

MIT Rocket Team
Project Proposal - USLI 2012



September 26, 2011

TABLE OF CONTENTS

1	Basic information	4
1.1	School Information	4
1.2	Facilities and Equipment.....	5
1.2.1	Lab space.....	5
1.2.2	Personnel and Equipment Needed	6
1.2.3	Computer Equipment	6
1.2.4	Web Presence.....	7
2	Safety.....	7
2.1.1	Team Mentor.....	7
2.2	Safety Plan	8
2.2.1	Procedures for NAR/TRA Personnel to Perform.....	8
2.2.2	Hazard Recognition and Accident Avoidance	8
2.2.3	Outline of Hazard Recognition Briefing	9
2.2.4	Pre-launch Briefing.....	10
2.2.5	Caution Statements.....	10
2.2.6	Cognizance of federal, state, and local laws regarding un- manned rocket launches and motor handling	11
2.2.7	Purchasing and Handling Rocket Motors.....	11
2.2.8	Transportation of Rocket to Huntsville	11
2.2.9	Safety Agreement	12
3	Mission Statement	12
3.1	Mission Motivation	12
3.2	Mission Statement	13
3.3	Constraints.....	13
3.4	Mission Requirements	13
3.5	System Requirements	14
4	Rocket Details.....	14
4.1	Rocket Design	14
4.2	Payload Details	16
4.3	Rocket and Payload Requirements	18
4.4	Challenges and Solutions	19
5	Project Plan.....	20
5.1	Timeline	20
5.2	Budget Summary	20
5.3	Testing	21
6	educational engagement.....	22

6.1	USLI – MIT Chapter community outreach	22
6.1.1	purpose of community outreach.....	22
6.1.2	Boston Museum of Science	22
6.1.3	MIT Splash and Spark Weekends.....	23
6.1.4	Rocket payload competition	24
	Appendix I: Signed Safety Agreements	25
	Appendix II: FAA regulations.....	27
	Appendix III: High Power Rocket Safety Code	30

1 BASIC INFORMATION

1.1 SCHOOL INFORMATION

ORGANIZATION NAME:	MIT Rocket Team Massachusetts Institute of Technology
FACULTY ADVISOR:	Dr. Paulo Lozano, Associate Professor Department of Aeronautics and Astronautics plozano@mit.edu
TEAM POINT OF CONTACT:	Christian Valledor, Team President valledor@mit.edu
SAFETY OFFICER:	Andrew Wimmer, TRA Level 3 awimmer@mit.edu Ben Corbin, Environmental Health & Safety Representative bcorbin@mit.edu
NAR CONTACT:	John Kane, Central Massachusetts Spacemodeling Society [CMASS], NAR Standards and Testing Co- Chair kane@mit.edu

MEMBERS: The MIT Rocket Team consists of approximately 20 active members ranging from first year undergraduates to doctoral candidates. The team has been organized into the following subgroups: (1) Payload; (2) Airframe; (3) Propulsion; (4) Recovery; (5) Modeling. There are approximately 4 members in each subgroup, though positions often overlap based on member interest.

KEY MEMBERS and ROLES:

Christian

- President, Team Lead
- Aeronautics and Astronautics, MIT 2012

Andrew

- Head Safety Officer
- Vehicle Lead
- Aeronautics and Astronautics, MIT 2012

Ben

- Assistant Safety Officer
- Propulsion Group Lead
- Aeronautics and Astronautics; Earth, Atmospheric, and Planetary Sciences, PhD candidate

Julian

- Treasurer
- Aeronautics and Astronautics, MIT 2013

Leo

- Payload Group Lead
- Aeronautics and Astronautics, MIT 2013

1.2 FACILITIES AND EQUIPMENT

1.2.1 LAB SPACE

The MIT Rocket Team has been assigned its own lab space on the main campus to conduct all activities associated with the design, fabrication, and storage of large-scale competitive rockets, and science payloads. The team's lab space in Building 17 of the MIT campus (the Wright Brothers Wind Tunnel Building) serves as the primary workspace, meeting space, and secure storage location. The Lab is part of the campus Environmental Health and Safety system and, as such, all health and safety standards are followed in the lab. The lab is open during normal institute hours, and core members can be issued a key to the building as needed for 24-hour access. The lab is furnished with various hand tools and select power tools commonly used for rocket fabrication.

The Rocket team also has access to the MIT Gelb Lab in MIT Building 33. This lab space serves as a common work area for the entire department of Aeronautics and Astronautics at MIT. The lab includes a full machine shop, group meeting spaces, worktables, and a small-scale wind tunnel for student use. In the machine shop team members are allowed to work under the guidance of a full time instructor, ensuring safety and accuracy in all manners of work. The wind tunnel is also open to any student wishing to use it, and may be used for the rocket team as needed. The Gelb Lab is

open 24 hours a day to all members of the Department of Aeronautics and Astronautics, and special access may be requested on a case-by-case basis. The machine shop is open from 9am until 5pm on weekdays, and is limited to course related work and projects related to the department, including the Rocket Team.

