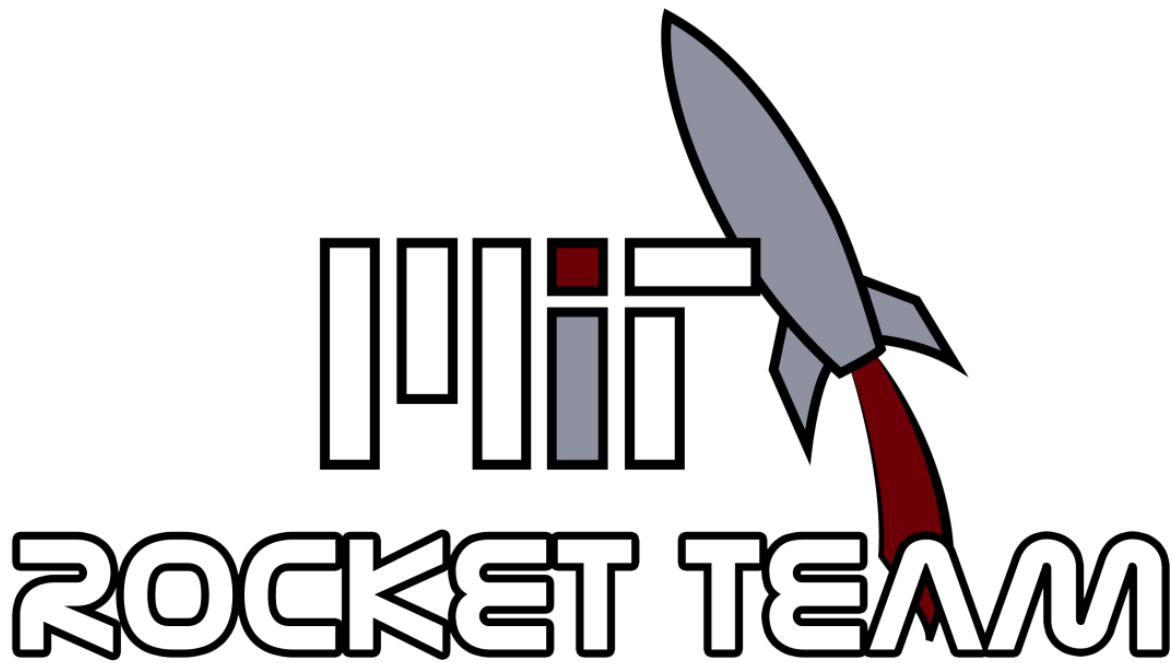




PROJECT AI³R: AERO ION INFRARED INTELLIGENCE ROCKET

USLI CDR 2012-2013

JANUARY 14, 2012

TABLE OF CONTENTS

1	Basic Personal Information	10
1.1	School Information	10
1.2	Facilities and Equipment	13
1.2.1	Lab Space.....	13
1.2.2	Personnel and Equipment Needed	13
1.2.3	Computer Equipment.....	14
1.2.4	Web Presence	15
1.2.5	Implementation of Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Stanards	15
2	Summary of CDR Report	21
2.1	Team Summary.....	21
2.1.1	Team Name and Mailing Address.....	21
2.1.2	Location	21
2.1.3	Mentor.....	21
2.2	Launch Vehicle Summary	22
2.2.1	Size and Mass	22
2.2.2	Motor Choice	22
2.2.3	Rail Size.....	23
2.2.4	Recovery System.....	23
2.2.5	Milestone Review Flysheet	23
2.3	Payload Summary.....	23
3	Changes Made.....	24
3.1	Since Proposal	24
3.2	Since PDR.....	24

4	Vehicle Criteria.....	26
4.1	Selection, Design, and Verification of Launch Vehicle	26
4.1.1	Mission Motivation	26
4.1.2	Mission Statement	27
4.1.3	Constraints.....	27
4.1.4	Mission Requirements	28
4.1.5	System Requirements.....	29
4.1.6	Mission Success Criteria.....	30
4.1.7	Milestones.....	30
4.1.8	System Level design review	30
4.1.9	Verification Plan.....	31
4.1.10	Manufacturing and Assembly Plans	35
4.1.11	Design Integrity.....	37
4.1	Subscale Flight Results.....	40
4.1.1	Impact on Full Scale Vehicle.....	41
4.2	Structures Subsystem	41
4.2.1	Airframe	42
4.3	Propulsion Subsystem	61
4.4	Avionics Subsystem	62
4.4.1	Hardware	62
4.4.2	Software.....	63
4.4.3	Mounting and Placement	63
4.5	Recovery Subsystem	64
4.5.1	Overview.....	64
4.5.2	Details.....	65

4.5.3	Deployment.....	67
4.5.4	Test Results.....	70
4.6	Communications Subsystem.....	70
4.7	Power Subsystem	70
4.8	Mission Performance Predictions.....	71
4.8.1	Mission Performance Criteria.....	71
4.8.2	Flight Profile Simulation	71
4.8.3	Stability Predictions.....	76
4.8.4	Kinectic Energy	77
4.9	Interfaces and Integration	77
4.9.1	Procedure	77
4.9.2	Tasking and Integration Schedule.....	79
4.9.3	Internal Payload Interfaces (Precision Fit and Compatibility of Elements)	79
4.9.4	Payload Installation and Removal.....	80
4.9.5	Simplicity of integration procedure	80
4.10	Launch Concerns and Operation Procedures	80
4.10.1	Summary of Rocket Assembly.....	80
4.10.2	Launch System and Platform.....	80
4.10.3	Recovery Preparation	90
4.10.4	Motor Preparation	90
4.10.5	Igniter Installation	91
4.10.6	Launcher Setup	91
4.10.7	Setup on Launcher	91
4.10.8	TroubleShooting	91
4.10.9	Post Flight Inspection	92

4.11	Safety and Environment (Vehicle)	93
4.11.1	Identification of Safety Officers	93
4.11.2	Rocket Risks	93
4.11.3	Safety Analysis	95
4.11.4	Analysis of Failure Modes and Mitigations	95
4.11.5	Personal Hazards	98
4.11.6	Environmental Concerns	102
5	Payload Criteria	102
5.1	Selection, Design, and Verification of Payload Experiment	103
5.1.1	Mission Motivation	103
5.1.2	Mission Statement	104
5.1.3	Constraints	104
5.1.4	Mission Requirments	105
5.1.5	System Requirements	106
5.1.6	Requirement Verification By Design	106
5.1.7	Payload Hypothesis	106
5.1.8	Success Criteria	106
5.1.9	Milestone Schedule	107
5.1.10	Overview of Flight Operations	107
5.1.11	Overview of Data Acquisition Plan	109
5.1.12	Overview: SPRITE	111
5.1.13	Overview: HALO	140
5.1.14	Safety	149
5.1.15	Instrument Percision and Measurement Repeatability	150
5.1.16	Expected Final Data	151

5.1.17	Design Integrity.....	151
5.2	Payload Concept Features and Definition.....	155
5.2.1	Creativity and Originality	155
5.2.2	Uniqueness and Significances	155
5.2.3	Suitable Level of Challenge	156
5.3	Science Value	156
5.3.1	Science Payload Objectives	156
5.3.2	Payload Success Criteria.....	157
5.3.3	Experimental Logic, Approach, and Method of Investigation	157
5.3.4	Test Measurements, Variables, and Controls	158
5.3.5	Relevance of Expected Data	160
5.3.6	Accuracy and Error Analysis.....	160
5.3.7	Preliminary Experiment Process Procedures.....	161
5.4	Safety and Environment (Payload).....	162
5.4.1	Identification of Safety Officers	162
5.4.2	Safety Analysis	162
5.4.3	Analysis of Failure Modes and Mitigations.....	162
5.4.4	Personal Hazards	162
5.4.5	Environmental Concerns.....	163
6	Safety Plan.....	164
6.1	Procedures for NAR/TRA Personnel to Perform	164
6.2	Hazard Recognition and Accident Avoidance	164
6.3	Outline of hazard Recognition Briefing.....	165
6.4	Pre-launch Briefing.....	167
6.5	Caution Statements.....	167

6.6	Cognizance of Federal, State, and Local Laws Regarding Rocket Launch and Motor Handling	167
6.7	Purchasing and Handling Rocket Motors	168
6.8	Transportation of Rocket to Huntsville	168
6.9	Safety Agreement	168
7	Project Plan	169
7.1	Budget Plan	169
7.2	Funding Plan	170
7.3	Timeline	170
7.4	Community Support Plan	172
7.4.1	Expertise	172
7.4.2	Equipment/Supplies	172
7.4.3	Monetary Donations	172
7.4.4	Services	172
7.4.5	Advertisements	172
7.4.6	Partners with Schools	173
7.4.7	Partners with Industry	173
7.5	Major Programmatic Challenges and Solutions	173
7.6	Project Sustainability Plan	173
7.6.1	Acquiring and Maintaining Partnerships	173
7.6.2	Engaging Students in Rocketry	173
7.6.3	Partners in Industry/community	173
7.6.4	Recruitment of Students	174
7.6.5	Funding Sustainability	174
7.7	Outreach Plan and Educational Engagement	174

7.7.1	Purpose of Community Outreach.....	174
7.7.2	Current Schedule	174
7.7.3	Rocket Dat at the Boston Museum of Science.....	175
7.7.4	Rocket Day at the MIT Museum.....	176
7.7.5	MIT Splash and Spark Weekends.....	176
7.7.6	Lab Tours and Rocketry WorkShops	178
7.7.7	Work with Massachusetts Afterschool Partnership (MAPS).....	178
7.7.8	Science on the Street.....	179
8	Conclusion	179
9	Appendix	180
9.1	Rocket Master Equipment List	180
9.2	Quadrotor Bill of Materials.....	181
9.3	Schedule	182
9.4	CAD Models	184
9.5	Mechanical Drawings	184
9.6	Circuit Schematics	184
9.7	PCB Designs.....	184
9.8	Manufacturing Plan	184
9.9	Code Overview.....	184
9.10	NIMBUS	184
	NIMBUS	184
	Mission Motivation	184
	Mission Statement.....	184
	Mission Requirments.....	184
	Payload Details	185

Theory	185
List of Components	188
Operations During Rocket Ascent	191
Budget.....	191
9.11 Descope Plan.....	192
9.12 Observed Regulations and Safety Requirements	192
9.13 Signed Documents.....	192
9.13.1 Safety Agreements	192
9.13.2 Educational Engagement Form	194
9.14 FAA Regulations	196
9.15 High Power Rocket Safety Code.....	200
10 Misc Sample Documents.....	203
10.1 Advertisements	203
10.1.1 Official 2012 Departmental Poster.....	203
10.1.2 Multimedia Display	203
10.1.3 Briggs Field Flyer.....	204
10.1.4 MIT Tech Newspaper	204
10.2 Outreach Activity	204
10.2.1 Lesson Plans	204
10.2.2 Activity Sheets	204
10.2.3 Sign-In Sheets	204
11 Works Cited.....	204

1 BASIC PERSONAL INFORMATION

1.1 SCHOOL INFORMATION

Table 1 Key personnel

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	Leonard Tampkins, Team President leot@mit.edu
SAFETY OFFICER	Julian Lemus, NAR Level 2 lemusj@mit.edu Ben Corbin, Environmental Health & Safety Representative bcorbin@mit.edu
TEAM MENTOR/NAR CONTACT	Andrew Wimmer, NAR/TRA Level 3 awimmer@alum.mit.edu
ADULT EDUCATORS	Christian Valledor valledor@alum.mit.edu Zahra Khan zahrak@alum.mit.edu

MEMBERS: The MIT Rocket Team consists of approximately 15 active members ranging from first year undergraduates to doctoral candidates. The team has been organized into the following subgroups: (1) Payload Avionics; (2) Payload Structures; (3) Airframe; (4) Propulsion; (5) Recovery. There are approximately 3 members in each subgroup, though positions often overlap based on member interest.

KEY MEMBERS and ROLES:

Leonard Tampkins

- President, Team Lead
- Payload Avionics Group Lead
- Aeronautics and Astronautics, MIT 2013

Julian Lemus

- Head Safety Officer
- Airframe Group Lead
- Treasurer
- Aeronautics and Astronautics, MIT 2013

Ben Corbin

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

Eric Peters

- Propulsion Group Lead
- S.M. Candidate with the MIT Space Systems Laboratory

Matt Vernacchia

- Payload Group Lead
- Aeronautics and Astronautics, MIT 2015

Jed Storey

- UAV Specialist
- Aeronautics and Astronautics, MIT 2013

Henna Jethani

- Aeronautics and Astronautics, MIT 2014

Kayla Esquivel

- Computer Science, MIT 2015

Norman Cao

- Aeronautics and Astronautics and Physics, MIT 2015

Christopher Maynor

- Aeronautics and Astronautics, MIT 2015

Paco Holguin

- Aeronautics and Astronautics, MIT 2016

James D Logan

- Aeronautics and Astronautics, MIT 2015

Ceili A Burdhimo

- Aeronautics and Astronautics, MIT 2015

Rin Yunis

- Aeronautics and Astronautics, MIT 2015

Steven Gordan

- Foreign National
- Aeronautics and Astronautics, MIT 2014

Sally A Miller

- Aeronautics and Astronautics, MIT 2015

Joshua N Millings

- Aeronautics and Astronautics, MIT 2016

Todd Sheerin

- Physics, Harvard 2011
- Aeronautics and Astronautics, MIT

Aaron L Ashley

- Aeronautics and Astronautics, MIT 2015

Zaira Garate

- Aeronautics and Astronautics, MIT 2015

Alexander Y Chen

- Aeronautics and Astronautics, MIT 2015

Corinn M Herrick

- Aeronautics and Astronautics, MIT 2015

Emily Thomson

- Aeronautics and Astronautics, MIT 2015

Adrianna Rodriguez

- Aeronautics and Astronautics, MIT 2015

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 (The Wright Brothers Wind Tunnel Building: <http://whereis.mit.edu/?go=17>) of the MIT campus serves as the primary workspace, meeting space, and a 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 led, and as such will be under the direction of Team President Leonard Tampkins. To ensure all federal, state, and institute rules are followed the team advisor, Professor Lozano, and Safety Officers, Julian Lemus 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, MMMSC, CRMRC, METRA and MDRA. Individual subcomponent 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 contacts with members of MDRA 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:

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

In addition to software available campus wide, the MIT Rocket Team also purchased floating licenses of RockSim, 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. Last but not least, 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>. The text only version of the site can be found here:

<http://www.textise.net/showText.aspx?strURL=http%253A//web.mit.edu/rocketteam/www/index.html>.

1.2.5 IMPLEMENTATION OF ARCHITECTURAL AND TRANSPORTATION BARRIERS COMPLIANCE BOARD ELECTRONIC AND INFORMATION TECHNOLOGY (EIT) ACCESSIBILITY STANDARDS

The MIT Rocket Team must implement Title 36 (Parks, Forests, and Public Property) Part 1194 (Electronic and information Technology Accessibility Standards) of the Code of Federal Regulations. The table below sites the rules outlined in the current Code of Feral Regulations (current as of October 25, 2012) and how they are followed by the team.

Table 2 Code of Federal Regulations Technical Standards

Section	Standard	Implementation
1194.21 a	When software is designed to run on a system that has a keyboard, product functions shall be executable from a keyboard where the function itself or the result of performing a function can be discerned textually.	All custom software that requires user input will take in commands from the keyboard.
1194.21 b	Applications shall not disrupt or disable activated features of other products that are identified as accessibility features, where those features are developed and documented according to industry standards. Applications	All software used the design, testing, and operation of the rocket and payload will not disrupt or disable any accessibility features built in the operating system which it is run on.

	also shall not disrupt or disable activated features of any operating system that are identified as accessibility features where the application programming interface for those accessibility features has been documented by the manufacturer of the operating system and is available to the product developer.	
1194.21 c	A well-defined on-screen indication of the current focus shall be provided that moves among interactive interface elements as the input focus changes. The focus shall be programmatically exposed so that assistive technology can track focus and focus changes.	All custom software will emphasize focus using various methods of bold, underline, highlight, and color. These methods will be programmatically exposed.
1194.21 d	Sufficient information about a user interface element including the identity, operation and state of the element shall be available to assistive technology. When an image represents a program element, the information conveyed by the image must also be available in text.	All custom graphical user interfaces (GUIs) for software will have all its interface elements and their parameters documented. This document will be available to assistive technology. All images in custom GUIs will all be accompanied by text.
1194.21 e	When bitmap images are used to identify controls, status indicators, or other programmatic elements, the meaning assigned to those images shall be consistent throughout an application's performance.	All images in custom GUIs and their meanings will be consistent throughout the applications operation.
1194.21 f	Textual information shall be provided through operating	All software used the design, testing, and

	system functions for displaying text. The minimum information that shall be made available is text content, text input caret location, and text attributes.	operation of the rocket and payload will provide textual information.
1194.21 g	Applications shall not override user selected contrast and color selections and other individual display attributes.	All software used the design, testing, and operation of the rocket and payload will not override user selected contrast and color selections and other individual display attributes.
1194.21 h	When animation is displayed, the information shall be displayable in at least one non-animated presentation mode at the option of the user.	Not applicable. All custom software will not use animations during any part of their operation.
1194.21 i	Color coding shall not be used as the only means of conveying information, indicating an action, prompting a response, or distinguishing a visual element.	All custom software will use various methods of conveying information, et al, including but not limited to: bolding, italicizing, boxing, underlining, and changing the font size.
1194.21 j	When a product permits a user to adjust color and contrast settings, a variety of color selections capable of producing a range of contrast levels shall be provided.	Not applicable. All custom software will not permit a user to adjust color and contrast settings.
1194.21 k	Software shall not use flashing or blinking text, objects, or other elements having a flash or blink frequency greater than 2 Hz and lower than 55 Hz.	Not applicable. All custom software will not use flashing or blinking elements.
1194.21 l	When electronic forms are used, the form shall allow people using assistive technology to access the information, field elements, and functionality required	Not applicable. All custom software will not use electric forms.

	for completion and submission of the form, including all directions and cues.	
1194.22 a	A text equivalent for every non-text element shall be provided (e.g., via “alt”, “longdesc”, or in element content).	All images in custom GUIs will all be accompanied by text.
1194.22 b	Equivalent alternatives for any multimedia presentation shall be synchronized with the presentation.	All presentations will include text and sound. The team will work with USLI officials if they believe this requirement is not being met.
1194.22 c	Web pages shall be designed so that all information conveyed with color is also available without color, for example from context or markup.	All web pages are designed so that color is only used for mainly ascetics and not as the only source of conveying information of a particular element such as a link or button.
1194.22 d	Documents shall be organized so they are readable without requiring an associated style sheet.	All documents can be downloaded in pdf format. Other formats including doc, docx, and pdf can be sent to any interested parties upon email request.
1194.22 e	Redundant text links shall be provided for each active region of a server-side image map.	Not applicable.
1194.22 f	Client-side image maps shall be provided instead of server-side image maps except where the regions cannot be defined with an available geometric shape.	Not applicable.
1194.22 g	Row and column headers shall be identified for data tables.	As per standard team practice all published data tables have row and column headers.
1194.22 h	Markup shall be used to associate data cells and header cells for data tables	As per standard team practice all published data tables use markup when

	that have two or more logical levels of row or column headers.	needed.
1194.22 i	Frames shall be titled with text that facilitates frame identification and navigation.	Not applicable.
1194.22 j	Pages shall be designed to avoid causing the screen to flicker with a frequency greater than 2 Hz and lower than 55 Hz.	Not applicable. All web pages a designed not to contain elements which would cause the screen to flicker at any frequency.
1194.22 k	A text-only page, with equivalent information or functionality, shall be provided to make a web site comply with the provisions of this part, when compliance cannot be accomplished in any other way. The content of the text-only page shall be updated whenever the primary page changes.	A text only version of the webpage can be found in the website section of this document also the team will have a link to this version on the website by Spring 2013.
1194.22 l	When pages utilize scripting languages to display content, or to create interface elements, the information provided by the script shall be identified with functional text that can be read by assistive technology.	Not applicable. All webpages do not contain scripting elements as they are written in basic html.
1194.22 m	When a web page requires that an applet, plug-in or other application be present on the client system to interpret page content, the page must provide a link to a plug-in or applet that complies with § 1194.21(a) through (l).	Not applicable. All webpages do not require applets or plug-ins.
1194.22 n	When electronic forms are designed to be completed on-line, the form shall allow	Not applicable. All custom software and webpages will not use electric forms.

	people using assistive technology to access the information, field elements, and functionality required for completion and submission of the form, including all directions and cues.	
1194.22 o	A method shall be provided that permits users to skip repetitive navigation links.	Not applicable. All webpages and custom software are designed so that repetitive navigation links do not exist.
1194.22 p	When a timed response is required, the user shall be alerted and given sufficient time to indicate more time is required.	Not applicable. All custom software will not have any timed responses.
1194.23 k 1194.26 a 1194.26 b	(k) Products which have mechanically operated controls or keys, shall comply with the following: (1) Controls and keys shall be tactilely discernible without activating the controls or keys. (2) Controls and keys shall be operable with one hand and shall not require tight grasping, pinching, or twisting of the wrist. The force required to activate controls and keys shall be 5 lbs. (22.2 N) maximum. (3) If key repeat is supported, the delay before repeat shall be adjustable to at least 2 seconds. Key repeat rate shall be adjustable to 2 seconds per character.	The ground station support equipment (GSE) has been designed with these standards in mind. For more information be see the GSE section of this documents.

	(4) The status of all locking or toggle controls or keys shall be visually discernible, and discernible either through touch or sound.	
1194.26 c	When biometric forms of user identification or control are used, an alternative form of identification or activation, which does not require the user to possess particular biological characteristics, shall also be provided	Not applicable. Biometric forms of user identification will not be used.
1194.26 d	Where provided, at least one of each type of expansion slots, ports and connectors shall comply with publicly available industry standards.	Only publicly available ports and connectors which comply industry standards will be used.

2 SUMMARY OF CDR REPORT

2.1 TEAM SUMMARY

2.1.1 TEAM NAME AND MAILING ADDRESS

MIT Rocket Team

Building 17 Room 110

70 Vassar St

Cambridge, MA 02139

2.1.2 LOCATION

The team's lab space in Building 17 (<http://whereis.mit.edu/?go=17>) of the MIT campus (the Wright Brothers Wind Tunnel Building) serves as the primary workspace, meeting space, and a secure storage location.

2.1.3 MENTOR

Andrew Wimmer is our primary mentor. He graduated from MIT's Aero/Astro department in 2012, is Tripoli L3 certified and has flown 15 successful dual deploy L2 or L3 class flights. He's been building rockets since age 8 and entered the world of high powered rocketry about 9 years ago. He has been involved with or led a total of 4 SLI/USLI teams over the years. He currently works as a systems engineer at Aurora Flight Sciences in Manassas, VA.

2.2 LAUNCH VEHICLE SUMMARY

The purpose of the launch vehicle is to reach an apogee of 1 mile and deploy the payload after descending to an altitude of 500 feet. Diagrams of the vehicle are providing below in the rocket section.

The carbon fiber airframe will be 10 feet in length, the inner diameter of the rocket tube is designed to be 6.18 inches, and the outer diameter of the fins is 17.286 inches. Furthermore, the mass of the rocket is projected to be a maximum of 49 lbs (including a payload mass of 10 pounds) and ballast (in the nosecone and at the rear of the rocket) as necessary in order to reach an apogee of 5280 feet using a single commercial Cesaroni L1115 motor. At 500 feet, a sabot housing the payload will be pulled out of the airframe tube by the drogue parachute. When the team is given the "go-ahead" by the RSO, a radio controlled electronic solenoid will be powered, releasing a lock, allowing the sabot to separate using expansion springs.

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

2.2.1 SIZE AND MASS

The launch vehicle is designed to have a length of 124.5 inches, with a diameter of about 6.286 inches and a mass of 10.375 pounds.

2.2.2 MOTOR CHOICE

The Rocket will be powered by a Cesaroni L1115 commercially available solid rocket motor. This motor was chosen because it is commercially available and does not require any modifications in order to reach the goal flight altitude of 5280 feet based off preliminary mass estimates. This motor is more powerful than necessary based on preliminary mass estimates, but this will ensure that even with potential mass creep as the design of the rocket and payload matures, the rocket will be able to be optimized to reach the target altitude with the addition of ballast.

The Cesaroni L1115 is 75mm in diameter, 24.5 inches in length, and has a total impulse of 4908 Newton-seconds over a 4.49 second burn time.

For the full-scale test, the Cesaroni K661 solid rocket motor will be used. The CTI K661 has enough power to launch the full system up to an altitude of 1400 feet and has the same diameter as the L1115, so minimal changes will need to be made to the launch system for the full-scale test flight.

The Cesaroni K661 is 75mm in diameter, 13.78 inches in length, and has a total impulse of 2436 Newton-seconds over a 3.8 second burn time.

2.2.3 RAIL SIZE

We will be using a Vaughn Brother's Rocketry "High Power Launch Pad" with a 10ft extruded aluminum T-slot rail. Please refer to section 4.10.2 for more information.

2.2.4 RECOVERY SYSTEM

The Launch Vehicle will utilize a 5 foot diameter drogue parachute to be deployed at apogee, and a 14 foot diameter main parachute that will be deployed at 500 feet AGL. The Recovery System will be described in greater detail in [section 4.5](#) of the document.

2.2.5 MILESTONE REVIEW FLYSHEET

Please see the MIT Rocket Team's website.

2.3 PAYLOAD SUMMARY

SPRITE: Specialized Rotorcraft for IR Communications, Object Tracking and On-board Experiments

HALO: High Altitude Lightning Observatory

The scientific payload for the 2012 -2013 year will be a custom built composite quadrotor carrying a system of payloads to exhibit object tracking and recognition in dynamic environments and to quantitatively measure high-altitude atmospheric lighting events. This system will include a linux based OS running on a microprocessor which will communicate with the payload peripherals. The payload peripherals include: jpeg cameras, magnetometer, VLF receiver, lightning sensor, a custom EM sensor, and a custom Langmuir probe. The data from the sensors will be stored on the computer, transmitted to the ground station during decent and recovery, and analyzed after

recovery. The quadrotor will be under parachute for the majority of its flight and will only use its motor when its velocity falls below an acceptable limit, but not before clearance from the range master. The rocket payload will consist of an apparatus located on a fin and inside the rocket avionics bay to measure the effect of peristaltic acceleration on the neutral flow across rocket fins during an actual flight. These experiments will be useful for: (1) understanding how to make cheap, robust, and versatile unmanned aerial vehicles (UAVs) more practical; (2) quantifying and validating theoretical high-atmosphere weather models; (3) increase the practicality of the application of peristaltic actuators in aerospace systems and demonstrate its potential usefulness in a non-controlled test bed setting.

3 CHANGES MADE

3.1 SINCE PROPOSAL

No major changes were made to the vehicle or payload criteria (just extensions of the proposal). Except in order to comply with requirement 3.3 and 3.4 the rotorcraft sabot will be mechanically held shut by a RC controlled solenoid until the RSO is permission for craft deployment.

3.2 SINCE PDR

No major changes were made to the vehicle or payload criteria (just extensions of the PDR). Answers to the questions found in the PDR feedback form can be found in the table below.

Table 3 PDR Feedback Form Questions and Answers

Question	Response/Action
May be a good idea to use thicker bulkheads. For a 45+ lb rocket, 1" would be better.	The MIT Rocket has had years of experience launching 45+ lb rockets of this design. In addition, analysis on 0.5" bulkheads was performed and presented in the PDR. To address the concerns of the reviewers, the bottom bulkhead will be increased to 1". Further changes will be made depending on the results of further FEA analysis and structural testing.
KE values for a few of the sections are relatively close to the constraint. Do these predictions take it to account	The mass values given in the PDR were worst case conservative estimates which take into account mass growth.

mass growth?	
Is this the same configuration for deploying the UAV as the team used 2 years ago?	Yes, however many modifications of the design have been made to in order to ensure that payload deployment is lighter, safer, and more reliable. Please see the payload deployment section of the PDR and CDR for more information.
Can the main parachute be deployed without deploying the UAV?	Yes, as stated in the PDR report “the rotorcraft sabot will be mechanically held shut by a RC controlled solenoid until the RSO is permission for craft deployment.” The deployment process for the rocket and payload was further clarified in the CDR. Please see the rocket and payload deployment section of the PDR and CDR for more information.
What type of system remotely deploys the Sprite/Halo payload?	A multi-channel RC transmitter and receiver system remotely deploys the Sprite/Halo payload. The deployment process for the payload was further clarified in the CDR. Please see the payload deployment section of the PDR and CDR for more information.
The quadrotor is autonomous? RC controlled?	As stated in the PDR the quadrotor is autonomous, but controls can be manually overridden at any time. This process was further clarified in the CDR.
What happens if the quadcopter not function properly after deployment? 1 or more motor failures? What is the failure mode?	All modes for the quadcopter were depicted in figure 1 Concept of Operations Diagram of the PDR documentation. Due to format errors the figure was hard to read; this has been clarified in the CDR. In brief, the quadrotor as an emergence parachute function. Please see the payload deployment section of the PDR and CDR for more information.
Will the quadcopter have its own safety chute?	As stated in the PDR, the quadrotor falls initially on a safety chute and also as a emergency chute. This process was further clarified in the CDR. Please see the payload deployment section of the PDR and CDR for more information.
What is the rod that retains the motor attached through?	From 4.2.1.6 MOTOR RETENSION SYSTEM of the PDR report. “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.”
With the main parachute deploying at 3000 ft, is there concern with drift?	In response to this the rocket simulations were performed again at higher wind velocities. As a result, the size of the main parachute was reduced and the deployment altitude was changed to 500ft. Drift simulations can be found in the CDR documentation.
Is the predicted apogee expected to be over 1 mile?	No, from the simulations the drag added to the rocket by increasing the fins’ height by an inch puts apogee below a mile.
How long is the team planning on flying the Sprite/Halo package?	The quadrotor will descend with the rocket and hover 5 to 10 feet for no more than 3 minutes at the rocket recovery location. The total expected flight time is 10 to 15 minutes.

Thanks for the questions. Your feedback is greatly appreciated.

4 VEHICLE CRITERIA

VORTEX: Versatile Omni-Task Rocket Experiment

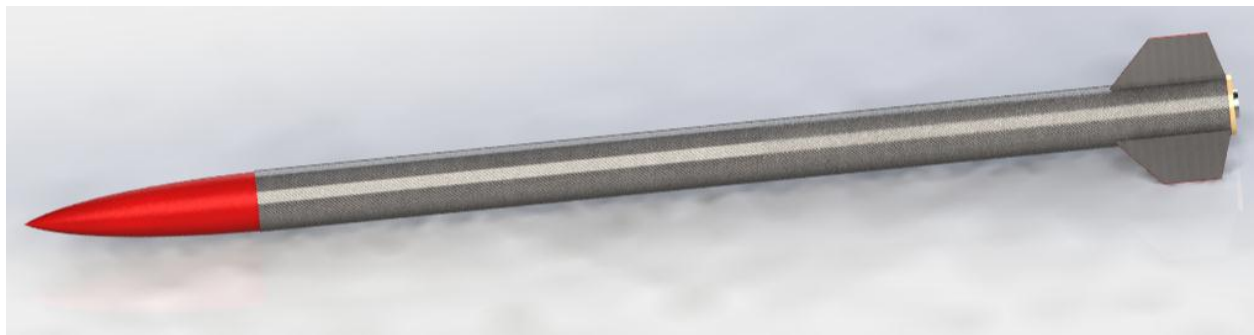


Figure 2 VORTEX

4.1 SELECTION, DESIGN, AND VERIFICATION OF LAUNCH VEHICLE

4.1.1 MISSION MOTIVATION

When designing and building rockets, the team mainly focuses on rapid rocket body construction, customization, reliability, and re-launch capabilities. With these attributes in mind, the team is looking to improve the composite body/fin layup and motor retention/avionics bay structure. Ultimately, a more robust, streamlined, and cost effective design will be implemented for this year's rocket.

4.1.2 MISSION STATEMENT

The MIT Rocket Team aims to develop a rocket which will successfully deploy a quadrotor at the desired altitude in addition to meeting all USLI constraints/requirements and serving as a device which will help the science payload to meet its mission statement (noted below).

The MIT Rocket Team aims to develop an inexpensive and reusable rocket system in order to rapidly deploy a quadrotor. The goals of the quadrotor design are to reduce quadrotor ascent time and to test new methods of communication between mobile targets. Using the quadrotor as a mobile platform, the team also intends to develop a payload to study the cause of high altitude lightning discharges and their effect on the surrounding environment, with the goal of validating existing mathematical models that lack in situ data.

4.1.3 CONSTRAINTS

The vehicle and payload must follow all rules of NASA USLI 2012-2013, 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 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
- Unmanned aerial vehicle (UAV) payloads of any type shall be tethered to the vehicle with a remotely controlled release mechanism until the RSO has given the authority to release the UAV.
- Any payload element which is jettisoned during the recovery phase, or after the launch vehicle lands, shall receive real-time RSO permission prior to initiating the jettison event.
- 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.

4.1.4 MISSION REQUIREMENTS

The mission requirements for the rocket and payload are as follows:

- The VORTEX Rocket will meet the following objectives:
 - Safely house quadrotor payload during launch and ascent
 - Safely deliver the quadrotor payload to an altitude of 500ft during decent
- The SPRITE Payload will meet the following objectives:
 - Exhibit a controlled deployment from a descending rocket
 - Safely house all hardware and electronics during all phases of the mission: launch, normal operations, and recovery
 - Relay telemetry and video to the ground station
 - Relay telemetry to the nose cone via optical communication
 - Track the nose cone and ground station
- The HALO Payload will meet the following objectives:
 - Ability to detect high altitude “lightning” events
 - Gather atmospheric measurements of: the magnetic field, EMF radiation, ULF/VLF waves, and the local electric field.

- Gather atmospheric measurements of: pressure, temperature, relative humidity, solar irradiance, and ultraviolet radiation at a frequency no less than once every 5 seconds upon decent, and no less than once every minute after landing.
- Take at least two still photographs during decent, and at least 3 after landing.
- All pictures must be in an orientation such that the sky is at the top of the frame.
- All data must be transmitted to ground station after completion of surface operations.

