middle of the section between the avionics bay and the high school science payload
- In the nose cone shoulder

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 attached to the upper 12" section of body tube using 4 stainless steel 4-40 bolts. The upper body section is attached to the science payload 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 3/16 " G10/FR4. They will have dimensions as shown in Figure 2.

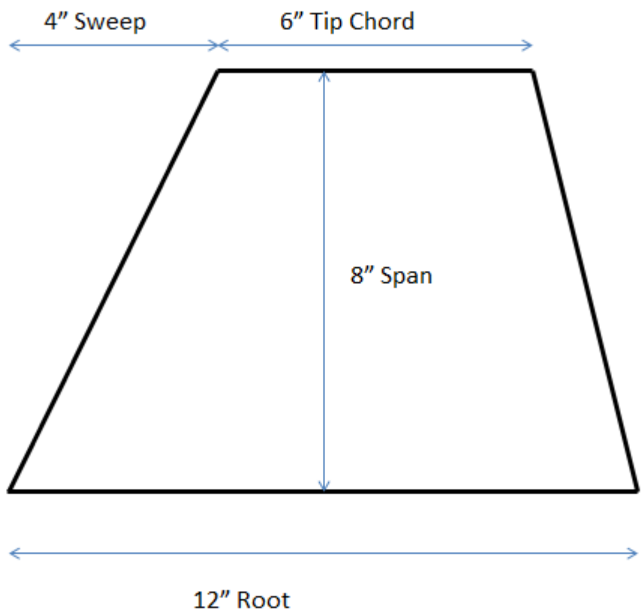


FIGURE 2: FIN

Additionally, the 3 test fins will have dimensions similar to those above, with different thicknesses and spans. The fins will have root chords, tip chords and sweep lengths identical to the main fins, however, their spans with be 6", 9" and 8", for the 1/32", 1/16" and 1/8" fins, respectively. 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. The fins are then sandwiched between a pair of plywood fin holders and bolted in place. These fin holders then interlock with 3 centering rings: 1 on either end and one in the middle. This is shown in figure Figure 3 & Figure 4. The fins are slid between the vertical plywood slats.

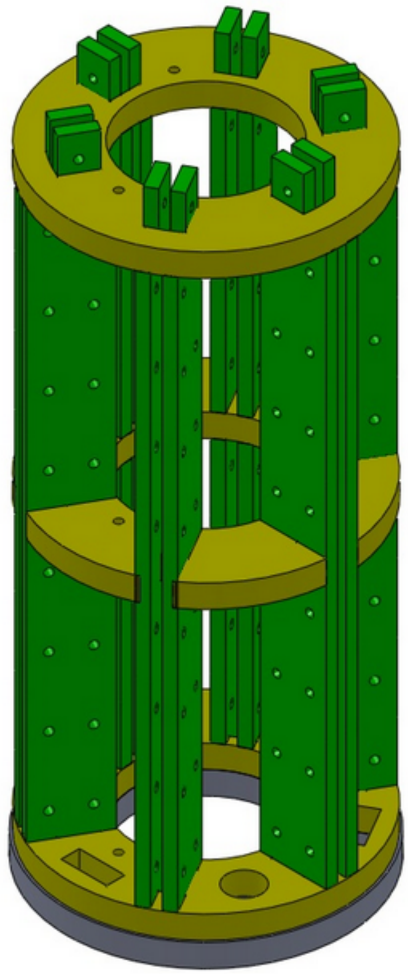


FIGURE 3: FIN HOLDER WITHOUT FINS

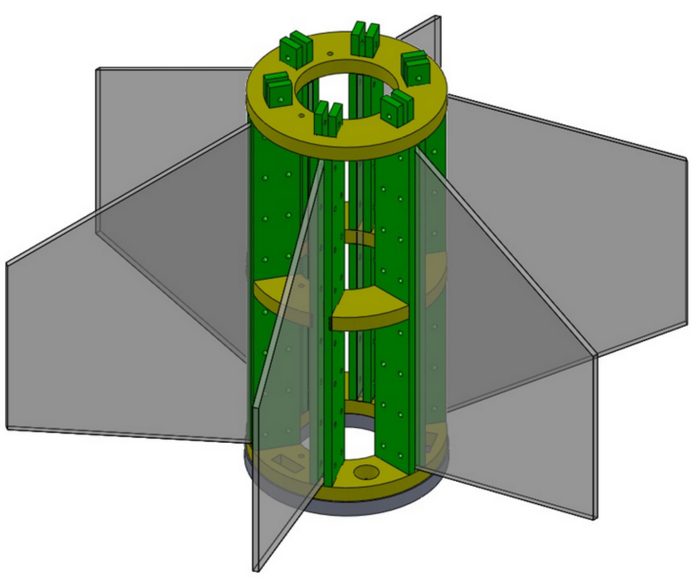


FIGURE 4: FIN HOLDER WITH FINS

The motor mount will consist of a commercial 75mm motor tube from LOC Precision and waterjet-cut, plywood centering rings. There will be four centering rings in total, one on either end of the motor mount tube, one at the front of the fins and one in the middle of the fins. The forward rings 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. The airframe will be bolted to the motor mount and fin assembly with a series of 4-40 wood screws into the aft centering ring.

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 5 below.

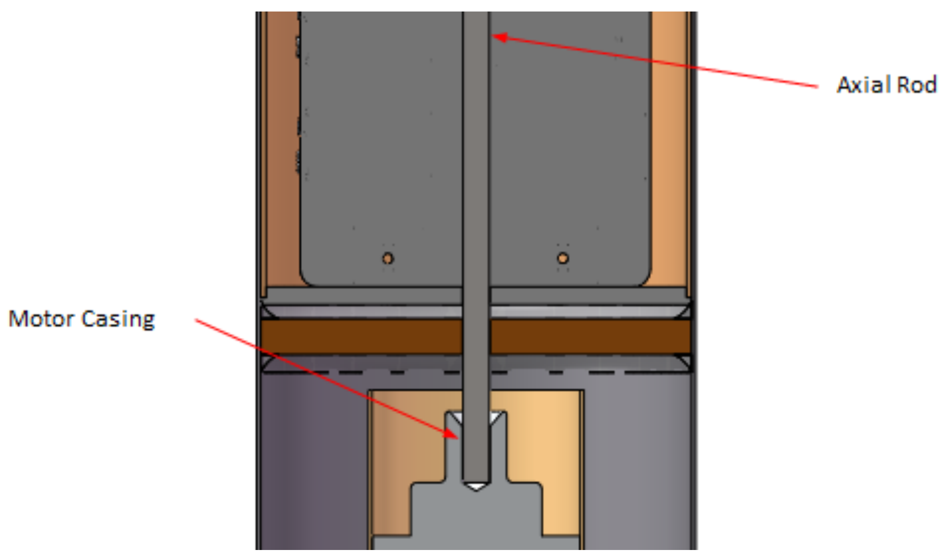


FIGURE 5: MOTOR RETENTION

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 2x 4-40 screws to prevent the avionics bay from rotating within the rocket and blocking the vent holes.

Recovery and Deployment

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.

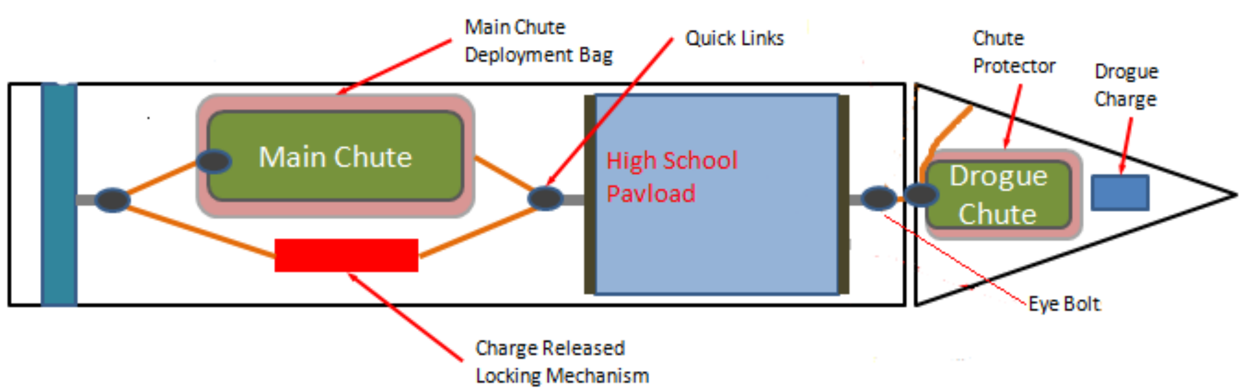


FIGURE 6:RECOVERY COMPONENT STACKING

The deployment then occurs as follows:

- Just after apogee, nose cone ejection charge fires
- Nose cone separates with upper 12” of airframe attached, 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 with associated 12” of airframe tube, 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.

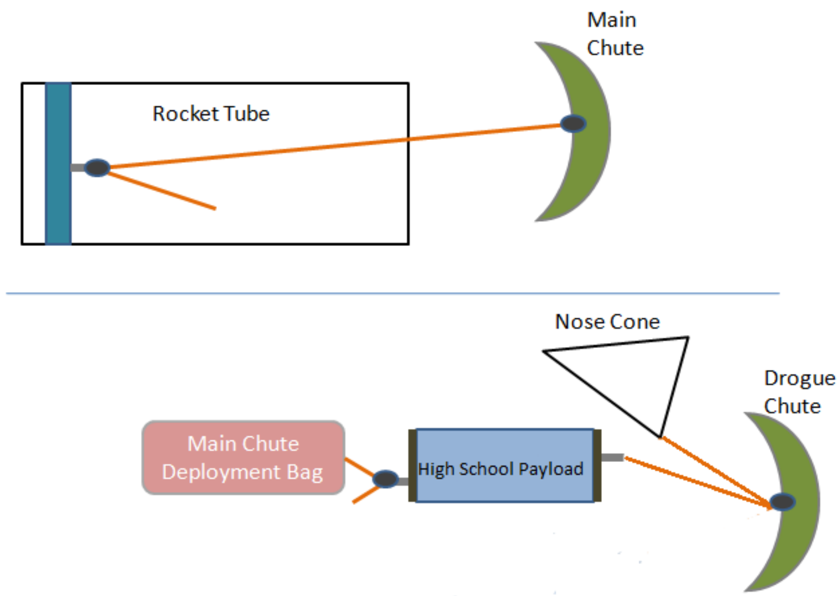


FIGURE 7:DEPLOYED RECOVERY COMPONENTS

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. Additionally, 1” tubular nylon webbing will run the length of the high school science payload and provide a load path from the drogue to the Tender Descender while the rocket is falling under drogue.

Finally, Big Red Bee 70cm trackers 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 mass estimates and the actual mass of the vehicle flown for the full scale test flight.

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.

<u>Avionics/Communications</u>

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 8 shows the Stratologger altimeter.

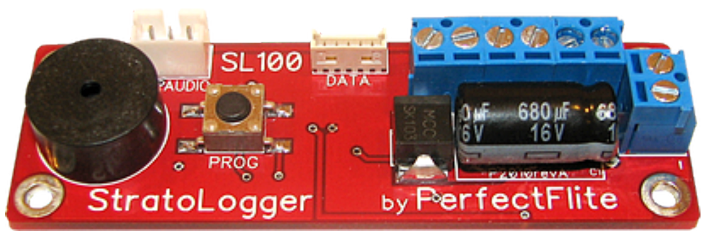


FIGURE 8: STRATOLOGGER ALTIMETER (PERFECTFLITE.COM)

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
Raven2	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.