1.2.2 PERSONNEL AND EQUIPMENT NEEDED

The MIT Rocket Team, is fully student lead, and as such will be under the direction of Team President Christian Valledor. To ensure all federal, state, and institute rules are followed the team advisor, Professor Lozano, and Safety Officers, Andrew Wimmer and Ben Corbin will review all steps of the design, construction and testing process. Flight- testing of the rockets will be conducted with assistance of the local NAR chapter, CMASS, and more distant rocket clubs, CRMRC, METRA and MDRA. Individual sub-component testing will be conducted on the Massachusetts Institute of Technology campus, at various suitable locations. The MIT Rocket Team will obtain any and all materials necessary to complete the USLI competition while following all stated rules. For additional help, we have been in contact with members of CMASS and have multiple members on the team with high power rocketry experience.

1.2.3 COMPUTER EQUIPMENT

All members of the MIT Rocket Team have access to a variety of computers on campus to aid in the design, simulation, modeling, and analysis of our designs. Although the Rocket Team does not maintain a computer specifically for the team, many computers are made available to the members.

The MIT computer network, MITnet, consists of a wireless network that covers 100% of the campus, as well as all dormitories and MIT fraternities, sororities, and independent living groups. Along with access to high speed internet MITnet includes 345 computers, known as Athena Workstations, scattered across campus that are open to all members of the MIT community. A majority of these Athena workstations run a customized Linux distribution [named Athena], however there are also traditional Windows, and Mac machines available. All Athena workstations have access to a wide range of software made available to students for free.

With access to the Athena, and other campus licensing agreements all

members of the MIT Rocket Team are able to use sophisticated software including but not limited to:

- o MATLAB
- o Mathematica
- o SolidWorks
- o FEMAP/NEiNASTRAN
- o Maple
- o ProEngineer
- o Altium
- o Microsoft Office

In addition to software available campus wide, the MIT Rocket Team also purchased 8 floating licenses of RockSim 8, which is used extensively for initial design and modeling.

Furthermore, MIT Rocket Team members may also use their own personal computers when working on USLI related items. A majority of all work is done by members on these personal machines. As such the computer resources available to the team are virtually limitless, and are available to us at all times. Finally at all times members of the MIT Rocket Team will adhere to any and all regulations concerning computer systems as dictated by the USLI organizers.

1.2.4 WEB PRESENCE

In accordance with USLI rules, the MIT Rocket Team has established a website that will host all information related to the USLI project. The website is hosted by dedicated machines on the MIT network, and is accessible at: <http://web.mit.edu/rocketteam>

2 SAFETY

2.1.1 TEAM MENTOR

Andrew Wimmer is our intended primary mentor. Depending on the success of a few other unrelated rocket team projects, we may need to find another mentor that meets the USLI requirement that the mentor have 15 successful dual deployment flights on the mentor's certification before PDR, as Andrew is a couple of flights short of that number. Contact was

made with CMASS last year and a variety of local club members offered their assistance. If the need comes, Jack Kane, a former MIT employee, would likely be able to offer assistance. If he is unable to help, the team has a support network with METRA, MDRA, CRMRC and THOR and will be able to find the necessary mentor.

2.2 SAFETY PLAN

2.2.1 PROCEDURES FOR NAR/TRA PERSONNEL TO PERFORM

The NAR/TRA mentors or a student team member that is NAR/TRA certified to the level required will be responsible for all motor handling operations. This includes purchase, storage, transportation and use at the launch site. They will be responsible for assembly of the motor and possession of it until it is installed in the rocket. They will also officially be the owner of the rocket, as is required for insurance purposes.

The NAR/TRA mentors or certified student team members will be responsible for overseeing hazardous materials operations and handling. Although it is not required by NAR/TRA rules that they perform operations regarding non-motor related hazardous materials, they will generally be more informed and experienced with the handling of ejection charges and igniters, and thus will either perform hazardous materials operations or closely supervise them.

2.2.2 HAZARD RECOGNITION AND ACCIDENT AVOIDANCE

Students will be briefed on hazardous recognition and accident avoidance at points in time that are relevant to associated hazards. MIT's EHS lab guidelines will be referenced prior to any activities that may involve hazard. These documents are available on the EHS's website (<http://ehs.mit.edu>). The lab also has a dedicated EHS representative who's part of the team, who will ensure EHS guidelines are followed. Prior to launch activities, specifically the scale test launch, the full scale test launch, and the launch in Huntsville, the team members attending will be briefed via a Power Point Presentation covering the hazards of high power rocket launch activities, range safety codes (NFPA and NAR/TRA Safety codes-see Appendix), and standard procedures and etiquette at launches. The NAR/TRA mentors or team members that are sufficiently experienced will perform these briefings. All pertinent safety documents, including the safety presentations, will be available on the team website for ease of reference.