4.1.5 SYSTEM 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 imply 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,

The system requirements for the rocket and payload are as follows:

- System must be less than \$5000 fair market value at time of flight
- Rocket must reliably and accurately achieve apogee of 5280ft
- Reliably deploy quadrotor at safe working altitude of 500ft
- Stream telemetry, and video to ground station
- Employ video and beacon tracking systems.
- Quadrotor must have attitude control within 5 degrees of accuracy during normal operations
- Quadrotor must have basic altitude control with 6 feet (2 meters) of accuracy during normal operations
- Quadrotor must be able to hover for a minimum of ten minutes and operate for 45 minutes in a low power state (no power supplied to the propulsion system).

A further listing of payload, vehicle and program specific requirements are as follows:

- 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.
- 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

4.1.6 MISSION SUCCESS CRITERIA

For the launch vehicle mission to be determined a success it must meet all of the launch vehicle requirements/constraints set forth by the team, USLI officials, and USLI regulations.

4.1.7 MILESTONES

The full schedule for rocket and payload development may be found in Timeline section 7.3. Key dates are presented below for reference.

- 9/29: Project initiation
- 10/29: PDR materials due
- 11/18: Scaled test launch
- Nov and Dec: CDR payload design
- 1/14: CDR materials due
- Dec, Jan, and Feb: Scale quadrotor testing and hardware manufacturing
- Late Jan and Early Feb: Full-scale rocket manufacturing
- Feb: Full-scale test launch
- Early Mar: Payload verification testing
- 3/18: FRR materials due
- Late March: Full-scale test launch
- 4/17: Travel to Huntsville
- 4/20: Competition launch
- 5/6: PLAR due

4.1.8 SYSTEM LEVEL DESIGN REVIEW

4.1.8.1 DRAWINGS AND SPECIFICATIONS

Vehicle mechanical drawings can be found in section 9.5.

4.1.8.2 ANALYSIS AND MODEL RESULTS

Analysis of vehicle models can be found in section 4.1.8.2.

4.1.8.3 TEST DESCRIPTION AND RESULTS

A description of vehicle tests and results can be found in section 4.1.8.3.

4.1.8.4 FINAL MOTOR SELECTION

The final motor will be a Cesaroni L1115.

4.1.9 VERIFICATION PLAN

4.1.9.1 FUNCTIONAL REQUIREMENTS VERIFICATION

Verification of the compliance with NASA 2012-2013 USLI handbook requirements and the team's set requirements will be completed as follows.

Table 4 Requirements and verification

Requirement	Design Features that Meet this Requirement	Verification of Compliance
Rocket must reliably and accurately achieve apogee of 5280ft	The motor is sized so that apogee is 5280 ft.	To be verified after testing
At no time may a vehicle exceed 5600ft.	The motor is sized so that apogee is less than 5600 ft.	To be verified after testing
Must carry one NASA designated altimeter for official altitude record	A Perfectflite Straologger and Raven will be used for dual deployment and altitude determination.	Inspection
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.	The electronic schematics for the rocket and payload systems can be found in the respective rocket and payload avionics sections of this document. The	Inspection
Recovery and payload		

electronics must be independent from each other.	schematic show that these requirements are met.	
At all times the system must remain subsonic.	An estimated velocity profile of rocket demonstrating subsonic flight can be found in the rocket propulsion/design section of this document.	Verified by simulation and full scaled launch.
Shear pins must be used in the deployment of both the drogue and main parachute.	Shear pins have be incorporated in the rocket design.	Inspection
All components of the system must land within 2500ft of the launch site in a wind speed of 15 mi/hr.	An estimated drift distance of components can be found in the rocket propulsion/design and recovery section of this document.	Simulation
Each tethered section, of which there may be no more than 4 of, must land with kinetic energy of less than 75 ft-lbf	As per design	To be verified after testing
The vehicle must recovery safely	As per design	To be verified after testing
Unmanned aerial vehicle (UAV) payloads of any type shall be tethered to the vehicle with a remotely controlled release mechanism until the RSO has given the authority to release the UAV.	The sabot will not open until RSO permission is given. The quadrotor descends on chute until RSO permission is given.	Verified by design
Any payload element which is jettisoned during the recovery phase, or after the launch vehicle lands, shall receive real-time RSO permission prior to initiating the jettison event.		Verified by design
Scientific method must be used in the collection,	As per design	Consulting scientists

analysis and reporting of all data.		
Electronic tracking devices must be used to transmit the location of all components after landing.	As per design	To be verified after testing
Only commercially available, NAR/TRA certified motors may be used.	As per design	Verified by design
Full-scale flight model must be flown prior to FRR.	As per design	Inspection
\$5000 maximum value of rocket and science payload as it sits on the launch pad.	As per design	Verified by design
Reliably deploy quadrotor at safe working altitude of 500ft	As per design	To be verified after testing

4.1.9.2 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.

4.1.9.3 STRUCTURAL COMPONENT TESTING

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

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

4.1.9.4 DEPLOYMENT TESTING

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

- Deployment altitude will be verified using barometric testing. The team has constructed a small vacuum chamber, which is capable of roughly simulating ambient pressure. As a result, the avionics package will be placed into the vacuum chamber to ensure that it sends charge ignition commands at the right times.
- In order to verify the failure force of the shear pins, a representative tube will be used with a representative nose cone, with the open side of the tube covered. The shear pins are mounted into the relevant brackets in flight orientation. The black powder charge will be ignited at the closed end to validate the mass of black powder to be used.
- Quadrotor deployment will also require testing, which can be performed in a couple of phases: (1) the force of the drogue parachute on the sabot can be simulated to ensure that the sabot separates from the tube and the quadrotor deploys and (2) integrated deployment tests from a balloon platform. This test will be described further in the payload testing section.

4.1.9.5 RECOVERY TESTING

Prior to the full scale test launch all recovery systems including altimeters, ejection charges, and TenderDescenders will be tested to insure functionality at expected flight

conditions. Ejection charge testing will take place in the team's small vacuum chamber to simulate low atmospheric pressures.

4.1.9.6 AVIONICS TESTING

A series of avionics tests will also be performed. A summary of the tests is provided below. Greater detail can be found in the system testing section.

- The emergency locator beacons (transmitters and receiver) operation will be checked, by searching for the beacons in a representative location.
- Each computer will also be checked to see if they downlink properly to the ground station. This will be performed on the ground in a field and then on a balloon platform using a representative ground station and rocket.

4.1.9.7 SCALED TEST LAUNCH

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

4.1.10 MANUFACTURING AND ASSEMBLY PLANS

To produce components of a high caliber the MIT Rocket Team has decided to use a four-stage fabrication and assembly process. After the finalization of the designs, the team moved straight into a fabrication-testing period where possible manufacturing methods were evaluated for their feasibility. In this period the team decided on the appropriate technique and materials needed for the fabrication of each component of the flight vehicle. In this stage, fabrication methods were tested on representative components sized to the approximate dimensions of the specified design. The testing phase of production has been completed as of mid-January and the team has now moved into the prototyping phase for the flight vehicle.

In the prototype phase, full-scale components will be constructed using the methods determined during the testing phase of development. The resulting components will then be assembled into a full-scale prototype with extra components being produced for destructive testing methods. When the components are all fully tested, the any components needing design changes will be refabricated to the new specifications and a proto-flight model will be constructed.

The purpose of the proto-flight model is to allow for full-scale flight-testing procedures with, and without the completed payload. It is expected that the proto-flight model will be

completed in early February to allow for multiple launch attempts before the Flight Readiness Review. Upon successful flight testing of the proto-flight vehicle, any necessary design changes and repairs will be made to the airframe for the flight model to be launched in Huntsville AL. Furthermore spare components will be manufactured to the specifications of the flight model to mitigate the loss of components in transit to AL.

As stated above, the team is currently in the prototype phase of fabrication on track for completion in early February. The team is purchasing all materials necessary to construct a complete vehicle as well as a set of spare components. Construction is currently underway and the components will be tested.

4.1.10.1 MACHINING TASKS AND SCHEDULE

For each individual component in the rocket Table 5 outlines the material used, what tasks to perform on a specific machine to form the part, and the estimated time it takes to make the part. Including margin it takes 12 man-hours to machine the entire rocket. For this reason, the last 2 weeks of January have been devoted to machining the main rocket structures.

Table 5 Estimated Machining Tasks and Time

Structure	Materials	Machines	Task	Estimated Time	Estimated Time with Margin
Top and bottom bulk heads	Plywood	- Water Jet - Drill Press	Cut rings from stock to desired inner and outer diameter Drill holes where necessary	1½ Hours	2 Hours
Centering rings	Plywood	Water Jet	Cut rings from stock to desired inner and outer diameter	1 Hour	1½ Hours
Fins	Plywood	- Water Jet - Drill Press	Cut trapezoids from stock to desired geometry Drill holes where necessary	1½ Hours	2 Hours
Sabot end caps	Plywood	- Water Jet - Drill Press	Cut disks from stock to desired outer diameter Drill holes where necessary	1½ Hours	2 Hours
Avionics	Plywood	Water Jet	Cut disks from stock to	1½	2 Hours

bay top and bottom caps		• Drill Press	desired outer diameter Drill holes where necessary	Hours	
Avionics bay panels	Plywood	• Vertical Band Saw	Cut rectangles from stock to desired geometry	1 Hour	1½ Hours
Body tube	Phenolic	• Horizontal Drill Press	Cut tubes from stock to desired length	½ Hour	1 Hour

4.1.11 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.

4.1.11.1 SUITABILITY OF SHAPE AND FIN STYLE FOR MISSION

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. The fins are constructed of G10, a material commonly found in rockets of similar size. As was shown in the sub-scale test flight, the fins perform their objective of keeping the rocket flying straight.

4.1.11.2 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. In previous MIT Rocket Team launches these structural elements of the rocket performed their objectives. Verification will also be done through analysis of the upcoming full scale test flight.

4.1.11.3 PROPER ASSEMBLY PROCEDURES

The design of the rocket dictates the assembly procedures. These procedures shall be tested during the full scale test flight in order to determine their reliability and functionality.

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 outer diameter (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.

4.1.11.4 MOTOR RETENTION AND MOUNTING

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.

4.1.11.5 DRAWINGS

Mechanical drawings can be found in section 9.5.

4.1.11.6 MASS STATEMENT

Table 6 Rocket mass properties

Component	Mass (lbs)
Nose cone	1.75
Tracker and nose cone retention	2
Upper body tube	2.37
Tube coupler	0.34
Sabot	1.74
Quadrotor	10
Drogue parachute	0.23
Lower body tube	2.37
Fin set	2.79
Motor tube	0.56
Avionics bay	5
Bulkheads	0.74

Motor	9.71
Main parachute	0.57
Mass Under Drogue	8.2
Mass Under Main	14.17
Support	6
Total Mass	46.17

4.1.11.7 SAFETY AND FAILURE ANALYSIS

4.1.11.7.1 RISKS, MITIGATION, AND FAILURE MODES

An overview of the risks, mitigations, and failure modes of the rocket can be found in the Analysis of Failure Modes and Mitigations section of this document.

4.1.11.8 CHALLENGES AND SOLUTIONS

Table 7 Rocket challenges

Challenge	Solutions
Requirement for the rocket to reach as close to 5,280 ft AGL as possible	Targeting a specific altitude is a difficult requirement, so it will be necessary to perform a great deal of modeling, which will include a RockSim model (that is validated against actual flight hardware mass/positioning data), an actual test launch for model verification, and potentially a custom validation model in MATLAB
Dependence on launch conditions for apogee	A flexible ballast will be used so that it is possible to tune the mass of the rocket on flight day
Deployment of the quadrotor in a "clean" manner	The quadrotor will be deployed with the drogue parachute active and using a sabot that will separate using the spring-loaded wings of the craft. A redundant deployment system may be used if deemed necessary. Furthermore, the quadrotor will be deployed under a recovery parachute. Separation of the vehicle and the parachute occurs after approval from the range officer has been attained.

Recovery of all components of the rocket	In order to assist in recovery of rocket components, the parachutes will be sized in accordance with range restrictions, a Beeline Tracker will be placed on the rocket. Furthermore, an additional MATLAB model may be used to extrapolate predicted landing site from telemetry.
Reliability of recovery charges	In all cases, two charges will be used for the flight rocket
A custom fabricated rocket is not qualified as a kit would be	Structural qualification testing will be performed on all components, including the airframe, bulkheads, and fins

4.1 SUBSCALE FLIGHT RESULTS

To test the aerodynamic properties of our design, the scale test flight occurred on December 15th at a MDRA sport launch. Team member James performed the test flight. The flight occurred with an exactly half scale rocket (3 in diameter) constructed of LOC Precision components with plywood fins. A Cesaroni H1225 was used and the rocket was launched off a standard 8' 1"x1" rail.



Figure 3 Sub-scale test flight

The scale rocket was not scaled in weight because doing so would have required a much larger and more expensive motor. The goal of the scale test launch was to test rocket stability, and it was determined that this goal could be achieved using a smaller motor. A summary of the specifications of the $\frac{1}{2}$ scale rocket can be found in Table 8.

Table 8 Scale Model Dimensions

Specification	Value
Diameter	3.13 inches
Length	62 inches
Mass (without motor)	3.12 pounds
Mass (with motor)	3.76 pounds
CG (measured with motor)	37.5 inches from nosecone tip
CP (OpenRocket Prediction)	43.2 inches from nosecone tip
Stability Margin	1.81

By adding mass, the CG of the scale test rocket was placed at the scaled location of the predicted CG of the full scale rocket. This resulted in a very similar stability margin to that predicted by OpenRocket for the full scale rocket. The rocket was launch three times. For each launch it flew straight and stable.

4.1.1 IMPACT ON FULL SCALE VEHICLE

The subscale launch was conducted in accordance with the USLI guidelines. No major changes were made to the full scale vehicle due to the stable flight performance of the sub-scale launches.

4.2 STRUCTURES SUBSYSTEM

As described in the summary section, the purpose of the rocket is to reach 1 mile and deploy the sabot housing the rotorcraft payload at an altitude of 500 feet, and release the vehicle when instructed by the range safety officer. This will be accomplished with a Cesaroni L1115 motor and a 10.375 foot long, 6 inch diameter airframe. The sabot will be located just aft of the nosecone. The drogue parachute will be above the sabot, the main parachute below the sabot, and the avionics below the recovery system.

The overall rocket can be seen in Figure 4.

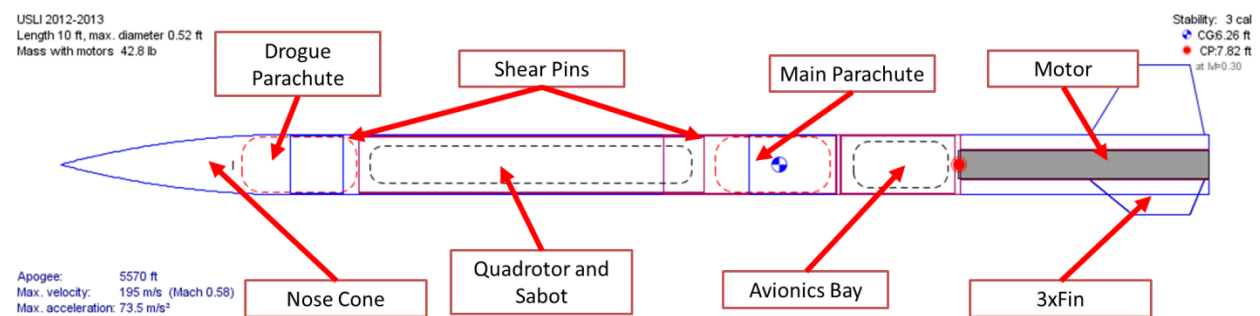




Figure 4 Overall Rocket

Furthermore, the rocket budget summary (for mass and cost) can be seen in section 4.2.1.8.

In order to verify the design of the rocket, a battery of analysis was applied to the rocket airframe, bulkheads, and mechanisms. The order of analysis is as follows:

- Define loading conditions
- Design part
- Use hand calculations to size the part
- Validate hand calculations using finite element method
- Re-size as necessary

4.2.1 AIRFRAME

As can be seen in the figure, the rocket is 8.375 feet in length, with an airframe diameter of 6.28 inches and a fin semi-span of 6.5 inches. The mass of the rocket is projected to be 26.56 pounds, with a margined payload mass of ten pounds, for a system total of 36.56 pounds, and a system wet mass of 46.27 pounds. Simulations for the current preliminary design project an apogee of approximately 5400 feet with 1.5 pounds of ballast in the nosecone. The ballast can be optimized to fine tune the final desired altitude, allowing for margin as the design matures.

The airframe is comprised of the following components:

- Body Tube
- Nose Cone
- Fins
- Motor Retention System

Each of these will be described in detail below.

4.2.1.1 LOADING CONDITIONS

Determining loading conditions for a vehicle that must withstand a variety of largely unknown dynamic and static loading is a difficult task. Furthermore, the rocket airframe can be significantly overdesigned without applying too significant of a penalty to the mass budget. As a result, the loading conditions were often estimated using significant margin to account for uncertainty.

Launch Loading is summarized in Table 9.

Table 9 Launch Loading

Launch Loading		
Aero Loading	90	lbf
Peak Thrust	385	Lbf
Payload Mass	15	Lbm
Max Acceleration	8	G
Total Axial	595	Lbf
MUF	1.5	
Design Axial	892.5	Lbf
Total Lateral	150	Lbf
MUF	1.5	
Design Lateral	225	Lbf

Aerodynamic loading is determined from the Rocksim model, peak thrust is determined from the Cesaroni L1115 Thrust Curve, payload mass is determined from the quadrotor design and sabot, and maximum acceleration is determined from the Rocksim model. The maximum acceleration is found by dividing the peak thrust by the total estimated rocket mass. The total axial force is the sum of the aerodynamic loading, peak thrust, the product of the payload mass and the maximum acceleration. Although many of these peak loads are applied independently from each other, to provide for a conservative calculation, the loads are summed to create a total load, which is then margined by a 1.5 model uncertainty factor, resulting in a design axial load of 890 lbf. Lateral loading is determined by summing half of the aerodynamic and payload forces and margining by a 1.5 model uncertainty factor. This is assumed to be highly margined since as much as half of each of these loads is unlikely to be applied in the lateral direction. Regardless, the design lateral load is therefore 225 lbf.

Recovery shock calculations are determined by examining the change in momentum of the rocket due to deployment, as shown in Table 10

Table 10 Recovery Shock Calculations

Recovery Shock Calculations

Initial Rate	64	Ft/s
Final Rate	18	Ft/s
G	32	Ft/s ²
T	0.1	S
Acceleration	460	Ft/s ²
Gs	14.375	
Rocksim Gs	8	
MUF	2	
Design Gs	28.75	
Design Force	431.25	Lbf

Recovery calculations show the descent rates of the system prior to deployment (under the drogue) to be 64 ft/s and of the main rocket after deployment (under the main) to be 18 ft/s. Assuming a deployment time of 0.1s, this results in 14 Gs. Adding a model uncertainty factor of 2 to this results in 29 Gs, which (given the mass of the payload system) results in a design recovery shock force calculation of 430 lbf.

4.2.1.1.1 FINITE ELEMENT ANALYSIS

1. Motivation for finite element analysis:

In examining the effects of various aerial loads on the rocket body while in flight, we decided that the methods of finite element analysis would prove useful. Finite element methods are often used in structural analysis in order to make well informed, critical design decisions.

2. Overview of Finite element equations

The basic premise of displacement-based finite element analysis is an extension of the displacement method of beam and truss structural analysis. The general steps involved in the analysis of these structures using the displacement based finite element method are as follows¹:

1. Idealize the structure as an assemblage of beam and truss elements that are connected at structural joints.

2. Identify the unknown joint displacements that completely define the displacement response of the structural idealization.

3. Formulate the force balance equations corresponding to these unknown displacements and solve these equations.

4. Calculate the internal element stress distributions based on the solution of the displacements found in step (3) using the stress-strain law.

5. Interpret the solution of the structural idealization based on the assumptions made.

To summarize, the actual structural geometry will be divided up into elements, each with several nodes that define compatibility of the element with the other elements in the structure. The nodal displacements are found in each element by solving the linear matrix equation:

$$\mathbf{KU} = \mathbf{R}$$

where K represents the stiffness matrix, U represents the nodal displacements of each element, and R represents the nodal forces that cause these displacements. The displacements in three dimensions are:

$$\mathbf{U}(X,Y,Z) = \begin{bmatrix} U \\ V \\ W \end{bmatrix}$$

The strains corresponding to these displacement are:

$$\epsilon^T = [\epsilon_{XX} \quad \epsilon_{YY} \quad \epsilon_{ZZ} \quad \epsilon_{XY} \quad \epsilon_{YZ} \quad \epsilon_{ZX}]$$

$$\epsilon_{XX} = \frac{\partial U}{\partial X}; \epsilon_{YY} = \frac{\partial V}{\partial Y}; \epsilon_{ZZ} = \frac{\partial W}{\partial Z}; \epsilon_{XY} = \frac{\partial U}{\partial Y} + \frac{\partial V}{\partial X}; \epsilon_{YZ} = \frac{\partial V}{\partial Z} + \frac{\partial W}{\partial Y}; \epsilon_{ZX} = \frac{\partial W}{\partial X} + \frac{\partial U}{\partial Z}$$

Stresses corresponding to this material are given by the stress strain law, using the elasticity matrix C:

$$\boldsymbol{\tau} = \mathbf{C}\boldsymbol{\epsilon}$$

$$\boldsymbol{\tau}^T = [\tau_{XX} \quad \tau_{YY} \quad \tau_{ZZ} \quad \tau_{XY} \quad \tau_{YZ} \quad \tau_{ZX}]$$

The superscript T denotes the matrix transpose. The actual physical problem can involve many different applied loads to the structure. A body can be subjected to externally applied body forces (forces per unit volume), surface forces (forces per unit area), and concentrated (point) loads. In order to lump all of these into the $KU = R$ formula above, we use the principle of virtual work:

$$\iiint \bar{\boldsymbol{\epsilon}}^T \boldsymbol{\tau} \, dV = \iiint \bar{\mathbf{U}}^T \mathbf{f}^B \, dV + \iint \bar{\mathbf{U}}^T \mathbf{f}^S \, dS + \sum_i \bar{\mathbf{U}}^{iT} \mathbf{R}_c^i$$

The overbars represent a “virtual” strain and displacement, which is an arbitrarily chosen continuous function independent from the actual physical displacement. The “virtual” displacements can be considered as a thought experiment of sorts that allows us to establish the virtual work principle. The left hand side of this equation represents the internal virtual work, and the three terms on the right hand side represent, in order: the effect on virtual work of applied body forces, applied surface forces and concentrated loads, summed over all points. The superscript implies that this is the displacement to be evaluated on the particular surface of interest.

The final derivation necessary is the governing equations for each finite element. Because this is an assemblage of discrete finite elements connected at nodal points, we need a function to interpolate the nodal displacements across each element. Therefore for each element m we have

$$\mathbf{u}^{(m)}(x, y, z) = \mathbf{H}^{(m)}(x, y, z) \hat{\mathbf{U}}$$

where $\mathbf{B}^{(m)}$ is the displacement interpolation matrix, and the superscript denotes the element m . $\mathbf{u}^{(m)}$ is a vector of the displacements at each nodal point. From here we obtain the strains,

$$\boldsymbol{\epsilon}^{(m)}(x, y, z) = \mathbf{B}^{(m)}(x, y, z) \hat{\mathbf{U}}$$

where $\mathbf{C}^{(m)}$ is the strain interpolation matrix. $\mathbf{C}^{(m)}$ is found by appropriately differentiating the elements of $\mathbf{B}^{(m)}$. This follows from the equations relating strain to displacement. Virtual strains and displacements can be equated in the same manner as the real displacements.

We now rewrite the principle of virtual work as a sum of integrations over all finite elements:

$$\sum_i \iiint \bar{\boldsymbol{\epsilon}}^{(m)T} \boldsymbol{\tau}^{(m)} dV^{(m)} = \sum_i \iiint \bar{\mathbf{u}}^{(m)T} \mathbf{f}^{B(m)} dV^{(m)} + \sum_i \iint \bar{\mathbf{u}}^{S(m)T} \mathbf{f}^{S(m)} dS^{(m)} + \sum_i \bar{\mathbf{u}}^{iT} \mathbf{R}_c^i$$

and substitute the strains and displacements using the interpolation formulation previously mentioned to obtain:

$$\begin{aligned} \bar{\mathbf{U}}^T \left[\sum_m \iiint \mathbf{B}^{(m)T} \mathbf{C}^{(m)} \mathbf{B}^{(m)} dV^{(m)} \right] \hat{\mathbf{U}} \\ = \bar{\mathbf{U}}^T \left[\left\{ \sum_m \iiint \mathbf{H}^{(m)T} \mathbf{f}^{B(m)} dV^{(m)} \right\} + \left\{ \sum_m \iint \mathbf{H}^{S(m)T} \mathbf{f}^{S(m)} dS^{(m)} \right\} + \mathbf{R}_c \right] \end{aligned}$$

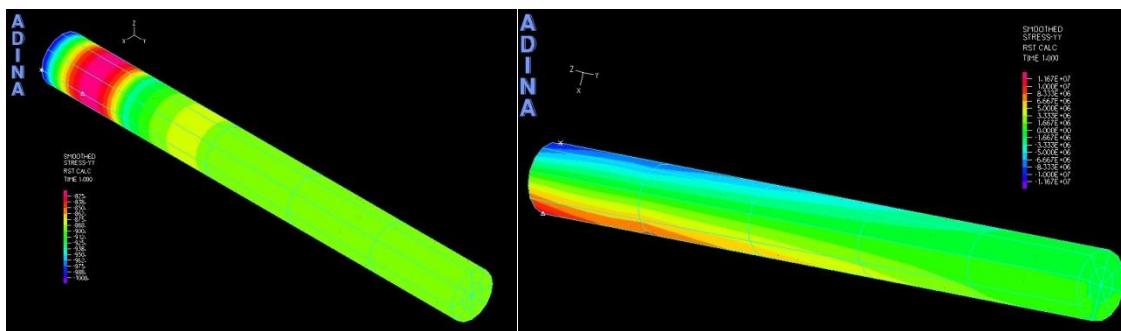
Again the superscript signifies evaluation of the matrix on the proper surface coordinates. $\mathbf{R}_c$ is a vector of concentrated nodal point forces with the same dimensions as the nodal displacement vector $\mathbf{U}$, and the matrix $\mathbf{K}$ is the element's elasticity matrix. From here we can construct the final matrix equation $\mathbf{KU} = \mathbf{R}$, using the following integrals:

$$K = \sum_i \iiint B^{(m)T} C^{(m)} B^{(m)} dV^{(m)}$$

$$R_B = \sum_i \iiint H^{(m)} f^B(m) dV^{(m)}$$

$$R_S = \sum_m \iint H^{S(m)T} f^S(m) dS^{(m)}$$

It is also clear from this that the m th integral represents the stiffness matrix and loading vectors of the particular element m .



These three integral equations allow us to construct the matrix equation $KU = R$ for any arbitrary geometry in three dimensions, and we can then use the solution of these equations to find displacement, stress, and strain in the material. In practical application, the use of computer software is necessary to solve these equations quickly and efficiently. The basic version of finite element software ADINA with the capacity for very simple problems is used to examine a simplified version of the rocket body tube. We are continuing to search for ways to model the rocket accurately, however we have acquired some preliminary analysis of the body tube.

4.2.1.2 BODY TUBE

The body tube is a carbon fiber laminate tube of inner diameter 6". The laminate is a 2-ply layup of Soller Composites 14.5 oz/sqyd biaxial sleeve carbon fiber fabric and Aeropoxy 2032/3665 matrix. 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. The biaxial sleeve was chosen due to difficulties in fabricating wrinkle-free tubes. All layups for the rocket are done in-house using a custom oven in the rocket team lab. For fabrication and transportation reasons, it would be difficult to make the entire tube in one segment. As a result, the body tube is split into 2 segments, with a "seam" just below the base of the sabot. The two segment lengths

are 52" for the upper segment and 48" for the lower segment. The seam between the tubes is joined together by the use of a phenolic coupler that is epoxied to the upper segment. This coupler is reinforced with carbon fiber.

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

- Just above the fins in the propulsion section
- Avionics bay: the hole for the switches will double as a pressure relief hole
- In the middle of the section between the avionics bay and the sabot
- In the nose cone

4.2.1.2.1 ANALYSIS

As described in the design section, the body tube is made from Soller Composites Biaxial Weave carbon fiber. The modulus and strength are taken from Soller Composites and the resulting strain allowable is derived, as shown in Table 11.

Table 11 Carbon Fiber Properties

Material Properties		
E	4675000	psi
v	0.3	
E (claimed)	34	Msi
E_{lam} (claimed)	4.675	Msi
Strength	110	ksi
Strain	0.02352941	strain
Factor of Safety (FOS)	3	
Strain w/MOS	7843.13725	μstrain

Using these properties, hand calculations could be performed for axial compression, global buckling, and bending. These intermediate calculations as well as the resulting margins of safety can be seen in Table 12 through Table 14. It should be noted that, for the sake of being conservative, lateral loads are taken to be applied at the top of the rocket and restrained at the base.

Table 12 Axial Stress Calculations

Axial Stress		
ID	6.155	in
OD	6.247	In
Area	0.89612673806	In ²
Axial Stress	1021.4859	Psi
Strain	0.00002185	Strain

	218.4999658	μ strain
MOS	34.8954211	

Table 13 Buckling Calculations

Buckling		
r/t	81.5217391	
Z	62136.005	
Kc	4000	
Fcr	3182.89745	psi
L/r	28.266666667	
Axial Load	2780.98402	Lbf
MoS	2	
Axial Load Allowable	1390.49201	Lbf
MOS	0.55797424	

Table 14 Bending Calculations

Bending		
I	7.620816554	In ⁴
Z	3.75	In
M	23850	In-lbf
Stress	11735.94711	Psi
Strain	0.002510363	Strain
	2510.363018	μ strain
MOS	2.124304015	

In order to verify these calculations, a finite element model was solved using Solidworks SimulationXpress. The applied boundary conditions of the axial case are shown in Figure 5. The boundary conditions in the lateral load case are shown in Figure 6.

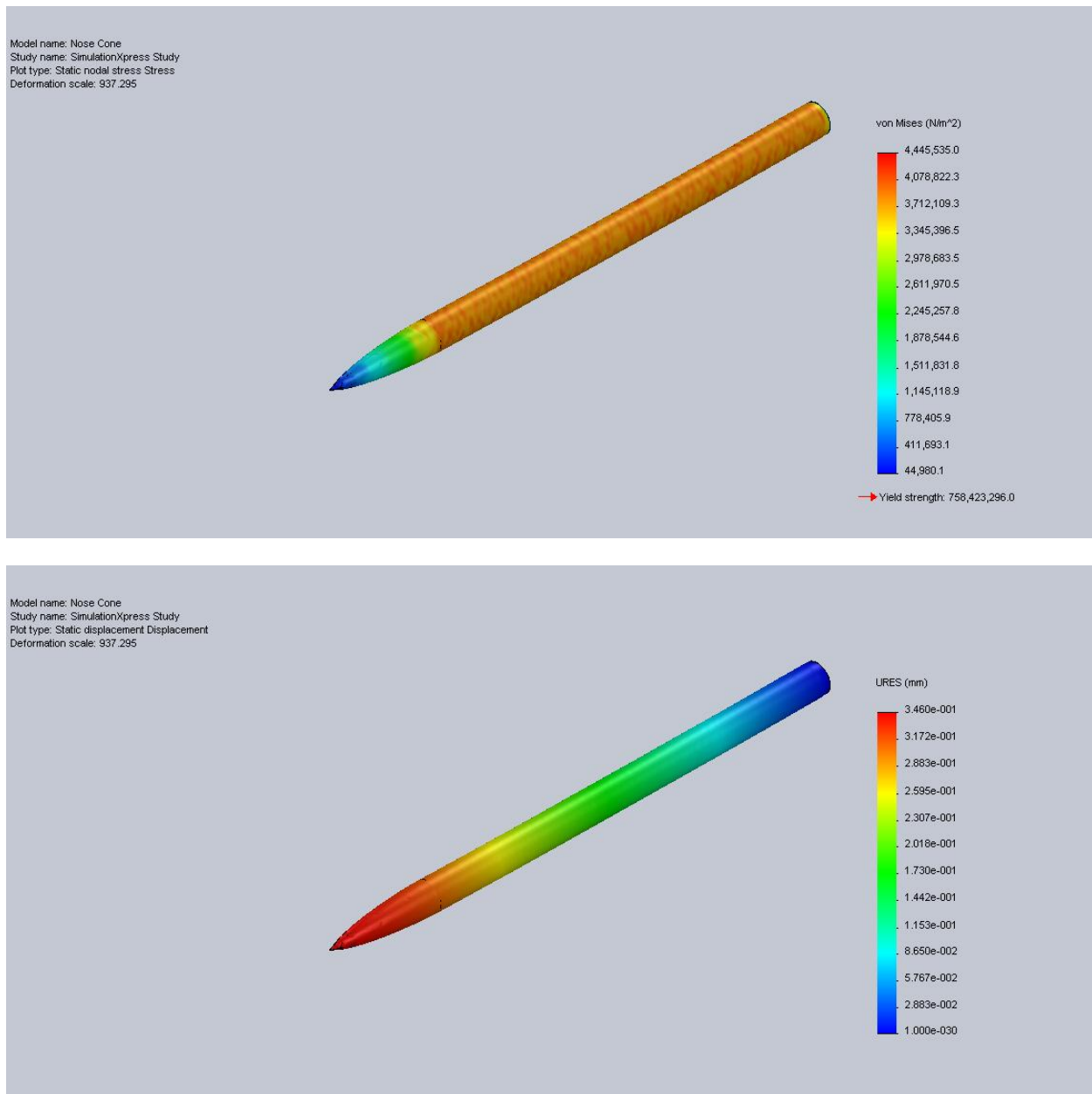


Figure 5 Axial Case

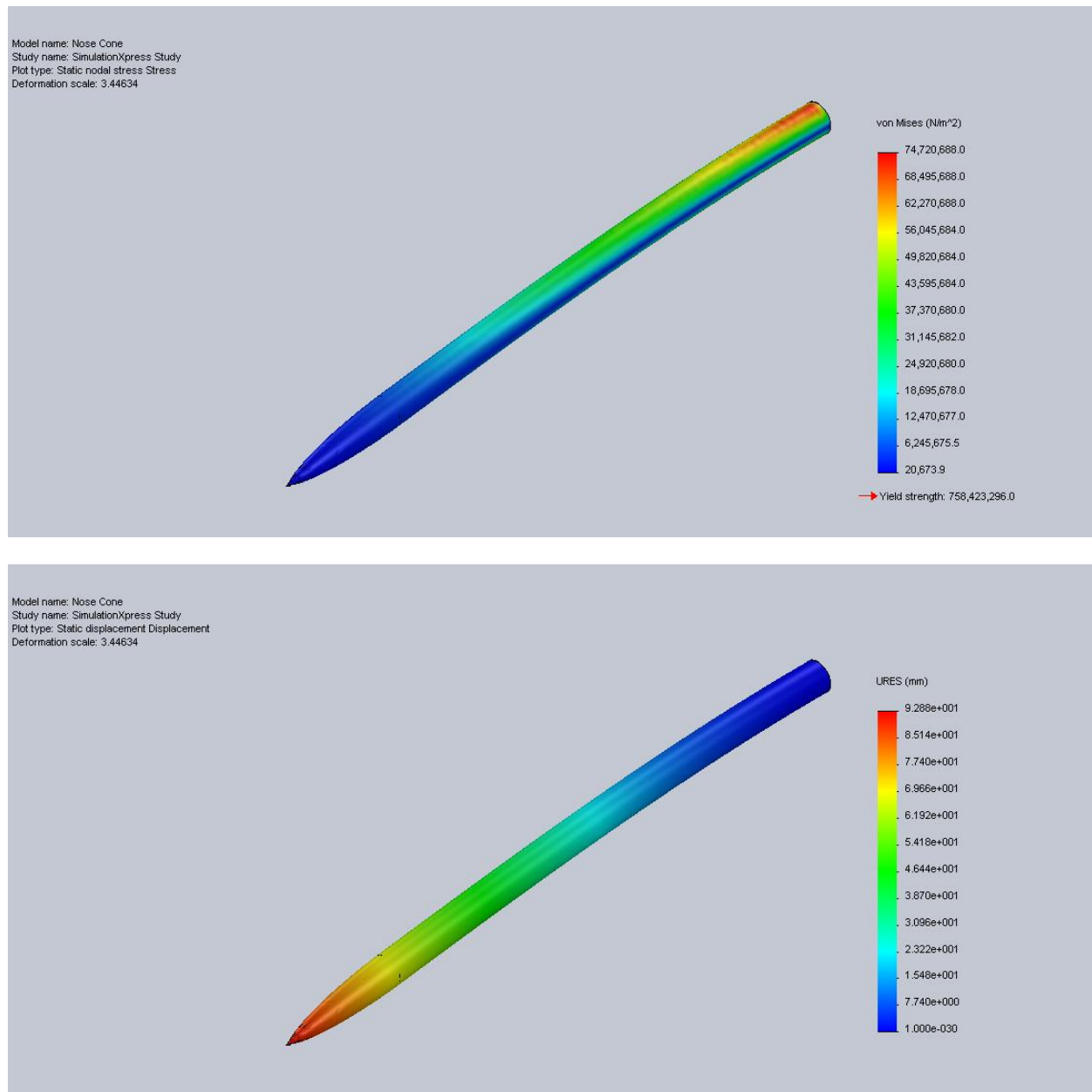


Figure 6 Lateral Case

4.2.1.2.2 RESULTS

The hand calculations and computer simulations demonstrate that the current rocket body tube should operate nominally under maximum expected loading conditions for both the axial and lateral case.