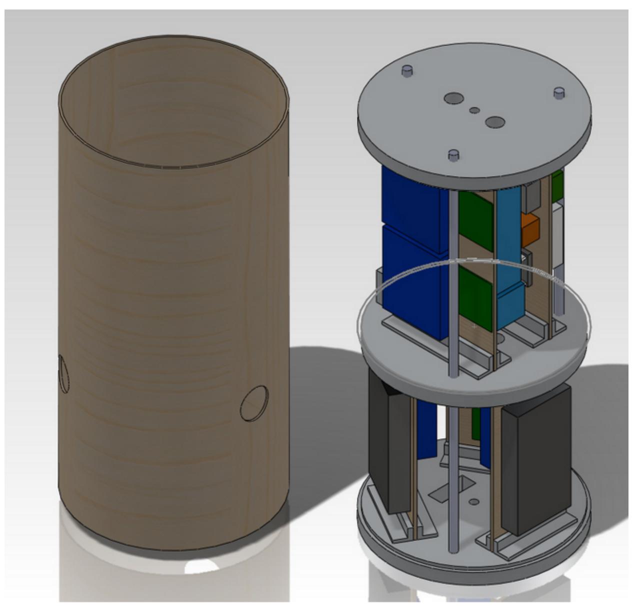


FIGURE 9: AVIONICS BAY CONFIGURATION

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. This assembly is shown in **Error! Reference source not found.Error! Reference source not found.** and **Error! Reference source not found.**.

Figure 10 shows the wiring diagram for deployment avionics. This diagram shows independence of the redundant systems in place.

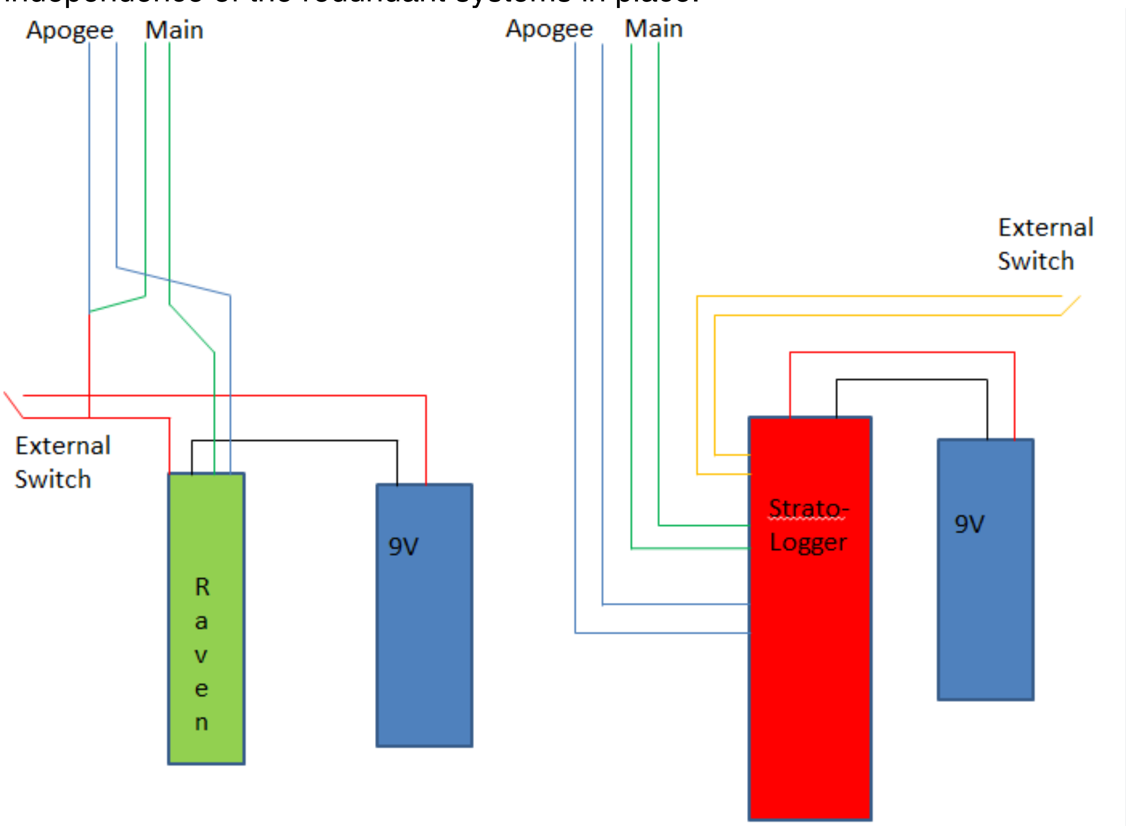


FIGURE 10: AVIONICS WIRING DIAGRAM

3.2.4 TEST DESCRIPTIONS AND RESULTS

A variety of tests on the vehicle and subsystems have taken place since PDR. These are summarized below:

Tube and coupler crush tests:

The tubes and couplers were loaded laterally and axially with a variety of loads, up to a maximum of 1800 N. No signs of flexing or failure were seen.

Fin Testing

Once assembled, the completed fin mounting unit was placed under loading to ensure that it would remain structural during flight. It was determined that the unit was able to handle expected drag loading. Lateral loads were unable to be quantified; however, test flight results verified its structural integrity.

Deployment Altitude

The altimeters were placed in a small vacuum chamber and monitored to ensure that the altitude they were reporting closely represented the altitude reported by the chamber. These tests were successful and verified by the successful test flight

Sheer Pin Tests

The rocket was set up in flight configuration and a 6 gram ejection charge was fired to ensure that the nose cone and drogue parachute successfully deployed. This test was successful.

3.2.5 FUNCTIONAL REQUIREMENTS VERIFICATION

The mission-specific requirements are as follows:

1) Launch rocket with 6 fins of different thicknesses, geometry, and materials
    i) Analytically demonstrate rocket stability with 6 fins and additionally only the 3 non-fluttering fins.
    ii) Attach strain gauges to fins to measure predicted versus actual strain
    iii) 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
    i) Use image post-processing software to accurately track fin movement

Of these, only the stability and high school payload delivery requirements are directly vehicle related. RockSim analysis and flight tests have shown that the vehicle is stable, including during fin flutter and fin liberation events. The flight test also successfully delivered the high school payload.

In addition, 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	Fin flutter analysis	Inspection

science payload of the team's choosing	experiment	
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 27" from the base of the rocket	Inspection
The recovery system shall be shielded from all onboard transmitting devices	The upper avionics bay bulkhead 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	Rocksim simulations place	Altimeter data from flight

subsonic at all times	the vehicle maximum velocity at 700 feet/sec	testing will provide an 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 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 -1 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 65ft-lbf. The K.E. of the fins is <8.4 ft-lbf,	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 before launch	Bench tests of electronics

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. Small, custom trackers will be attached to the tips of liberating 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 due to the thrust ring
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.	Inspection
The rocket must not use hybrid motors	The L1395 uses APCP and APCP only	Inspection
The rocket must not use sparky motors	The L1395 is not a sparky motor	Inspection
The team shall have and	Safety checklists are being	Checklists are included in

use safety checklist	developed and will be revised as needed.	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

3.2.6 APPROACH TO WORKMANSHIP

Through past experiences, the MIT Rocket Team has identified that the workmanship of individual components plays an integral role in the final outcome of any project. With this in mind, the team has set in place schedule of testing and teaching of the various skills necessary for the fabrication and assembly of the rocket components. Construction methods used by the team are learned from experienced sources, and all methods are vetted through experienced personnel before being used. Team members are taught basic fabrication methods under the instruction of more senior members, and all components are inspected and tested as necessary before they are used.

Additionally, checklists are used during flight preparations to ensure that steps in the preparation of the rocket are not missed.

3.2.7 ADDITIONAL TESTING

The team intends to perform at least 2 more test flights. These will provide more data on fin flutter and provide additional support that the rocket and recovery system function as designed.

Future flight tests will also involve the data acquisition system, which will be tested on the ground prior to flight tests.

3.2.8 MANUFACTURING STATUS

The manufacturing aspects of the rocket have been completed and if necessary, the rocket flown during the January test flight could be flown for the Huntsville launch. The team will likely re-do a few of the parts, mostly for aesthetic reasons.

-The airframe tubes will likely be reproduced in order to allow for a cleaner, less rushed finished. These will be completed and re-flown for the next test flight.
-The avionics bay will be reconstructed to house the payload electronics. The avionics bay flown on the test flight was designed only to house the flight electronics.
-The payload electronics and interfaces need to be integrated into the rocket airframe.
-The high school payload bay needs to be re-constructed to the new length of 21”, down from the original 24”.

3.3 DESIGN INTEGRITY

Design integrity is an important aspect to a project such as USLI. As such, the vehicle has been designed using common design practices in high powered rocketry and has also been influenced by the experience of the team.

3.3.1 FIN SHAPE AND STYLE

The fin style and shape in use was chosen due to its common use in rocketry. As a standard trapezoidal fin, it is easily modeled in RockSim and also flutter calculators. The fins are constructed of G10, a material commonly found in rockets of similar size. As was shown in the full scale test flight, the fins perform their objective of keeping the rocket flying straight.

3.3.2 PROPER USE OF MATERIALS

The structural elements in the vehicle are commonly used in high powered rocketry. They include phenolic tubing wrapped in carbon fiber, fiberglass fins and a wood fin and motor retention system. As was shown in the full scale test flight, the structural elements of the rocket performed their objectives.

3.3.3 PROPER ASSEMBLY PROCEDURES

The design of the rocket dictates the assembly procedures. These procedures were tested during the full scale test flight and were shown to work.

Structural components are self-aligning. Connects are made with fasteners are made. Holes for such connections are not exactly rotationally symmetric, however, internal markings allow for proper alignment.

Load paths through the rocket are transferred into the rocket from the thrust ring on the motor directly into the aft centering ring. From there, the motor mount tube, which is glued to the aft centering ring, transfers load to the avionics bay. The aft centering ring also transfers load to the airframe tube via the lip on the centering ring that extends to the OD of the tube. The airframe tube then transfers load to the airframe coupler tube and all components above it.

All recovery loading is directed to the recovery eye-nut. This is connected by a piece of threaded rod directly to the top of the motor case. From there, the load paths are similar to that of the rocket under thrust.

3.3.4 MOTOR RETENTION

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.

3.3.5 VERIFICATION STATUS

With the conclusion of the full scale test flight on January 15, the majority of the items in the verification plan were verified. The only remaining open items are confirmation of the descent rate with the larger R16 parachute, a re-flight of an identical airframe that is more aesthetically pleasing and testing of the payload and payload integration plan.

3.3.6 VEHICLE MASS

The vehicle mass during the test launch was 44.8 pounds. The rocket was flown with 8 pounds of sand to simulate the high school science payload but without the payload electronics. As the rocket did not reach the intended target altitude, the high school science payload mass allocation has been reduced to 4 pounds. This will leave approximately 2 pounds of margin after the addition of the high school science payload. This margin will be used by the larger parachute and to reduce the launch weight to reach the target altitude. This leaves approximately 8 ounces of margin, or slightly more than 1%. As the completed rocket has been flown and the performance is known, this is seen as suitable. In the instance that it the mass margin is insufficient, the high school payload allocation can be further reduced.

3.3.7 SAFETY AND FAILURE ANALYSIS

Safety and failure analysis is an important aspect of this project. The full section on vehicle safety along with failure analysis can be found in the safety and environment section 3.10 later in this document.

This section includes safety and failure analysis concerning the launch vehicle and has been updated since PDR.