2.2.3 OUTLINE OF HAZARD RECOGNITION BRIEFING

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:
 - a. Equipment
 - b. Tools
 - c. Procedures
 - d. Materials Handling
 - e. Other Concerns
- b) Be cognizant of your own actions and those of others
 - a. Point out risks and mitigate them
 - b. Review procedures and relevant MSDS before commencing potentially hazardous actions
- c) Safety Equipment
 - a. Only close-toed shoes may be worn in the lab

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-toe 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 of 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 facemasks and respirators when sanding, cutting, grinding, etc.
 - ii. Always wear gloves when handling pre-cured composites
 - iii. Always wear goggles when handling composites
 - iv. Always wear puncture-resistant gloves when handling post-cured composites
 - v. 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

2.2.4 PRE-LAUNCH BRIEFING

The pre-launch briefing will include an overview of the hazards of high-power rocket launch activities, range safety codes (NFPA and TRA/NAR Safety codes – see Appendix), and standard procedures and etiquette at launches.

2.2.5 CAUTION STATEMENTS

Caution statements will be printed into all plans, procedures, and other working documents that are related to risky activities. The documents include, but are not limited to: checklists, operating procedures, lay-up procedures, and chemical handling procedures. MSDS for all materials used in the lab will be available in the lab and on the team website. See Appendix for a list of all relevant MSDS.

2.2.6 COGNIZANCE OF FEDERAL, STATE, AND LOCAL LAWS REGARDING UNMANNED ROCKET LAUNCHES AND MOTOR HANDLING

The safety officer for the team will brief the team in a meeting regarding unmanned rocket launches and motor handling. This will be in addition to the pre-launch briefings. The following will be covered in this briefing:

1. Federal Aviation Regulations 14CFR, Subchapter F, Part 101, Subpart C - Amateur Rockets
2. 14CFR Part 55 – The Handling and use of Low-Explosives (Ammonium Perchlorate Rocket Motors, APCP) and Fire Prevention (Note: As of Judge Reggie B. Walton's March 16, 2009 Ruling, APCP is no longer an explosive and thus must not be sold and handled as such).
3. NFPA1127–Code for High Power Rocket Motors

* See Appendices II and III

Each team member is required to understand and abide by the safety information in the Student Safety Agreement, including the NAR safety code for high-powered rocketry and key USLI safety regulations. This information will also be posted on the project webpage in the Safety and Mission Assurance section.

2.2.7 PURCHASING AND HANDLING ROCKET MOTORS

The motor casing and reload(s) will be purchased online by one of our Level 2 or Level 3 certified members. Level 2 and Level 3 members will also be the only ones permitted to handle the motor reload(s), which will be stored in a specified and dedicated location in the MIT Rocket Team's lab fire-safety cabinet. The safety officer will make sure the reload(s) are properly stored and, when required, transported in an appropriate container. The safety officer will oversee all building of reload(s) and loading of rocket motor(s).

2.2.8 TRANSPORTATION OF ROCKET TO HUNTSVILLE

In light of the recent ruling regarding APCP's status as an explosive, the only federal regulations pertaining to the control of rocket motors are those regarding commercial transportation of motors (DOT) and NFPA regulations. The motors will be transported either via car or

shipped directly from a vendor to a designated location in Huntsville prior to the launch. They will only be handled by our certified team members or a certified NAR/TRA mentor. Given we are not in commerce, travelling with them via car requires no special permits other than a NAR/TRA certification.

2.2.9 SAFETY AGREEMENT

A safety agreement (located in Appendix I) was created to ensure that members understood all of the safety hazards, and read the applicable safety regulations.

3 MISSION STATEMENT

3.1 MISSION MOTIVATION

Fin flutter is a phenomenon that can adversely affect the performance of a rocket as it is in flight. When flutter occurs the forces acting on the fins can greatly exceed those of the nominal flight conditions. In these cases flutter can have disastrous effects as the induced vibrations can move the rocket off course, or even cause damage to the fins or airframe.

In the high-powered rocketry community many failed flights have been attributed to the phenomenon of fin flutter. However there has been little evidence to support this claim. Furthermore, many flight videos of suspected flutter may in fact be examples of a well-documented artifact of digital video sensors. With this in mind, the MIT Rocket Team has chosen to investigate this phenomenon further by instrumenting this year's rocket with strain gauges and high-speed video equipment.