4.2.1.3 NOSE CONE

The nose cone is a commercial PML fiberglass nosecone. A piece of standard phenolic tubing has been attached to the shoulder to allow the nosecone to fit properly in the tube. A beeline tracker is also integrated into the bulkhead in the nosecone. The shape is a tangent ogive and the length was chosen to fit the drogue parachute and maintain stability of the rocket. The length is 27in.

The nose cone is mounted to the body tube using 4 nylon 2-56 bolts (MMC 97263A077), which will act as shear pins. Just like in the tube coupler above, shear area is provided using doublers on both the top of the tube and the inner portion of the nose cone. Similarly, the doublers are on the outside of the tube to allow the sabot to cleanly exit the body tube. Bolts are used because they can be easily threaded into the inner doubler during integration and will fail at low loading since they are plastic.

4.2.1.4 FINS

Three fins were chosen with the dimensions as shown to achieve rocket stability. The fins are a carbon fiber, 3/16" FR4/G10, carbon fiber sandwich laminate to maximize stiffness with minimum mass. The fins are located in position and angle relative to the rocket using slots that are laser-cut into the motor centering rings. Oversized slits added to the body tube to allow the fins to pass through, but provide no DOF restrictions. Fabrication of the fins is as follows:

- Laminate the FR4 core with a ply of carbon fiber on each face using standard plate lamination techniques (see manufacturing plan section)
- Obtain body tube with motor tube and centering rings installed
- Affix fins to the centering rings using 5 minute epoxy and let cure
- Apply another layer of carbon fiber across and between the fins, i.e. "Tip-to-Tip"

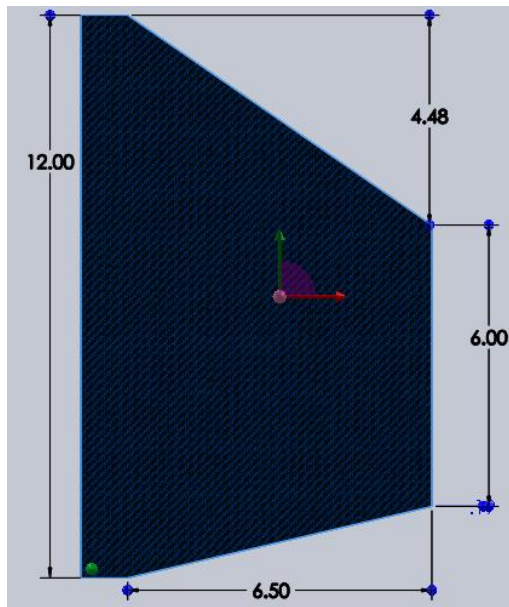


Figure 7 Fin Dimensions

Table 15 FR/G10 Material Properties

Material Properties		
Elastic Modulus	2700000	psi
Poisson's Ratio	0.125	
Density	0.0668355	Lb/in ³
Tensile Strength	45	ksi
Compressive Strength	60	Ksi
Yield Strength	58	ksi

4.2.1.4.1 ANALYSIS

Analysis in SolidWorks SimulationXpress was performed on the fins to determine if they could withstand the aerodynamic loads. Plywood was initially chosen as the fin core material; however, near the fin root stresses exceeded the allowed design margin. The figures below depict the results of flight loading conditions a FR4 fin.

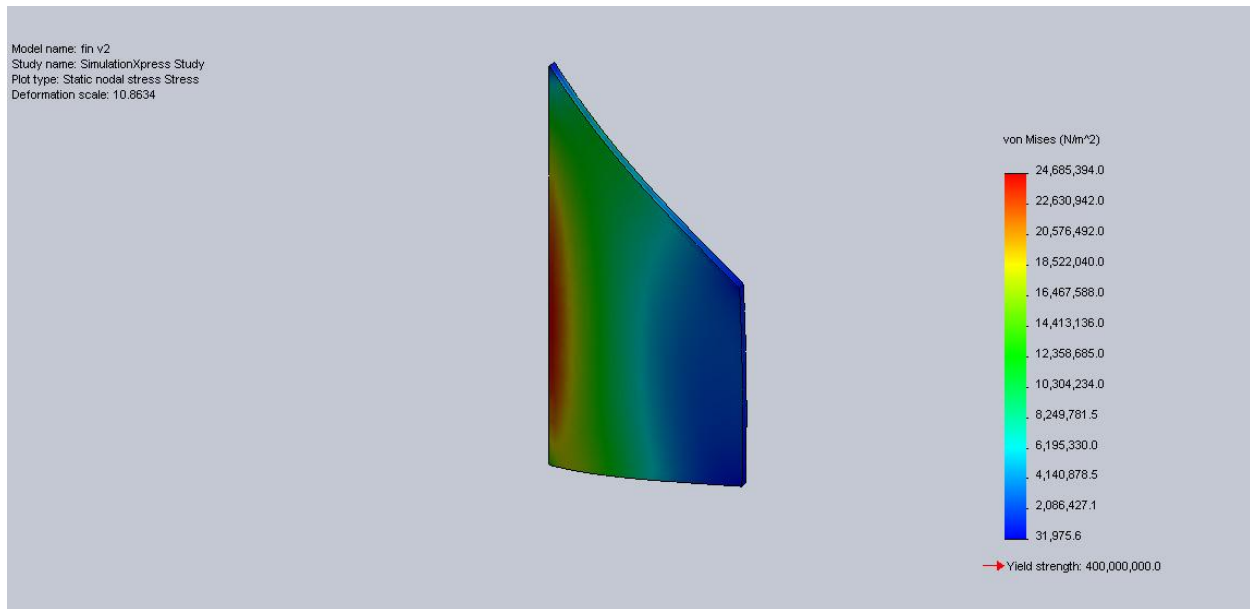


Figure 8 Simulated Fin Stresses

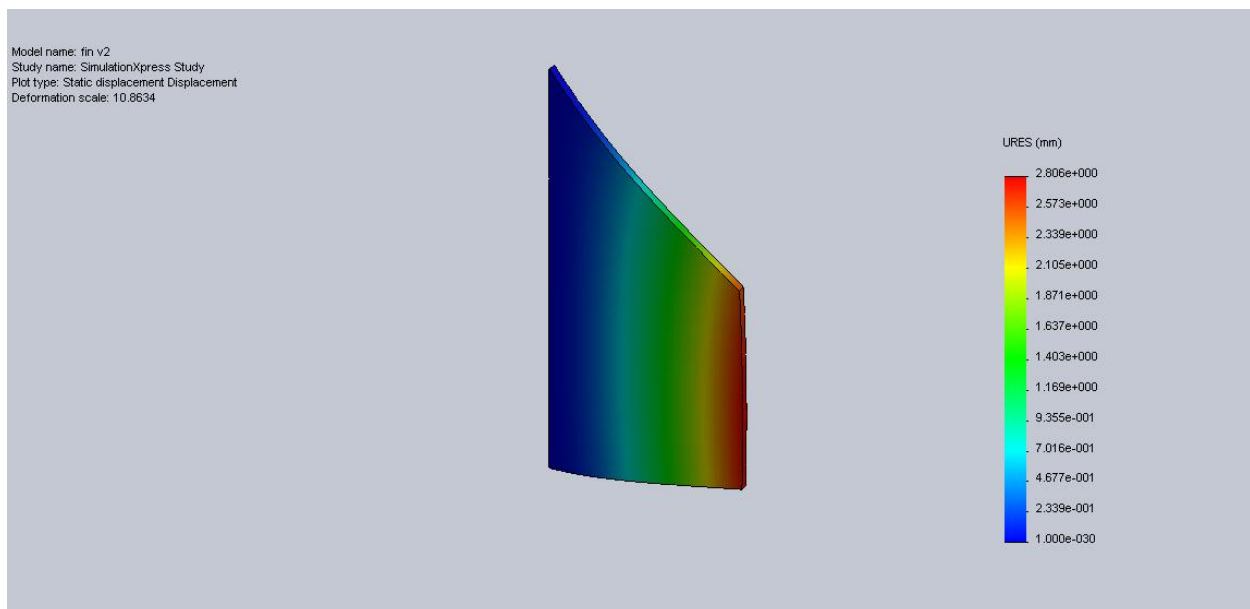


Figure 9 Simulated Fin Deflections

4.2.1.4.2 RESULTS

Analysis shows that 3/16 inch FR4 fin sandwiched between carbon fiber will withstand aerodynamic loading conditions during flight.

4.2.1.5 THREADED ROD SIZING

The 3/8" threaded rod is used to connect the parachute shock loads to the motor retention system, as shown in Table 16.

Table 16 Threaded Rod Sizing

Threaded Rod Sizing		
Rod Diameter	0.2983	in
Total Area	0.069887	In^2
Stress	6170.67566	Psi
Allowable Stress	33000	Psi
MoS	4.34787466	

4.2.1.6 MOTOR RETENSION SYSTEM

The motor mount will consist of a commercial 75mm motor tube and laser-cut, plywood centering rings. There will be four centering rings in total, one located at each end of the motor tube and two in the middle. The farthest forward will be made from 1/2" plywood. The farthest aft centering ring will be made from two rings of 3/16" 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 some of the thrust load through compression of the aft centering ring, rather than through shear in the epoxy joints holding the motor mount in the body tube. The middle centering rings will be made from 1/2" plywood, with three slots to accept the fins, which will have 3/4" tabs (the 6.5" span fin does not include the tab length inside the tube). One will be located near the forward edge of the fin tabs and the other near the aft edge of the fin tabs, close to the aft-most 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. There is a thrust ring on our 75mm hardware that prevents the motor casing from moving forward during burn.

The mounting and retention system can be seen below in Figure 10.

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 the figure below.

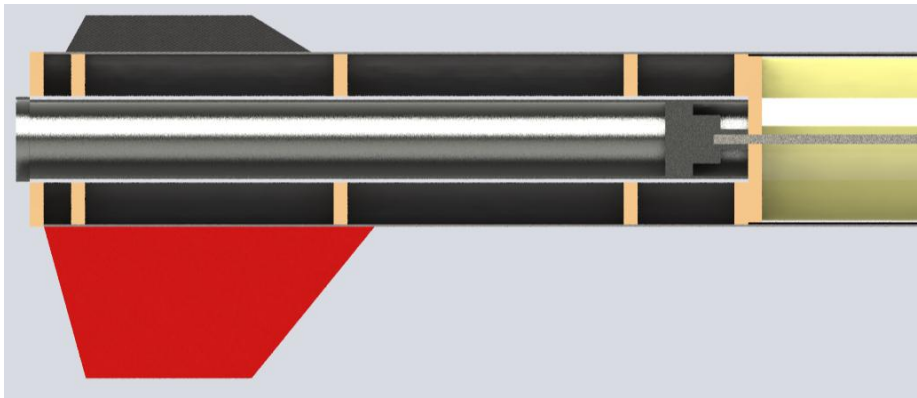


Figure 10 Motor Centering and Retention

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 tube with a 1/2" 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.

4.2.1.6.1 ANALYSIS

Since the threaded rod transfers shock load to the motor retention system, the motor retention system must be able to react to the load of the deployment. It must also, however, be able to react to the original axial load. The initial sizing calculations are as shown in Table 17.

Table 17 Motor Retention Sizing

Motor Retention Sizing		
# Used	3	
Thk	0.5	in
ID	3	In
OD	6	In
Avd D	4.5	In
"b"	14.1371669	In
I	0.14726216	In ⁴
M	669.375	In-lbf
Z	0.25	In
Stress	1136.366629	Psi
Failure Stress	1500	Psi
MoS	0.31999691	

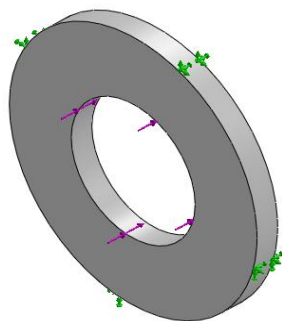


Figure 11 Motor Retention BCS

The resulting displacement is shown in

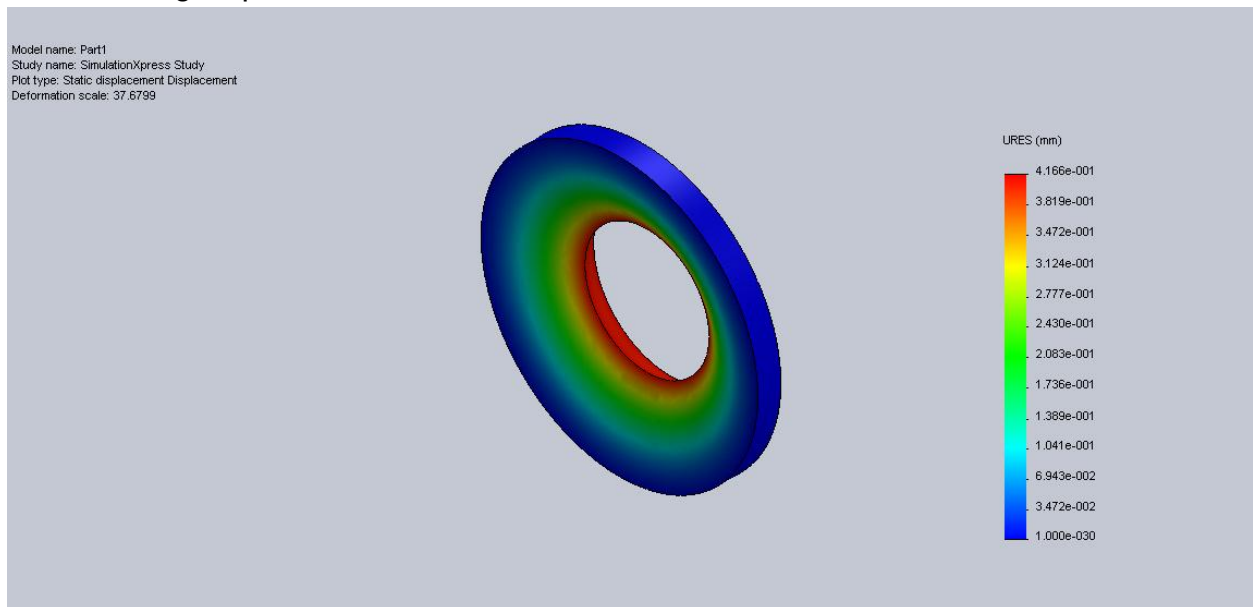


Figure 12 and the stress is shown in Figure 13.

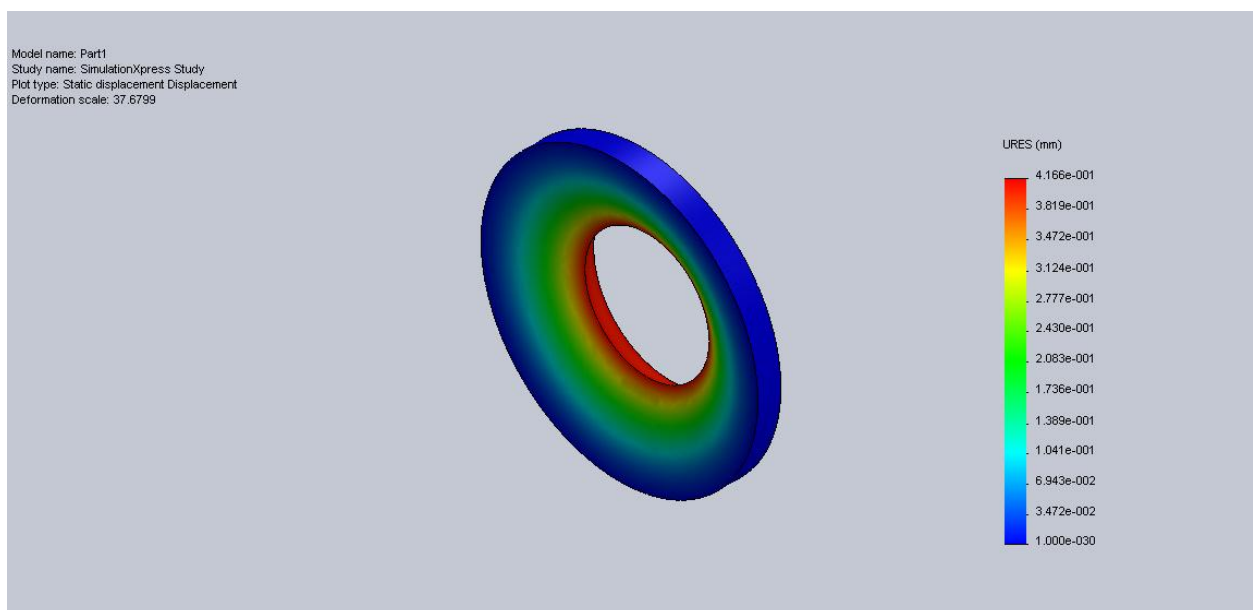


Figure 12 Motor Retention Displacement

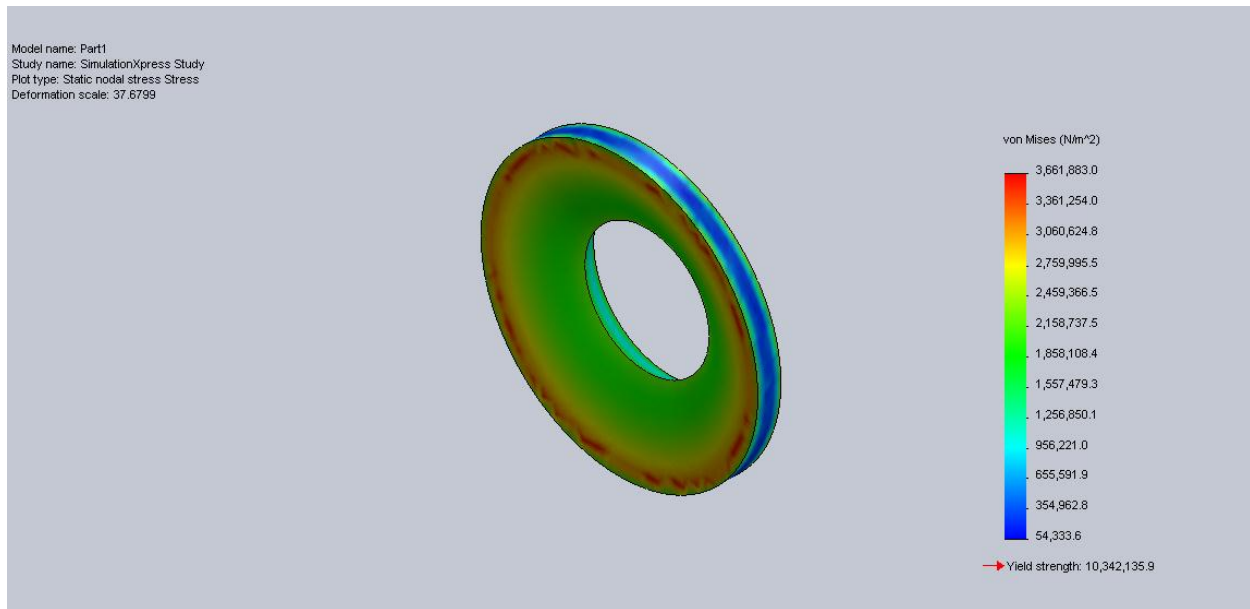


Figure 13 Motor Retention Stress

4.2.1.6.2 RESULTS

Judging by the above analysis the motor retention system will be able to secure the motor to the rocket body.

4.2.1.7 SABOT STRINGER SIZING

As described in the design portion of the document, the stringers are 4x #10 rods that connects the top and bottom parts of the sabot together. The size of these aluminum threaded rods can be verified as shown in Table 18 Stringer Sizing.

Table 18 Stringer Sizing

Stringer Sizing		
Stringer diameter	0.1318	in
Number	4	
Total Area	0.05457336	In ²
Stress	7902.20724	Psi
Density	0.041	Lb/in ³
Length	50	In
Sabot Diameter	6.5	In
Mass	0.11187539	Lbm
Allowable Stress	33000	Psi

MoS

3.17604841

4.2.1.8 BUDGET SUMMARY

Table 19 Rocket Budget Summary

System	Mass (kg)	Cost (USD)
Propulsion	9.71	552.00
Airframe-Body	14.75	455.09
Avionics/Communications	5	347.38
Payload Support Equipment	2	152.24
Recovery	4.83	434.60
Subtotal	36.29	1941.31

4.3 PROPULSION SUBSYSTEM

The Rocket will be powered by a Cesaroni L1115 commercially available solid rocket motor. This motor was chosen because it is commercially available and does not require any modifications in order to reach the goal flight altitude of 5280 feet based off preliminary mass estimates. This motor is more powerful than necessary based on preliminary mass estimates, but this will ensure that even with potential mass creep as the design of the rocket and payload matures, the rocket will be able to be optimized to reach the target altitude with the addition of ballast.

The Cesaroni L1115 is 75mm in diameter, 24.5 inches in length, and has a total impulse of 5015 Newton-seconds over a 4.49 second burn time.

For the full-scale test, the Cesaroni K661 solid rocket motor will be used. The CTI K661 has enough power to launch the full system up to an altitude of 1400 feet and has the same diameter as the L1115, so minimal changes will need to be made to the launch system for the full-scale test flight.

The Cesaroni K661 is 75mm in diameter, 13.78 inches in length, and has a total impulse of 2436 Newton-seconds over a 3.8 second burn time.

4.4 AVIONICS SUBSYSTEM

4.4.1 HARDWARE

4.4.1.1 FLIGHT COMPUTERS AND ALTIMETERS

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.

Table 20 Hardware Specifications

Hardware	Operating Voltage	Minimum Current	Dimensions	Mass	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	N/A	0.80"W, 1.8"L, 0.55"T	8 grams	N/A	-14C to 85C	N/A

4.4.1.1.1 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 14 shows the Stratologger altimeter.



Figure 14 Stratologger Altimeter (Perfectflight.com)

4.4.1.1.2 RAVEN2 (FEATHERWEIGHT ALTIMETER)

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.

4.4.1.2 POWER AND ARMING SWITCHES

A toggle switch that is recessed within the airframe with a horizontal throw will be used for each altimeter to provide power. The power and arming switches are used in order to prevent premature firing of ejection charges and power usage before the rocket is on the launch pad.

4.4.2 SOFTWARE

The Raven and Stratologger's settings (deploy altitude, delay, launch detect, telemetry, etc) will be configured via their respective downloadable software.

4.4.3 MOUNTING AND 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 a way so that their pressure and acceleration readings are not disturbed. This means that the barometric sensor on both the Raven2 and Stratologger would have to have at least a 0.25 inch 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.

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 devices 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.

Figure 15 shows the wiring diagram for deployment avionics. This diagram shows independence of the redundant systems in place.

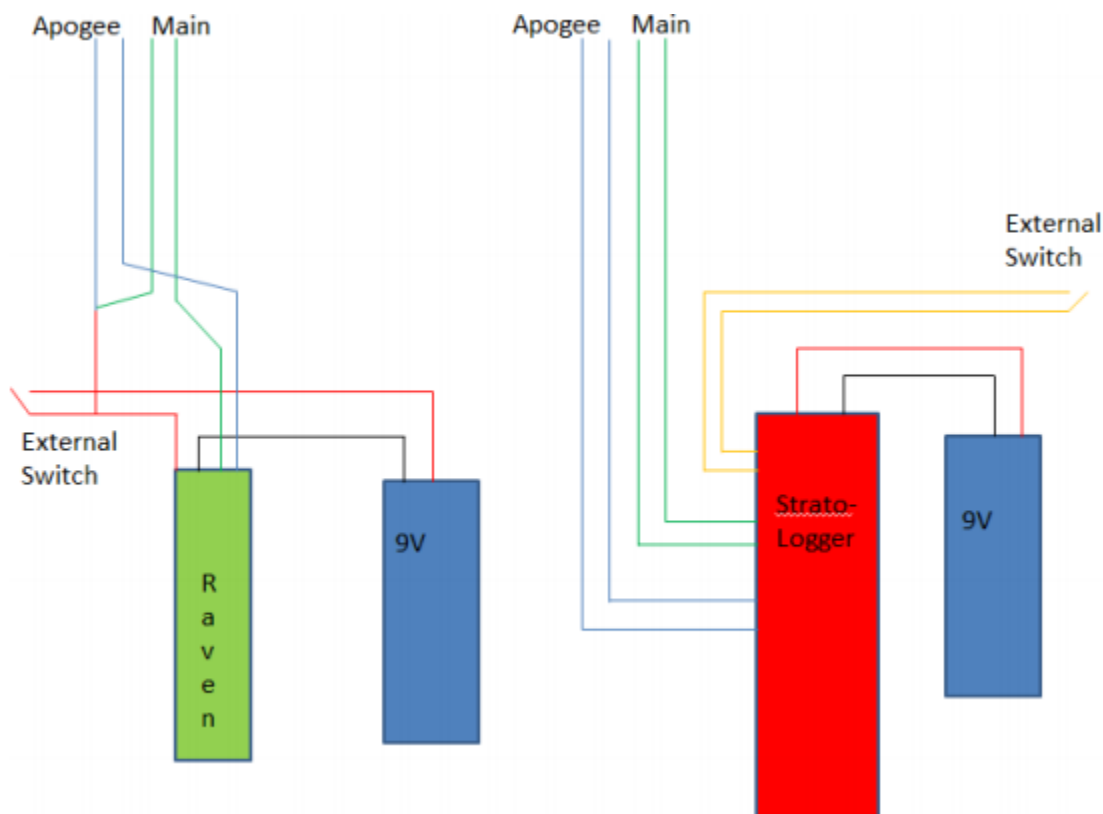


Figure 15 Rocket Avionics Wiring Diagram

4.5 RECOVERY SUBSYSTEM

4.5.1 OVERVIEW

The recovery system will consist of the deployment of a 36 inch diameter surplus, tanglefree, pilot parachute at apogee and a Rocketman R14 at 500 feet. 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 75 feet/second until 500'. At 500', 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 400'. 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 successful in several flights in previous rockets with very similar recovery system designs. The rocket will land in two tethered pieces, the 3 pound nosecone/sabot and the 23.56 pound rocket body. The nose cone/sabot section will land at approximately 13.9ft/sec for a total energy of 19.8 ft-lbf (12.2 joules). The lower section will land at approximately 13.9ft/sec for a total landing energy of 70.7 ft-lbf (95.91 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.



Figure 16 Recovery Package Consisting of Dual Deployment via Tender Descender

4.5.2 DETAILS

When the drogue parachute is deployed at apogee, it will need to support a total system mass of 36.6 lbs. A 3ft diameter parachute will be used to achieve a descent rate of 64 ft/s.

Once an altitude of 500 ft AGL is reached, the tether securing the sabot inside the rocket will release, allowing the drogue parachute to pull the sabot and the main parachute out of the rocket. At this point, the rocket body will separate from the sabot/nose/drogue section and free fall as the main parachute deploys. This will allow for a considerable gap between the rocket body and the sabot, decreasing the risk of the deployed quadrotor colliding with the rocket or becoming entangled in the main parachute.

With the quadrotor deployed and the sabot separated from the rocket body, the remaining structure has a mass of 23.6 lbs. With a 8ft diameter parachute, a final descent rate of 19.8 ft/s can be achieved. Under the 3ft parachute, the nose cone and sabot will have a final descent rate of 70.7 ft/s.

Table 21 Parachute Descent Rates

Final Descent Rate	
System Under Drogue	70.7 ft/s
Nose/Sabot Final Descent Rate	69.7 ft/s
Rocket Body Under Main	19.8 ft/s

The drogue parachute and nose cone are directly connected to the sabot. This assembly is initially connected to the recovery system retention threaded rod via the Tender Descender.

The main parachute is also secured directly to the recovery system threaded rod (not by the Tender Descender). Its deployment is constrained by the sabot.

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

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

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

$$\text{shear force} = A * \tau$$

where A is the cross-sectional area of the bolt, and τ is the shear strength. For a 2-56 screw, the minimum pitch diameter is 0.0717 in.³ This leads to a shear force of 40 lbf. With four pins, the charge will have to provide a minimum force of 120 lbf. Adding 25% margin, the charge will need to provide a total force of 150 lbf. This leads to a required black powder mass of 2.1 g.

From previous testing, it was decided that a charge containing 3.5 grams of black powder and two shear pins should be used. Also, previous testing of the Tender Descender has confirmed that the manufacturer's recommended charge size of 0.2 grams is sufficient to operate the device.

4.5.2.1 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 or 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 the rocket Avionics/Communication section.

4.5.3 DEPLOYMENT

Deployment of the quadrotor, sabot, and parachutes is as follows.

Initially, the stacking of the rocket above the recovery system bulkhead is as follows (as seen in Figure 17 and

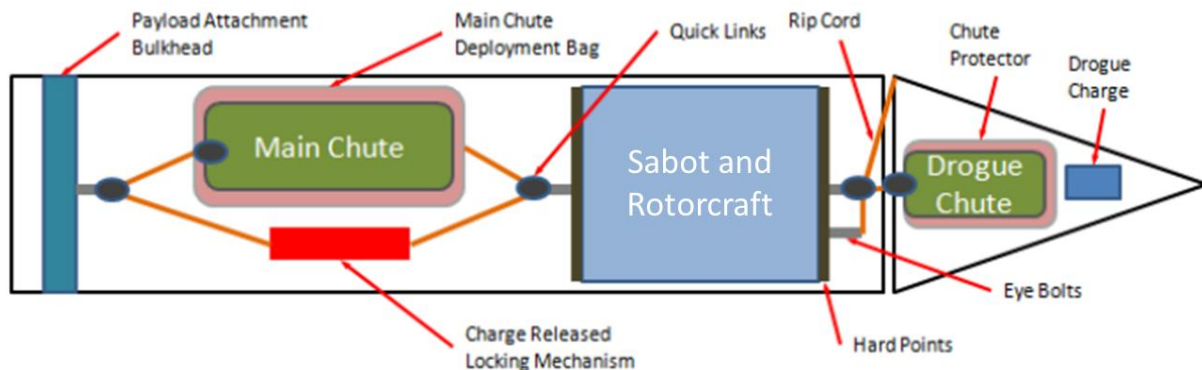


Figure 18):

- Payload Bulkhead attachment quick links
- Charge released locking mechanism
- Main parachute
- Sabot base hardpoint
- Sabot halves (cradling quadrotor)
- Sabot top hardpoint
- Drogue parachute quick link
- Drogue parachute
- Nose cone ejection charge

Note: There is a redundant igniter in the charge in the nose cone and a redundant igniter in the charge released locking mechanism.