3.4 SUBSCALE FLIGHT RESULTS

The scale test flight occurred on December 28 at a farm outside Wisner, Nebraska. Team member Andrew performed the test flight. The flight occurred with an exactly half scale rocket constructed of LOC Precision components with plywood fins. A CTI F240 was used and the rocket was launched off a standard 8’ 1”x1” rail. **Error! Reference source not found.** shows the rocket being prepared on the launch pad.

FIGURE 11: SUBSCALE TEST FLIGHT

3.4.1 FLIGHT DATA

Figure 12 shows the data from the Perfectflite Stratologger flown on the subscale launch. The drogue was deployed at an apogee of 279’ and the main at 200’.

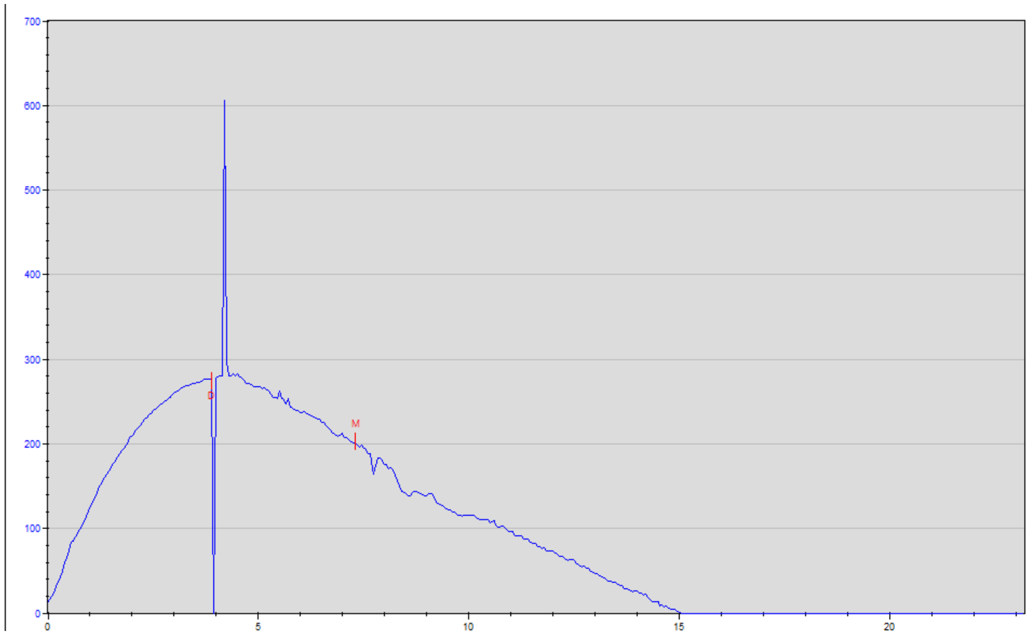


FIGURE 12: ALTITUDE VS TIME FOR SCALE TEST FLIGHT

3.4.2 COMPARISON TO MODELS

The Rocksim modeling done prior to the launch of the scale rocket predicted an altitude of 280' for a launch weight of 51 ounces. The launch weight of the rocket was 51 ounces, and the altitude measured (279') very closely matches the altitude seen in simulations.

3.4.3 IMPACT ON FULL SCALE VEHICLE

The subscale launch was conducted in accordance with the USLI guidelines; however, because the nature of our experiment does not fully scale down to this level, no additional information was gained from this experience. The team decided to move into the full scale test flight stage early in an attempt to sort out any design issues well before the FRR deadline

3.5 FULL SCALE FLIGHT RESULTS

A full scale test flight was conducted on January 15th with MDRA near Price, MD. The flight occurred with the full-up rocket, using test fins of thicknesses of 1/32", 1/16" and 3/32". The primary fins used were 3/16" and all fins were of the same design. The high school payload canister was weighted down with 8 pounds of sand housed in a plastic bag. Payload electronics and sensors were not flown and aerodynamic fairings were attached to the rocket in place of the mirror mounts.

The rocket was launched off a 12' section of 1515 rail, angled 2 degrees perpendicular to the wind to control the fin landing locations. Liftoff weight was 44.8 pounds on the CTI L1395. The 1/32" fin was liberated 2.3 seconds into flight. Apogee was at 4,899' approximately 17 seconds into flight and the drogue deployed as planned. The rocket descended under the drogue at approximately 52 feet/second until 700' when the tender descender released the R12 main parachute flown on this flight. 144' later the parachute was inflated and lowering the fin unit at approximately 20 feet per second. The sections landed shortly afterwards nearby. Figure 13 shows the altitude, acceleration and velocity as reported post-flight by the Raven2.

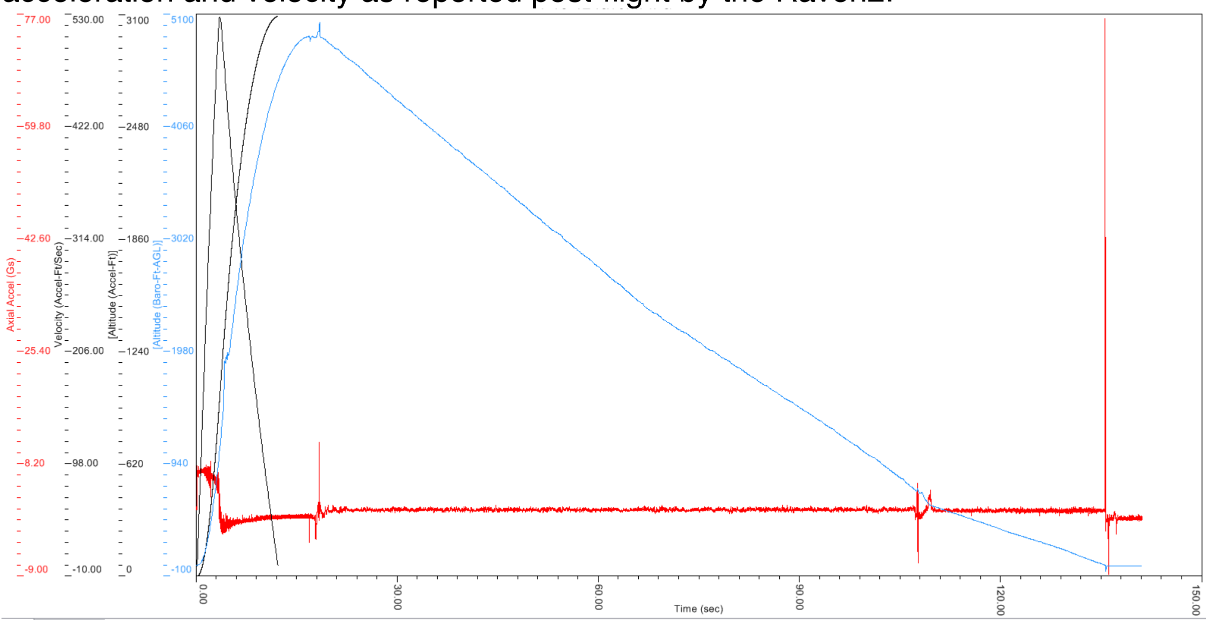


FIGURE 13: TEST FLIGHT FULL DATA

There were a variety of interesting aspects to this flight. They are listed below:

-The descent rate on the R12 was much higher than anticipated. A 20fps descent rate is nominal for a 40 pound rocket. The section attached to the R12 was on the order of 28 pounds. This has resulted in an increase in the main parachute size from an R14 to an R16.
-Only the 1/32" fin failed. The 1/16" fin was also expected to fail but didn't.
-The streamer recovery of the fins did not work as planned. The Kevlar cord attached to the fin ripped through the attachment point resulting in the fin free-falling. The fin was recovered at what appeared, but unmeasured speed. Trackers were not attached to the fins for this flight.
-The main parachute took 144' to deploy. This, along with 3 data sets from flights last year with very similar recovery setups, backs up our drift-reduction measure of deploying the main parachute at 300'.
-The accelerometer underreported velocity and estimated altitude by a factor of approximately 1.6. In discussion with the altimeter manufacture, the case for this is currently unknown. In response to this, we will be fly a 16g, 3 axis accelerometer

sampling at at least 1000hz on future flights, as valid velocity data is essential for the fin flutter experiment.

Figure 14 shows the lateral and axial accelerations, along with the integrated velocity for the first 7 seconds of flight.

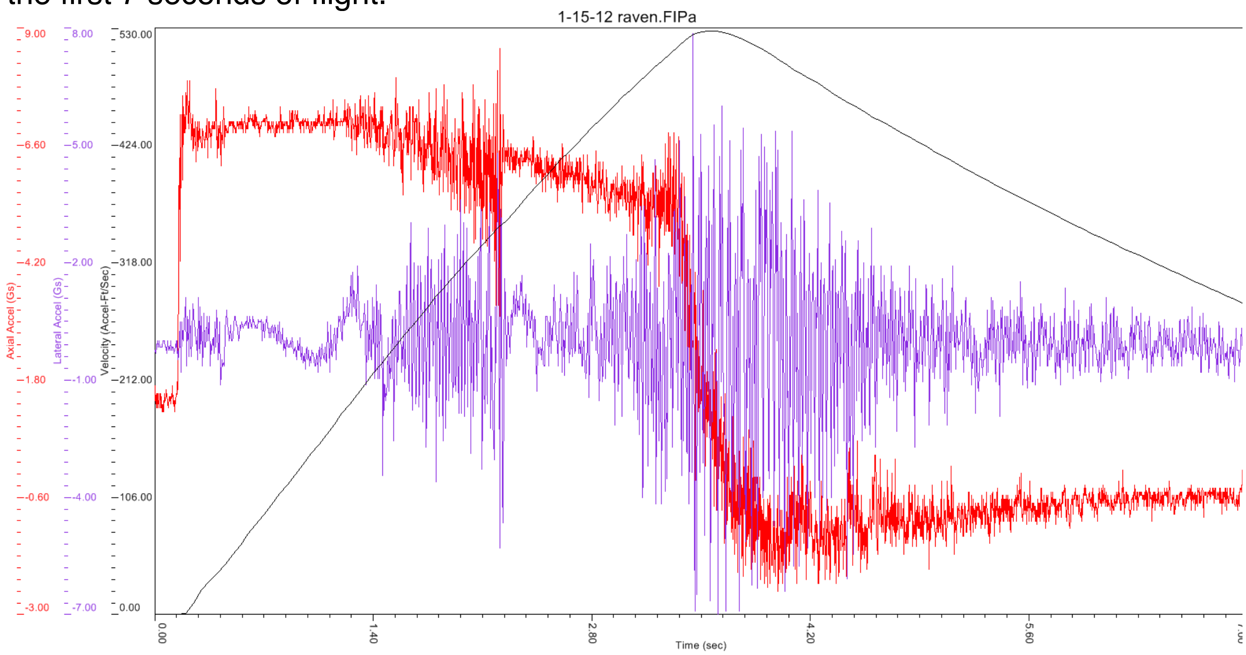


FIGURE 14: ACCELERATION AND VELOCITY FOR FIRST 7 SECONDS OF FULL SCALE LAUNCH

As can be seen, the fin liberation event greatly reduces the data noise at approximately 2.3 seconds. As the velocity increases, the effects of the fluttering from the 1/16" thick fin can also be seen near the end of the burn. It is also worth noting that the simulated velocity was approximately 660fps, while the measured velocity was only around 530fps. This, combined with the underreported integration based apogee calculation of 3100' vs 4900' show that there are unresolved issues with the accelerometer.