In summary the team aims to:

- Develop a reliable analysis technique based off existing flutter calculators to predict the effects of flutter on fin designs.
- Develop an airframe employing fins expected to display non-fatal flutter effects.
- Develop a system of high-speed cameras to record video of the fins throughout flight.
- Record data from strain gauges and other sensor mounted on or around the fins.
- Analyze video and other data to better understand flutter.

3.2 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.

3.3 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.
- Must carry one PerfectFlight MAWD, or other NASA designated altimeter for official altitude record
- 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.
- 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.

3.4 MISSION 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 confirm fin flutter with high speed camera and custom mirror system
 - a) Use image processing software to accurately track fin movement

3.5 SYSTEM REQUIREMENTS

The system requirements are as follows:

- 1) System must be less than \$5000 fair market value at time of flight
- 2) Rocket must reliably and accurately achieve apogee of 5280ft
- 3) Stream telemetry, and video to ground station
- 4) Employ video and beacon tracking systems.

4 ROCKET DETAILS

4.1 ROCKET DESIGN

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 5.1-1.

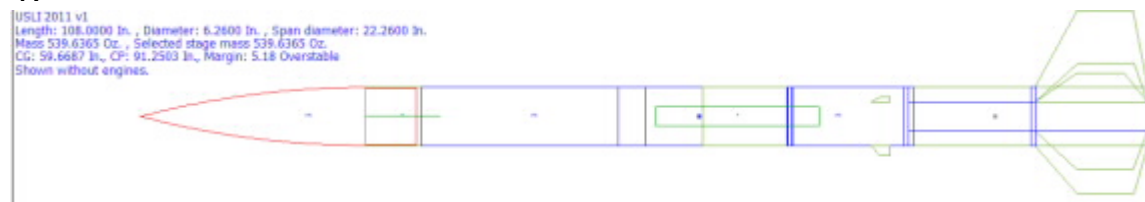


Figure 5.1-1: Cross-section of Rocksim model

As can be seen in the figure, the rocket is 9'0" in length, the inner diameter of the rocket tube is 6.16", and the fin span is 9". The three fins used to analyze fin flutter have a span of 5", 6" and 8" respectively. Furthermore, the mass of the rocket is projected to be 42.4 pounds for a payload mass of 8 pounds and ballasted in the nose cone as necessary in order to reach an

apogee of 1 mile. Current design projections show a 5700' apogee, which will be left as margin throughout the design process. The exact specifications of payload deployment depend on the experiment chosen, although a 24" long by 5.8" ID tube will remain available for use. The exterior dimensions will remain the same and the payload will be ballasted as necessary to reach the 8 pound design weight. The tubing will be made from Soller-Composites carbon fiber sleeve wrapped around a 6" diameter PML tube as a mandrel. These tubes will be constructed similarly to the ones used for last year's USLI project. 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. The total cost of the loaded motor is also considerably less expensive than an Aerotech equivalent.

The recovery system will consist of the deployment of a 60" diameter surplus, tangle-free, pilot parachute at apogee and a Rocketman R14 at 700'. 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 700'. At 700', 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 650'. The pilot parachute will pull the payload module out of the rocket, followed by the main parachute deployment bag. This deployment system has been flight tested and shown to be 100% successful over 3 flights. The rocket will land in two tethered pieces, the 13 pound nosecone/payload and the 24 pound rocket body and fin unit. The nose cone/high school payload section will land at approximately 19.16ft/sec for a total energy of 98.2 joules, or 72 ft-lbs. The lower section will land at approximately 12.89 ft/sec for a total landing energy of 82.3 joules or 60 ft-lbs of energy. These numbers are calculated using an online parachute descent rate calculator that also closely matches the published values for the Rocketman

parachute we are using. Each section will contain a BigRedBee 70cm tracker for location after launch. The larger, lower section will also likely contain a BigRedBee 2m GPS tracker for the same purpose.

4.2 PAYLOAD DETAILS

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, solid state memory, and data/video telemetry devices. Together, these systems will allow the rocket to communicate to the ground station fin flutter data, to allow the processing of the data in real-time. Using the data to find test fin stress, strain, deflection as a function of time and position, a 1st mode fin flutter model will be created and compared to expected models and stress behavior as dictated by fundamental fin flutter equations. In addition, commercial-off-the-shelf recovery components (an altimeter and an accelerometer) will be flown on the rocket.

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 dimensions of the fin were chosen, using a fin flutter estimator provided by Rocketry Online, to display 1st mode fin flutter at a velocity expected to be achieved by the rocket and as to not interfere with the overall stability of the rocket. Each fin will be fitted with at least 4 Omega 1-Axis Precision Strain Gauges to record and transmit stress, strain, and deflection data in each fin during flight. The lead wires will be integrated into the rocket body tube such that gauges can be connected to a male wire terminal which plugs into a female wire terminals located on the bottom of the avionics and cameras bay, located near the top of the bottom rocket body tube. The terminal will be connected to three Omega Bridge Completion modules and the on-board computer, an Arduino Mega, which will be programed to read amplified voltages of the connected gauges, and to calculate the resulting stress, strain, and deflection over time. This data is then saved to a 2 GB SanDisk Flash memory card and outputted to a Xbee Pro 900mhz transmitter which sends the data to the ground station during flight. This data can then be compared to the expected stress strain response as

documented by fin flutter equations and simulations for a given test fin.