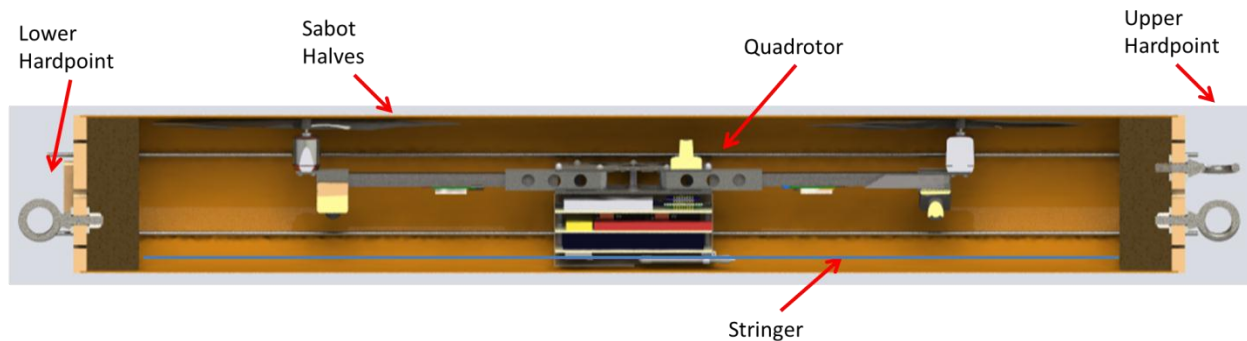


Figure 17 Sabot Overview

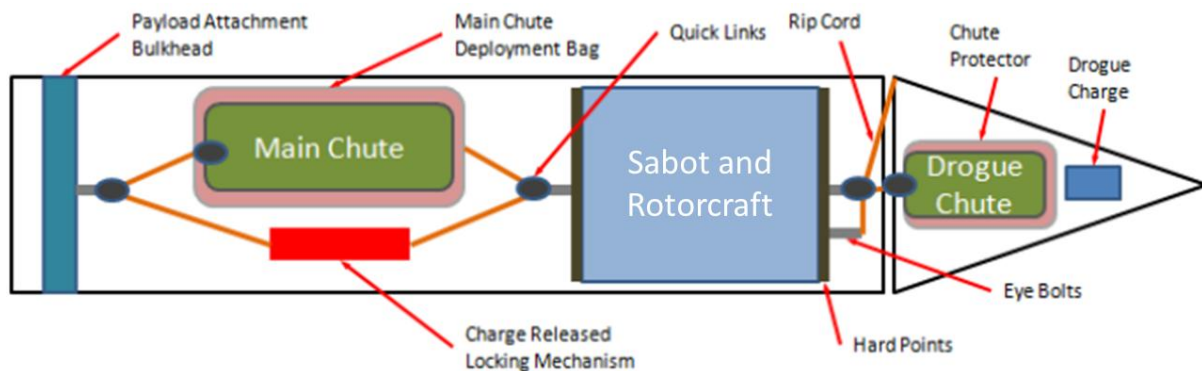


Figure 18 Payload Integration Stacking

The deployment then occurs as follows:

- Just after apogee, nose cone ejection charge fires
- Nose cone separates, but remains attached to the drogue parachute
- Drogue parachute deploys
- Rocket descends to 500 feet

- At 500 feet, the charge released locking mechanism fires. Mechanism to be used is the “FruityChutes L2 Tender Descender”
- The drogue parachute pulls the sabot out of the rocket tube
- As the sabot leaves the tube, the spring-loaded quadrotor arms push the sabot halves apart
- The sabot pulls the main parachute 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 19:

- Sabot and nose cone, which are attached to the drogue parachute via the upper hardpoint and a shock cord
- Main body tube, which is attached to the main parachute via the recovery system bulkhead and a shock cord

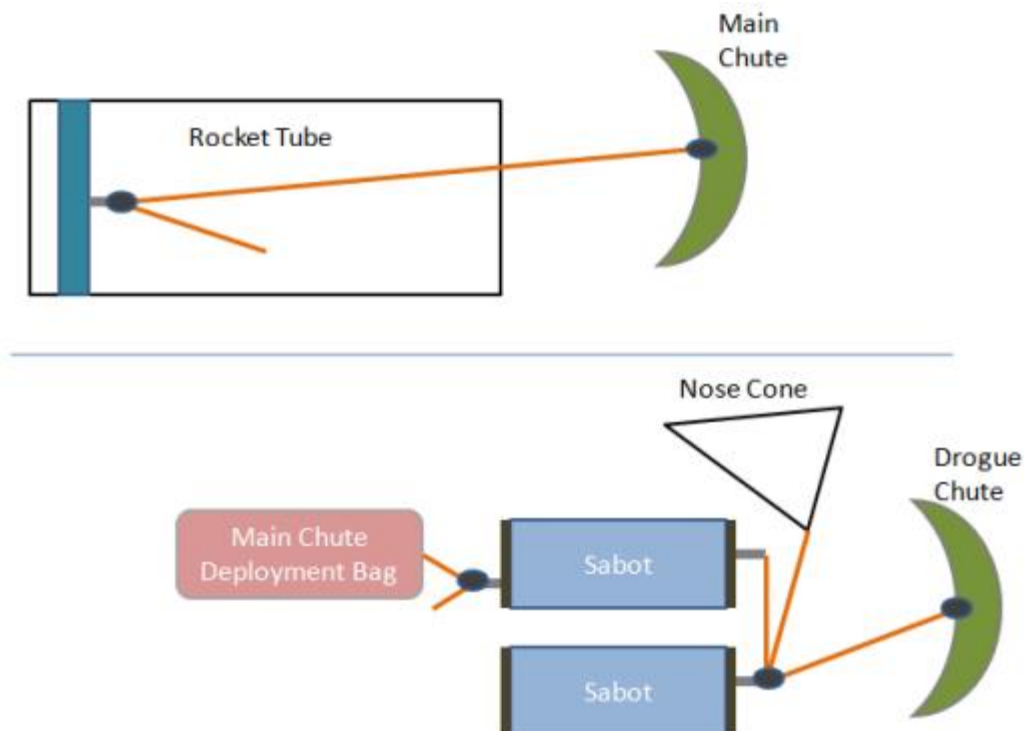


Figure 19 Deployed Recovery Components

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

As described above, the quadrotor is encased within the two sabot halves, which are made of foam and laminated in a ply of fiberglass so as to maintain shape. Force will be transferred between the hardpoints using a 4x 10-24 aluminum threaded rods, which will mount to the upper and lower hardpoints using clearance holes and nuts. Finally, plywood hardpoints are glued to the upper and lower ends of the sabot halves. These hardpoints enable recovery and deployment system fixtures to be attached to the sabot. One of these hardpoint sets is shown in Figure 20. As can be seen below, the hardpoint halves overlap to ensure force transfer between halves when in tension. Adhesive is applied as shown in the figure. An eye bolt is threaded into the lower hardpoint half, which serves as the attachment points for:

- Lower hardpoint: the charge released locking mechanism
- Upper hardpoint: the drogue parachute and upper shock cord (attaches to nose cone)

It should be noted that the upper hardpoint will require eye bolts in both hard point halves due to ensure both sabot halves remain attached to the drogue parachute.

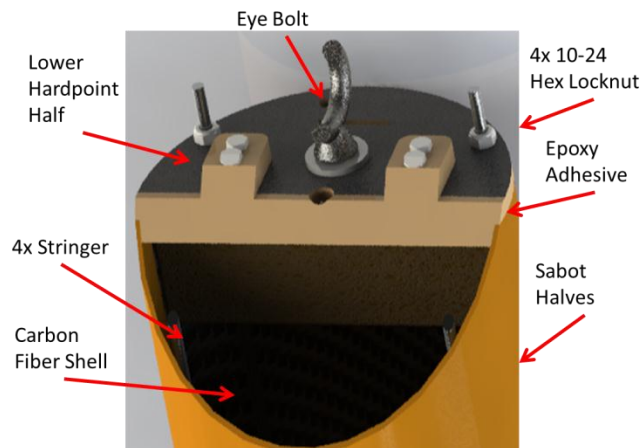


Figure 20 Sabot Hard Point

4.5.4 TEST RESULTS

4.6 COMMUNICATIONS SUBSYSTEM

The rocket avionics system will not communicate telemetry to the ground stations before, after, or during launch.

4.7 POWER SUBSYSTEM

Two 9 volt batteries will provide power for the flight computers; transmitters (Beelines) contain their own rechargeable battery. 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.

4.8 MISSION PERFORMANCE PREDICTIONS

4.8.1 MISSION PERFORMANCE CRITERIA

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

- Achieve an altitude as close to 5280 feet (1 mile) as possible. (It is preferable to undershoot the target, as the flight score penalty for overshooting is twice as great.)
- Eject nose cone and deploy drogue parachute at apogee
- Deploy quadrotor and main parachute at an altitude of 500 ft
- The quadrotor must unfold its wings and start the primary science mission objective.
- Land safely (intact and reusable with no necessary repairs) on the ground.

4.8.2 FLIGHT PROFILE SIMULATION

For the Critical Design Review flight profile simulations, RockSim was used. A model of the rocket was built in RockSim. Parachute descent rates were verified against the MATLAB parachute sizing model. The figure below shows the RockSim model.

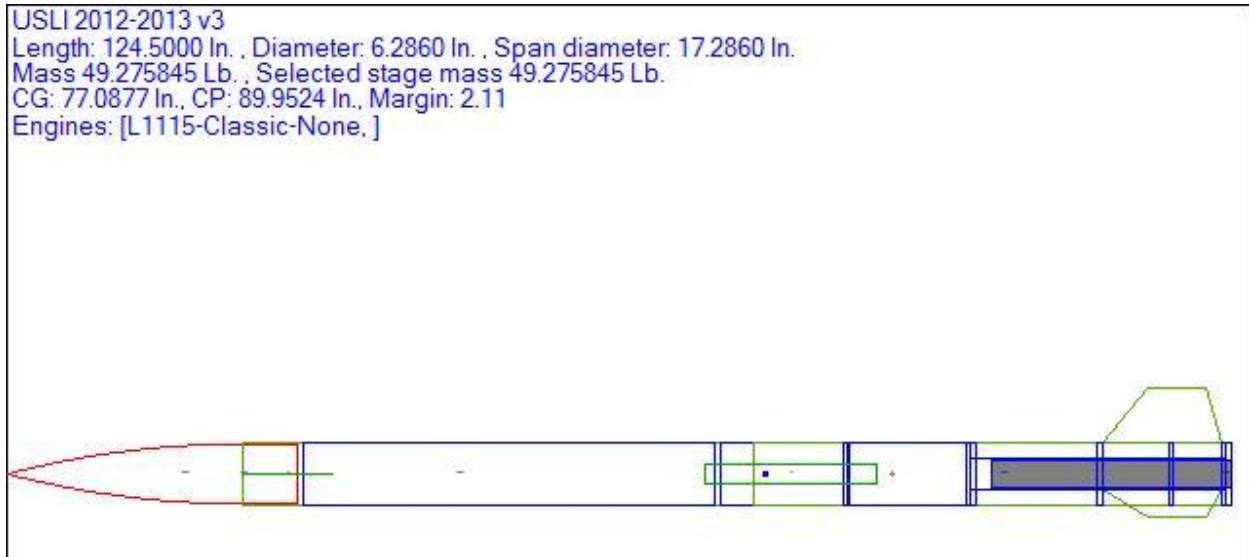


Figure 21 Predicted CM and CP Locations

A battery of simulations was run, taking into account the approximate location and altitude of the launch site and average temperature, pressure, and humidity conditions. It was known that the Cesaroni L1115 would be more powerful than necessary and propel the rocket higher than the target altitude. With no added ballast or winds, the rocket flew over 800 feet above the target altitude. This was expected and desired, especially considering the mass margin of the payload and other components, the masses of which have only been measured up to this point. Initially, the RockSim model had a mass of 19.75 kg and an initial stability margin of 2.26, which is comfortably stable but makes the rocket susceptible to angling toward gusting winds.

At $t = 0$, the Cesaroni L1115 is ignited. Burnout occurs at 4.49s, and apogee occurs at approximately 19.9 seconds. At this time, the first charge is ignited to eject the nosecone and deploy the drogue chute, which pulls the sabot out of the rocket. At an altitude of 500 feet, the second charge is ignited. This charge disengages the Tender Descender, separating the nosecone, drogue chute, and sabot (which is housing the quadrotor) from the rest of the rocket body tube, and deploys the main parachute. The sabot/ nose cone assembly will continue to fall under the drogue parachute until the RSO gives the team approval to release the quadrotor, at which time a remotely controlled solenoid lock will be powered on, allowing the spring loaded sabot to separate and release the quadrotor.

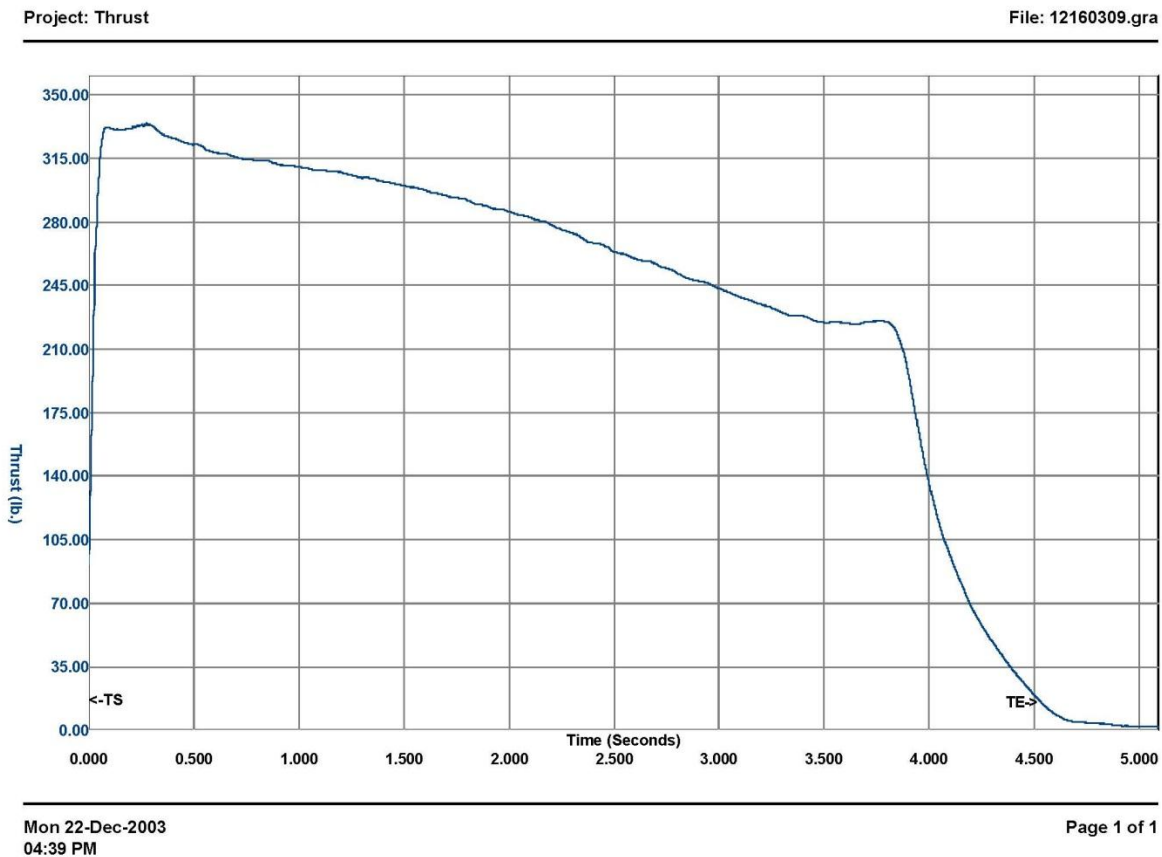


Figure 22 Cesaroni L1115 Thrust Curve

Figure 23 shows the acceleration and velocity of the rocket during the first 30 seconds of flight (the remaining flight time was omitted for clarity). The maximum speed occurs near burnout, and does not exceed Mach 0.51. The maximum predicted acceleration occurs at the parachute deployment, as expected. While the magnitude of the maximum acceleration is high compared to what was expected, this is still within the range that the carbon fiber structure of the rocket can stand. An initial concern was that the parachute cords could rip the body tube apart during high-speed deployment. Future modeling will try to reconcile the nearly instantaneous parachute deployment featured in RockSim and the expected unraveling time of the chute to prevent such high accelerations in simulations.

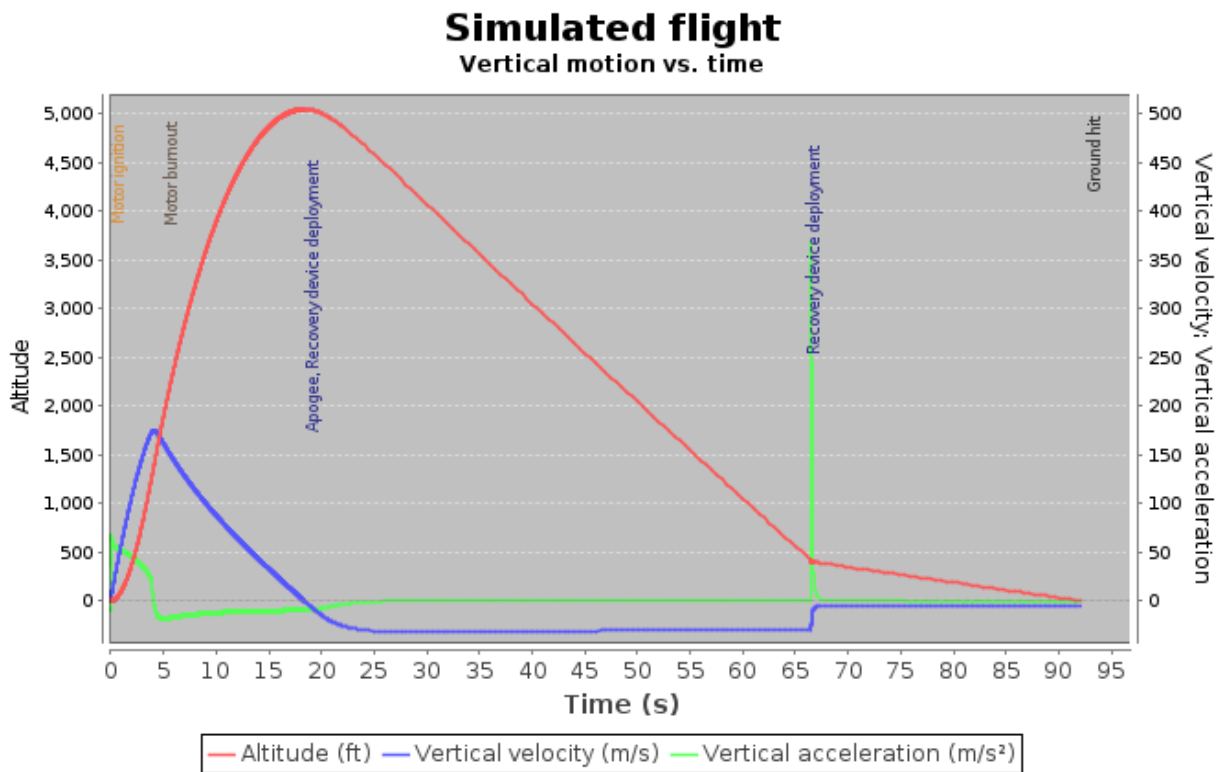


Figure 23 Predicted Acceleration and Velocity Profiles

Figure 24 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 70s.

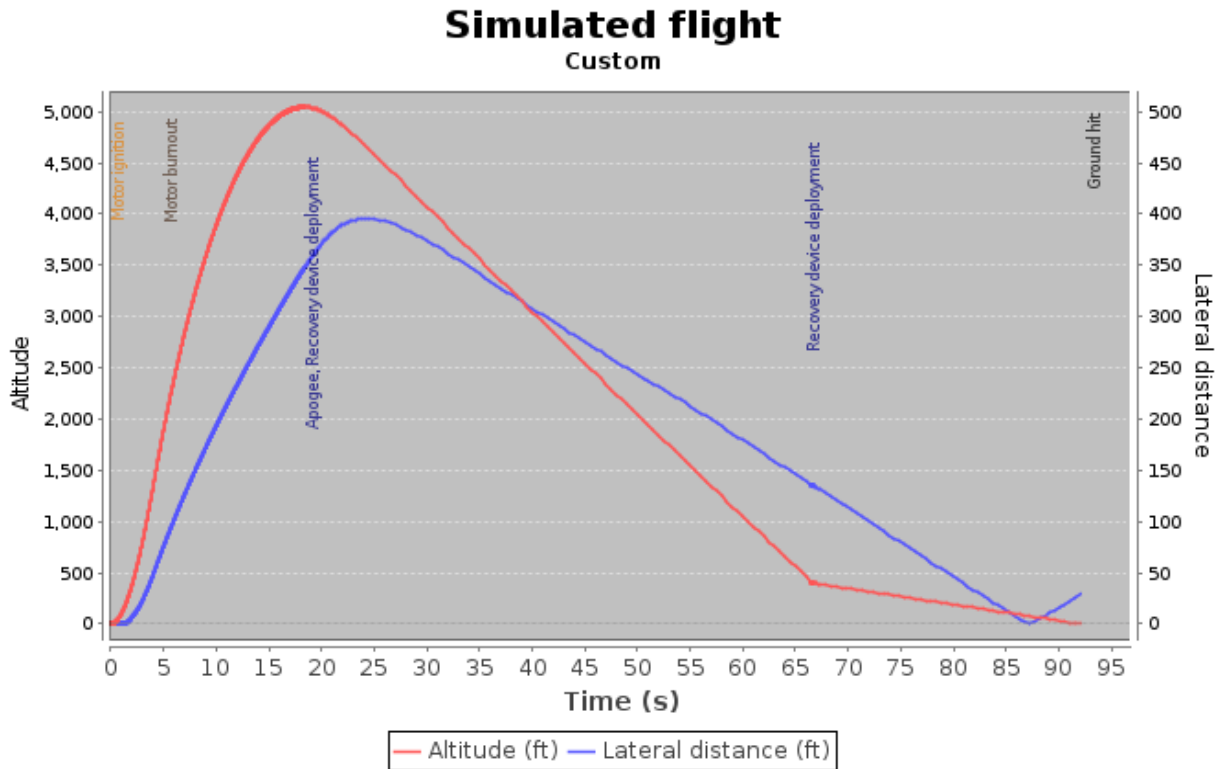


Figure 24 Simulated Altitude Profile and Drift Distance for a 2.0 mph Wind Speed

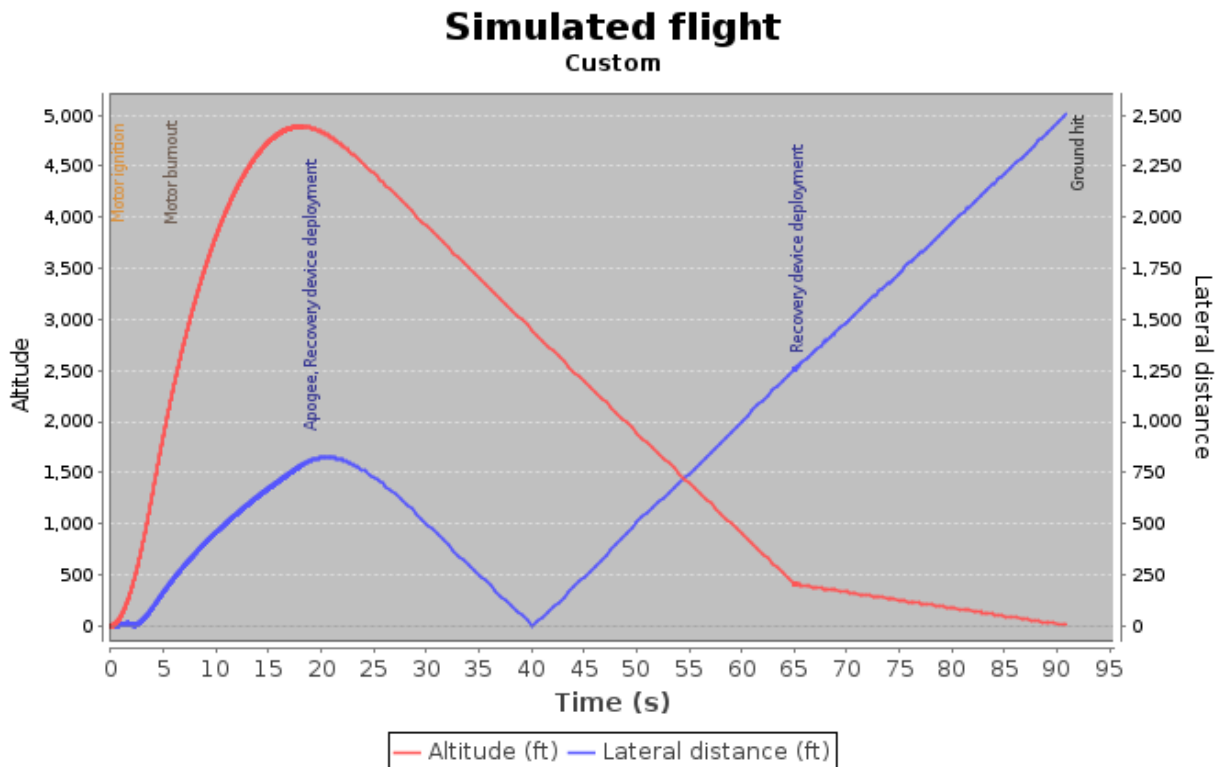
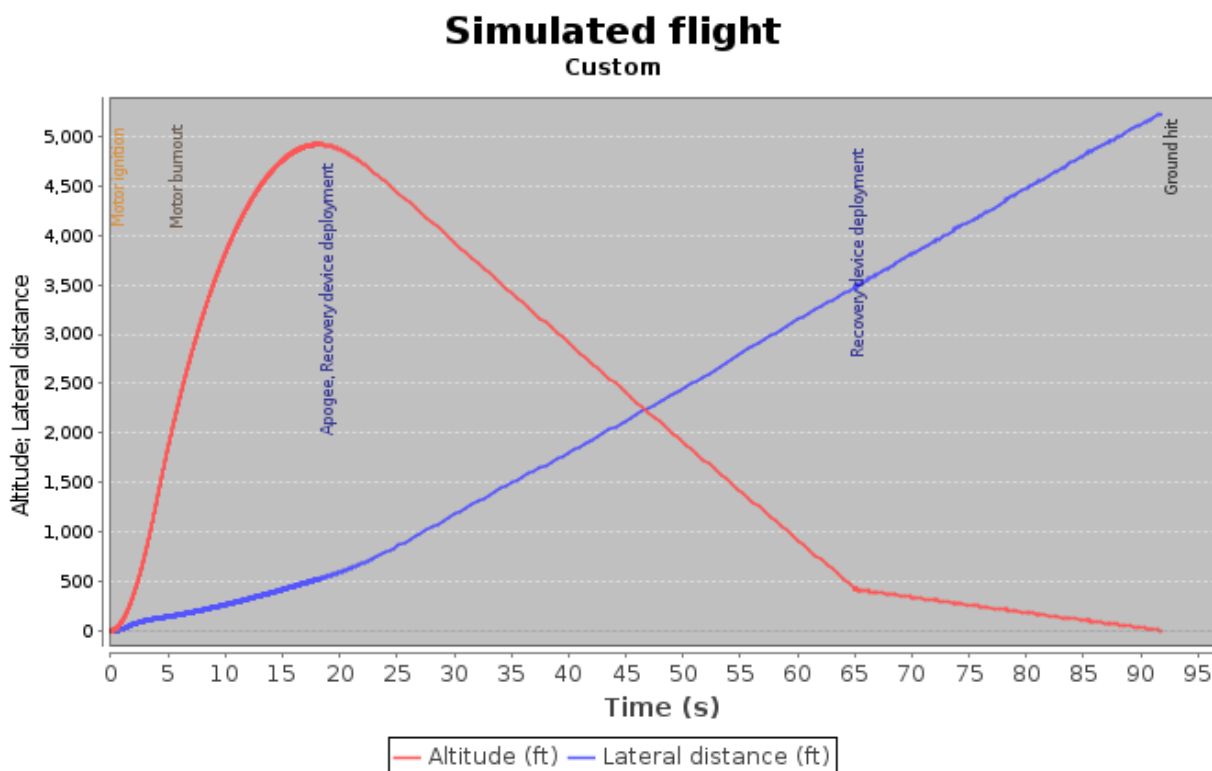


Figure 25 Simulated Altitude Profile and Drift Distance for a 15 mph Wind Speed**Figure 26 Simulated Altitude Profile and Drift Distance for a 20.0 mph Wind Speed**

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

4.8.2.1 ALTITUDE SENSITIVITY ANALYSIS

4.8.3 STABILITY PREDICTIONS

The preliminary static margin for the launch vehicle is 2.11. This is an appropriate static margin for a rocket with a large length to airframe diameter ratio. Additionally, the higher stability margin will allow some margin in the event that there are unexpected changes in the masses of some of the components that could jeopardize overall stability.

During flight, the static margin will increase as the propellant is burned, and the center of mass moves toward the nose of the rocket. At burnout, the static margin is 3.52.

4.8.4 KINETIC ENERGY

In compliance with USLI regulations, the kinetic energy of all components will be less than 75ft-lbf at landing. Table 22 shows the associated energies.

Table 22 Rocket decent properties

	Decent Rate (ft/sec)	Total Energy (joules)	Total Energy (ft-lbs)	Chute Diameter (ft)
Drogue Decent Rate	13.9	12.2	19.8	5
Main Decent Rate	13.9	95.9	70.7	14
Quadrotor Rate	21.2	94.5	69.7	5.5

4.9 INTERFACES AND INTEGRATION

4.9.1 PROCEDURE

- 1) Integrate Avionics Bay
 - a) Integrate avionics boards and Emergency Locator Transponder onto avionics plate
 - b) Integrate 3 New Batteries
 - c) Test electronics (turn on)
 - d) Attach avionics plate onto top cap with L-brackets and 5/8" 4-40 screws
 - e) Attach avionics plate onto bottom cap with L-brackets and 1/2" 4-40 screws
 - f) Slide assembly into tube
 - g) Slide recovery system bulkhead into rocket and secure with screws
 - h) Check all connections
 - i) Check pressure holes

Figure 27 Rocket Avionics Bay Assembly

- 2) Make Black Powder Ejection Charges

- a) Safety Officer will oversee this step
- b) Connect to avionics
- 3) Recovery
 - a) Fold drogue parachute (use talcum powder)
 - b) Integrate drogue parachute and parachute protector
 - i. Attach to upper sabot hardpoint with quick link
 - c) If main parachute is not already properly folded in the parachute bag, fold main parachute (use talcum powder)
 - d) Integrate main parachute and parachute protector (Figure 28)
 - i. Attach main shock cord to payload eye bolt with quick link
 - ii. Attach main parachute to shock cord with quick link
 - iii. Attach parachute bag to lower sabot hardpoint
 - e) Attach charge release locking mechanism to payload eye bolt
 - i. Connect leads to avionics
 - ii. Attach to lower sabot hardpoint
 - f) Nose Cone
 - i. Attach secondary shock cord between nose cone and sabot with quick links
 - ii. Emergency Locator Transponder
 - g) Nose Cone, Drogue, and Sabot should not be attached to main shock cord
 - h) Check all quick links (tighten with wrench)

Figure 28 Main Parachute/Shock Cord Attached to Eye Bolt and Recovery System Bulkhead

- 4) Integrate rocket body with sabot/rotorcraft assembly
 - a) Attach two rocket body segments together (Figure 28)
 - i. Thread four 6-32 1/2" bolts through doublers
 - b) Slide sabot (with rotorcraft) in routing the wires from the avionics assembly through the raceway

Figure 29 Tube-Tube Interface

- 5) Integrate Nose Cone
 - a) Slide into upper body tube (Figure 30)

Figure 30 Nose Cone/Upper Body Tube Interface

Figure 31 Integrated Avionics Assembly, Main Parachute, Sabot and Quadrotor Assembly

4.9.2 TASKING AND INTEGRATION SCHEDULE

Table 23 Tasking & Integration Schedule

Overall Task	Number of People*	Time in Minutes
Integrate avionics assembly	3	15
Assemble quadrotor	2	5
Integrate main parachute	2	15
Integrate quadrotor assembly with recovery system	3	5
Integrate drogue parachute	2	5
Integrate nose cone	2	2
Integrate motor	2	4

Total time: Approximately 60 minutes

- This includes one person with the checklist who will be supervising

4.9.3 INTERNAL PAYLOAD INTERFACES (PRECISION FIT AND COMPATIBILITY OF ELEMENTS)

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.

4.9.3.1 LAUNCH VEHICLE AND GROUND INTERFACES

A wireless transmitting interface will be used to activate the NIMBUS experiment before launch.

4.9.3.2 LAUNCH VEHICLE AND 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

4.9.4 PAYLOAD INSTALLATION AND REMOVAL

4.9.5 SIMPLICITY OF INTEGRATION PROCEDURE

4.10 LAUNCH CONCERNS AND OPERATION PROCEDURES

4.10.1 SUMMARY OF ROCKET ASSEMBLY

4.10.2 LAUNCH SYSTEM AND PLATFORM

4.10.2.1 LAUNCH PAD

We will be using a Vaughn Brother's Rocketry "High Power Launch Pad" with a 10ft extruded aluminum T-slot rail.