The following figures (Figure 15 & Figure 16) show pre and post flight conditions of the rocket at the launch.

FIGURE 15: PART OF TEAM WITH ROCKET BEFORE LAUNCH

FIGURE 16: MAIN BODY AFTER LANDING WITH MISSING LIBERATED FIN

3.6 RECOVERY SUBSYSTEM

Additional details about the recovery system can be found in section 3.2.3

3.6.1 HARDWARE DESCRIPTION

The drogue parachute is a 60” diameter surplus military parachute that uses a porous mesh as shroud lines to prevent tangling. The nose cone contains a ½” bulkhead that is epoxied in place and has a ¼” u-bolt mounted to it. The nose cone is connected to the drogue with 1” tubular nylon webbing. A continuous 16’ piece runs from the nose cone to the top of the high school science payload. The drogue is attached 4’ from the nose cone with a girth hitch.

A 3/8” forged eye bolt is attached to the high school science payload cylinder through a ½” bulkhead that is epoxied to the tube. A piece of 1” tubular nylon webbing runs down the side of the high school science payload tube. This piece of webbing is attached to the eye bolt and the drogue harness. This piece of webbing attaches to the Tender Descender, which is located just above the avionics bulkhead, below the main parachute. The Tender Descender is attached to the recovery system eye bolt with a short length of 7mm nylon climbing accessory cord. The webbing is also attached to the top of the deployment bag.

The main parachute, a Rocketman R16 Standard, is packed inside a Giant Leap 5.5” deployment bag that has been modified to fit inside loosely inside the 6” tube. The top of the bag is attached to the top quick link on the Tender Descender. The main parachute is attached to a 39” section of 1” tubular nylon webbing which is attached to the recovery system eye bolt.

The recovery system eye bolt is attached to a 3/8” threaded rod that screws into the top of the motor.

3.6.2 ELECTRICAL COMPONENTS

A Perfectflite Strattologger and a Featherweight Raven2 will be used to deploy the drogue and main parachutes. The altimeters will be set up to deploy at the barometrically detected apogee and at 300’ on the way down. They will be wired and act completely independently such that a total failure of either altimeter and associated wiring would not result in any ill-effects on the vehicle assuming the other altimeter operated nominally. The electrical components, schematics and wiring diagrams are further discussed near the end of section 1.2.3 under Avionics/Communication

3.6.3 KINETIC ENERGY

In compliance with USLI regulations, the kinetic energy of all components will be less than 75ft-lbf at landing. Table 3 shows the associated energies.

TABLE 3: KINETIC ENERGY OF COMPONENTS

Final Descent Rate & Energy		
System Under Drogue	55 ft/s	1782ft-lbf

Nose/Payload Final Descent Rate	19.1 ft/s	72ft-lbf
Rocket Body Under Main	13 ft/s	65ft-lbf
Liberated Fin	<40 ft/s	<9 ft-lbf

The kinetic energy of the fins was determined through a combination of drop tests and analytical calculations. It was shown that the thicker, 1/16” fins with a span of 9” fall at 39ft/s with an energy of 8.4 ft-lbf. The 1/32” fins with a span of 6” fall at a rate of 28ft/s and an energy of 1.4 ft-lbf. Although streamers were flown on the fins on the test flight, they were not successfully deployed. It was also determined through later testing that the streamers increased the descent rate of the fins.

3.6.4 TEST RESULTS

As discussed in section 3.2.4, ejection charge and altimeter testing successfully took place. It was found that a 6 gram ejection charge was sufficient to separate the nose cone from the main body. Additionally, the successful operation of both altimeters during the test flight further reinforced their effectiveness.

3.6.5 SAFETY AND FAILURE ANALYSIS

Safety and failure analysis is an important aspect of this project. The full section on vehicle safety along with failure analysis can be found in the safety and environment section 3.10 later in this document.

This section includes safety and failure analysis concerning the recovery system and has been updated since PDR.

3.7 MISSION PERFORMANCE PREDICTIONS

3.7.1 FLIGHT PROFILE SIMULATIONS

For the Critical 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. With the mass of the rocket set to 43.1 pounds, the rocket flies to approximately 5,350’. This mass, as discussed above, is a reasonable estimate of what the final launch mass will be, and will likely include 1-2 pounds of ballast. Figure 17 shows a 3D rendering of the rocket.

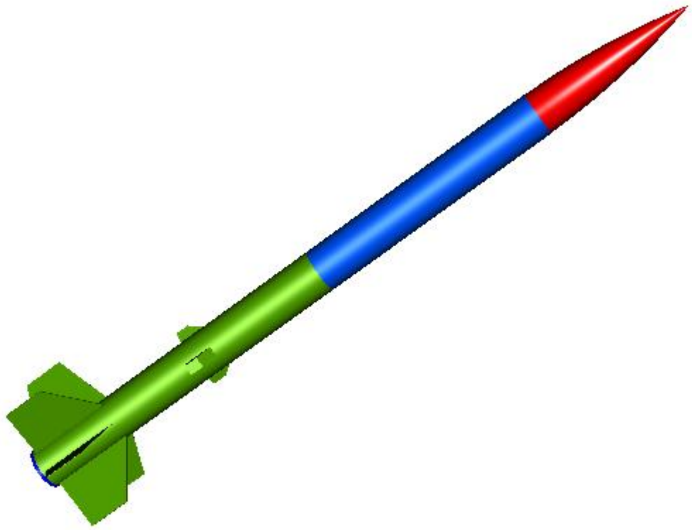


FIGURE 17: 3D ROCKET MODEL

At t = 0, the Cesaroni L1395 is ignited. Burnout occurs at 3.5s, and apogee occurs at approximately 18 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 18 shows the acceleration and velocity of the rocket during the time to apogee (the remaining flight time was omitted for clarity). The maximum speed occurs near burnout, and does not exceed Mach 0.6. The maximum predicted acceleration, although not shown, occurs at the parachute deployment, as expected.

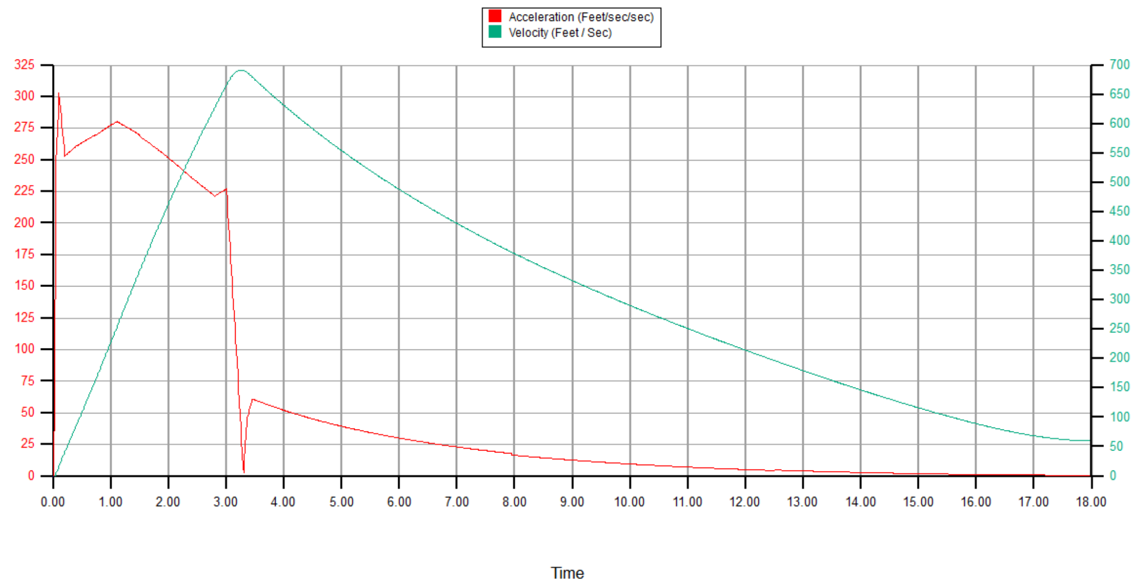


FIGURE 18:VELOCITY AND ACCELERATION DURING FIRST 30SEC OF FLIGHT

Figure 19 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.