The avionics and cameras tube also contains the rocket altimeters and flight computers 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. If need be, the cameras will be wired to an external battery source in the bay in order to extend the filming time of each camera to be greater than 2 hours. Also, the shutter and power switches for each camera will be wired together, respectively, and connected to physical switches which are accessible during rocket integration. 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.

During flight each camera will record test fin movement at approximately 420 frames per second and store this video data on a Transcend 8 GB HC SecureDigital Class 6 (SDHC) Card. Video data will also be transmitted to the ground station using three 2.4GHz Aerial Video Systems transmitters, one for each camera. Video frames will be analyzed by the ground station during and after flight using OpenCV, a C based open source computer vision programming language. Using the OpenCV algorithms of shape and contour recognition, the team will write executables to track 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 test fin 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 then these equations can be compared to the expected 1st mode fin flutter functions for a given test fin.

4.3 ROCKET AND PAYLOAD REQUIREMENTS

The rocket and payload must meet a variety of requirements. Many of these requirements are listed in section 3.3 Constraints, and duplicated in the NASA USLI Request for Proposals starting on page 7. All of these program level requirements have been met with our current vehicle design. Additionally, the program fully intends to comply with all NAR, Tripoli and other requirements set out by various authorities having jurisdiction (AHJ's), such as the FAA, MIT EHS, MIT Association of Student Activities, METRA launch rules, MDRA launch rules, A further listing of payload, vehicle and program specific requirements are as follows:

- The vehicle design must allow the measurement of induced flutter in the fins. To do this:
 - The rocket must reach a velocity at which the fins can flutter
 - The fins must be designed to flutter at or below the expected flight velocity
 - The video recording system must be designed to be robust and allow measurements of fin flutter during flight
 - The data recording system on the strain gauges on the fins must be designed to operate in a rocket flight environment
- The vehicle must recovery safely
 - This includes drogue and main parachute deployment systems must be ground tested to ensure their reliability
 - All sections must land with energy of less than 75ft-lbs. This will require any fins that are expected to be liberated from the vehicle from flutter to be tethered to the vehicle.
- The vehicle must be flight tested successfully prior to FRR
 - This will require scheduling to allow multiple test opportunities to allow for vehicle or recovery failure.
 - This will require time commitments from members of the team to complete the vehicle and payload in time to perform flight tests
- The rocket must deliver the high school payload canister as expected
 - In the event this violates the requirement that student team members doing all of the work on the project, the payload canister may be flown without a payload. In that event, it is

likely the rocket would be flown on the smaller L1355, as the liftoff mass would be reduced by 8 pounds.

- The team must work with local high schools and afterschool programs to develop a payload that is educationally engaging.

4.4 CHALLENGES AND SOLUTIONS

The following table of challenges and solutions is not all-inclusive; while the team has a great deal of experience with high power rocketry and scientific data acquisition, in our experience, there are always unknown challenges that require solutions. The following table is a list of anticipated challenges, and their proposed solutions or methods to mitigate the risk the challenge brings to the project.

Challenge	Solution
Modeling fin flutter	Perform research on previous flutter modeling projects, including aircraft wing flutter and existing fin flutter spreadsheets for rocket us
Development of the high speed camera system	Use off the shelf components and standard high power rocketry methods for mirror mounting. Purchase cameras early and start development work prior to CDR
Strain gauge data acquisition	Request assistance from MIT faculty and staff that have worked with data acquisition systems in the past. Work with them early and often to develop a robust system.
Rocket safety with fluttering fins	Design rocket to be stable with 3 fins that will not flutter. If fins are expected to be liberated during flight, tether outside of fin to rocket body so it is captured and does not fall free
New member education	Due to a large group of new members to the team, educational sessions on high power rocketry and other relevant topics will be held to keep the team up to date

5 PROJECT PLAN

5.1 TIMELINE

The timeline for this year's project will closely follow the competition schedule with added milestones for project related tasks. The milestones and projected dates for each can be found below. A more detailed project timeline will be completed as planning stages ramp up in early October.