Features:

- 200lb capacity
- Folds for easy transportation
- Holes in feet for staking the pad to the ground
- 12inch x 0.1inch thick steel blast deflector
- Accepts launch rods 1/4" - 3/4" and launch rails (with adapter)

4.10.2.2 CHECKLISTS AND STANDARD OPERATING PROCEDURES

4.10.2.2.1 CAUTION STATEMENT

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

4.10.2.2.2 EQUIPMENT PACKING CHECKLIST

1. Support Equipment and Tools
 - a. Safety Gear
 - i. Goggles
 - ii. Rubber Gloves
 - iii. Leather/Work Gloves
 - iv. Face Masks
 - v. All Safety Documents and References
 - b. Furniture
 - i. Tent (1x)
 - ii. Tables (2x)
 - iii. Chairs (6x)
 - iv. Rocket assembly benches
 - c. Generator
 - i. Gas
 - ii. Power Strip(s) (3x)
 - iii. Extension Cord(s) (3x)
 - d. Tools
 - i. Corded Drill
 - ii. Cordless Drill
 - iii. Cordless Drill Batteries
 - iv. Charger
 - v. Drill Bit Index(s)
 - vi. Wrench Set
 - vii. Pliers
 - viii. Screwdriver Set
 - ix. Hex Keys Set
 - x. Files
 - xi. Sandpaper
 - xii. Knives
 - xiii. Flashlight
 - xiv. Soldering Iron
 1. Solder
 2. Solder Wick
 3. Sponge
 - xv. Wire Cutter/Stripper(s)
 - xvi. Extra Wire (Black and Red)
 - xvii. Pocket Scale
 - e. Adhesive

- i. 5-minute Epoxy (2 part)
 - ii. CA and Accelerant
 - iii. Aeropoxy (2 part)
 - iv. Epoxy Mixing Cups
 - v. Popsicle Sticks
 - vi. Foam (2-part)
 - vii. Foam (solid)
 - f. Other supplies
 - i. Tape
 - 1. Duct Tape
 - 2. Scotch Tape
 - 3. Vacuum Tape
 - 4. Electrical Tape
 - 5. Masking Tape
 - 6. Gaffer's Tape
 - ii. Trash Bags
 - iii. Isopropyl Alcohol (general clean up)
 - iv. Water Bottle
 - v. Camera Lens Cleaning Supplies
 - vi. Paper Towels
 - vii. Wipes
 - viii. Spare Hardware
 - ix. Lithium/Silicon Grease (for building reload; other)
 - x. Zip-ties
 - xi. Talcum Powder (for parachutes)
- 2. Ground Station
 - a. Antennas
 - i. Rocket (1)
 - ii. Quadrotor (3)
 - iii. Antenna Mounts
 - b. Emergency Locator Transponder (Quadrotor and Rocket) (3x)
 - c. Emergency Locator Receiver
 - d. Quadrotor Main "Pilot" Computer
 - e. Quadrotor Secondary Computer
 - f. Rocket Ground Station Computer
 - g. Quadrotor Manual R/C Controller
 - h. Monitors
 - i. Power Adapters for all Computers
 - j. Mice (3x)
 - k. Cables

- i. Antennas
 - ii. Monitors
 - iii. Other
 - I. Miniature Weather Station (wind speed/direction, temperature)
- 3. Launching Equipment
 - a. Launch Pad
 - b. Launch Rail
 - c. Stakes for Pad
 - d. 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
 - ii. Drogue (2x)
 - iii. Main (2x)
 - iv. Nomex Parachute Protectors (3x)
 - v. Shock Cord
 - vi. Ejection Charges
 - 1. Black Powder
 - 2. Charge Holders (4x)
 - 3. Igniters (4x)
 - vii. Charge Released Locking Mechanism (2x)
 - viii. Quick links (10x)
 - c. Motor
 - i. Casing
 - ii. Reload (2x)
 - iii. Retention
 - 1. Retention Plate
 - 2. Retention Hardware
 - d. Avionics
 - i. Avionics Bay
 - ii. Altimeters
 - 1. Stratologger (1x)
 - 2. Raven (1x)
 - iii. Antenna (attached to outside of rocket body)

- iv. 9V Batteries (10x)
 - v. Emergency Locator Transponders (one in Bay, one in nose cone) (3x)
 - vi. Hardware
 - 1. 4-40x1" bolts (10x)
 - 2. 4-40 locknuts (6x)
- 5. Quadrotor
 - a. Quadrotor
 - b. Motor (2x)
 - c. Quadrotor Propeller (3x)
 - d. Quadrotor Lithium Polymer Batteries (2x) and Spare Batteries (3x)
 - e. Lithium Polymer Battery Charger/Balancer
 - f. Spare motors (2x)
 - g. Spare Control Linkages
 - h. Sabot
 - i. Avionics
 - i. Flight Computer
 - ii. Back up Sensor Logging Board
 - iii. Sensors
 - iv. Manual Control Receiver (Back Up: 72MHz)
 - v. Antennas (72MHz, 900MHz, 2.4GHz)
 - vi. Emergency Locator Transponder
- 6. Miscellaneous
 - a. Digital Camera
 - b. Video Camera
 - c. Extra Batteries
 - d. Binoculars
 - e. Two-Way Radios
 - f. Two-Way Radio Chargers

4.10.2.2.3 PRE-FLIGHT CHECKLIST

- 1. Ground Station
 - a. Furniture Set Up
 - b. Generator
 - i. Full Tank
 - ii. Extra Gas

iii. Connect Extension Cord(s)/Power Strip(s)

c. Computers

i. Set Up

ii. Plug in Power Adapters

iii. Mice

iv. Set Up Monitors

v. Power Up

d. Antennas

i. Mount and Set Up

1. 2.4GHz

2. 900MHz

ii. Connect to Computers

e. Set Up Emergency Locator Transponder Receivers

i. Test on each of 3 channels

2. Quadrotor

a. Mechanical

i. Inspect rotorcraft (follow detailed checklist)

1. Internal Structure

2. External Structure

3. All Electronics/Avionics Mounts

4. Motor Mounted Securely

iii. Test/inspect Arm Folding Mechanism

1. Fold and let Unfold at least twice

2. Adjust as necessary

iv. Inspect all Hinges

v. Test All Folding Hinges

1. Fold and let Unfold
2. Adjust as necessary

vi. Unfold Everything

vii. Inspect All Control Surfaces

1. All should be free and clear to rotate
2. Inspect and Move All Hinges
3. Inspect Control Linkages and Servos

viii. Inspect Camera Dome

1. Clean Dome if necessary
2. Check Connection to Fuselage
3. Check Camera Mount
1. Clean if necessary

b. Power Systems

- i. Inspect Motor
- ii. Check if Propeller Secure
- iii. Give Motor a Test Spin (by hand)
- iv. Inspect Motor Controller
- v. Make sure all electronics are Switched Off
- vi. Connect and Secure Charged Lithium Polymer Batteries

c. Avionics

- i. Install Flight Computer
- ii. Install Back up Sensor Logging Board
- iii. Install Video Board and Video Camera
- iv. Install Digital Camera

- v. Install Manual Control 72MHz Receiver (Back Up)
- vi. Inspect All Sensors
- vii. Install Emergency Locator Transponder
- viii. Connect Everything
- d. Communication/Controls
 - i. All servos connected to proper channels
 - ii. All Avionics Connected
 - iii. Power On
 - v. Test Motor (using standard/manual R/C 72MHz transmitter)
 - 1. Clear objects/people from the plane of the propeller
 - 2. Throttle Up
 - 3. Throttle Down
 - vi. Power Motor/Motor Controller Off
 - vii. Test Flight Computer
 - 1. Communicating with Ground Station
 - viii. Test Data Feeds (turn quadrotor avionics on)
 - 1. Temperature
 - 2. Humidity
 - 3. Solar Irradiation
 - 4. UV Irradiation
 - 5. Pressure
 - ix. Test IMU/GPS
 - 1. Transmitting Telemetry
 - x. Test Autopilot (Make sure control responds correctly)
 - xi. Test Data Logging

1. Digital Camera Still Shot Recorder
 2. Back Up Sensor Data Logging
 - xii. Test Video Feed
 1. Receiving Video
 - xiii. Test Emergency Locator Transponder
 1. Receiving Emergency Locator Transponder signal
 - xiv. Power Up Motor/Motor Controller
 - xv. Flight Test with Manual R/C Control (no autopilot)
 1. Receiving All Data
 2. Proper Control Responses
 - xvi. Ground Test of Point-and-Click Control (with autopilot)
 1. Receiving All Data
 2. Proper Control Responses
 - xvii. Aerial Test of Point-and-Click Control
 1. Trim control surfaces before flight
 2. Back Up with Manual R/C Control
 - e. Switch out Lithium Polymer Batteries
 - f. Final Overall Inspection
 - g. Install rotor into Sabot
3. Rocket
- a. Lay-out rocket sections in order
 - b. Check Body Antenna
 - c. Install Ballast into appropriate sections of sabot and body tube
 - d. Refer to Payload Integration Plan
 - i. Follow, then continue with this checklist

- e. Install all shear pins
- f. Prepare Motor Reload
 - i. Safety Officer will oversee this step
- g. Slide motor casing into rocket
- h. Screw on motor retention
 - i. Make sure the tube-tube and tube-nose cone interfaces are secure
- j. Inspect rail guides
- k. Do a pre-launch briefing

4.10.2.2.4 LAUNCH CHECKLIST

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

14. Get approval from event administration for launch

The following depend on procedures outlined by event administration:

15. Check to see if range and skies are clear

16. Insert key into ELS check continuity

17. Countdown from 5

18. Launch

19. Remove key from ELS

20. Disconnect ELS from battery

21. Recover Rocket and Quadrotor

4.10.3 RECOVERY PREPARATION

Using a short length of nylon webbing, attach the inside of the deployment bag to the loop at the top of the main parachute.

Using a short length of nylon webbing, attach the inside of the deployment bag to the loop at the top of the main parachute.

Next, fold the canopy width-wise so it can fit inside the deployment bag.

Fold the leader connecting the deployment bag and the parachute in a “figure 8” and secure with a rubber band. Place inside deployment bag. Begin placing the canopy inside the bag, folding it over itself in an Z pattern.

4.10.4 MOTOR PREPARATION

One of the team’s L2 members will supervise motor assembly. All fire hazards, e.g. people smoking, lighters, potential ignition sources, will be removed from the immediate surroundings during motor preparation.

See Appendix document for official and detailed Pro75 motor preparation instructions.

The assembled motor will be slid into the motor tube, and motor retention will be screwed on.

4.10.5 IGNITER INSTALLATION

Once the rocket is on the pad, tipped vertical, and all electronics are armed, the motor igniter will be installed. Care will be taken to fully insert the igniter into the motor. The igniter will be held in with tape and a 1/8" dowel, which will be easily pushed out when the motor lights. Launch lead clips will be securely attached to the igniter leads at the appropriate time.

4.10.6 LAUNCHER SETUP

The launcher will be assembled following the manufactures instructions by at least 3 team members.

4.10.7 SETUP ON LAUNCHER

Refer to Section 4.10.2.2.4 for Launch Checklist. After preparation is completed, the rocket will be carefully carried out to the launch pad. The launch pad will be oriented such that the rocket sits on the downwind side of the rail to avoid torque on the rail-buttons. The launch rail will be tipped over to allow the rocket to be slid on horizontally. Care will be taken when sliding the rail buttons into the rail slot. Then the rocket and rail will be carefully tipped up to vertical.

Once the rocket is on the pad, tipped vertical, and all electronics are armed, the motor igniter will be installed. Care will be taken to fully insert the igniter into the motor. The igniter will be held in with tape and a 1/8" dowel, which will be easily pushed out when the motor lights. Launch lead clips will be securely attached to the igniter leads at the appropriate time.

4.10.8 TROUBLESHOOTING

Electronics will be disarmed any time the rocket is approached while on the pad. Table 24 summarizes possible problems and solutions with the rocket while it is on the pad.

Table 24 Possible Launch Failure Modes

Problem	Possible Causes	Possible Solutions
Launch Button suppressed, but rocket does not launch.	1. Lead acid launch battery is dead. 2. Igniter lights, but motor does not. 3. Igniter does not light, but lead acid launch battery is charged.	1. Change out battery. 2. Change out igniter. 3. Check all wire connections.
Rocket electronics do not arm when switched on.	1. The electronics" batteries were not properly installed or connected. 2. The electronics" batteries are dead	1. Take rocket off of pad, 2. Take rocket off of pad and replace electronics" batteries.
Avionics fail to report full continuity	1. Charges are likely not properly connected	ot properly connected 1. Restart electronics to see if it fixes the issue. If not, remove rocket from pad and troubleshoot situation at prep table
Rail-button pulls out upon sliding rocket onto pad.	1. Not enough care was taken when installing the rocket on the pad.	1. Scrub launch attempt, bring rocket back to work station, and repair.

4.10.9 POST FLIGHT INSPECTION

Given the nature of the USLI Launch field, it is unlikely launch organizers will allow more than 2 people to recover the rocket and quadrotor. Given the large size of the vehicle, it will be important to plan ahead to be able to carry it back. A small duffle bag will be carried by one team member to pack the parachute and other items into after recovery.

Before reaching the rocket and quadrotor, pictures will be taken for future reference before disturbing any part of it

Upon approaching the rocket, the two ejection charges will be carefully inspected to ensure they are no longer live. If one is still live, its wire leads will be cut with a pliers and it will be placed in a safe location (not to be carried directly by a person). The main parachute will be disconnected from the shock cord and it will be rolled up and placed in the bag. The rocket and nosecone section will be repacked for transport. The rocket will be carried back in one piece by both people. The quadrotor will be retrieved either

concurrently by the same team if it is determined that one group of people can carry it back with the rocket, or separately by a different team. Similar photo documentation techniques will be used.

In the event of a contingency during recovery, plans will be made to adjust to these situations. Pyrotechnics safety will be a top priority during any situation.

Upon return to the prep area, data will be collected from data logging devices and the rocket will be prepared for the trip back.

4.11 SAFETY AND ENVIRONMENT (VEHICLE)

4.11.1 IDENTIFICATION OF SAFETY OFFICERS

Julian Lemus 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.

4.11.2 ROCKET RISKS

Table 25 Potential Risks

Risk	Likelihood	Effect of Project	Risk Reduction Plan
Catastrophe at Take-Off	Low	Total mission failure	To mitigate this risk, we have detailed setup, integration, and launch procedures. We will conduct safety checks at every stage to ensure adherence to all safety guidelines.
Structural Failure	Low	Total mission failure	Large safety factors accounted for during the design process reduce the impact

			that launch loads will have on weaker structural areas
Bird Strike	Low	Flight path altered	Follow all NAR launch rules, holding launch if any wildlife overhead.
Shear Pins Do Not Fail	Low	No parachute deployment; catastrophic failure	Extensive deployment testing will be conducted to validate the amount of black powder being used for deployment is sufficient to break pins.
Sabot Not Deploying	Medium	Payload not deployed; main parachute not deployed	Extensive testing. Wing release locking mechanism will keep wings locked until sabot exits body tube. This will prevent premature opening of the sabot, decreasing the possibility of the sabot binding inside the rocket body.
Drogue Parachute Not Deploying	Low	No force available to pull sabot and main parachute from rocket body;	Extensive deployment testing will be conducted to find optimal packing

		catastrophic failure	method for drogue parachute.
Entanglement of Main Parachute	Medium	Partial mission failure. Payload deployment still viable. Recovery of main rocket body unlikely	Parachute will be properly packed.
Failure of Recovery System Attachment Point	Medium	Partial mission failure. Payload deployment still viable. Recovery of main rocket body unlikely	Ensure extensive testing of recovery system attachment points to ensure their ability to meet strength requirements
Sabot Fails to Separate After Ejection From Rocket	Low	Rotorcraft unable to deploy; mission failure	Extensive testing to ensure wing rotator locking mechanism disengages after sabot exits rocket body, and 46 that spring force of deploying wings is sufficient to separate sabot halves.
Motor Fails to Ignite	Low	Unable to launch; mission failure	Replace igniter

4.11.3 SAFETY ANALYSIS

4.11.4 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 26 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	Perform pull tests on unrated components to ensure their strength. Components to be tested to 50g shock loads
Recovery System failure to deploy	Property Damage, Injury	Follow rocket's descent path visually, move if needed	Ensure rigorous testing of black powder charges, Tether release mechanisms and deployment altimeters and power supplies. Don't forget to arm altimeters
Recovery Device deployment on ground	Property Damage, Injury (especially eye)	Avoid placing body in path of parts if electronics are armed. Wear safety glasses if necessary.	Shunt charges until they are attached to recovery electronics. Do not move the rocket with armed electronics.
Unstable Vehicle	Property Damage,	Stand up, follow	Ensure actual CG

	Injury	rocket's path visually, move if needed. Confirm vehicle stability before launch.	position is acceptable relative to calculated CP
Brush Fire	Fire damage, injury	Have fire protection equipment and personnel trained in its use onsite	Follow NFPA table for dry brush around pad area.
Mid-Flight vehicle destruction (excessive forces on vehicle)	Loss of vehicle, Injury, Property damage	Follow rocket's path visually and move if needed if vehicle does come apart	Design, construct and test vehicle to assure successful flight. Use standard construction procedures for LII-LIII rockets, including sufficient bulkheads, fins, motor retention and couplers.
Failure of quadrotor to deploy	Loss of science value, potential failure of main recovery device	Visually track vehicle & quadrotor, and move if needed	Rigorously test quadrotor deployment method as an integrated component in the rocket recovery system. Ensure all other aspects of the rocket flight succeed
Failure to successfully integrate vehicle in allotted 4 hour time period	Loss of launch opportunity	N/A	Practice integration techniques under time constraints to ensure they are achievable in allotted time.
Failure of vehicle to reach desired altitude	Loss of competition points and potential loss of science value	N/A	Use multiple simulation programs and data from actual

			flight tests to fine tune rocket mass and motor selection
Quadrotor Scientific data is unrecoverable	Loss of science value	N/A	Perform range communication tests with all flight hardware in flight configuration. Allow electronics to be quickly reconfigurable in case of frequency conflicts.

4.11.5 PERSONAL HAZARDS

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

4.11.5.1 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.

4.11.5.2 TOOL USE INJURY POTENTIALS AND MITIGATIONS

Table 27 Mitigation procedures for potential tool related injuries

Tool	Potential Injury	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

4.11.5.3 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 the Appendix.

4.11.5.4 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., layups.
 - 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

4.11.6 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:
 1. Aeropoxy 2032 Epoxy Resin
 2. Aeropoxy 3660 Hardener
 3. Ammonium Perchlorate Composite Propellant
 4. Black Powder

See Appendix 7 for complete MSDS specifications on these materials.

5 PAYLOAD CRITERIA

The main payload of the rocket will be a quadrotor. The quadrotor will be equipped with GPS navigation and radio telecommand devices, an IMU, pressure sensors, an onboard computer, CMOS cameras, IR emitters/detectors, and an autonomous flight stabilizer. In addition to these components, the craft will also serve as the housing for the SMD

and high altitude weather payloads (described in the next section). Together these systems will allow the quadrotor to communicate science data and the relative location of the ground station to the descending rocket via an optical communication link. A radio transceiver allows the nose cone under the drogue chute to communicate relevant science and state information with the ground station. In addition, commercial-off-the-shelf science payloads (an altimeter and an accelerometer) will be flown on the rocket.



Figure 32 The Current Design of Quadrotor and Science Sensor Suite Configuration

5.1 SELECTION, DESIGN, AND VERIFICATION OF PAYLOAD EXPERIMENT

5.1.1 MISSION MOTIVATION

Quadrotors are a common tool used for reconnaissance gathering, object tracking, and recognition. Their ability to hover at a specified altitude as well as their ability to perform aerial maneuvers that fixed-winged UAVs cannot makes them a perfect platform for this science mission. However, as with most small UAVs, the quadrotor requires a long lead time before the craft can reach high altitudes. Thus, the team aims to reduce this lead time by building and testing a rotorcraft that can be deployed from high-powered rockets.

In addition, to provide real-time measurements and control, the quadrotor must establish a secure and reliable communications channel with the ground user. For this purpose, optical transmissions and communications have been employed with success in other applications. However, thus far a robust and cost effective high bandwidth optical transmission and control method between mobile targets for civilians does not

yet exist. The team aims to improve on current methods and develop an optical transmission and control method that can successfully transmit real-time data and commands to a quadrotor deployed from a rocket.

To provide a comprehensive test of the quadrotor systems, the quadrotor will be equipped to validate high altitude lightning models through direct measurement. Many mathematical models used to determine the weather at high altitudes, specifically in regards to lightning and electrostatic fields, remain untested or unconfirmed due to the lack of proper in situ measurements, and correlation between changes in the surrounding environment and visual confirmation of sprite phenomenon. To remedy this, ultra/very low frequency waves (ULF/VLF), electric field, and magnetic field measurements have to be taken simultaneously with measurements of lightning detection and visual data that provide sprite/lightning visual confirmation.

In summary the team aims to:

- Decrease deployment time for quadrotor high altitude missions
- Improve information acquisition, processing, and transmission on and between mobile targets in a dynamic environment
- Validate high altitude lightning models via direct measurements

5.1.2 MISSION STATEMENT

The MIT Rocket Team aims to develop an inexpensive, customizable, and reusable rocket system in order to rapidly deploy a quadrotor. The goals of the quadrotor design are to reduce quadrotor ascent time and to test new methods of communication between mobile targets. Using the quadrotor as a mobile platform, the team also intends to develop a payload to study the cause of high altitude lightning discharges and their effect on the surrounding environment, with the goal of validating existing mathematical models that lack in situ data.

5.1.3 CONSTRAINTS

Follow all rules of NASA USLI 2012-2013, 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 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 500ft 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
- Unmanned aerial vehicle (UAV) payloads of any type shall be tethered to the vehicle with a remotely controlled release mechanism until the RSO has given the authority to release the UAV.
- Any payload element which is jettisoned during the recovery phase, or after the launch vehicle lands, shall receive real-time RSO permission prior to initiating the jettison event.
- 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.

5.1.4 MISSION REQUIREMENTS

The mission requirements are as follows:

- The SPRITE Payload will meet the following objectives:
 - Deployable from a rocket
 - Safely house all hardware and electronics during all phases of the mission: launch, normal operations, and recovery
 - Relay telemetry and video to the ground station
 - Relay telemetry to the nose cone via optical communication
 - Track the nose cone and ground station
- The HALO Payload will meet the following objectives in addition to the NASA Science Mission Directorate requirements:
 - Ability to detect high altitude “lightning” events
 - Gather atmospheric measurements of: the magnetic field, EMF radiation, ULF/VLF waves, and the local electric field.

- Gather atmospheric measurements of: pressure, temperature, relative humidity, solar irradiance, and ultraviolet radiation at a frequency no less than once every 5 seconds upon decent, and no less than once every minute after landing.
- Take at least two still photographs during decent, and at least 3 after landing.
- All pictures must be in an orientation such that the sky is at the top of the frame.
- All data must be transmitted to ground station after completion of surface operations.

5.1.5 SYSTEM REQUIREMENTS

The system requirements are as follows:

- System must be less than \$5000 fair market value at time of flight
- Rocket must reliably and accurately achieve apogee of 5280ft
- Reliably deploy quadrotor at safe working altitude of 500ft
- Stream telemetry, and video to ground station
- Employ video and beacon tracking systems.
- Quadrotor must have attitude control within 5 degrees of accuracy during normal operations
- Quadrotor must have basic altitude control with 2 meters of accuracy during normal operations
- Quadrotor must be able to hover for a minimum of five minutes and operate for 30 minutes in a low power state (no power supplied to the propulsion system).

5.1.6 REQUIREMENT VERIFICATION BY DESIGN

5.1.7 PAYLOAD HYPOTHESIS

1. A composite based quadrotor with a maximum weight of 10lbs and a maximum cost of \$2000 dollars can track an object up to 300 feet away, recognized objects on the ground while at a minimum distance of 1000 feet in the air, and can collect and transmit data to the ground.
2. The HALO suite of sensors can reliably and robustly collect, store, and transmit data.

5.1.8 SUCCESS CRITERIA

The payload mission shall be deemed a success if the team is able to assess all aspects of the payload hypothesis.

5.1.9 MILESTONE SCHEDULE

The full schedule for rocket and payload development may be found in Timeline section 7.3. Key dates are presented below for reference.

- 9/29: Project initiation
- 10/29: PDR materials due
- 11/18: Scaled test launch
- 1/14: CDR materials due
- Jan: Scale quadrotor test
- Jan: Avionics sensors test
- Feb: Deployment test
- Feb: Full-scale test launch
- 3/18: FRR materials due
- 4/17: Travel to Huntsville
- 4/20: Competition launch
- 5/6: PLAR due

5.1.10 OVERVIEW OF FLIGHT OPERATIONS

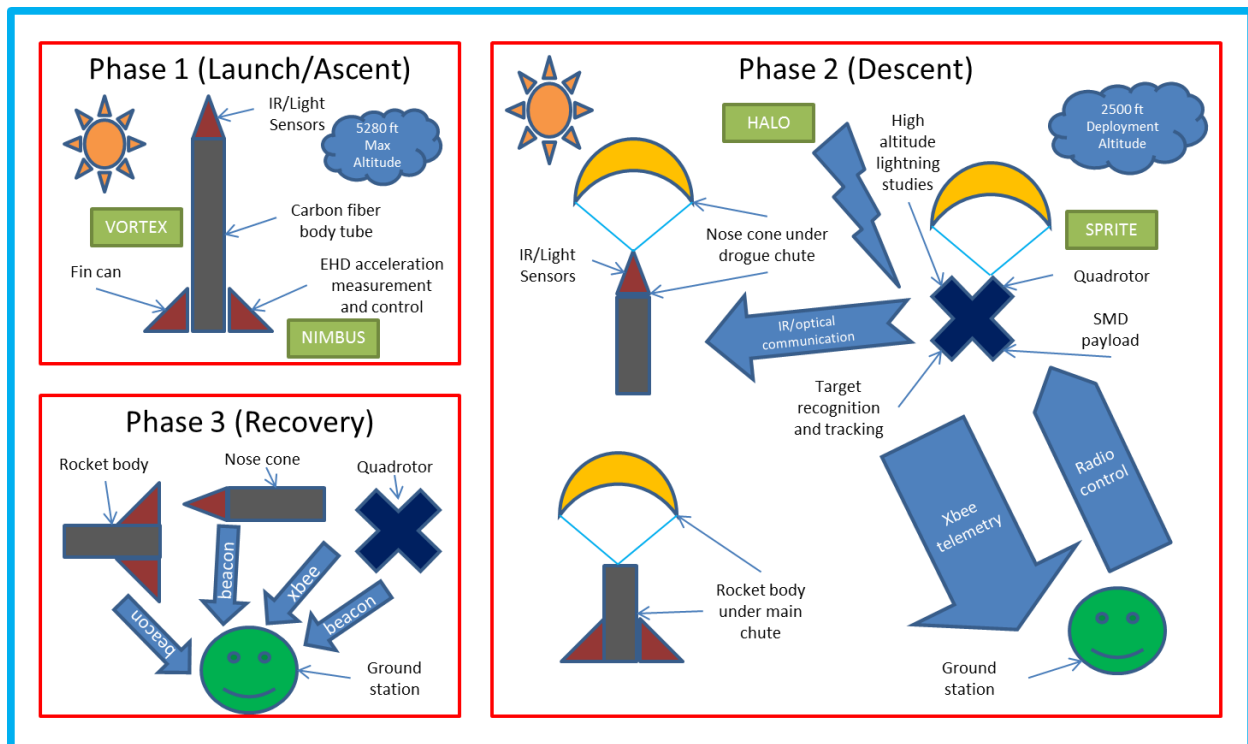


Figure 33 Payload overview diagram

5.1.10.1 PRE-LAUNCH

Pre-launch operations are outline in the vehicle pre-launch procedures section.

5.1.10.2 LAUNCH

The neither the rocket nor the payload will transmit data to the ground station or receive commands from the ground station during launch. Sabot deployment is outlined in the launch vehicle deployment section.

5.1.10.3 DECENT

When the sabot is released from the rocket, the ground crew will wait for permission from the range safety officer to deploy the quadrotor. When the ground crew triggers a switch on their radio transmitter, a solenoid will release the spring-loaded arms of the quadrotor, separating the sabot from the craft. The quadrotor will then descend under its recovery chute until the range officer gives the ground station permission to remotely turn on the quadrotor propulsion system and disconnect the recovery chute.

Immediately after sabot separation HALO and SMD payload sensors on the craft will begin to collect data. This data is saved on a solid state SD memory card and is transmitted via an optical communication link to the nose cone which is descending under the drogue chute. The nose cone which contains its own set of IR sensors, records this data to a solid state SD memory card. The quadrotor's autopilot and onboard cameras system for object tracking will position the craft such that it maintains a line of sight with the nose cone and the ground station. The ground station will have full control of the quadrotor at all times due to radio controlled actuators on the quadrotor and a video/telemetry downlink. This allows the team to manually override the control algorithms. At the end of the descent the quadrotor will land near the rocket or a predetermined safe location depending on landing conditions.

The quadrotor will carry a freefall detector and reserve parachute system. If at any point during decent the freefall detector reads a freefall state for longer than 5 seconds, or loses radio signal for more than 5 seconds, it will deploy a reserve parachute. This redundancy will limit the damage to the payload and the risk to ground personnel in the event of an unexpected failure of the quadrotor.

5.1.10.4 RECOVERY

During recovery the rocket body, nose cone, and quadrotor will all emit a beacon signal via a Beeline tracker (one Beeline tracker for each independent section). The quadrotor will also continue to transmit HALO and SMD payload data including images and video.

5.1.11 OVERVIEW OF DATA ACQUISITION PLAN

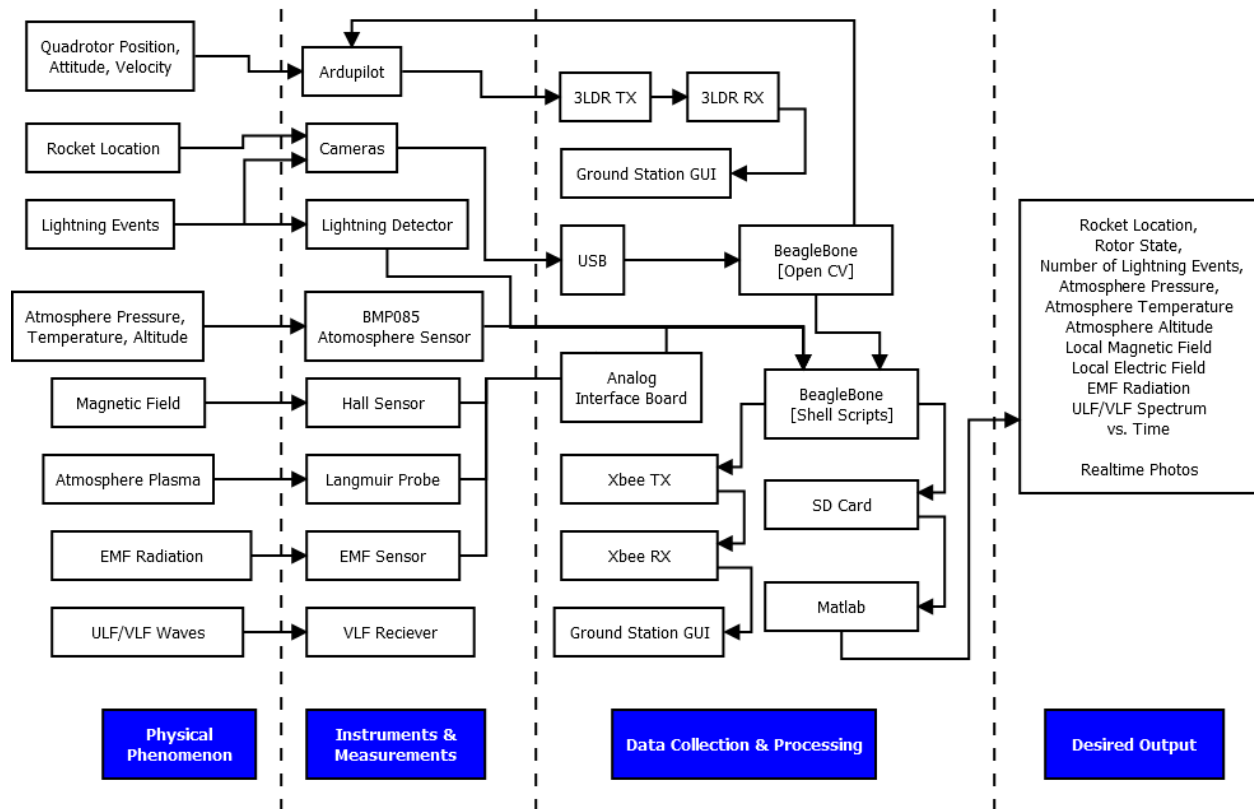


Figure 34 Conceptual Flow of Data

Figure 34 highlights how data in its final plotted form is acquired starting from the measured physical states. Specifically, these measured physical states are the magnetic field, plasma (ion and electron energy and density), EMF radiation, ULF/VLF radiation, the number of lightning events, atmospheric pressure, atmospheric temperature, relative rocket location, and quadrotor state (position, attitude, and velocity). Data on the physical properties of magnetic field strength, local plasma properties, EMF radiation, and ULF/VLF spectrum is collected by the analog sensors, as described in section 5.1.13.2.1.1.1. The voltages and currents are sent through an amplification and current sensing circuit. The amplification subunit consists of a standard Texas Instrument operational amplifier with a gain of at 10 (typically INA122).

The current sensing subunit is used to sample the current from the Langmuir probe to a measurable voltage. It consists of a 400 ohm sensing resistor and a current sensing operational amplifier (Analog Devices ADM4073). These voltages are then recorded by the Beaglebone. Using a shell script to access the linux I/O ports the voltages are collected and using the equations derived from the calibration procedures the voltages are converted to their respective physical values: particle energy in units of electron volts, magnetic field in units of tesla, and particle density in units of particles per cubic meter. All of the collected data points and photos are then time-stamped, saved to the SD, and transmitted to the ground via an Xbee. Data from 5 cameras is transmitted to the single USB port on the Beaglebone through an USB-hub. This data is sampled by OpenCV to determine the relative rocket location. This result is then sent to the Ardupilot and transmitted to the ground via the Xbee transmitter. The Ardupilot keeps track of the quadrotor state and transmits this data to the ground via a 3LDR transmitter. The received data is then plotted using Matlab and/or display in real-time using a GUI.