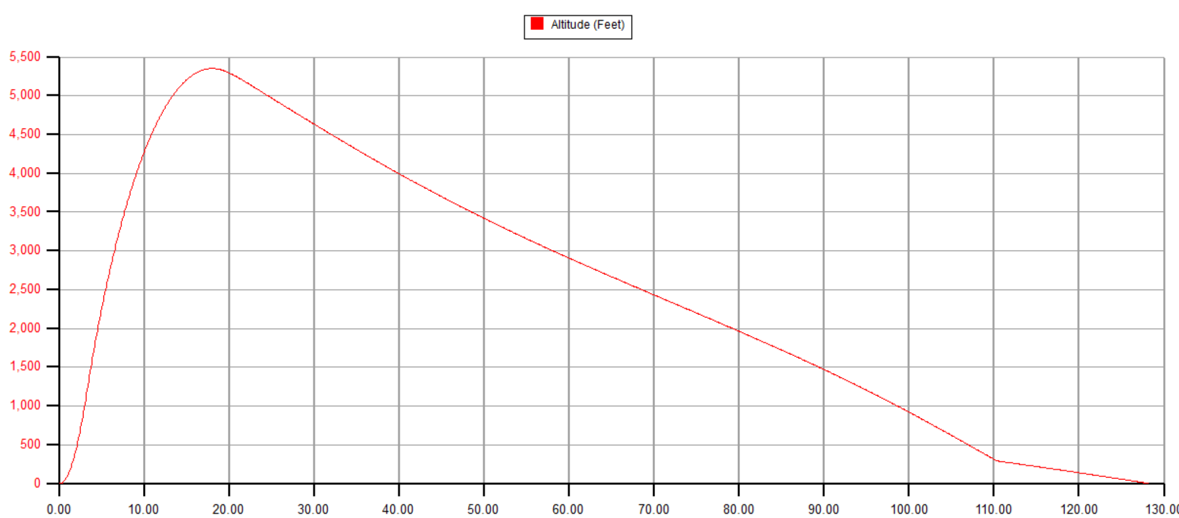


FIGURE 19: ALTITUDE VS TIME

Finally, Figure 20 shows the thrust curve for the L1395

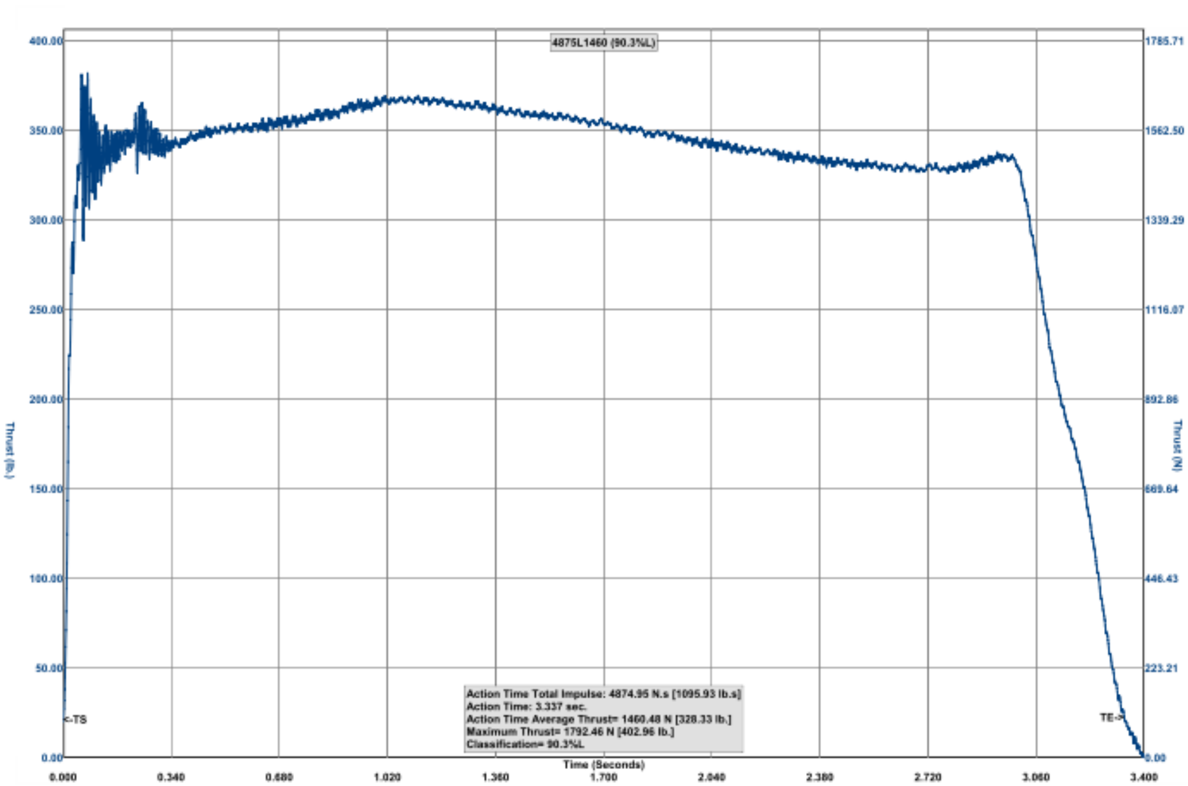


FIGURE 20:L1395 THRUST PROFILE

Pre-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.

3.7.2 VALIDITY OF RESULTS

In simulations done after the full scale test flight, taking into account realistic launch site conditions (winds of 15-20mph, launch angle of -2 degrees, launcher length of 12’, liftoff weight of 44.8 pounds, etc), an average altitude of 4,856’ was found in simulations. This closely matches the approximately 4,890’ apogee recorded by the altimeters.

This simulation will be further refined with future test flights to help more accurately predict the altitude for the Huntsville flight.

3.7.3 STABILITY

Current Rocksim modeling shows that the CP will be 92.0" from the nose tip. Actual testing shows that the rocket has an unloaded CG 68" from the nose tip, which gives a launch CG at 74" and a burnout CG at 71". This provides 3.0 calibers of stability at launch, which is slightly over the 1.8 calibers needed given the length to diameter ratio of the rocket. With only the 3 primary fins, the static stability margin is 2.0 calibers at launch. Although the possibility of reducing the stability margin was discussed after the results of the first test flight were known, the lack of weathercocking on the first test flight has eliminated the need for this. Additionally, stability during fin liberation events was not seen as an issue during the test flight.

3.8 PAYLOAD INTEGRATION

3.8.1 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.

3.8.2 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.

3.8.3 LAUNCH VEHICLE AND GROUND INTERFACES

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.

3.8.4 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

3.9 LAUNCH OPERATIONS PROCEDURES

3.9.1 CHECKLISTS AND STANDARD OPERATING PROCEDURES

Caution Statement

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. 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
d. Adhesive
   i. 5-minute Epoxy (2 part)
   ii. CA and Accelerant
   iii. Aeropoxy (2 part)
   iv. Epoxy Mixing Cups
   v. Popsicle Sticks
e. 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

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
            2. Main
            3. Nomex Parachute Protectors (3x)
            4. Deployment Bag
        ii. Shock Cord
            1. 10’ of 7mm nylon cord
            2. 4’ section of webbing
            3. 16’ section of webbing
            4. 20’ section of webbing
        iii. Ejection Charges
            1. Black Powder
            2. Quest Q2G2 igniters
            3. Spare shooter’s wire
        iv. Tender Descender
        v. Quick links (3x)
    c. Motor
        i. Casing
        ii. Reload

        iii. Wrench
        iv. Closures
    d. Avionics
        i. Avionics Bay
        ii. Altimeters
            1. Raven2 (2x)
            2. Stratologger (2x)
        iii. 9V Batteries (5x)
        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
    g. Inverters

Pre-Flight Checklists:

1) Integrate Avionics Bay
    a) Integrate the altimeters
    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 and Motor
    a) Follow Manufacturer’s instructions for motor assembly
    b) Follow Manufacture’s instructions for Tender Descender Assembly
    c) Use double-width duct tape for ejection charge assembly
    (Safety Officer will oversee this step)
3) 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
g) Thread ejection charge wires through outside slot in high school payload
h) Thread webbing through outside slot in high school payload
i) Insert high school payload into center tube
j) Attach webbing on bottom side to tender descender shock cord
k) Attach wiring to ejection charge wires from avionics bay
l) Slide middle tube onto lower tube and secure with screws

4) 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 high school payload with water knot
   e) Place ejection charges in nose
   f) Fold and pack parachute in nose
   g) Attach ejection charges to wires from high school payload
   h) Tie webbing from high school payload to high school payload eye bolt. Cut off excess

Launch Checklist:

1. Get approval from event administration to set up pad 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. Arm Electronics
   a. Listen for proper beeps
      i) Stratologger will have a series of 3 high pitch beeps
      ii) Raven2 will have a series of 2 high pitch and 2 low pitch beeps
8. Connect launch clips
9. Attach igniter to dowel rod and insert into motor
10. Clear launch area/back up appropriate distance
11. Get approval from event administration for launch

The following depend on procedures outlined by event administration:

12. Check to see if range and skies are clear
13. Insert key into the launch system to check continuity

14. Countdown from 5
15. Launch
16. Remove key from launch system
17. Disconnect launch system from battery
18. Recover Rocket

Troubleshooting:

The most likely item that will require troubleshooting is electronics problems. In the event that continuity is not seen on all 4 pyro channels, the rocket should be removed from the pad, brought back to the prep area, disassembled and checked for continuity issues until the issue is resolved.

Other issues include rocket-pad interface problems and weather related issues. These issues are unlikely and due diligence will be used when dealing with unknown situations.

Post flight inspection:

The first order of business upon finding the rocket will be taking pictures of the landing before disturbing it. After this, the ejection charges will be checked to ensure they have fired. If they have not, they will be removed and disassembled at the landing site. The parachute will be disconnected and stuffed into the deployment bag. The rocket will be picked up and carried back to the prep area. Once at the prep area, the altimeter bay will be removed and the official altimeter will be brought to the NASA official.

3.10 SAFETY AND ENVIRONMENT

3.10.1 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.

3.10.2 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 4: 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 manufacturer'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 Failure (bulkheads, shockcords, etc)	Property Damage, Injury	Follow rocket's descent path visually, move if needed	Use components such as eye bolts, threaded rod and attachment points rated to well beyond (40x) weight of rocket
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	Follow NFPA table for dry brush around pad

		trained in its use onsite	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. Test vehicle before Hunstville flight to ensure it can survive.
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

3.10.3 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 5: 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
CNC Water cutter	Cuts, loss of limbs/appendages	Only trained personnel use this tool
Rotary Tools	Eye injury, cuts	Wear eye and respiratory protection, avoid putting face in plane of cutting head

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

3.10.4 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 TESTING AND DESIGN OF PAYLOAD EXPERIMENT

4.1.1 SYSTEM LEVEL DESIGN

The payload will meet the following objective:

Determine the accuracy of existing fin flutter simulations and equations by successfully comparing experimental fin flutter data to theoretical predictions. The predicted time, altitude, 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 determine test fin stress, strain, deflection 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 DEMONSTRATE DESIGN MEETS SYSTEMS-LEVEL FUNCTIONAL REQUIREMENTS

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 cut 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 velocities expected to be achieved by the rocket and so as not to interfere with the overall stability of the rocket. The fins will be attached to the rocket body using the fin retention system described in 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 velocities needed to “induce flutter”. The results from R.O. shows that for the given fin geometries, at least one of the test fins will not flutter until liberation at velocities less than or equal to the predicted maximum rocket velocity of 463 mph.

TABLE 6: FIN TRAPEZOIDAL DIMENSIONS

	1	2	3
Root Chord	30.48 cm	30.48 cm	30.480 cm
Tip Chord	15.24 cm	15.24 cm	15.240 cm

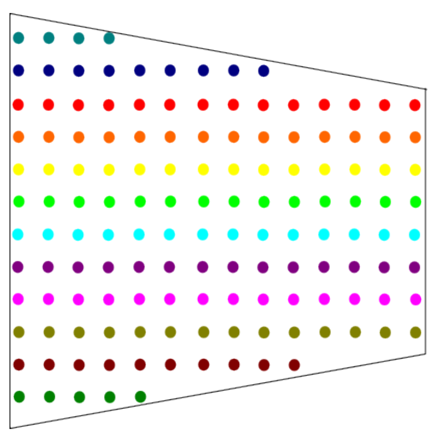
Span(Height)	22.86 cm	15.24 cm	20.32 cm
Sweep length	10.16 cm	10.16 cm	10.160 cm
Thickness	1.6 mm	0.8 mm	3.2 mm

TABLE 7: 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

FIN APPEARANCE

Each fin needs have certain features on its surface to aid in the analyzing the camera data by MATLAB and OpenCV. On each side of the fin there will be a black grid with a line thickness of 0.25in and a spacing of 1in and a grid of dots with a diameter of 0.25in and a spacing of 1in. For accuracy as well as ease of production these designs will be printed on sticker paper and these stickers will be placed on each fin. The type of stickers will be chosen as to not interfere with the fluttering of the fins that they are placed on.



FIN RECOVERY

Two of the fins are designed to induce fin flutter. There is a possibility that at most two fins are liberated from the rocket. The liberated fins will be recovered via a tracker tumble recovery. Fin recovery is further explained in the personal hazards section.

1. FIN FLUTTER MODELS

ROCKETRY ONLINE

Derivation based on the physical model of a Wilberforce pendulum. Analysis of the natural frequencies of the 2 degrees of freedom coupled harmonic oscillator.

$$V_f = \frac{(V_a)(G_E)}{\left(\frac{p}{p_0}\right)\left(\frac{\lambda+1}{2}\right)\left(\frac{39.3(A^3)}{\left(\frac{t}{c}\right)^3 (A+2)}\right)}$$

EQUATION 21: FLUTTER VELOCITY

Where:
Va is the speed of sound
GE is the shear modulus

AEROFINSIM 4.0

A structural analysis program that determines the strength of fins given their material and geometric properties. In their website they cite two equations that are used in their program in regards to fin flutter. Derivation based on 2-D airfoil bending and torsion spring model.

$$q_D = \frac{K_\alpha}{Se\,\frac{\partial C_L}{\partial \alpha}}$$

EQUATION 22: DIVERGENCE VELOCITY

Where, q_D = Divergence velocity, K_a = Torsion spring stiffness
S = Fin surface area, e = X_{ea} - $X_{ac.}$ $\partial C_L/\partial a$ = Fin lift slope = CL_a (2p for 2-D fins)

$$\frac{U}{b\omega_\alpha} = \sqrt{\left(\frac{2m}{\rho_\infty bS}\right)\frac{r_\alpha^{\,2}}{\frac{\partial C_L}{\partial \alpha}\left[x_\alpha + \frac{e}{b}\right]}}$$

EQUATION 23: FLUTTER VELOCITY

Where, U = Flutter velocity, w_a = Uncoupled torsion frequency, b = Average fin half-chord
m = Fin mass, S = Fin surface area, r_a = Fin radius of gyration, e = X_{ea} - X_{ac}
$\partial C_L/\partial a$ = Fin lift slope = CL_a (2p for 2-D fins), x_a = X_{cg} - X_{ea}.