Task	Date
Proposal	26-Sep
Final Schedule	10-Oct
School Notification	17-Oct
USLI Telecom	21-Oct
Web Presence	4-Nov
PDR	28-Nov
Scale Launch	Dec
Ejection Test	Jan
Camera Vibration Test	Jan
CDR	23-Jan
Full scale Launch	Late Feb
DAQ Test	Early Mar
FRR	26-Mar
Travel	18-Apr
Launch Day	21-Apr
PLAR	7-May

5.2 BUDGET SUMMARY

The following budget outlines our proposed expenditures for the USLI project. This budget is based off of actual component costs and margins are based off expenditures from last year's project.

System	Item	Cost
Rocket	Propulsion	563
	Airframe	400
	Avionics	700
	Payload Support Equipment	150
	Recovery	450
Payload	Cameras	720
	Strain Gauges	65

	Data loggers	125
	Data transmitters	300
Support	Testing	2500
	Spares	4000
	Team Support	5500
	Outreach	1000
Total		\$16,473

5.3 TESTING

A variety of testing needs to be performed for this project to succeed and to meet NASA test requirements.

A full scale test flight will be performed at a CRMRC launch in Maine in late February. METRA and MDRA will also be holding launches into March and April that will act as backup dates. The primary goal is to perform a successful test flight prior to FRR submission. With a variety of launch sites and dates available, this should be reasonable.

A sub scale test flight will be performed prior to CDR. This will involve a 3" diameter vehicle with an identical fin configuration and CP/CG relationship. This will show that the rocket can fly stability with asymmetric fins and also provide NASA with confidence in the team's abilities to fly rockets

The video system will be tested prior to the full scale test flight on MIT's Space Systems Lab's vibration table. This will allow the payload team to work out any issues with the video and mirror system prior to the full scale test flight

The strain gauge data acquisition will be ground tested multiple times during development and before integration. This will involve the simple recording of data and ensuring that it meets expectations.

Data on the structural properties of fin materials will be either found through research or produced from testing.

Ejection charges and recovery altimeters will be ground tested to ensure that they are able to fire charges and that the charges are sufficient to allow for parachute deployment. This will occur prior to the full-scale flight test.

6 EDUCATIONAL ENGAGEMENT

6.1 USLI – MIT CHAPTER COMMUNITY OUTREACH

6.1.1 PURPOSE OF COMMUNITY OUTREACH

Our goal as active members of our surrounding community is to extend our knowledge and interests to the younger population of the Greater Boston Area. To this end, we have organized three community events that will target middle school through high school students with the purpose of promoting higher education through mentoring students and sparking interest for the arts and sciences. In the spirit of the USLI competition, these events will focus on rocketry, including its history and inner workings, to inspire the youth that they are capable of performing rocket science.

6.1.2 BOSTON MUSEUM OF SCIENCE

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

- 1) **Film canister rockets**
- 2) **Parachute construction**
- 3) **Shortwave radio communications** (emulate mission control with delay)
- 4) **Bottle rocket demonstration**

- 5) **Full-scale hobby rockets and scaled down models of famous rockets**
- 6) **Demonstrations to demonstrate the scales of larger rockets**

The learning objectives for this activity will be the following:

- 1) **Ensure a basic understanding of the history of rocketry.** To understand rocketry and its development, we believe in the importance of explaining the history of rocketry through the ages and the key people and organizations that have advanced this field. Topics will include Wernher von Braun, Robert Goddard, NASA, the Space Race, and current commercial rockets such as SpaceX's Falcon 9.
- 2) **How does a rocket work?** The main premise for this activity is to explain how rockets work and prime our target audience with an interest in math and science through the amazing technology that are rockets. This portion of the presentation will introduce the importance of math and science in developing rockets by explaining the basic 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.

6.1.3 MIT SPLASH AND SPARK WEEKENDS

MIT's Educational Studies Program is a student group that offers services to student and community members alike. As part of its community outreach it offers student-taught classes all weekend long during the months of November (called Splash) and March (called Spark) on campus to a target group of 7th-12th graders. Registration to teach a class is simple

and we intend to offer several classes at these events. Our plan 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 rather it offers an exciting, fast-paced, and very innovative work environment. We aim to get the students enthusiastic about pursuing math and science beyond high school. Since these classes would be smaller and engaging, we plan to use entrance and exit surveys to quantitatively gauge the learning that occurred. This will be useful to know if we need any changes to the curriculum before presenting at the museum (which will occur after Splash).

6.1.4 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 (ie, 8lbs, 5.5” diameter by 24” long). In early 2012 we will select the best idea, and will then assist the ‘winning’ team in constructing their scientific payload. The final payload will be brought to Huntsville with us and flown aboard our USLI rocket in its official launch. We hope this competition will spark an interest in competitions like TARC and SLI among the schools and science clubs in our area.

In the case that NASA interprets this project as a violation of the requirement that team members do all of the work, the MIT Rocket Team would like to still continue with USLI with our fin flutter experiment.