5.1.11.1 GRAPHICAL USER INTERFACE DESCRIPTION

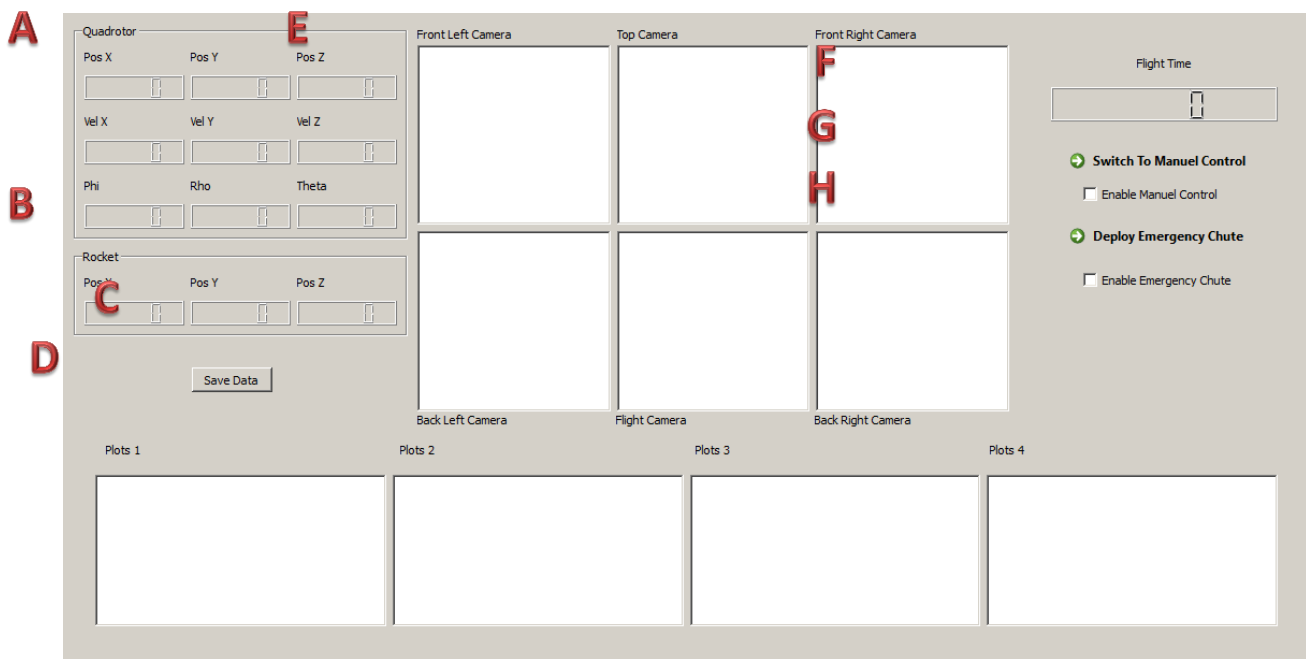


Figure 35 Ground Station User Interface

1. Quadrotor state

2. Rocket state
3. Save data function
4. Real-time science data plots
5. Real-time images from cameras mounted on rotorcraft
6. Time since quadrotor deployment
7. Manuel control switch
8. Emergency parachute deploy switch

5.1.12 OVERVIEW: SPRITE

Specialized Rotorcraft for IR Communications, Object Tracking and On-board Experiments

5.1.12.1 MOTIVATION

Please see section 5.1.1.

5.1.12.2 CONCEPT OF OPERATIONS

The Quadrotor will be packaged within a sabot inside the rocket. About 20 minutes before launch, the quadrotor avionics will be powered on, and will remain in a low-power dormant state. During decent, the sabot containing the quadrotor will be deployed from the rocket at an altitude of 2000ft.

The quadrotor will then wait for a signal indicating permission form the range officer to open the sabot. When the signal is received, springs within the quadrotor will push the sabot apart, and the quadrotor main parachute, packed in the sabot with the quadrotor, will unfold. The quadrotor will then descend suspended from the quadrotor main parachute. The quadrotor avionics will begin to broadcast telemetry data back to the ground station, and will continue to do so until turned off. The quadrotor will then activate its reserve parachute system. From this point on, a five-second fall or five second radio signal loss will cause the reserve parachutes to be deployed.

Next, the quadrotor will perform a series of checks to ensure that its arms have unfolded property, and that its motors, power supply, and sensors are in working order. If these checks fail, the quadrotor will remain on its main parachute for the entire decent. These checks will take approximately 1 second.

The quadrotor will then wait for a signal indicating that the range officer has given permission to detach from the quadrotor main parachute. When this signal is received

the quadrotor will cut away its main parachute, fall for 1 second to move itself away from the parachute, and will begin to fly under power.

The quadrotor will perform its flight mission, during which it will track and follow the rocket nosecone. At any time during the flight mission, the ground station crew may assume remote manual control of the quadrotor's flight, or may remotely deploy the reserve parachute. During the flight mission, the science payload will perform data collection and transmit data back to the ground station. The flight mission will last approximately 10 minutes.

After the flight mission is concluded, the quadrotor will enter a landing sequence. The quadrotor's autopilot will use GPS and barometer altitude data for the initial landing approach, and will use more accurate sonar data for the final approach once within 10 meters of the ground. Landing will be confirmed by contact sensors in the landing gear.

After landing, the recovery team will use GPS data transmitted by the quadrotor to locate and recover it. The team plans to recover the quadrotor within 20 minutes of landing.

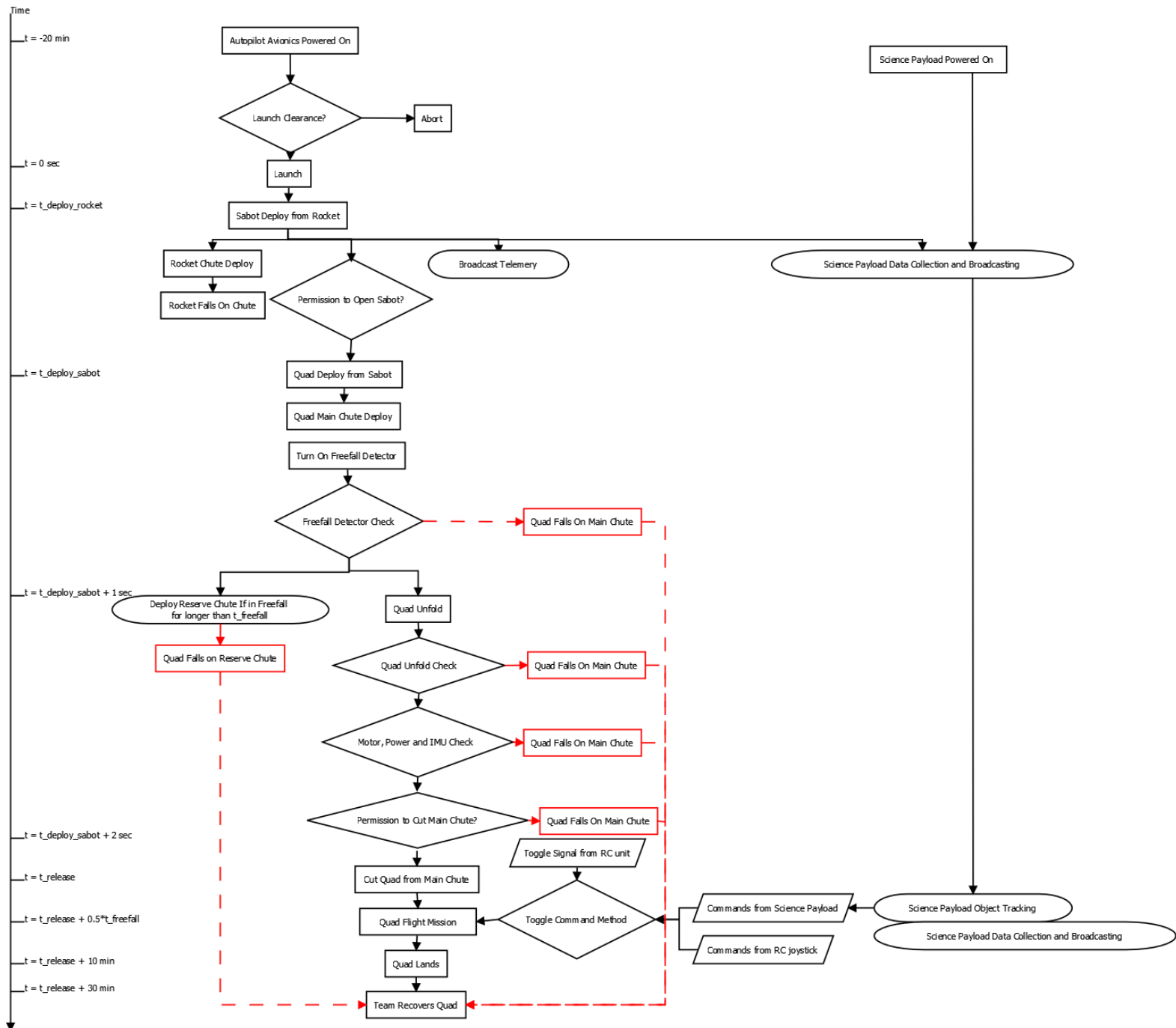


Figure 36 Concept of Operations Diagram - Time is shown on the downwards axis. Diamonds represent decisions, rectangles represent processes, rounded rectangles represent looping or continuous processes, and slanted parallelograms represent inputs. The black path indicates the intended operation; the dashed red paths indicate controlled failure modes.

5.1.12.3 STRUCTURES

The quadrotor will be housed inside a sabot in the body tube of the rocket. In order to fit within the confined space of the body tube, the vehicle will be designed with foldable arms which allow it to be compacted prior to flight. When the craft leaves the sabot, internal springs will open and lock into place the each of the four arms to prepare the vehicle for flight. The sabot will be made from a phenolic tube and filled with foam. Not only is this easy to assemble, it also gives the quadrotor shock protection and allows the craft to use the force of its extending arms to push apart the sabot. To ensure that all parts are recovered, the sabot sections will remain tethered to the rocket nose cone after quadrotor deployment.

The physical and mechanical properties for the quadrotor are defined based on rocket body size and mass constraints. The baseline design of the vehicle contains 4 motors, ESCs, arms, and non-folding propellers. As the quadrotor must fit within a 6 inch diameter, 3.5 foot long tube, the maximum arm length is 1.5 feet with a 6 inch buffer on each end. The arms and SPRITE components and science payloads are attached to the thick 5 inch diagonal square quadrotor base. This results in a maximum propeller diameter of about 1.5 foot which meets our design requirements. In terms of space, the limiting factor is the 6 inch tube diameter. After considering baffle, padding, and the tube case, the usable diameter reduces to 5.75 inches or a 2.875 inch radius. Assuming the propeller, motor shaft, and arm take up an inch of radius, then that leaves 1.875 inch (the reduces to 1 inch after wires are considered) when the arms are folded down. A direct drive brushless 830W Turnigy SK3 Motor with a 42 millimeter diameter was chosen as it provides suitable thrust for its size. The motor will be positioned below the propeller. The static thrust for the motor was calculated using www.ecalc.ch (good for static thrust with an accuracy of about +/-10%); this resulted in a thrust of 6.5 lbs per motor with a 7 minute flight time (with 4S, 6Ah LiPo per motor). This leads to a conservative weight of 24 lbs; with 50% margin this gives a maximum quadrotor weight, including payloads, of approximately 12 lbs.

The quadrotor will be built around an arm mounting block. The arm mounting block will confine the arms so that they rotate about a pivot in the horizontal plane of the quadrotor, and will contain a locking mechanism which will hold the arms in place once opened. The locking mechanism will consist of a button spring on each arm which will pop up into a hole in the arm mounting block when the arm is fully unfolded. Springs in the arm mounting block will push the arms into the unfolded and locked position when the arms are released from the folded configuration.

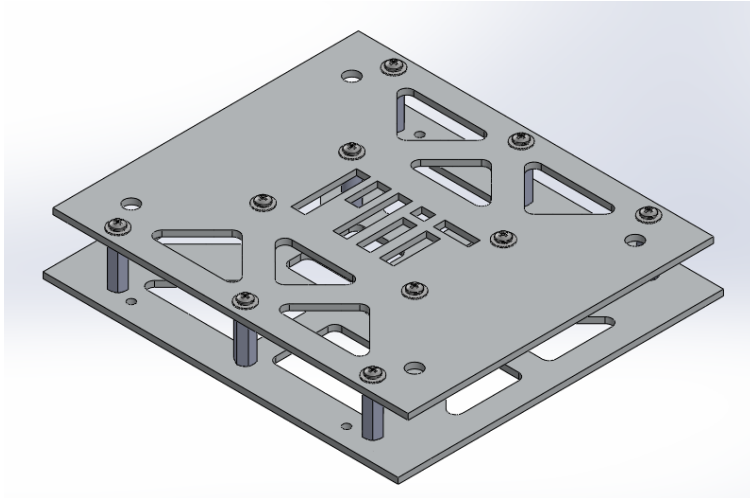


Figure 37 The Arm Mounting Block

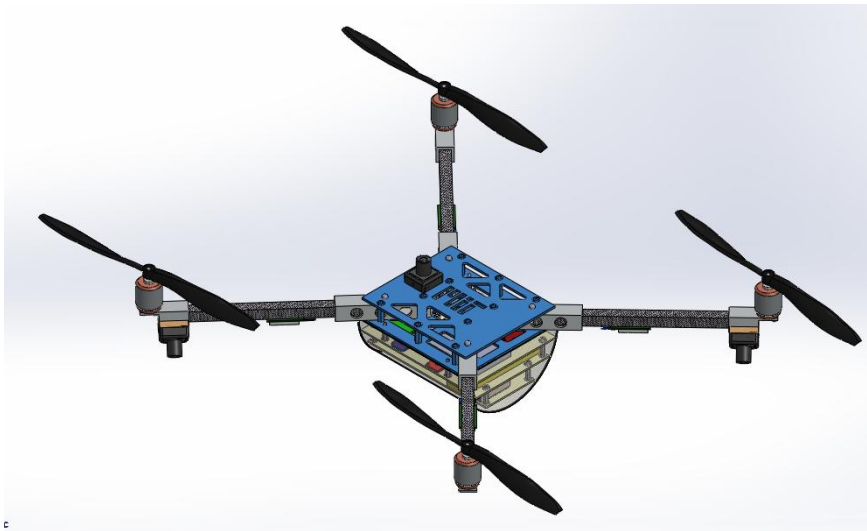


Figure 38 The Location of the Arm Mounting Block (highlighted in blue) within the quadrotor assembly

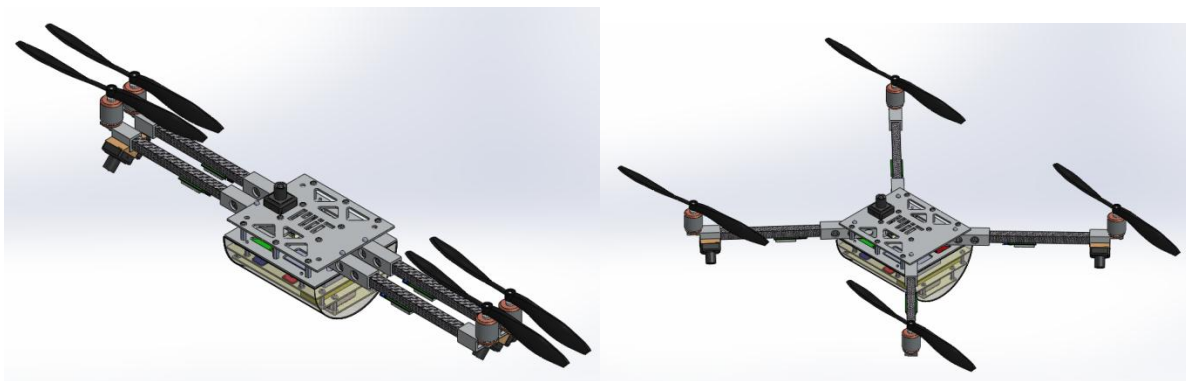


Figure 39 The Folded and Unfolded configurations of the quadrotor arms

The payload avionics and batteries will reside in trays suspended below arm mounting block. The trays will be made from G10 glass cloth laminate, which was selected for its light weight and high electrical resistivity (as opposed to carbon fiber). The heavier components, the batteries, will be mounded on lower trays to lower the quadrotor's center of gravity, and thereby improve its stability. The avionics trays will be covered in a sleeve made from Dacron[®] (polyethylene terephthalate cloth) to prevent debris from entering the trays and damaging the avionics.

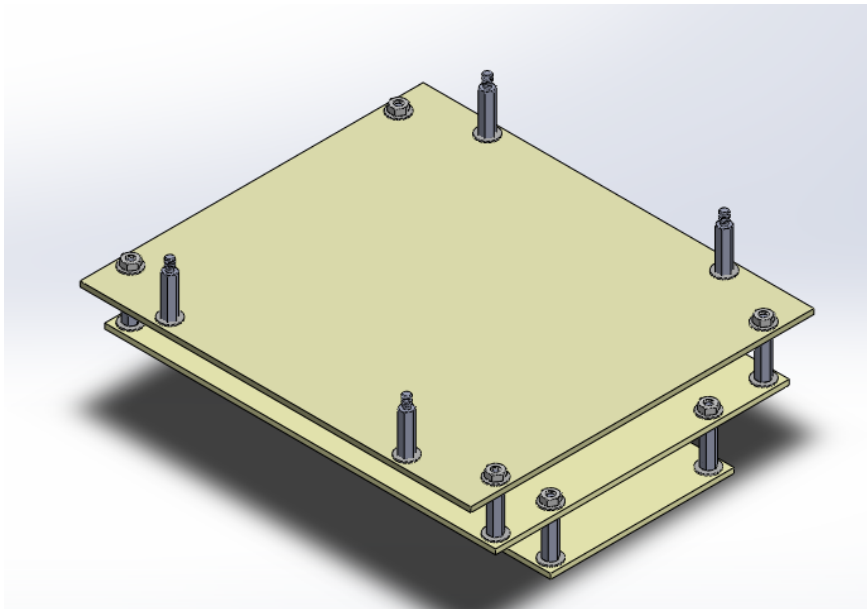


Figure 40 The Avionics Trays

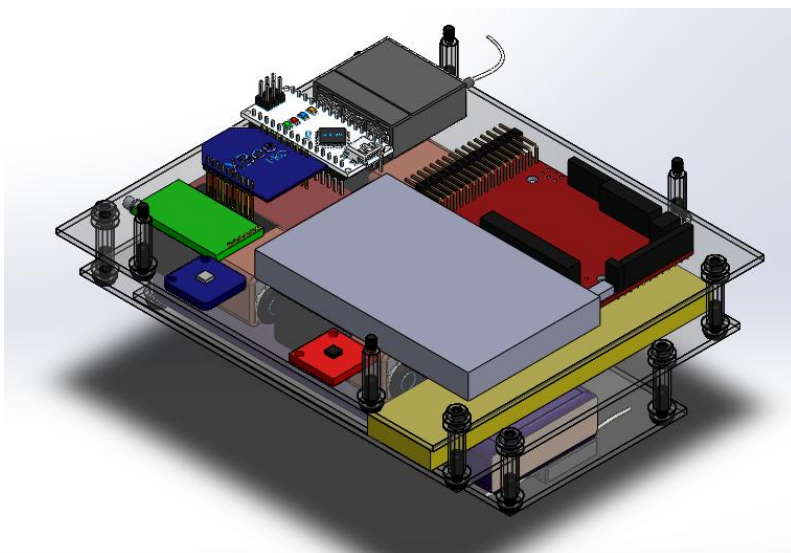


Figure 41 The avionics trays (transparent) populated with the quadrotor's avionics and batteries

Several avionics components will be mounted outside of the avionics tray. Two stereo camera pairs are mounted on the ends of the arms. This mounting gives a long stereo interaxial distance, which improves 3D vision at a distance. There will also be an upward-facing camera mounted on the top of the arm mounting block. The electronic speed controllers for the motors will be mounted on the underside of the arms, so that they will have more airflow for cooling, and so they will not heat other avionics.

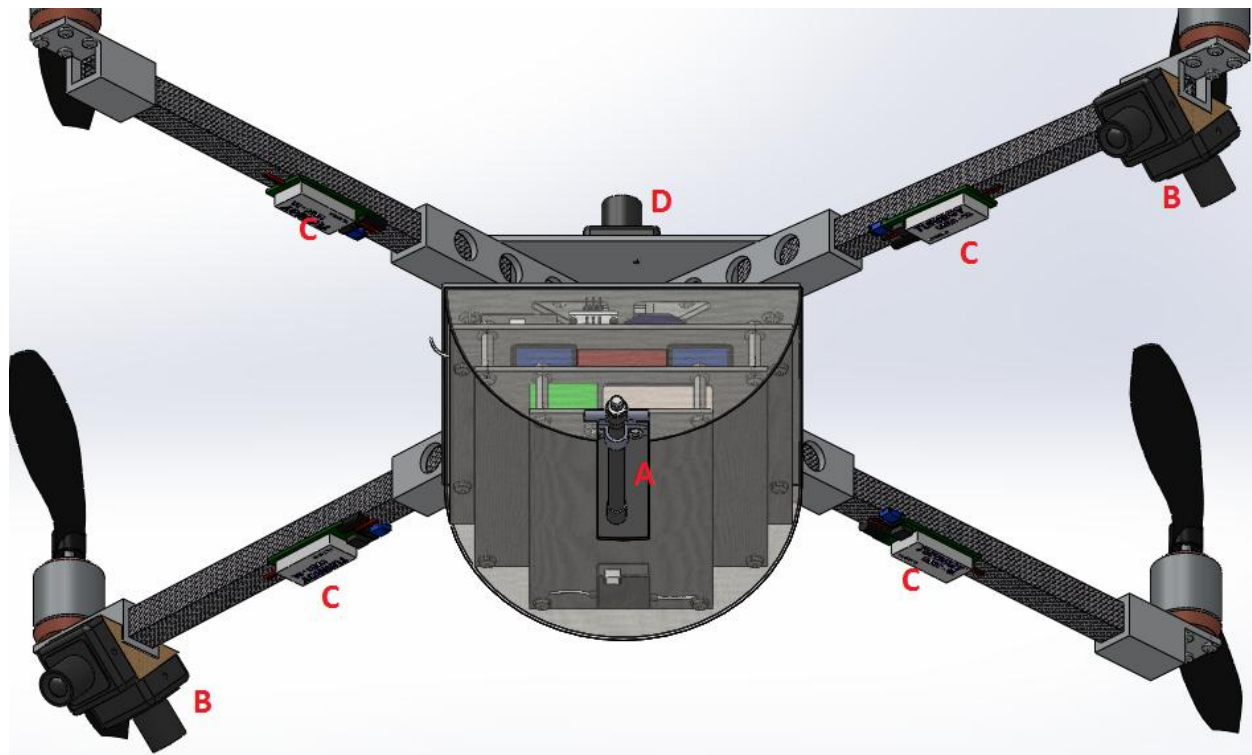


Figure 42 The Avionics tray mounted beneath the arm mounting block, covered by its Dacron® cover (transparent). The cover has a slit cut out of it for the natural radio receiver antenna (A). This view also shows the two stereo camera pairs (B), the electronic speed controllers (C), and the upward-facing camera (D).

5.1.12.3.1 FABRICATION

As the arm mounting block will need to fit precisely about the root of the arms for folding and unfolding, these components will be made from aluminum, which can be more precisely manufactured than composites. The arm mounting block will be made from two plates of aluminum held apart by standoffs. Calculations will be performed to determine the minimum thickness aluminum plate which can safely support the

expected loads. Patterns will be waterjet cut out of the aluminum plates to reduce mass. Then, holes will be drilled into the plates for mounting standoffs.

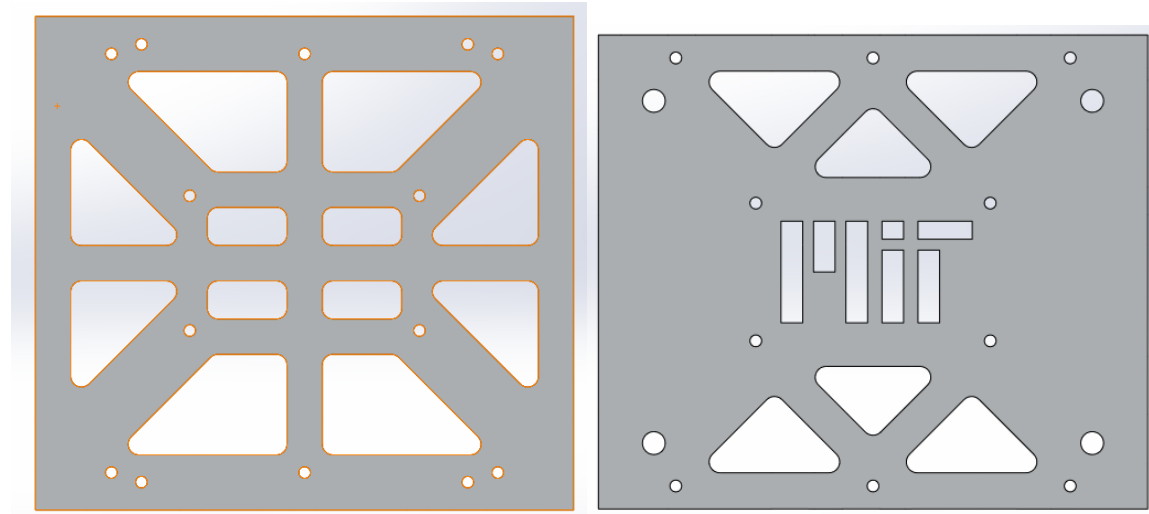


Figure 43 The bottom (left) and top (right) aluminum plates of the arm mounting block

The ends of the arms, where other components must be mounted, will be made from aluminum square rod. Holes will be cut from the aluminum components to reduce mass. The middle section of each arm will be made from carbon fiber composite in order to reduce mass. Four identical arms will be fabricated.

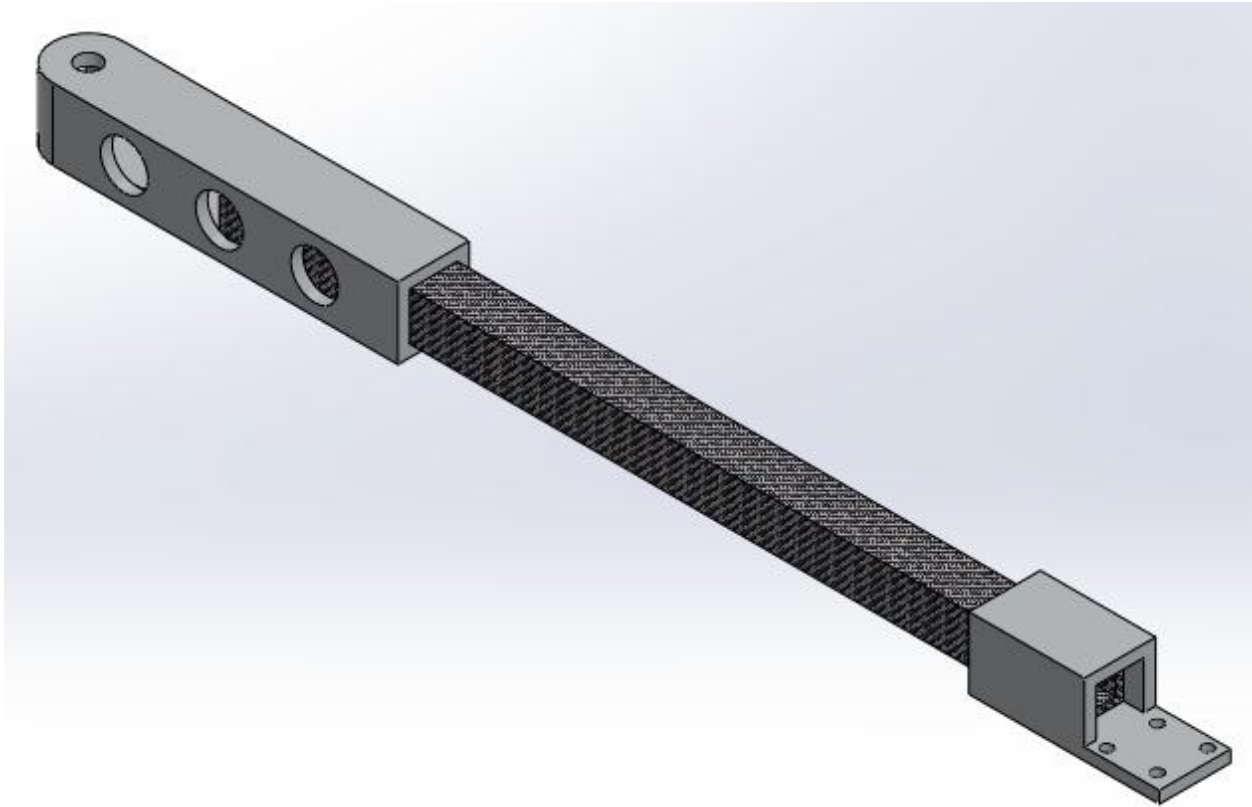


Figure 44 One of four arms, made from aluminum and carbon fiber.

Then the arms will be assembled into the arm mounting block. First, the bottom plate of the arm mounting block will be populated with standoffs (Assembly Step 1). The four rounded standoffs in the middle of the plate will be pivots for the arms. Second, the arms will be slipped onto their pivots (Assembly Step 2). Third, the top plate of the arm mounting block will be screwed to the standoffs, sandwiching the arms in place (Assembly Step 3).

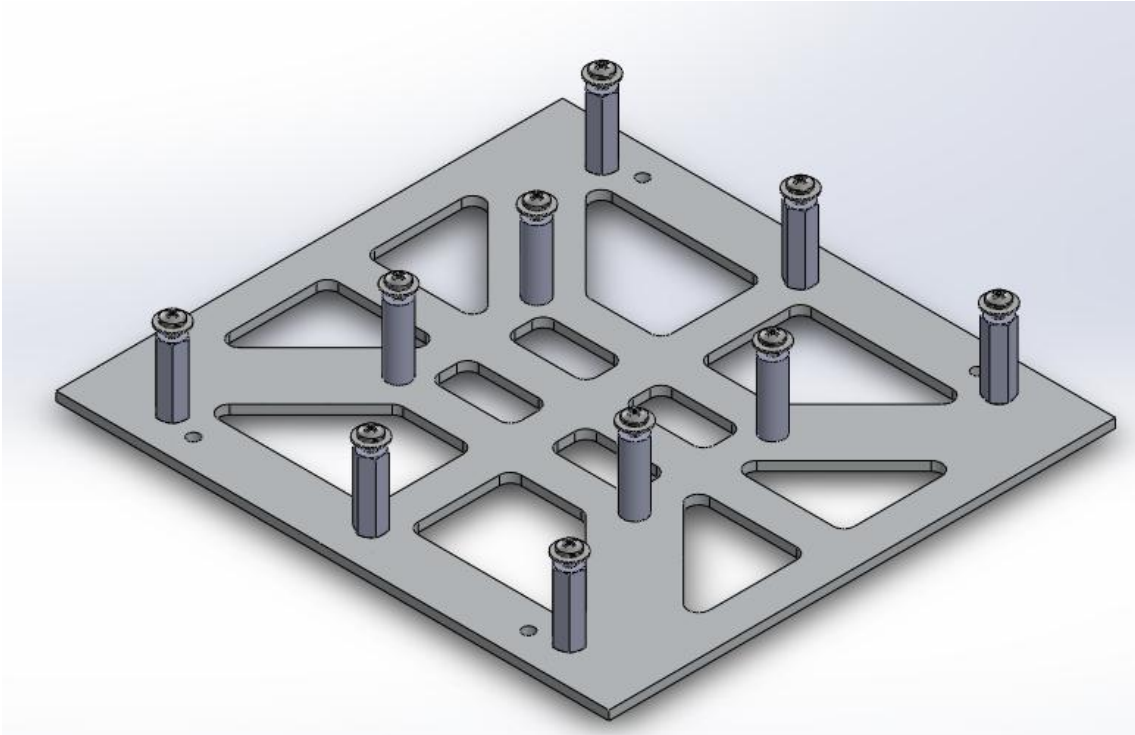


Figure 45 Assembly Step 1

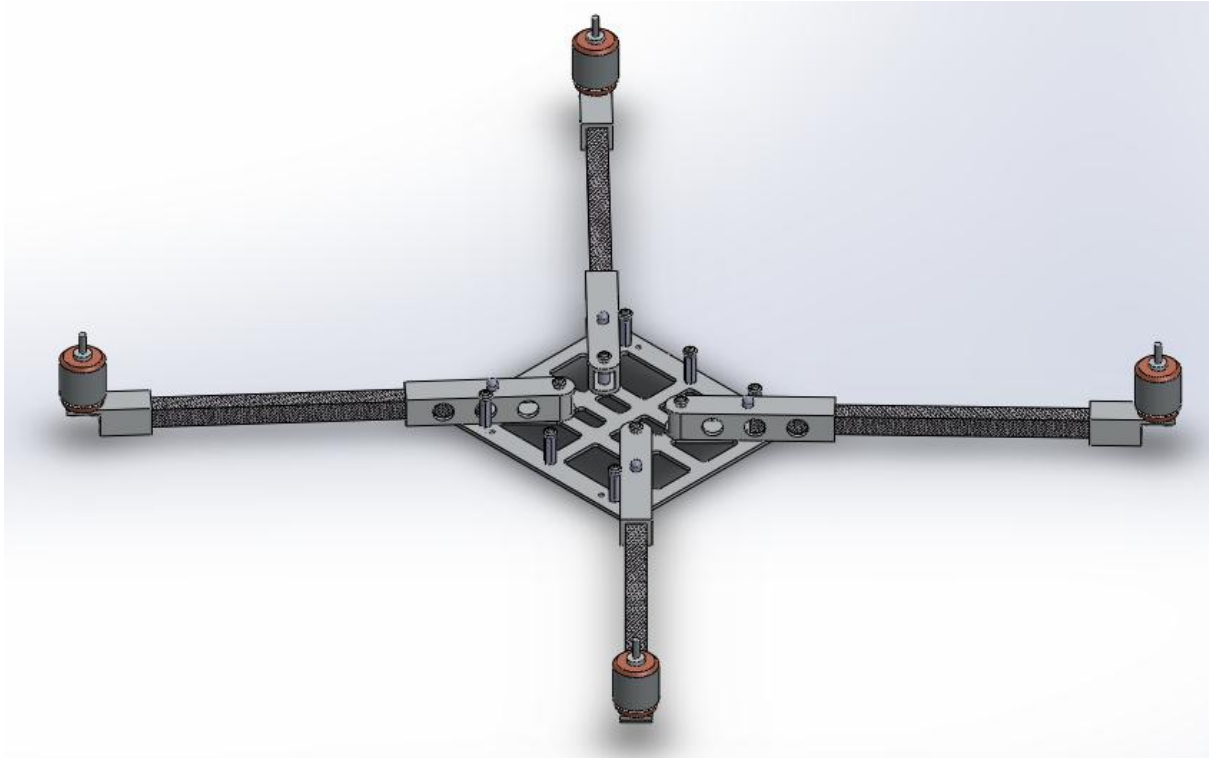


Figure 46 - Assembly Step 2

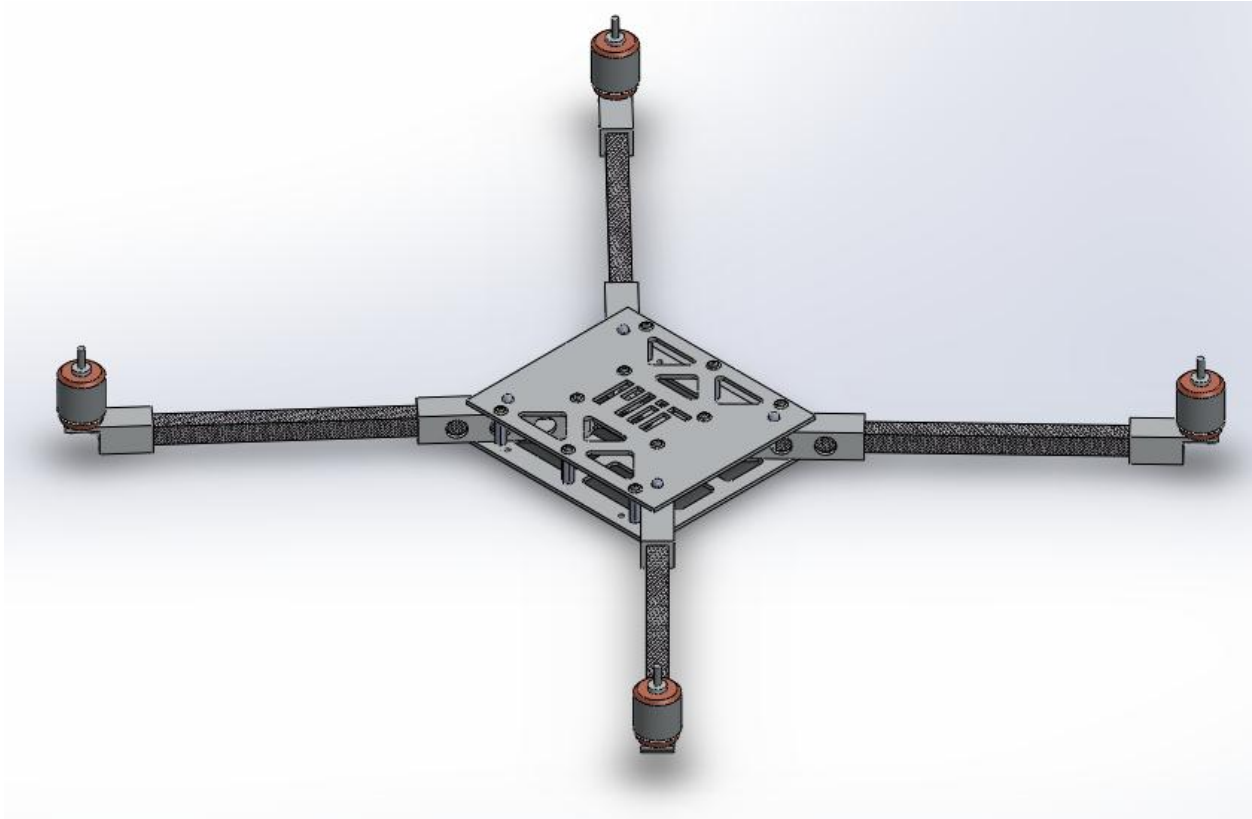


Figure 47 - Assembly Step 3

Next, the avionics trays will be cut from G10, and holes will be drilled for mounting the standoff which will hold the trays to each other. The trays will be stacked on top of each other, held together by standoffs (Assembly Step 4). The avionics will then be mounted onto the trays, and electrical wiring connections will be made and tested (Assembly Step 5).