"A NEW APPROACH TO THE EXPLANNATION OF THE FLUTTER MECHANISM"

Mario H. Rheinfurth and Fredrick W. Swift

January 1966

Derivation based on 2-D airfoil bending and torsion spring model and optimization from root locus methods.

$$V_T^{\,2} = \frac{2\,k_2}{\rho\,S\left|\overline{X}_P - \overline{X}_E\right|\frac{\partial C_L}{\partial \alpha}}$$

EQUATION 24: TORSION VELOCITY

$$V_B^{\,2} = \frac{2\,k_1}{\rho\,S\left|\overline{X}_P - \overline{X}_E\right|\frac{\partial C_L}{\partial \alpha}}$$

EQUATION 25: BENDING VELOCITY

$$V_F^{\,2} = \frac{2mr^2}{\rho\,\overline{X}_P\,S\,\frac{\partial C_L}{\partial \alpha}} \quad \left|\omega_1^{\,2} - \omega_2^{\,2}\right|$$

EQUATION 26: FLUTTER VELOCITY

MIT RT FLUTTER MODELS

Derivation using beam theory and spring mass systems to model fin flutter. Two 2-D models will be created, one that simulates bending motion only and one that simulates both bending and torsion in the fin. An example derivation of the bending model is shown below as well as the expected maximum fin flutter frequency and the expected flutter velocity.

2-D Model-- Bending**:**

Use Lagrangian methods to solve for the equations of motion of a fluttering fin.

Lagrangian = Kinetic Energy – Potential Energy

$L = T – U$

The potential energy is derived from the fin material properties

Moment -Curvature Relation

$E*I*d^2w/dx^2 = M(x)$

E = young's modules

I = moment of intertia = $(b*h^3)/12$ [for a rectangle]

w= displacement or deflection = SS $M(x)/(E*I)$

Distributed load $q(x)$

assume constant as the fin chord is small and $dq(x)/dx$ is nearly zero

hence $q(x)= q$ [force/length]

$dS/dx = q$ >$dM/dx=S = M =$ S $q*x\ dx = (q*x^2)/2$

$w =$ SS $(q*x^2)/(2*E*I)\ dx\ dx$

w(x) = (q*x^4)/(24*E*I) + C1*x+C2

BC @ x =0 w=0 > C2 = 0

assume max deflection is at the tip

dw/dx=0 @ x=L

C1= (q*L^3)/(6*E*I)

w= -(q*x^4)/(24*E*I) + ((q*L^3)/(6*E*I))*x

w(L)= (q*L^4)/(8*E*I)

q = (w*8*E*I)/L^4

U=S q dw = (w^2*4*E*I)/L^4

T = 1/2*Mt*v^2

motion constrained to the y axes only

T = 1/2*Mt*ydot^2

L = 1/2*Mt*ydot^2 – (y^2*4*E*I)/L^4

dL/dq – d/dt*dL/dqdot = 0

ydotdot – ((8*E*I)/(M*L^4))*y = 0

y(t) = A*sin(((8*E*I)/(M*L^4))^(1/2)*t)+B*cos(((8*E*I)/(M*L^4))^(1/2)*t)

Can be used to find the frequency of oscillation as well as the deflection for a given load

w = ((8*E*I)/(M*L^4))^(1/2)

T = (2*pi)/w [seconds]

f = 1/T [hertz]

(.2*(1/31)^3)/12

(.2*(1/32))*.3*1910

(((8*20000000*5.6*10^-7)/(3.6*0.15^4))^(1/2))/(2*3.14) = 35.3 hertz

MAX STRESS (G-10)

(FL)/(b*d)

Flexural Strength-LW-A-.125"	> 448 MPa	65,000 psi
Flexural Strength-CW-A-.125"	> 345 MPa	50,000 psi
Tensile Strength (.125") LW	> 310 MPa	45,000 psi

MAX DEFLECTION

q = (w*8*E*I)/L^4

CD = Fd/(qinf*S)

CD= drag coeffiecnt

D= drag force

Fd = normal drag force acting on fin = D*sin(alpha)

S = reference area

qinf = freestream dynamic pressure = ½ * rho * V^2

alpha = angle of attack

Fd = q

CD = 0.005 for Re (Renolyds number) > 10^5

S*(1/2)*rho*V^2*0.0005 = FD

S*(1/2)*rho*V^2*0.0005 = (w*8*E*I)/L^4

velocity deflection equation

stress = -z*E*d^2w/dx^2

max deflection = SS maxstress/(-z*E) dx dx

FLUTTER VELCOITY

S*(1/2)*rho*V^2*0.0005 = ((SS maxstress/(-z*E) dx dx)*8*E*I)/L^4

solve for v to get the flutter velocity

FIN FLUTTER MODELS: EXPECTED RESULTS

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 8: ROCKETRY ONLINE RESULT

	Rocket Velocity (mph)	Flutter Velocity	Divergence Velocity	Status
Fin 1	470	72	78	Flutter
Fin 2	470	122	135	Flutter
Fin 3	470	300	322	Ok

Aerosim Data

	Rocket Velocity (mph)	Flutter Velocity	Bending Velocity	Torsion Velocity	Status
Fin 1	470	57	55	48	Flutter
Fin 2	470	101	88	90	Flutter
Fin 3	470	349	297	325	Ok

Rheinruth and Swift Data

	Rocket Velocity (mph)	Flutter Velocity (Bend)	Flutter Velocity (Bend+Torsion)	Status
Fin 1	470	60	35	Flutter
Fin 2	470	232	147	Flutter
Fin 3	470	509	423	Ok

MIT RT Model Data

2. STRAIN GAUGE DESIGN

Each fin will be fitted with at least 4 Omega 1-Axis Precision Strain Gauges, arranged in a 'X' 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 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 uno, 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 UNO has to be as fast as possible. To decrease computation time on the Arduino UNO 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 UNO. 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 UNO wiring diagram.

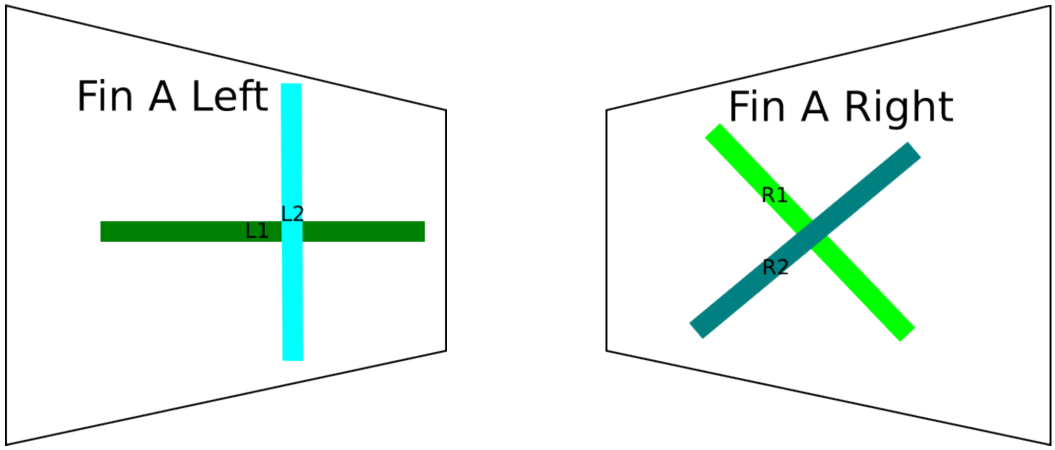


FIGURE 27: STRAIN GAUGE PLACEMENT

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 piezoelectric 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 permanently integrated to the rocket body after rocket body fabrication. The mirror holder is then screwed onto 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.

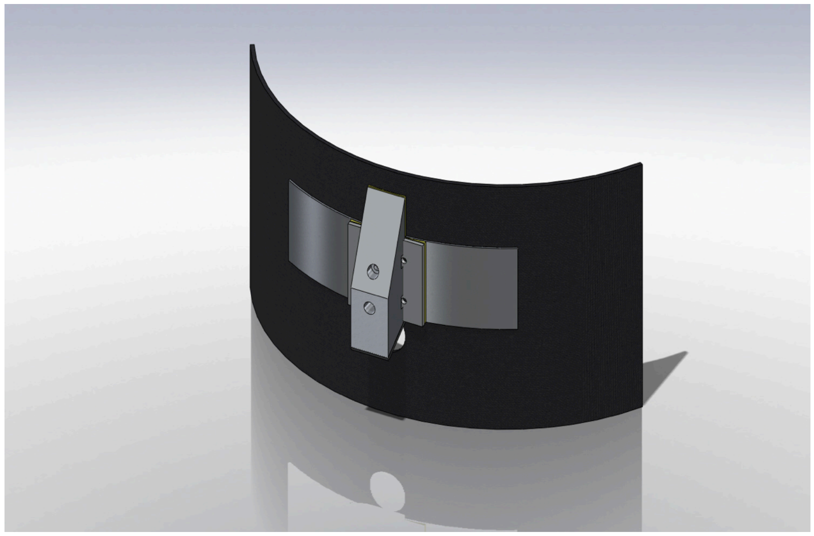


FIGURE 28: MIRROR ASSEMBLY

6. DATA RETRIEVAL AND PROCESSING

MATLAB Fin flutter Simulator

The team will write its own fin flutter simulator script using a set of equations that are different from the ones used on the R.O. simulator and AeroFinSim 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 frames will be analyzed after flight using OpenCV, a C based open source computer vision programming language. The video data will be 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 APPROACH TO WORKMANSHIP

Through past experiences, the MIT Rocket Team has identified that the workmanship of individual components plays an integral role in the final outcome of any project. With this in mind, the team has set in place schedule of testing and teaching of the various skills necessary for the fabrication and assembly of all payload components. Team members are taught basic electronic fabrication methods under the instruction of more senior members. All components are inspected and tested as necessary before they are used.

4.1.4 PLANNED COMPONENT TESTING

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.

4.1.5 STATUS AND PLANS FOR REMAINING TESTING/FABRICATION

Current progress has been made on proto-D board, working design is planned to be transferred to a flight ready configuration prior to next planned test launch.

4.1.6 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.

4.1.7 INSTRUMENT PERCISION AND MEASUREMENT REPEATABILITY

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 4.1.8.

The Arduino Uno can log data from all 6 of its analog inputs at around 1450 entries per second and the high speed cameras can capture images at 480 frames per second. The expected maximum flutter frequency is less than 100Hz. The frequencies of the measurements being taken are much greater than the expected flutter frequencies allowing reliable data and accurate recording of fin flutter deflection over time.