APPENDIX I: SIGNED SAFETY AGREEMENTS

MIT ROCKET TEAM SAFETY AGREEMENT

By signing this document, I _____ agree to abide by all the laws, regulations, safety standards, and procedural guidelines in the High Powered Rocketry Safety Code, the National Association of Rocketry Handbook, the Academy of Model Aeronautics Handbook, all pertinent Federal Aviation Regulations relating to high powered rocketry, all Massachusetts Environment and Safety Laws, and any Material Safety Data Sheets (MSDS) for all materials used from the design to the conclusion of the MIT Rocket Team's entry into the NASA University Student Launch Initiative (USLI). Initial here: _____

By signing this document, I also agree to abide by and/or accept any ruling of or command given by the Huntsville Area Rocketry Association (HARA) Range Safety Inspector. I understand that if any single one of us does not comply with Safety and Mission Assurance (SM&A), our team will not be allowed to launch any rocket. I agree to abide by the Minimum Distance Table when launching any rocket in any state for any purpose related to the MIT Rocket Team's entry in the NASA USLI competition, whether it be for testing, National Association of Rocketry (NAR) certification, or other launches. Initial here: _____

In addition, I agree to abide by any commands, rules, and procedures outlined by the MIT Rocket Team's Environment, Health, and Safety (EHS) representative, Team Faculty Advisor, and Team Leader at all times when working on anything related to USLI, working in the MIT Rocket Team laboratory, or during any MIT Rocket Team-related launch even when these safety rules go beyond what is required by any code or handbook mentioned in the first paragraph. I agree to use laboratory equipment related to the manufacture of composites only under the supervision of the Rocket Team Leader until granted permission to do so without supervision by the Team Leader or another person who has been approved with the power to grant permission to do so without supervision. Initial here: _____

I understand that my failure to comply with any of the above statements can result in me being permanently disbanded from the Rocket Team and all activities related to USLI.

Name (Printed)

Name (Signature)

Date

Rocket Team Leader

Date

Due to unavailability, the following members have expressed written consent to the above safety agreements:

Meera Chander
Barbara Schloss
Anna Ho
Henna Jethani
Andrew Wimmer
Leonard Tampkins

APPENDIX II: FAA REGULATIONS

CFR, SUBCHAPTER F, PART 101, SUBPART C – AMATEUR ROCKETS

§ 101.21 Applicability.

(a) This subpart applies to operating unmanned rockets. However, a person operating an unmanned rocket within a restricted area must comply with §101.25(b)(7)(ii) and with any additional limitations imposed by the using or controlling agency.

(b) A person operating an unmanned rocket other than an amateur rocket as defined in §1.1 of this chapter must comply with 14 CFR Chapter III.

[Doc. No. FAA–2007–27390, 73 FR 73781, Dec. 4, 2008]

§ 101.22 Definitions.

The following definitions apply to this subpart:

(a) *Class 1—Model Rocket* means an amateur rocket that:

(1) Uses no more than 125 grams (4.4 ounces) of propellant;

(2) Uses a slow-burning propellant;

(3) Is made of paper, wood, or breakable plastic;

(4) Contains no substantial metal parts; and

(5) Weighs no more than 1,500 grams (53 ounces), including the propellant.

(b) *Class 2—High-Power Rocket* means an amateur rocket other than a model rocket that is propelled by a motor or motors having a combined total impulse of 40,960 Newton-seconds (9,208 pound-seconds) or less.

(c) *Class 3—Advanced High-Power Rocket* means an amateur rocket other than a model rocket or high-power rocket. [Doc. No. FAA–2007–27390, 73 FR 73781, Dec. 4, 2008]

§ 101.23 General operating limitations.

(a) You must operate an amateur rocket in such a manner that it:

(1) Is launched on a suborbital trajectory;

(2) When launched, must not cross into the territory of a foreign country unless an agreement is in place between the United States and the country of concern;

(3) Is unmanned; and

(4) Does not create a hazard to persons, property, or other aircraft.

(b) The FAA may specify additional operating limitations necessary to ensure that air traffic is not adversely affected, and public safety is not

jeopardized. [Doc. No. FAA–2007–27390, 73 FR 73781, Dec. 4, 2008]

§ 101.25 Operating limitations for Class 2-High Power Rockets and Class 3- Advanced High Power Rockets.