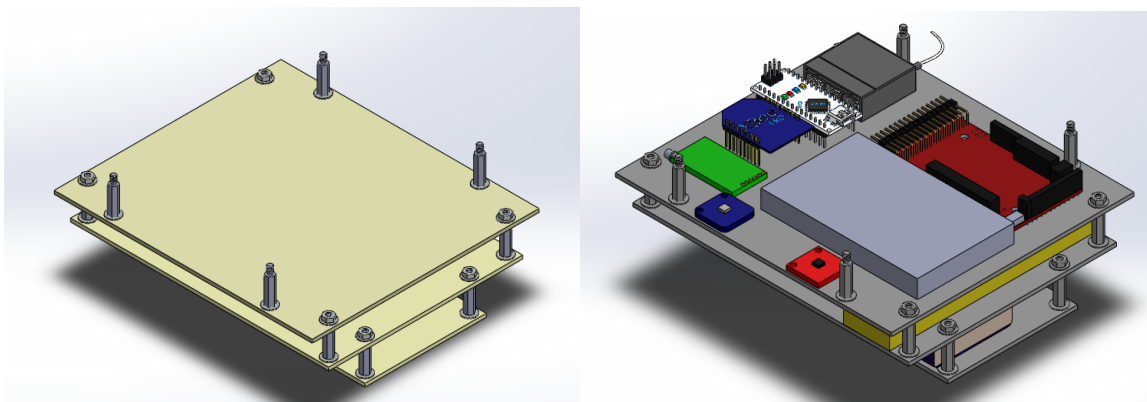


Figure 48 - Assembly Steps 4 (left) and 5 (right)

The avionics trays will then be mounted on the underside of the arm mounting block (Assembly Step 6). Cameras and electronic speed controllers will be mounted on the arms of the quadrotor, and electrical wiring connections will be made to these components (Assembly Step 7). The avionics system will then be tested to ensure that all components have been properly connected.

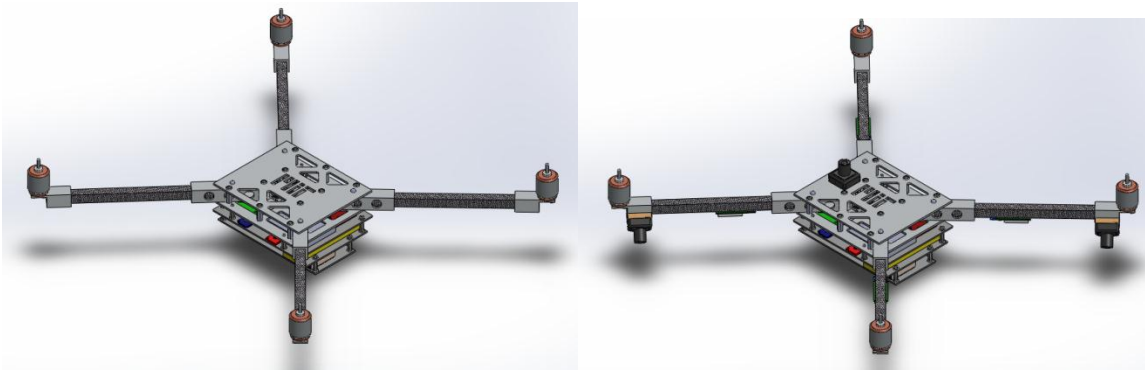


Figure 49 - Assembly Steps 6 (left) and 7 (right)

The cover will then be put over the avionics trays. The cover will be held onto the airframe with Velcro®, so that it may be easily removed if access is needed to the avionics (Assembly Step 8). Finally the propeller blades will be mounted on the motors. This is done last to minimize the risk of injury from a propeller accidentally spinning up during assembly.



Figure 50 - Assembly Step 8

5.1.12.4 AVIONICS

5.1.12.4.1 CONTROL ARCHITECTURE

Control of the quadrotor during its flight mission will be performed by ArduCopter, an open source autopilot for multi-rotor aircraft. ArduCopter provides stabilization and control, GPS navigation, and several autopilot routines such as flying to a GPS waypoint, and landing. ArduCopter has an extensive online user community which has documented and tested the system.

ArduCopter uses an 3-axis accelerometer and gyroscope to estimate the attitude and rotation rates of the quadrotor. Particularly, ArduCopter uses a nonlinear complementary filter (NCF) on the $SO(3)$ group to fuse the accelerometer and gyroscope data into an attitude estimate and attitude error estimate.

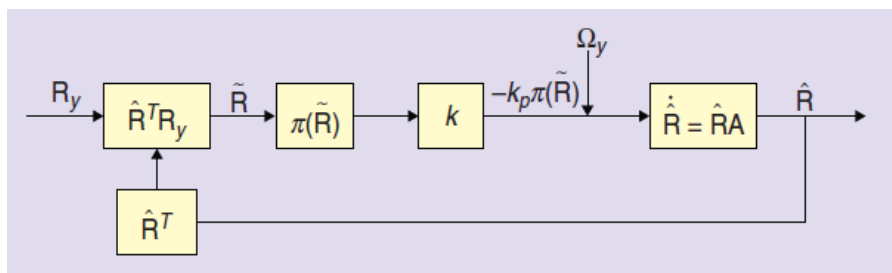


Figure 51 - Complementary Filter Diagram. R is a rotation matrix representing the attitude. Source: Lim et al, IEEE ROBOTICS & AUTOMATION.

ArduCopter implements a PI + P controller to stabilize the attitude of the quadrotor. The controller takes the NCF attitude data as input, and uses a 3 + 1 anti-windup gain on each axis.

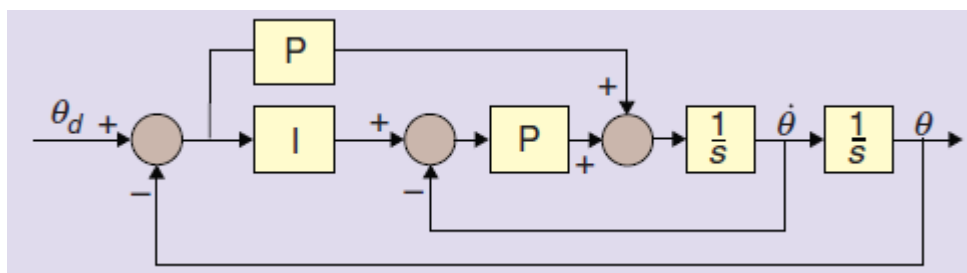


Figure 52 – ArduCopter PI + P Controller Diagram. Source: Lim et al, IEEE ROBOTICS & AUTOMATION.

5.1.12.4.2 GUIDANCE AND CONTROL

Navigation will be provided by a GPS receiver and magnetometer, which will give the quadrotor's position and orientation relative to the earth. Further, a barometer will provide an additional measure of altitude. The stereo vision system will track the position of the rocket nosecone relative to the quadrotor, and a guidance module will plan a path for the quadrotor to follow to keep the nosecone within its line of sight. The guidance module will then calculate a desired attitude and transmit this value to the ArduCopter controller. The controller will then actuate the motors of the quadrotor to achieve the desired attitude.

Once the quadrotor is below a certain altitude, the provided GPS waypoint feature of the ArduCopter autopilot will be used to fly the quadrotor to coordinates above a pre-determined safe landing area. The autopilot may also be configured to select and travel to the closest of several pre-determined landing areas. Once the quadrotor has

reached the waypoint above the landing area, the provided landing sequence feature of the ArduCopter autopilot will be used to land the quadrotor. At about 10 meters above the ground, relative altitude data from a sonar rangefinder will become available to augment the GPS and barometer altitude readings for a more precise landing.

5.1.12.4.3 COMMAND AND DATA HANDLING

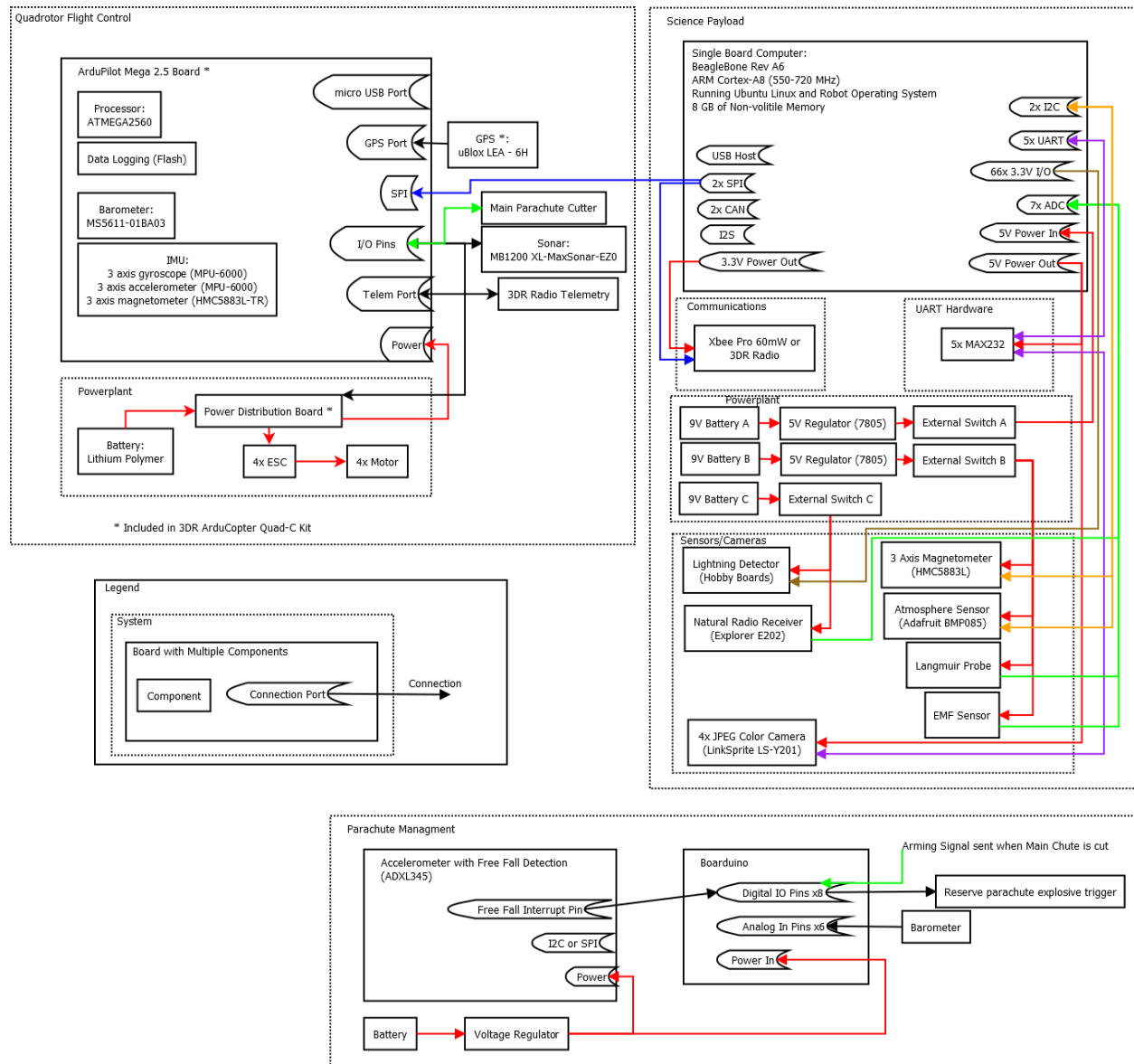


Figure 53 High-Level Avionics Interface Diagram

5.1.12.4.3.1 HARDWARE

The object tracking system consists of an array of four 120 degree wide JPEG cameras. Three of the cameras point outward with 120 degrees between them in a triangle configuration. Each of these cameras is also angled up 45 degrees from the base of the quadrotor. The fourth camera is located on the bottom of the vehicle and points downward perpendicular to the quadrotor base. Image data recording, processing, and object tracking occurs on the BeagleBone which interfaces directly with the cameras via 4 USB2.0 connectors. The BeagleBone will run standard an OpenCV image processing program for shape/contour recognition on a Linux OS. Image data and object tracking information is saved on the BeagleBone SD card memory and sent to quadrotor CPU.

The optical/IR communication system uses a simple arrangement of high intensity visual and infrared light emitting diodes as the transmitters and precision light and infrared sensors. After calibration and the application of low noise filters, the system will be able to detect quick pulses of visual/IR light. These analog pulses, outputted by the digital out (DIO) pins of the quadrotor/nose cone Arduinos, correspond to a high or low binary signal. The timing of an analog signal is measured by the analog pins of the quadrotor/nose cone Arduinos and is converted back into a binary signal. As both the nose cone and quadrotor have both visual/IR detectors and transmitters, digital information can be shared between them via these analog light pulses.

5.1.12.4.3.1.1 HARDWARE LIST

For a more complete list please see section 9.2.

Table 28 List of Quadrotor Flight Electronics

Name	Description	Quantity	Cost
XBee Pro 60mW	Telecommand RX/TX	1	37.95
3DR Radio	Telecommand RX/TX	1	74.99
BeagleBone	Quadrotor secondary CPU	1	89.95
Ardupilot	Quadrotor primary CPU	1	100.95
Power MOSFETS	IRF8714PbF	4	1.00
LiPo Battery	4S 6Ah	2	39.95
Turnigy Aerodrive SK3	4240-620kv Brushless Outrunner Motor	4	33.28
Turnigy Plush 6A	Speed Controller	4	7.98
Spektrum DX5	5Ch Transmitter and Receiver	1	99.00
Total Cost			485.05

5.1.12.4.3.1.2 REDUNDANCY AND EMERGENCY PARACHUTE

As the quadrotor will be flying at high altitudes, an unexpected failure would cause the quadrotor to fall with a kinetic energy exceeding the USLI requirements. To mitigate this risk, an emergency parachute will deploy from the quadrotor in the event of its entering free fall or losing radio signal.

The blades of a rotorcraft present a significant challenge for deploying a parachute. Several approaches exist to avoid tangling the parachute in the blades. First, the parachute may be deployed from the center of the quadrotor, which the blades do not pass over. However, the parachute is still close to the blades during deployment, so the parachute could easily become tangled if the quadrotor is not level and stable when the parachute deploys. Second, the blades can be removed from the rotorcraft prior to deploying the parachute system. This is the approach taken by the Kamov Ka-50 attack helicopter, in which explosive bolts detach the blades from the craft before the ejection seat and parachute deploy. However, building such a system would introduce great expense, weight, and mechanical complexity into our design. Third, a small cannon may be used to launch the parachute several meters away from the craft on a long shock cord. The parachute then unfolds far from the rotors, minimizing the risk of tangling. Two cannons mounted on opposite ends of the craft ensure that one parachute will always deploy upwards if the craft is tumbling. This design has been successfully used on UAV rotorcraft, such as Aleksey Zaitsevsky's Ecilop [<http://myresearch.it/blog/parachute/parachute.phtml>], and Photo Higher's Ballistic Parachute Emergency Recovery System. [<http://www.photohigher.co.nz/products/flight-control-systems/ballistic-parachute-emergency-recovery-system/>].



Figure 54 - The Ecilop deploying its parachute (left), and landing under parachutes (right). Images by Aleksey Zuitsevsky.

As the cannon recovery system reduces tangling risk while maintaining mechanical simplicity, and has been successfully implemented on UAV rotocraft, it will be used as the design for our system.

Parachute Sizing

To meet USLI's safety requirements, the quadrotor must fall with less than 75 lbf ft [102 J] of kinetic energy. Assuming a 6.6 lb [3 kg] quadrotor, the reserve parachute system must slow the terminal velocity to 26 ft/s [8 m/s]. Assuming a parachute with a coefficient of drag of 0.7, 11 ft² [1 m²] of parachute area is required. Each of the two parachutes will have this area, so that the quadrotor will still fall with an acceptable kinetic energy if only one parachute deploys successfully. 48 in diameter parachutes are the smallest standard size having at least 11 ft² [1 m²] of parachute area. Manufacturers list 48 in nylon parachutes as having a mass of 0.22 – 0.29 lbs [100 -130 g].

Design

The cannon will be made from a carbon-fiber tube with a circular aluminum plate at one end. Mounting hardware will attach the aluminum plate to the arm of the quadrotor.

The cannon must be made as light as possible while not failing under the pressure load from the explosive charge. Thinner walls on the tube and plate will reduce the mass of the system, but too-thin walls will rupture. To determine the optimal thickness, the load placed on the cannon by the explosion must be known. A Forward-Euler simulation was used to model the pressure in the cannon as the projectile moves down the barrel. The model assumes that the combustion gasses behave as an ideal gas.

Using a 2 in ID, 6 in [15 cm] long carbon fiber tube from DragonPlate, and assuming a 0.22 lb [100 g] parachute, and a 2 g black powder charge, the simulation indicates a maximum pressure of 1260 psi [8,700,000 Pa]. The simulation predicts that the exit velocity will be 40 ft/s [12 m/s], which should be sufficient to get the parachute clear of the rotors. Simulation graphs are shown below for 2 g and 4 g black powder charges. The simulation predicts that a 1 g charge will be insufficient to eject the parachute from the tube. .

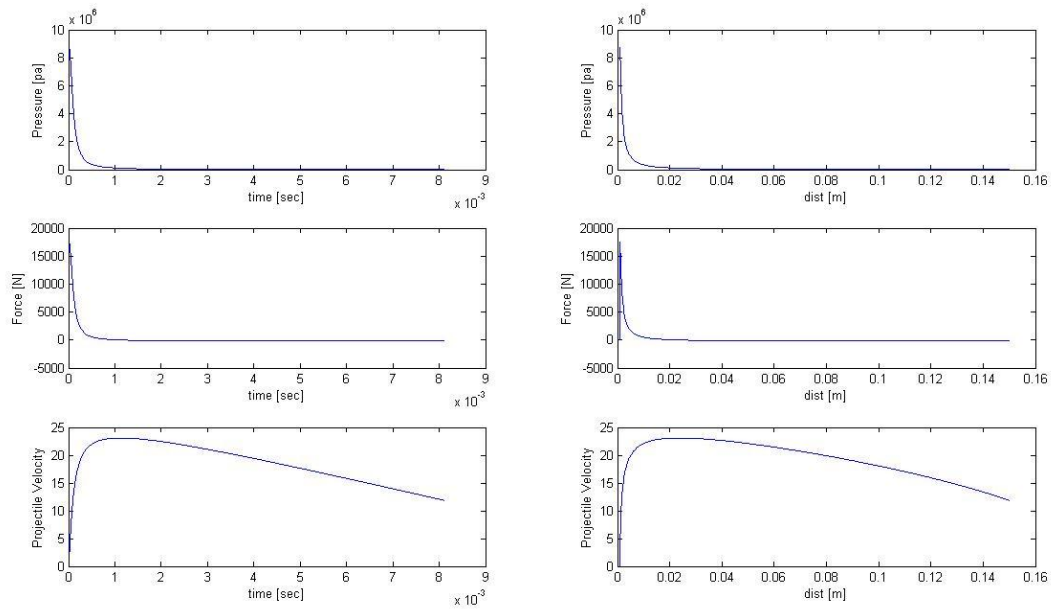


Figure 55 - Simulated pressure, force and projectile velocity from a 2 gram black powder charge

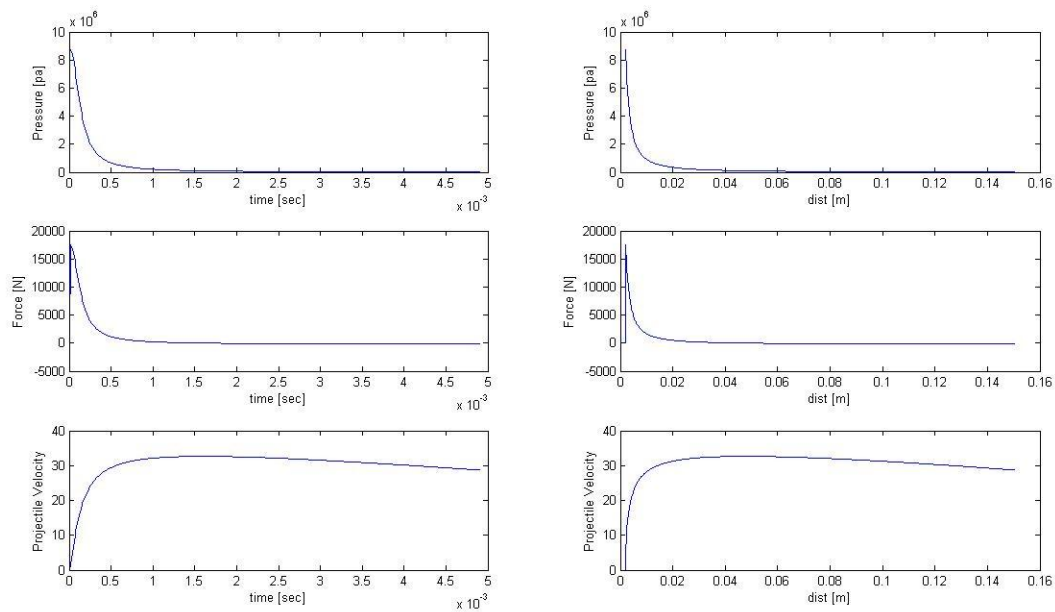


Figure 56 - Simulated pressure, force and projectile velocity from a 4 gram black powder charge

Using the maximum pressure predicted by the simulation, we can calculate the required thickness of plate. The equation for maximum radial stress in a circular plate with clamped edges and a uniform pressure load is

$$\sigma_{rr} = \frac{3 p a^2}{4 H^2}$$

Where p is the pressure, a is the radius of the circle, and H is the thickness of the plate. To provide a safety margin, we will solve for a thickness such that the maximum stress does not exceed 10% of the yield strength of the plate material (241 MPa for 6061-T6 Aluminum). The equation yields a plate thickness of 0.51 in [13 mm].

Using the hoop stress equation,

$$\sigma_{hoop} = \frac{\text{pressure} \times \text{radius}}{\text{wall thickness}}$$

Using the maximum predicted pressure and the lower bound of the wall thickness range (0.030 in), we find a hoop stress of 40,000 psi [276 Mpa]. This is 6.3% of the yield strength listed by DragonPlate, so the tube will be able to withstand the pressure of the parachute ejection charge.

Manufacturing and Assembly

Two mounting brackets will be water-jet cut from 1/32 in Aluminum sheet and folded into shape. The tabs on the two brackets will be folded in opposite directions.

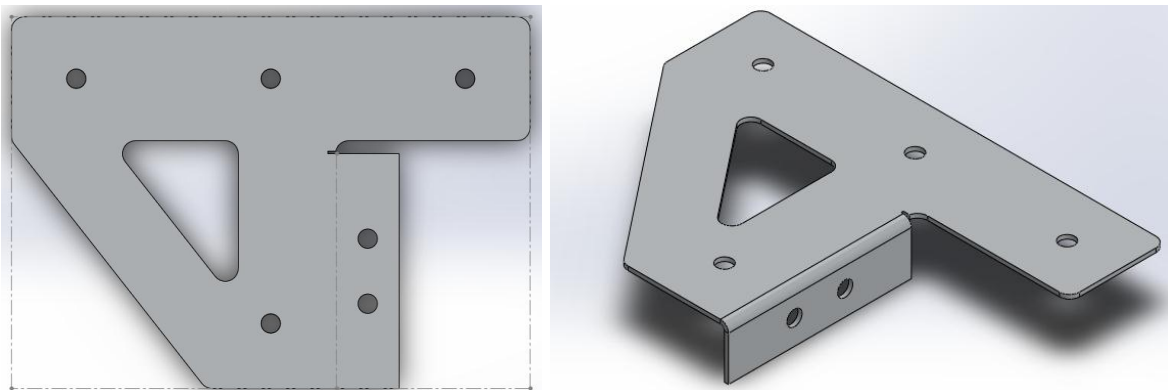


Figure 57 - One of the mounting brackets: flat pattern (left), and folded (right).

A 2 in diameter disk will be water-jet cut from 0.5 in [13 mm] thick aluminum. This disk will be the back plate of the cannon. Four 3mm diameter holes will be cut in the disk to mount the brackets on.

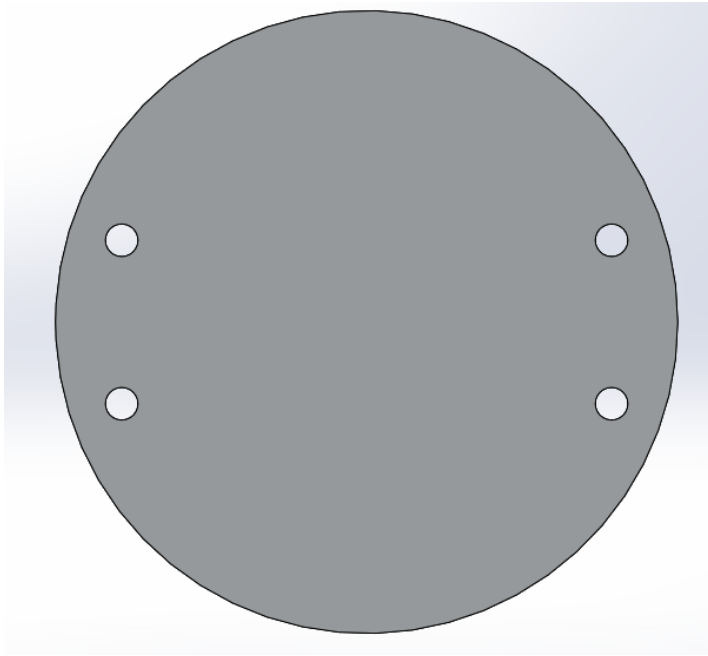


Figure 58 - The aluminum back plate.

Four 25 mm long, 3mm metric machine screws will be used to bolt the mounting brackets to the aluminum disk. An additional bolt will be affixed between the two brackets to provide a tie-off point for the parachute.

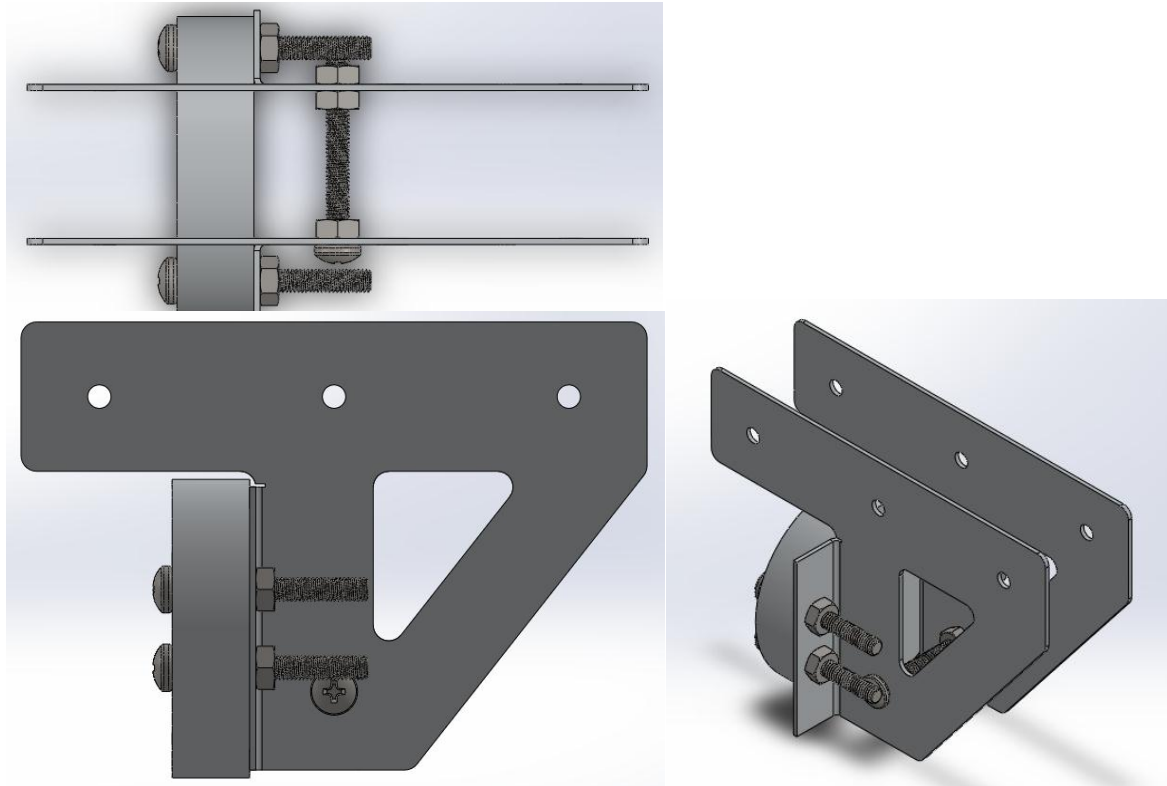


Figure 59 - The brackets bolted to the disk, in top, side and isometric view.

A 2 in inner diameter, 6 in [15cm] long carbon fiber tube will be affixed to the disk with epoxy. The outer surface of the disk and the inner surface of the carbon fiber tube will be scored with sandpaper and cleaned before applying the epoxy to improve the bonding. A small hole will be drilled into the tube just forward of the joint with the disk, so that an igniter can be inserted into the cannon to set off the parachute ejection charge.