4.1.8 PAYLOAD ELECTRONICS

DRAWINGS

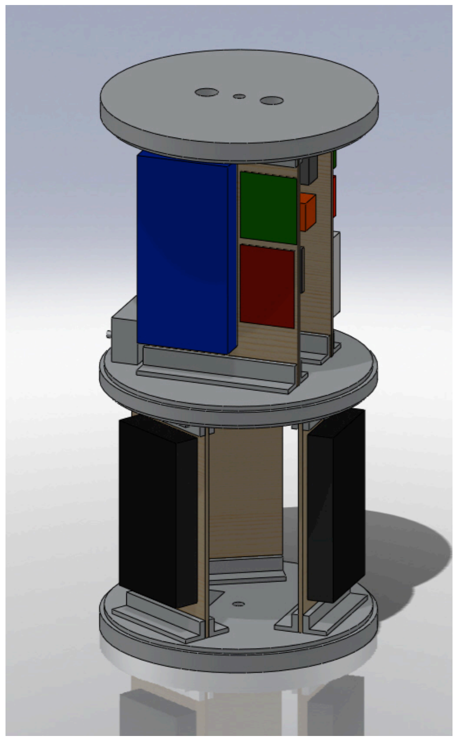


FIGURE 29: AVIONICS AND CAMERA BAY CAD MODEL VIEW 1

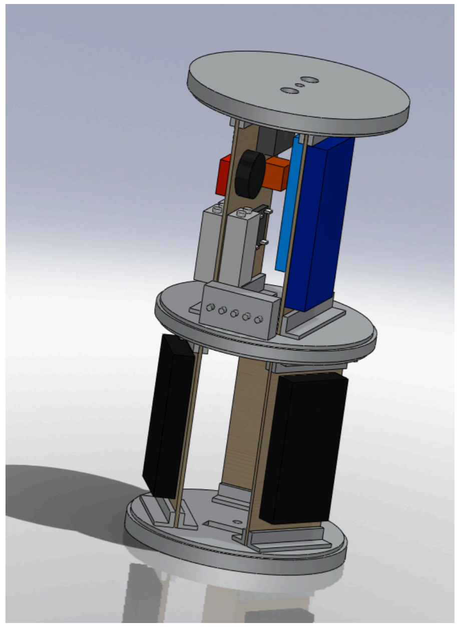


FIGURE 30: AVIONICS AND CAMERA BAY CAD MODEL VIEW 2

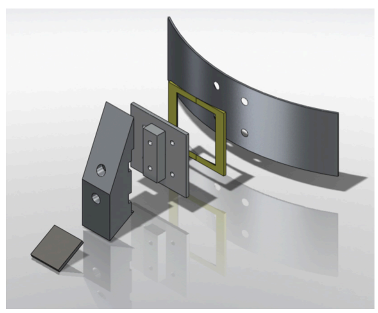


FIGURE 31: MIRROR MOUNT CAD MODEL VIEW

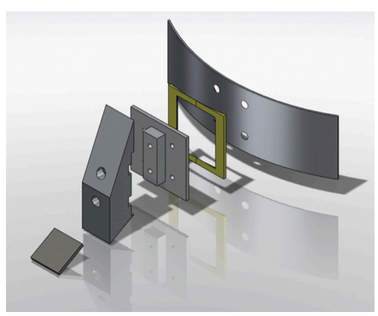


FIGURE 32: MIRROR MOUNT CAD MODEL FRONT VIEW

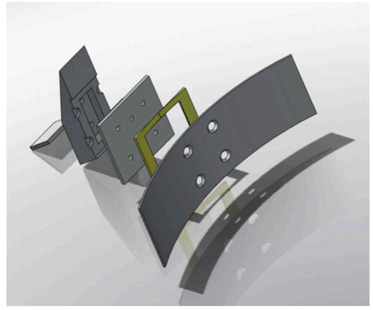


FIGURE 33:MIRROR MOUNT CAD MODEL BACK VIEW

SCHEMATICS

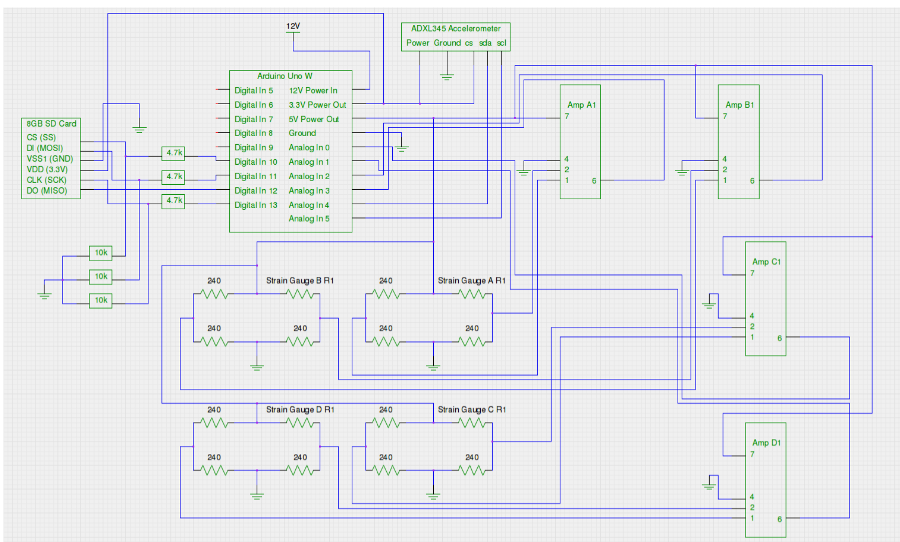


FIGURE 34: ARUINO WIRING DIAGRAM

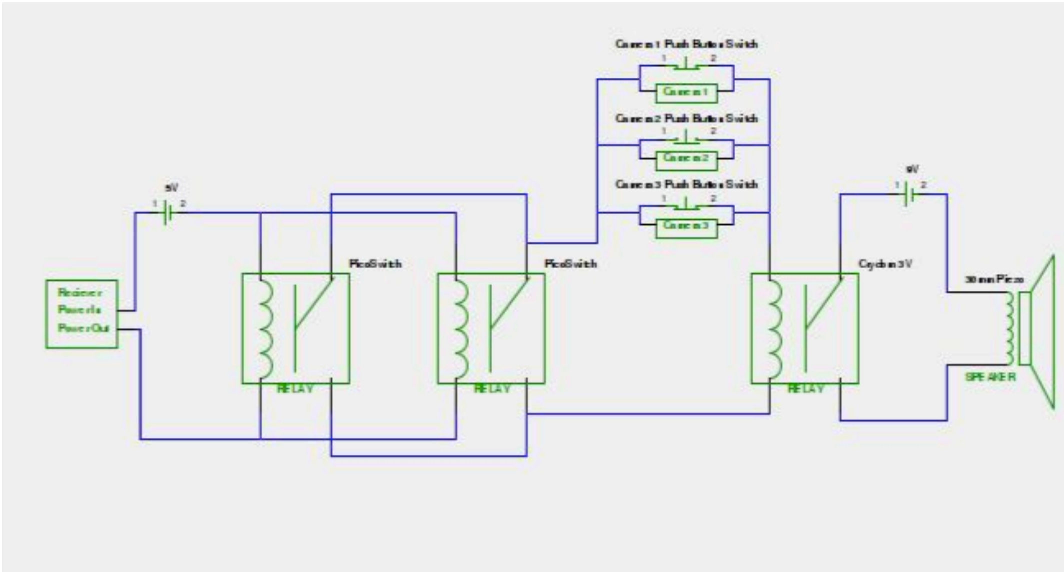


FIGURE 35: ARUINO WIRING DIAGRAM

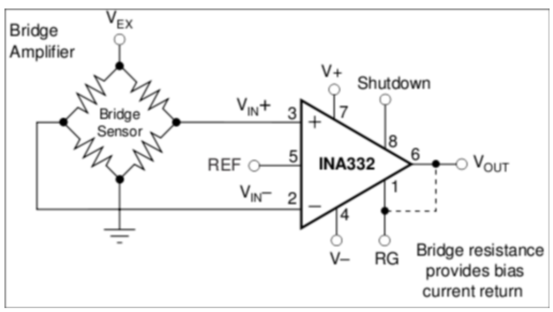


FIGURE 36: REMOTE SWITCH CIRCUIT DIAGRAM

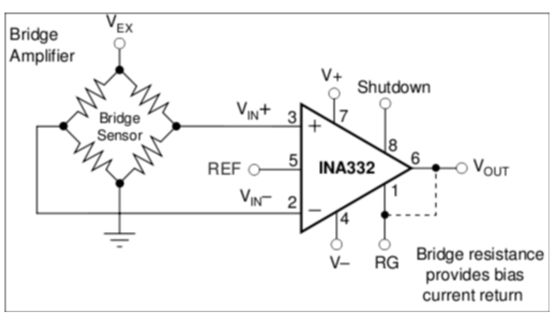


FIGURE 37: REMOTE SWITCH CIRCUIT DIAGRAM

DIAGRAMS

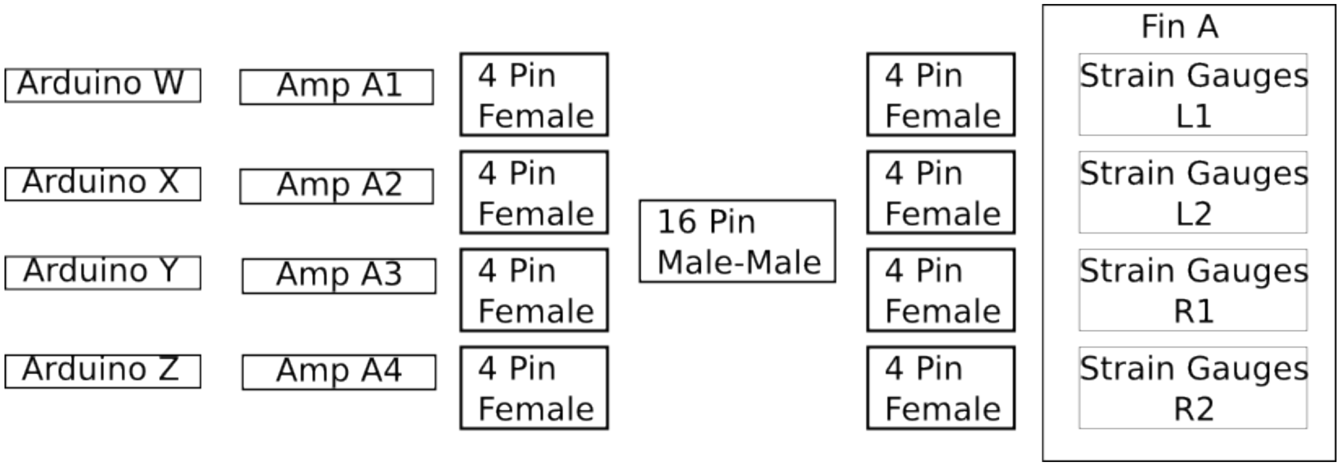


FIGURE 38: REMOTE SWITCH CIRCUIT DIAGRAM

KEY COMPONENTS

Arduino Uno

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.

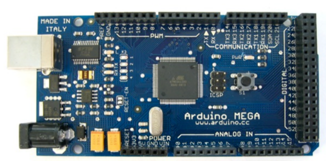


FIGURE 39: ARDUINO UNO

TABLE 9: ARUINO UNO SPECIFICATIONS

Recommended Input Voltage	7-12 V
Digital I/O Pins	14
Analog Input Pins	6
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)	2.80 in x 2.28 in x 0.63 in
Weight	66g

Casio Exilim EX-ZR15 High Speed Digital Camera:

The Casio Exilim EX-ZR15 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 40: CASIO EXILIM

TABLE 10: 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	NP-110 Rechargeable Lithium-Ion Battery Pack
Continuous Movie Recording Time (High Speed)	2 hours 50 minutes
Dimensions (WxHxD)	102 x 59 x 27mm
Weight	7.2 oz (176 g)

Omega 1-Axis Precision Strain Gauges (Omega SGD-150/240-LY40):

Used to measure strains for static and dynamic applications with a high degree of accuracy.