When operating *Class 2-High Power Rockets or Class 3-Advanced High Power Rockets*, you must comply with the General Operating Limitations of §101.23. In addition, you must not operate *Class 2-High Power Rockets or Class 3-Advanced High Power Rockets*—

- (a) At any altitude where clouds or obscuring phenomena of more than five-tenths coverage prevails;
- (b) At any altitude where the horizontal visibility is less than five miles;
- (c) Into any cloud;
- (d) Between sunset and sunrise without prior authorization from the FAA;
- (e) Within 9.26 kilometers (5 nautical miles) of any airport boundary without prior authorization from the FAA;
- (f) In controlled airspace without prior authorization from the FAA;
- (g) Unless you observe the greater of the following separation distances from any person or property that is not associated with the operations: (1) Not less than one-quarter the maximum expected altitude;
- (2) 457 meters (1,500 ft.);
- (h) Unless a person at least eighteen years old is present, is charged with ensuring the safety of the operation, and has final approval authority for initiating high-power rocket flight; and
- (i) Unless reasonable precautions are provided to report and control a fire caused by rocket activities. [74 FR 38092, July 31, 2009, as amended by Amdt. 101–8, 74 FR 47435, Sept. 16, 2009]

§ 101.27 ATC Notification for all Launches.

No person may operate an unmanned rocket other than a Class 1—Model Rocket unless that person gives the following information to the FAA ATC facility nearest to the place of intended operation no less than 24 hours before and no more than three days before beginning the operation:

- (a) The name and address of the operator; except when there are multiple participants at a single event, the name and address of the person so designated as the event launch coordinator, whose duties include coordination of the required launch data estimates and coordinating the launch event;
- (b) Date and time the activity will begin;
- (c) Radius of the affected area on the ground in nautical miles;

- (d) Location of the center of the affected area in latitude and longitude coordinates;
- (e) Highest affected altitude;
- (f) Duration of the activity;
- (g) Any other pertinent information requested by the ATC facility. [Doc. No. FAA–2007–27390, 73 FR 73781, Dec. 4, 2008, as amended at Doc. No. FAA–2007– 27390, 74 FR 31843, July 6, 2009]

§ 101.29 Information Requirements.

(a) *Class 2—High-Power Rockets.* When a Class 2—High-Power Rocket requires a certificate of waiver or authorization, the person planning the operation must provide the information below on each type of rocket to the FAA at least 45 days before the proposed operation. The FAA may request additional information if necessary to ensure the proposed operations can be safely conducted. The information shall include for each type of Class 2 rocket expected to be flown:

- (1) Estimated number of rockets,
- (2) Type of propulsion (liquid or solid), fuel(s) and oxidizer(s),
- (3) Description of the launcher(s) planned to be used, including any airborne platform(s),
- (4) Description of recovery system,
- (5) Highest altitude, above ground level, expected to be reached,
- (6) Launch site latitude, longitude, and elevation, and
- (7) Any additional safety procedures that will be followed.

(b) *Class 3—Advanced High-Power Rockets.* When a Class 3—Advanced High-Power Rocket requires a certificate of waiver or authorization the person planning the operation must provide the information below for each type of rocket to the FAA at least 45 days before the proposed operation. The FAA may request additional information if necessary to ensure the proposed operations can be safely conducted. The information shall include for each type of Class 3 rocket expected to be flown:

- (1) The information requirements of paragraph (a) of this section,
- (2) Maximum possible range,
- (3) The dynamic stability characteristics for the entire flight profile,
- (4) A description of all major rocket systems, including structural, pneumatic, propellant, propulsion, ignition, electrical, avionics, recovery, wind-weighting, flight control, and tracking,
- (5) A description of other support equipment necessary for a safe operation,
- (6) The planned flight profile and sequence of events,

- (7) All nominal impact areas, including those for any spent motors and other discarded hardware, within three standard deviations of the mean impact point,
 - (8) Launch commit criteria,
 - (9) Countdown procedures, and
 - (10) Mishap procedures.
- [Doc. No. FAA–2007–27390, 73 FR 73781, Dec. 4, 2008, as amended at Doc. No. FAA–2007– 27390, 74 FR 31843, July 6, 2009]

APPENDIX III: HIGH POWER ROCKET SAFETY CODE

NFPA 1127 “Code for High Power Rocket Motors”

[<http://www.nar.org/NARhpsc.html>]

1. **Certification.** I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.
2. **Materials.** I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.
3. **Motors.** I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.
4. **Ignition System.** I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the "off" position when released. If my rocket has onboard ignition systems for motors or recovery devices, these will have safety interlocks that interrupt the current path until the rocket is at the launch pad.
5. **Misfires.** If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.
6. **Launch Safety.** I will use a 5-second countdown before launch. I will

ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table, and that a means is available to warn participants and spectators in the event of a problem. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable.

7. **Launcher.** I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 if the rocket motor being launched uses titanium sponge in the propellant.

8. **Size.** My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.

9. **Flight Safety.** I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.

10. **Launch Site.** I will launch my rocket outdoors, in an open area where trees, power lines, buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater.

11. **Launcher Location.** My launcher will be 1500 feet from any inhabited building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.

12. **Recovery System.** I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery

system wadding in my rocket.

13. **Recovery Safety.** I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.