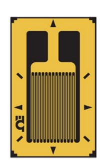


FIGURE 41: STRAIN GAUGE

TABLE 11: STRAIN GAUGE SPECIFICATIONS

Grid Dimensions	5.906 x 0.197in

Carrier Dimensions	6.496 x 0.354in
Pattern Type	Linear
Resistance	240
Maximum Voltage	35V

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 UNO. 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 42: BREAKOUT BOARD

TABLE 12: 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 UNO to detect a large change in acceleration in the vertical direction, ie launch; the Arduino UNO 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.

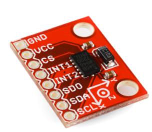


FIGURE 43: ADXL345 BREAKOUT BOARD

TABLE 13: 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 44: 30MM BUZZER

TABLE 14: 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.

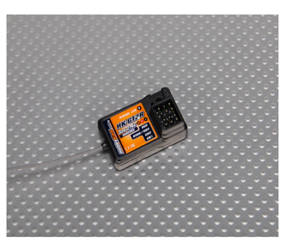


FIGURE 45: RECEIVER

TABLE 15: 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.

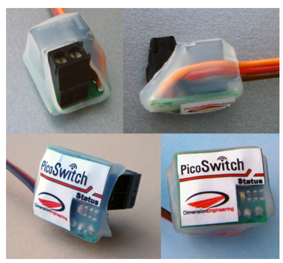


FIGURE 46: PICOSWITCH

TABLE 16: PICOSWITCH SPECIFICATIONS

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

Texas Instruments INA332

A 8-pin instrumentation amplifier used to amplify the analog signal coming from a strain gauge Wheatstone bridge configuration. To set gains greater than 5 one uses the equation: $G = 5 + 5(R2/R1)$

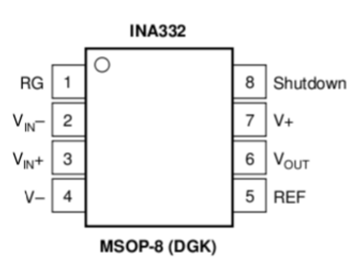


FIGURE 47: PICOSWITCH

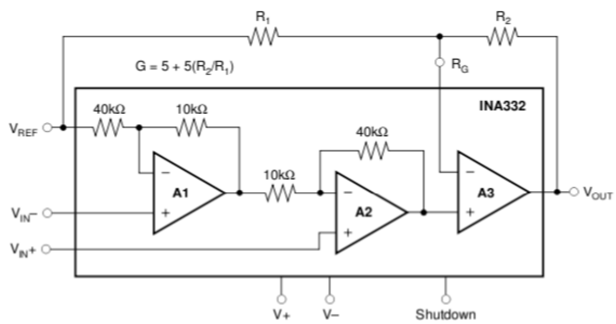


FIGURE 48: PICOSWITCH

TABLE 17: INA332 SPECIFICATIONS

Operating Voltage Range	2.5-5.5V
Maximum Supply Voltage	7.5V
Maximum Signal Input Voltage	0.5V
Operating Temperature Range	-55 to +125 degrees Celsius
Internal Gain	5V
Maximum Gain	100V (R1 = 10k and R2 = 190k)
Dimensions	5x6.5x1.2mm
Weight	

POWER DESIGN

TRANSMITTER INFORMATION

TEST PLAN

4.1.9 SAFETY AND FAILURE ANALYSIS

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.

4.2 PAYLOAD CONCEPT FEATRES AND DEFINITION

4.2.1 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 this technology to be applied to situations were cheap and rapid scientific data gathering is necessary.

4.2.2 UNIQUENESS OR SIGNIFICANCE

Fin flutter in high power rockets has been the supposed cause of many rocket failures over the history of the hobby. While a few methods of calculating the required amount of structure for fins exist, experimental testing in flight has, to our knowledge, not been performed to determine exactly when various types of fins flutter. By doing these experiments, we hope to validate the calculations that already exist and add to the knowledge body regarding fin flutter. By doing this, we hope to improve the average hobby rocketry enthusiasts' ability to properly design fins for their rockets.

4.2.3 SUITABLE LEVEL OF CHALLENGE

There are many challenges associated with the science mission the MIT Rocket Team has chosen to attempt this year. First and foremost the capture of high speed video from onboard the rocket is especially challenging. For one, to minimize negative flight characteristics, a custom mirror assembly has had to be designed. Furthermore, the topic of fin flutter is currently being researched throughout the industry. From contact with an engineer at Lockheed Martin, it has been discovered that even they are actively researching this topic.

Because of the significance of this project and the difficulties we expect to face, we believe that this project is more than adequate for a challenging for this year’s competition.

4.3 SCIENCE VALUE

4.3.1 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 EXPERIMENTAL MEASUREMENTS, VARIABLES AND CONTROLS

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

4.3.5 DATA RELEVENCE AND ERROR ANALYSIS

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 the theoretical models in order to provide models that have a higher degree of accuracy regarding the effects that lead to fin flutter.

Improved models will provide information about fin flutter conditions to individuals who require accurate data for the analysis of different potential rocket designs. These models 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.

4.3.6 EXPERIMENTAL 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.
- Develop mission success criteria
    - All data accurately acquired and stored properly
    - Still photographs acquired at SMD prescribed intervals
    - Communication between payload and ground station seamless
    - Semi-autonomous navigation capable of navigating to command coordinates
    - Safe landing of rocket and tethered pieces with use of parachutes
    - Safe landing of UAV, employing protective underside coat
- Ensure rocket, electric components, and other equipment are reusable after each mission

4.4 SAFETY OF THE ENVIROMENT (PAYLOAD)

4.4.1 TEAM SAFETY OFFICER

The safety officer is Andrew Wimmer, as stated in 3.10.1.

4.4.2 ANALYSIS OF FAILURE MODES, AND MITIGATION

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	medium	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 LISTING OF PERSONAL HAZARDS, AND MITIGATION

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.

- Fins not liberated

If we are not able to come up with an acceptable solution to keep the fins falling at safe speeds an 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

4.4.4 ENVIROMENTAL 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

Since PDR the project budget has been updated to include all planned components for the vehicle, payload and the various subsystems associated with them. The budget for ground support this year has been greatly reduced as we are able to reuse all ground station equipment procured last season. The travel budget has been carried over based on estimates from last year, but further refinements will be made as we get closer to the launch date. In the following tables you will find the breakdown of cost items for this year's project.

TABLE 20: BUDGET OVERVIEW

Subsection	Cost
Airframe	1081.85
Recovery	392.55
Avionics	627.95
Payload	1539.75
Total:	3642.10

TABLE 21: AIRFRAME BUDGET

Item	Notes	Unit Cost	Quantity	Total Cost
Nose Cone	PML 6" Fiberglass	99.95	1.00	99.95
Upper Section Phenolic	PML 6"	39.50	1.00	39.5
Lower Section Phenolic	PML 6"	39.50	1.00	39.5
Coupler	PML 6" Coupler	42.00	1.50	63
Payload Phenolic	Loc Precision 5.5" Cardboard	35.00	1.00	35
Fin Assembly	Custom plywood construction	15.00	0.33	4.95
Main Fins	Performance Hobbies 3/16" G10	40.00	1.50	60
Test Fin 1	Performance Hobbies 1/32" G10	15.00	0.50	7.5
Test Fin 2	Performance Hobbies 1/16" G10	20.00	0.50	10
Test Fin 3	Performance Hobbies 3/32" G10	25.00	0.50	12.5
Test Fin 4	Performance Hobbies 1/8" G10	30.00	0.50	15
Threaded Rod	3/8" all thread	5.00	2.00	10
Eye Bolt	3/8" forged eye nut	3.00	2.00	6
Carbon Fiber	Soller Composites 6" Biaxial Sleeve	7.46	9.00	67.14
Epoxy	Aeropoxy	118.95	0.25	29.7375
motor mount tube	PML 3" Phenolic	16.50	1.00	16.5
Rail Buttons	Doghouse Rocketry 1515 set	10.00	0.20	2
#10 Machine Screws	MMC 90279A104	4.59	0.75	3.4425
#10 Nuts	MMC 91841A011	4.30	0.75	3.225
Motor reload	CTI L1395 Blue Streak	246.95	1.00	246.95
Motor Hardware	Motor Casing and closure set	309.95	1.00	309.95
			TOTAL	**1081.845**

TABLE 22: RECOVERY BUDGET

Item	Notes	Unit Cost	Quantity	Total Cost
Drogue Parachute	Non Tangle Surplus	20.00	1.00	20
Main Parachute	RocketMan 16' standard	170.00	1.00	170
Tendered Descender		85.00	1.00	85
Tubular Nylon	Sold per foot	0.35	25.00	8.75
Deployment igniters	sold in set of 3	7.00	1.00	7
Black powder for Deployment	sold per pound	20.00	0.04	0.8
Parachute Deployment Bag		65.00	1.00	65
Nomex Charge Protector		16.00	2.00	32
Quest igniters	Sold in pairs	4.00	1.00	4
			Total	**392.55**

TABLE 23: AVIONICS BUDGET

Item	Notes	Unit Cost	Quantity	Total Cost
Perfect Flight Stratologger		79.95	1.00	79.95
Featherweight Altimeters Raven II		155.00	1.00	155
BeeLine transmitter		59.00	2.00	118
BeeLine GPS	2m transmitter version	265.00	1.00	265
Custom Fin Trackers	Custom built	5.00	2.00	10
			Total	**627.95**

TABLE 24: PAYLOAD BUDGET

Item	Notes	Unit Cost	Quantity	Total Cost
Ardunio Uno		23.00	5.00	115.00
Casio High Speed EXILIM EX-ZR100		263.95	3.00	791.85
Omega 1-Axis Precision Strain Gauges	SGD-150/240-LY40 150 mm Grid, 240 ohms (PKG OF 5)	135.00	3.00	405.00
Breakout Board for SD-MMC Cards		9.95	5.00	49.75
Triple Axis Accelerometer Breakout	ADXL345	28.95	1.00	28.95
Piezo Buzzer		0.99	1.00	0.99
Hobby King GT-2 2.4Ghz Receiver 3Ch		5.98	1.00	5.98
PicoSwitch radio controlled relay		19.99	3.00	59.97
3 volt relay		6.00	1.00	6.00
8 Pin Instrument Amplifier	Texas Instruments INA332	2.15	15.00	32.25
9 Volt Battery		2.67	3.00	8.01
12 Volt Battery	ZIPPY Flightmax 2200mAh 3S1P 20C	9.00	4.00	36.00
			Total	**1539.75**

5.2 TIMELINE

As previously discussed the majority of tasks for this year's project have taken 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 the following table.

TABLE 25: 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
	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 has, up to this point, held two community outreach events to inspire and educate the general public about space and space-related technologies in a hands-on fashion. The team intends to hold three more of these events and a competition over the course of the next few months! 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 26: OUTREACH EVENTS

MIT Splash Weekend	November 20 (Complete)
Ready, Set, Zoom! at MIT Museum	January 13 (Complete)
Rocket Day at Boston Museum of Science	Mid-February
Engineering Week at MIT Museum **(New!)**	February 19-25
MIT Spark Weekend	March 10
USLI Payload Competition	December-> February

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-February 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. MIT MUSEUM ROCKET DAY

We have now run one, and plan to soon run another, 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. We presented on January 13 for Ready, Set Zoom!, but the Museum has also now invited us back to present at their Engineering Week, from February 19-25!

12. MIT SPARK AND SPLASH

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.

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., 4lbs, 5.5" diameter by 21" 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 began accepting proposals in December, and will have a hard deadline for all proposals in the last week of January. Proposal selection and payload construction will occur throughout 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.