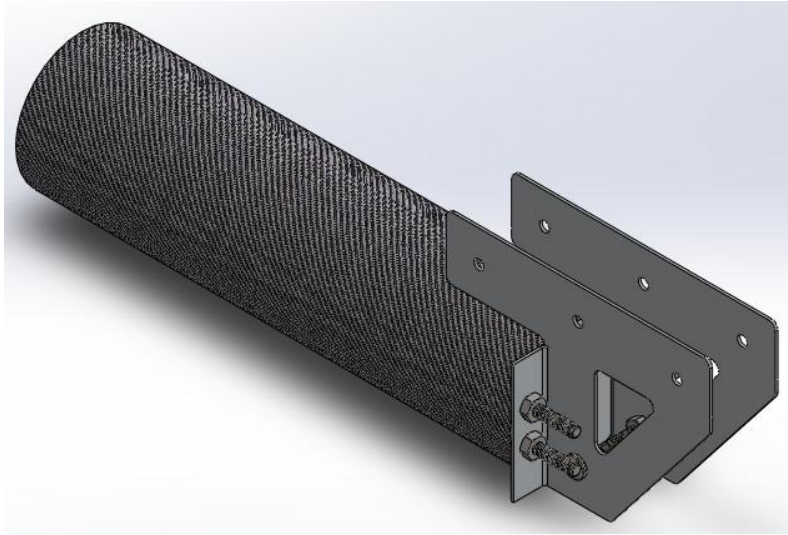


Figure 60 - The assembled cannon

The cannon will then be mounted to the quadrotor. The three holes on the mounting brackets will line up with three matching holes on the arm of the quadrotor, and three 25 mm long, 3mm metric machine screws will be bolted through these holes.

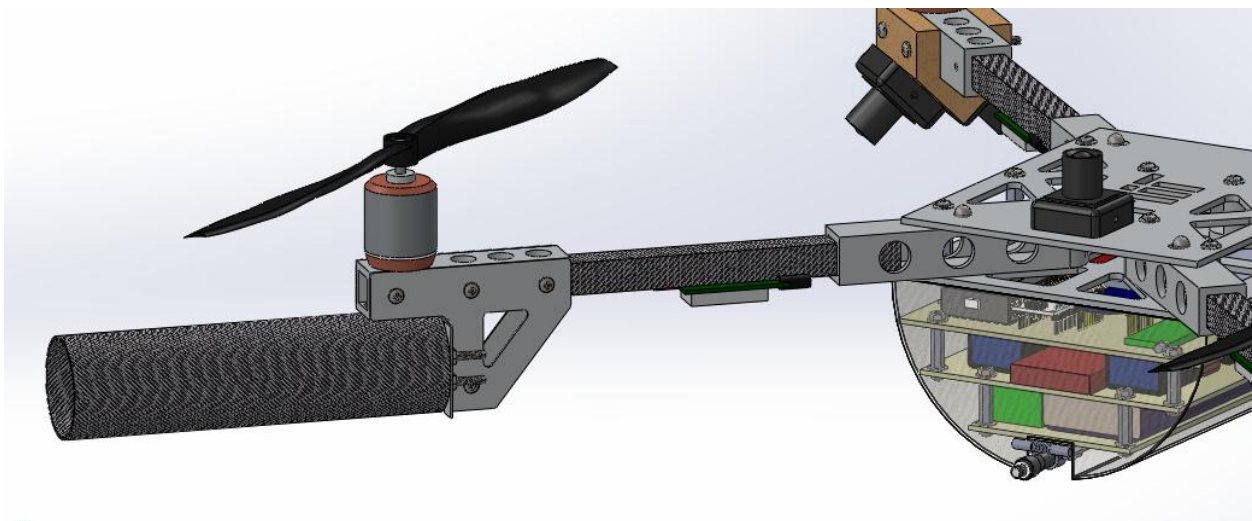


Figure 61 - The reserve parachute cannon mounted on the quadrotor's arm.

Loading the Reserve Parachute System

For safety, the reserve parachute system will not be stored loaded, and will only be loaded before launch or tests. First, the parachute ejection charge, 2 grams of black

powder, will be attached to an electric igniter passed through a small hole in the base of the carbon fiber tube. The charge and igniter will be slid to the back of the tube, and the igniter will be connected to the control circuit. To protect the parachute from the heat of the ejection charge, a 0.5 inch thick extruded polystyrene foam disk will be packed into the tube before the parachute. Next, the parachute will be tied to a 3 meter shock cord and folded. The folded parachute will be inserted into the tube, with the shock cord hanging out the open end of the tube. Most of the shock cord will be coiled into the tube, and about 10 in [25 cm] will be left free to tie off the parachute to the bolt between the brackets. Then, a paper or light plastic cover will be taped on the end of the tube. The cover will prevent debris from entering the tube and keep the parachute from sliding out, but will be blown off if the parachute ejection charge is fired. The cover will be colored bright orange to remind the ground crew to use caution around the loaded parachute system. This process will then be repeated on the second parachute cannon.

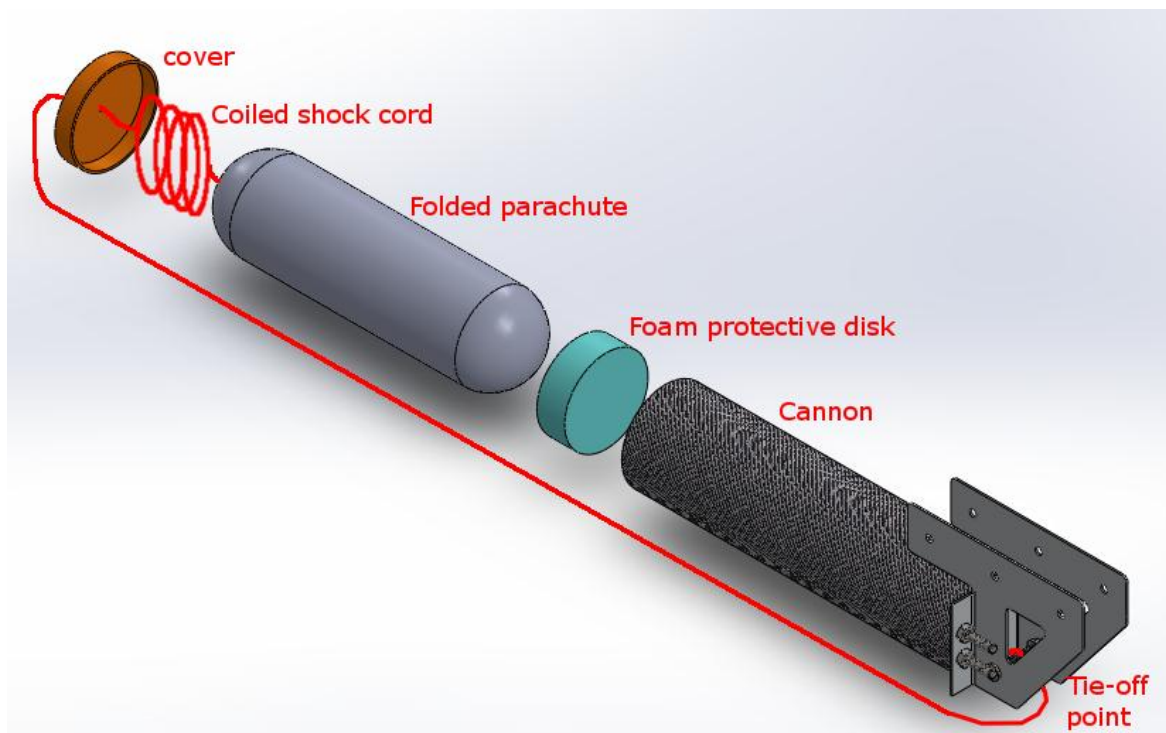


Figure 62 - Exploded view of the components packed into the reserve parachute cannon

Control

A small microcontroller (Arduino Nano) will control the reserve parachute. The microcontroller will monitor the output of the radio control receiver and a barometric sensor. The electric igniters in the parachute ejection charges will be connected to a

power supply through a transistor switched by one of the microcontroller's digital output pins.

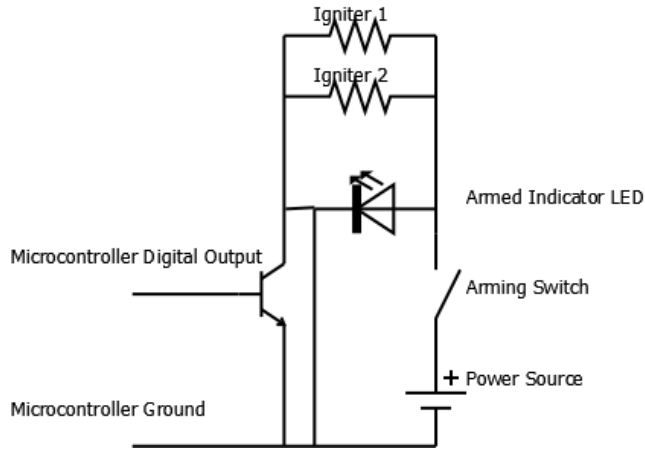


Figure 63 - The reserve parachute igniter circuit

The microcontroller will enter an active mode after the quadrotor sabot opens. In active mode, the microcontroller will apply current to the igniters if it detects a loss of signal on the radio control receiver, or if it detects barometer readings which indicate that the quadrotor is falling. The quadrotor may enter a failure mode in which it is falling at a dangerous rate but is not under significant acceleration (examples: falling near terminal velocity, weight slightly exceeds thrust for several minutes). Therefore it is useful to examine the decent rate inferred from the barometer, instead of an accelerometer, to determine if the quadrotor is falling. The reserve parachute system is designed to be triggered by any of the following conditions:

1. The radio receiver loses signal for more than 5000 ms
2. The accelerometer reads an average acceleration of less than 2 m/s^2 over the last 1000 ms
3. The barometer indicates an average rate of decent greater than 20 m/s over the last 5000 ms
4. The ground crew determines that the quadrotor is out of control, and manually trigger the reserve parachute system by turning off their radio transmitter, causing a loss of signal.

A simple simulation of the free-fall behavior of the quadrotor was used to inform the choice of thresholds in the above conditions. The simulation uses the drag equation,

$$F_d = \frac{1}{2} \times \text{air density} \times C_d \times \text{Area} \times \text{velocity}^2$$

and assumes the quadrotor has a C_d of 1 and a downward facing area of 0.04m^2 . Rough predictions of the acceleration, velocity and position are plotted below.

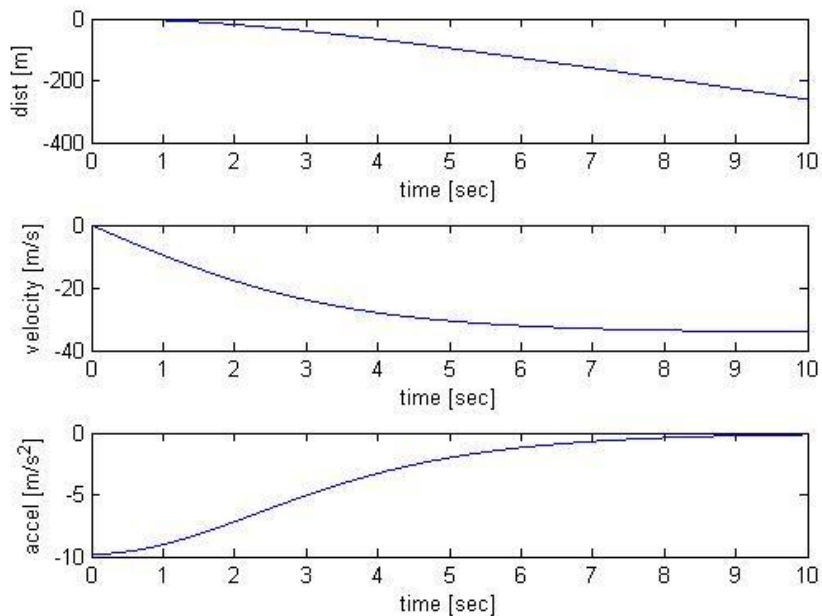


Figure 64 - A rough prediction of the quadrotor's free-fall kinematics

Testing

We will test ejecting the parachute upwards from a stationary platform on the ground to determine whether the black powder charge is sufficient to properly eject the parachute. The charge will be triggered by a remote ignition circuit, shields will be placed around the system, and all personnel will be at least 30m away when the test occurs.

We will verify the control circuitry's free-fall detection in a drop test. We will replace the igniter with bright LEDs, and will package the control circuitry in a protective case. We will then drop the package from a tall structure, and observe whether the LEDs flash on during the fall.

5.1.12.4.3.2 SOFTWARE

The custom HALO software functions to be written on the BeagleBone in addition to their parameters and outputs are defined below:

GetImages (camera#)

Takes a specific camera as a parameter and returns the image from that camera

Signal Bus: TTL

Pins: Depends on camera number (), TX RX

P9.24 (D15, UART1_TXD); P9.26 (D16, UART1_RXD)

P9.21 (B17, UART2_TXD); P9.22 (A17, UART2_RXD)

P9.13 (U17, UART4_TXD); P9.11 (T17, UART4_RXD)

P8.37 (U1, UART5_TXD); P8.38 (U2, UART5_RXD)

Convert: Hex signals to JPEG

Returns JPEG

CVStereo (IpImage1, IpImage2)

Takes two images as a parameter and returns a 3-d image

GetandSaveSensor ()

Calls ReadRadioReciver (), Readmagnetometer (), ReadAtmosphericData (), ReadLangmuir (), and ReadEMF () methods and then saves their data.

FindObject (3d-image)

Takes a 3-d image as an parameter (from the CV stereovision) and returns a 3d-position

Return Array [double] X, Y, Z (meters)

FollowObject (3d-pos)

Takes a 3-d pos as a parameter, and calls CalculateDesiredPos (). Then calls CommToAutoPilot ()

CommToAutoPilot ()

Sends RC commands to the autopilot.

TransmitSensorData ()

Gets the saved sensor data and sends via radio them to the ground

Signal Bus: SPI

Pins: USB UART0

PredictObjectPos ()

Finds the trajectory of the object it is following

Curve fit X, Y, Z as functions of time

Calculate time until separation distance (Z axis) is desired distance

Calculate X and Y after time has elapsed

write equations and geometry

CalculateDesiredPos ()

Calls PredictObjectPos () and returns the next position to be in to continue following the nosecone.

Customization for Auto-Pilot:

Dormant Phase ()

Activated before launch. Nothing will occur until the quad rotor is ejected from the rocket

ArmFreefallDetector ()

Activates the freefall detector. If freefall is detected for longer than a certain time, the reserve chute will be released.

CheckFreefallDetector ()

Checks the freefall detector against the other detector

CheckBattery ()

CheckUnfolding ()

Checks to see that the quad rotor arms unfolded correctly. Mechanism TBD.

CheckMotors ()

Checks that motors are rotating (and not caught up in the parachute)

CutChute ()

Will be called from the ground. The main chute will be cut.

ToggleRC ()

The computer will switch to manual control using the RC inputs. It will also ignore signals from the science payload (tracking of the nosecone)

ToggleScience ()

The computer will switch control to the science payload. It will receive simulated RC inputs from FollowObject ()

getTouchInfo ()

Gets the status of the physical touch sensor on the bottom of the quadcopter

5.1.12.4.4 CALIBRATION PROCEDURES

5.1.12.5 COMMUNICATIONS

Communications is done through a 3DR radio and Xbee Pro transceiver.

5.1.12.6 POWER AND PROPULSION

A direct drive brushless 830W Turnigy SK3 Motor with a 42 millimeter diameter was chosen as it provides suitable thrust for its size. The motor will be positioned below the propeller. The static thrust for the motor was calculated using www.ecalc.ch (good for static thrust with an accuracy of about +/-10%); this resulted in a thrust of 6.5 lbs per motor with a 7 minute flight time (with 4S, 6Ah LiPo per motor).

5.1.13 OVERVIEW: HALO

High Altitude Lightning Observatory

5.1.13.1 STRUCTURES

The structure the suite of sensors is located on can be found in the quadrotor structures overview section.

5.1.13.2 AVIONICS

A high level overview of the HALO avionics system and its interfaces can be found in section 5.1.12.4.

5.1.13.2.1 COMMAND AND DATA HANDLING

5.1.13.2.1.1 HARDWARE

The HALO suite of sensors is located on the deployed quadrotor. As an experiment designed to measure the effects of high altitude lightning on the surrounding environment it consists of two categories of avionics systems: lightning detectors and environmental sensors. The lightning detectors are comprised of a Hobby Boards Lightning Detector and nearly spherical array of USB cameras (the same set used for object tracking). A magnetic north sensor, triple axis magnetometer, ULF/VLF receiver, custom EMF sensor, and custom Langmuir probe will encompass the set of environmental sensors. Both avionics systems are integrated on a Beaglebone either through a USB, SPI, or analog interface. The Beagle Board serves as the main payload CPU that runs the payload software and handles science data collection. Science data on the Beagle Board is saved internally and transferred to the SPRITE quadrotor communication CPU via a SPI connection. HALO contains atmospheric sensors to obtain local pressure and temperature values during quadrotor descent. A Beaglebone acts as the sub-system's CPU, records these values to a SD card, and transmits this information via an Xbee Pro.

A custom Langmuir probe will be built to measure plasma energy and density. This analog sensor's design is based off of the design outlined Noah Warner's 2001 Master's Thesis. (Warner, 2001) Using the Langmuir probe the plasma will be sampled for intervals greater than 10 seconds to an accuracy of ± 1 eV and $\pm 1 \times 10^{10}$ number of particles/m³. This ensures that the energy and density requirement, as stated in the project hypothesis, is being met and it ensures that a large sample is size taken. The 10 second window allows the sensor to capture short random variations in the data which reduces random variation in the point estimates of the post processed data. To derive the plasma properties the current and voltage outputted from the probe are sampled and plotted with respect to each other. For the geometry of the resulting graph the ion

and electron energy and density can be found. (Krehbiel, Brace, Theis, Cutler, Pinkus, & Kaplan, 1980)

To capture the magnetic field strength, for independent variable verification, a Honeywell (SS49E) linear Hall-effect sensor will be used. This IC is also an analog sensor as it outputs a voltage proportional to the magnetic field strength with a 3 microsecond response time. A Hall-effect sensor was chosen over a magnetometer due to ease of data collection and limitations in magnetic field sensing range. The chosen sensor can operate within the field strength range of the project as it has a +/- 0.1 tesla magnetic range with a 1.4mV/0.0001 tesla sensitivity. With an operating temperature of -40 C to 100 C the sensor can function nominally given under the heat generated by the coils. The hall sensor requires a 2.7 – 6.5 supply voltage so both it and the Langmuir probe can be operated using a low voltage source of 5.5 volts. This power source can be achieved from a 9 volt or 12 volt battery in series with a Texas Instrument 7805 5 volt linear regulator

5.1.13.2.1.1.1 SENSORS

Name	BMP085
Manufacture	Adafruit
Vendor	Adafruit
Part Number	391
Cost	19.95
Dimensions	See B.O.M.
Weight	See B.O.M.
Input Voltage	3-5V
Pressure Range	300-1100 hPa
Pressure Resolution	0.25m
Operational Temperature	-40 to +85C
Temperature Accuracy	+/- 2C

Description

Barometric pressure/temperature/altitude sensor	
Name	Lightning Detector
Manufacture	Hobby Boards
Vendor	Hobby Boards
Part Number	LD4-R1-A
Cost	32.50
Dimensions	See B.O.M.
Weight	See B.O.M.
Input Voltage	9V
Range	50 miles with 24in antenna
Signal	1-wire

Description

Can detect the electromagnetic pulse from a lightning discharge. Used conjunction with the other set of HALO sensors a correlation between lightning discharges and the state of the surrounding environment (particularly in regards to local electric field and emitted ULF/VLF waves) for various altitudes can be found.

Name	Triple Axis Magnetometer Breakout – HMC5883L
Manufacture	Sparkfun/Honeywell
Vendor	Sparkfun
Part Number	SEN-10530
Cost	14.95
Dimensions	0.7 x 0.7 in
Weight	See B.O.M.
Input Voltage	2.3-3.4V
Sensor Resolution	5 milli-gauss
Operational Temperature	-40 to +85C
Signal	I2C

Description

Part of the HALO suite of sensors; it measures the local magnetic field. Once the sensor is calibrated for tilt and local magnetic field disturbances any significant changes to the magnetic field can be attributed to natural or artificial sources. More insight on lightning's effect on the local magnetic field can be gained if the magnetometer is run at the same time as the lightning detectors.

Name	Explorer E202 Natural Radio Receiver
Manufacture	SISTEL
Vendor	SISTEL
Part Number	E202
Cost	299.55
Dimensions	See B.O.M.
Weight	See B.O.M.
Input Voltage	9V
Frequency Response	3Hz-10Hz and 120Hz-10kHz
Pressure Resolution	0.25m
Signal	Signal output to PC

Description

Explorer E202 natural radio receiver
Name

JPEG Color Camera

Manufacture	LinkSprite
Vendor	Sparkfun
Part Number	SEN-10061
Cost	49.95
Dimensions	32mm x 32mm
Weight	29.4g
Video Resolution	640x480p
Camera Angle	120 degrees
Signals	TTL

Description

TTL Camera

5.1.13.2.1.1.2 DATA LOGGING AND COMPUTERS

Name	BeagleBone
Manufacture	BeagleBoard
Vendor	Digikey
Part Number	BB-BONE-000-ND
Cost	89
Dimensions	3.4 x 2.1 in
Weight	See B.O.M.
Input Voltage	3-5V
Processor	ARM Cortex –A8 700 MHz
Memory	256MB DDR RAM
Operating Systems	Linux, WinCE
Signals	Analog, SPI, UART, I2C, PWM, USB

Description

Serves as the main CPU for the HALO payload and suite of sensors. Runs camera tracking algorithms, saves incoming data and images, and sends telemetry to the Xbee to be transmitted to the ground station.

5.1.13.2.1.1.3 PLACEMENT AND MOUNTING

The placement of the avionics components is shown in Figure 65.

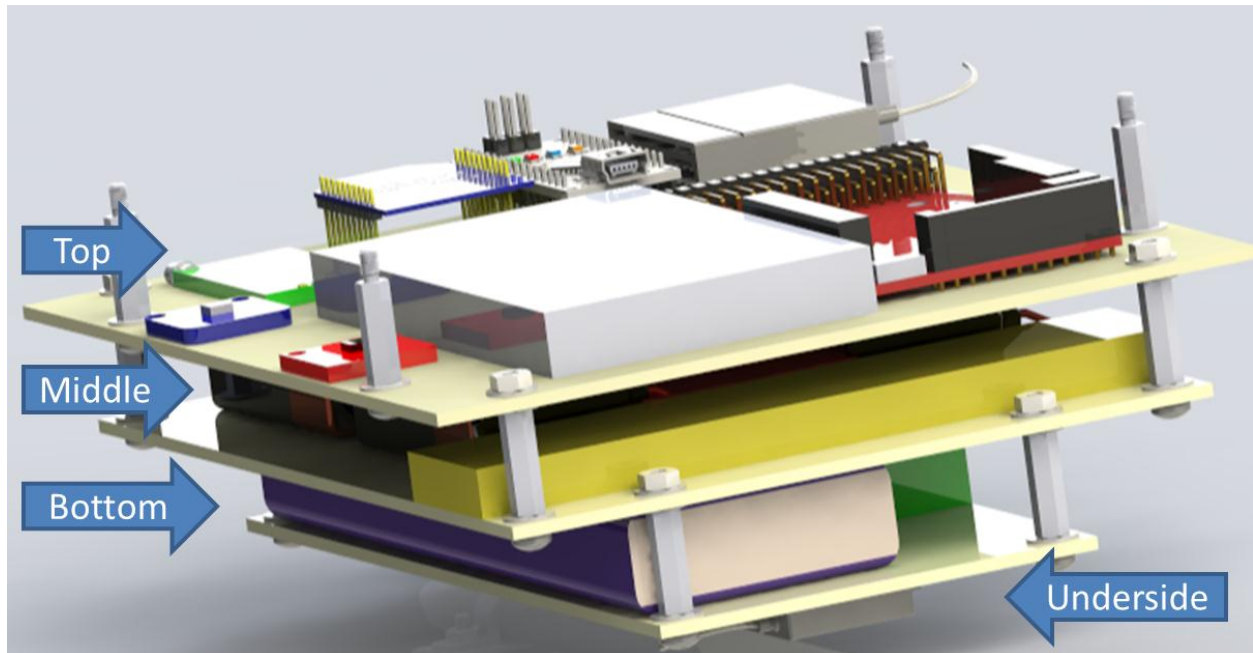


Figure 65 Placement of avionics hardware

Top

- RC Receiver
- Arduino Nano
- Xbee Pro
- 3DR Radio
- Atmospheric Sensor
- Magnetometer
- Ardupilot
- BeagleBone

Middle

- 9 Volt batteries x 4
- VLF Receiver Board
- Custom Langmuir probe and EM sensor board

Bottom

- Electric Motors LiPo Battery
- Lightning Sensor

Underside

- VLF Antenna
- RC Receiver Antenna

5.1.13.2.1.1.4 REDUNDANCY

Telemetry and commands can be communicated to the ground by either the 3DR radio, Xbee transceiver, or the RC receiver (for simple rotorcraft commands).

5.1.13.2.1.2 SOFTWARE

The custom HALO software functions to be written on the BeagleBone in addition to their parameters and outputs are defined below:

ReadRadioReciver ()

Returns radio receiver data

Signal Bus: ADC

Pins: P9.33 (C8, AN4)

Returns: Voltage

Convert: Voltage to Magnitude (dB)

Returns: double Magnitude (dB)

ReadMagnetometer ()

Returns magnetometer data

Signal Bus: I2C

Pins: P9.17 (A16, I2C1_SCL); P9.18 (B16, I2C1_SDA)

Returns: Array of Hex Values

Convert: Hex Values to X, Y, and Z Magnitude (Tesla)

Returns: Array [double] X, Y, and Z Magnitude (Tesla)

ReadAtmosphericSensors ()

Returns atmospheric sensor data

Signal Bus: I2C

Pins: P9.19 (B17, I2C2_SCL); P9.20 (D18, I2C2_SDA)

Returns: Array of Hex Values

Convert: Hex Values to Pressure (Pa)

Returns: Array [double] X, Y, and Z Magnitude (Pa)

ReadLangmuir ()

Returns Langmuir data

Signal Bus: ADC

Pins: P9.35 (A5, AIN6)

Returns: Voltage

Convert: Voltage to electric potential

Returns: electric potential (Volts)

ReadEMF ()

Return EMF data

Signal Bus: ADC

Pins: P9.37 (B7, AIN2)

Returns: Voltage

Convert: Voltage to EMF

Returns: double EMF (Volts)

GetImages (camera#)

Takes a specific camera as a parameter and returns the image from that camera

Signal Bus: TTL

Pins: Depends on camera number (), TX RX

P9.24 (D15, UART1_TXD); P9.26 (D16, UART1_RXD)

P9.21 (B17, UART2_TXD); P9.22 (A17, UART2_RXD)

P9.13 (U17, UART4_TXD); P9.11 (T17, UART4_RXD)

P8. 37 (U1, UART5_TXD); P8.38 (U2, UART5_RXD)

Convert: Hex signals to JPEG

Returns JPEG

5.1.13.2.2 CALIBRATION PROCEDURES

The calibration equations for the hall sensor will be derived based on the Helmholtz coil testing. The MIT Space System's Laboratory has a test stand in which the Helmholtz current to magnetic field relationship has already been characterized. To find the calibration equation, measure a range of magnetic field strengths from these coils with the un-calibrated hall sensors. Plot the measured versus actual field strength and Microsoft Excel and use the trend tool to find the linear relationship; this function is the calibration equation. Calibrating the Langmuir probe utilizes a similar procedure. Calibrate the un-calibrated probes against a calibrated probe measuring a particle source. Again, to find the calibration equation plot the measured values versus the values recorded by the calibrated probe in Microsoft Excel and use the trend tool.

5.1.13.2.3 DATA RETREIVAL AND PROCESSING

5.1.13.3 COMMUNICATIONS

Name	Xbee Pro 60mW Wire Antenna – Series 1 (802.15.4)
Manufacture	Digi
Vendor	Sparkfun
Part Number	WRL-08742
Cost	37.95
Dimensions	
Weight	
Input Voltage	3.3V
Data Rate	250kbps
Range	1 mile
Description	
Used for transmitting data from the BeagleBone.	

5.1.13.4 POWER

As shown in Figure 66 the central computer and all the science peripherals are powered by three 9 volt batteries.

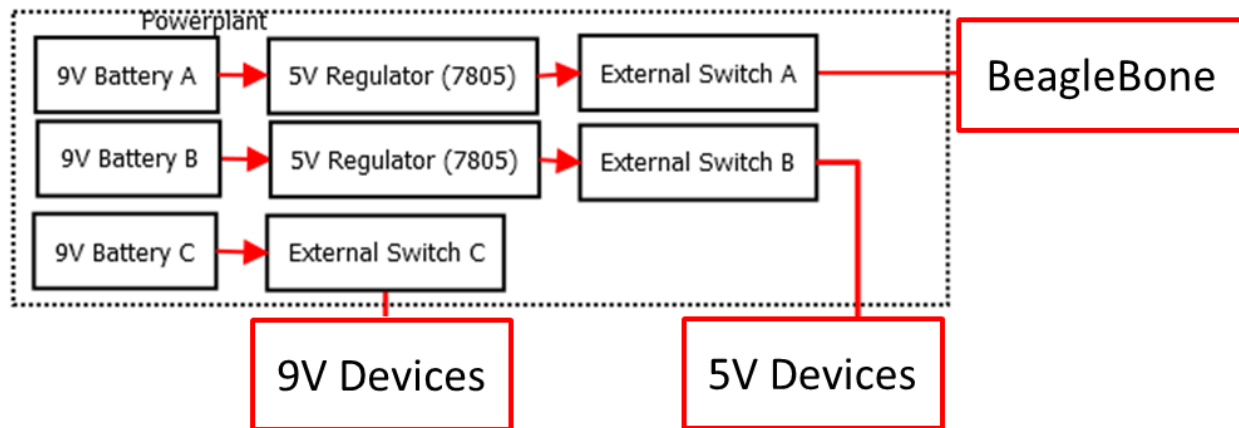


Figure 66 HALO Power Distribution Overview

5.1.13.5 THERMAL

The current design does not call for any thermal control systems as the electronics emit gained heat through radiation, conduction with the quadrotor structure, and convection into the surrounding air. As the system does not contain any particularly hot or cold element the only factor is the dry air temperatures on launch day. Based on public atmospheric records of the highest temperature of Alabama in April of 2012 (88 F or 31.11 C) and the estimated temperature at 1 mile above sea level (40 F and 5 C) one can assume that the launch day temperatures will most likely not be a risk factor with regards to thermal management (assuming a nominal temperature operational range of -40 C to 85 C).

5.1.14 SAFETY

5.1.14.1 FAILURE MODES

Please see the above sections.

5.1.14.2 PERSONAL HAZARDS

Please see the above sections.

5.1.14.3 ENVIRONMENTAL CONCERNS

Please see the above sections.

5.1.15 INSTRUMENT PRECISION AND MEASUREMENT REPEATABILITY

Instrumentation precision plays a large role in the payload mission, as the sensors must be able to detect changes in the surrounding atmosphere at rates greater than that of the rotorcrafts change in position and attitude. For these reasons sensors with a high degree of accuracy and a fast processor was carefully chosen. Also, the sensors will be rigorously tested and calibrated in order to get consistent and accurate measurements. The VLF receiver will be calibrated using the VLF transmitter borrowed from the MIT Space Systems Laboratory. A set of Helmholtz coils with known parameters will be used to calibrate the magnetometer. An electric field generator from the MIT Electronics Research Society shall be used to calibrate and test the Langmuir probe and EM sensor. The computer vision program openCV was chosen to analyze the collected image, as it can be programmed to quickly calculate minute distances in the images.

There are two areas which effect precision of the data collected beyond the precision of the sensors themselves since data is recorded in two ways; transmission to the ground station and storage on non-volatile memory. Data transmitted to the ground station has a lower precision than the data collected by the sensors due to the need to encode the floating point data into integer values for sake of compatibility. This results in the maximum precision shown in the table below. The precision for the sensors is shown in

Figure 67 Precision of Transmitted Data

Data	Decimal Places
Pressure [Pa]	0
Temperature [degrees Celsius]	1
Magnetic Field [Tesla]	3
VLF Waves [Amplitude in nm]	2
Langmuir Probe	1
EM Sensor	1

Data	Sensor	Precision
Pressure	BMP085	100Pa (1.45x10 ⁻² psi)
Temperature	BMP085	0.1 C (0.18 F)
Magnetic Field	HMC5883L	5.0x10 ⁻⁷ tesla (5 milli-gauss)
VLF Waves		

It is worth noting that the flight computer also logs data from the sensors connected to it at their precision as this data is not transmitted and so does not need to be converted to integer values for compatibility.

Given the changing nature of the atmosphere repeatability of data collection is synonymous with reusability of the data collection hardware and by extension the rotorcraft and rocket. To this extent all aspects of the rocket, rotorcraft and avionics have been designed with reusability in mind.

5.1.16 EXPECTED FINAL DATA

- Time stamped color images for each camera
- Two sets of time stamped stereographic images
- List of frames with a positive feature recognition (rocket)
- List of frames with a positive feature recognition (ground)
- Local electric field versus time
- Local magnetic field versus time
- Received VLF waves versus time
- Local pressure versus time
- Local temperature versus time
- Number of detected lightning strikes versus time

5.1.17 DESIGN INTEGRITY

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

A high level of integrity is expected of the quadrotor design as otherwise the science payload will be left incapable of completing the mission. The integrity of the rotorcraft design can be noted throughout the manufacturing, testing and analysis sections. The beginning of the design process included ample use of SolidWorks and team meetings with senior team members to ensure that all systems and subsystems will be of high enough caliber and structural reliability to meet the requirements set by the mission.

5.1.17.1 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 wooden

motor retention system. The performance of the structural elements will be shown in the full scale test flight.

5.1.17.2 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.

5.1.17.3 MASS

Table 29 Quadrotor mass and cost characteristics

System		Mass (lbs)	Cost (USD)
Quadrotor	Structure	1.89	62
	Motors/Propellers	3.32	161.92
	Flight Avionics	0.5	581.39
	Science Avionics	1.5	736.65
	Total	7.21	1541.96

5.1.17.4 SAFETY AND FAILURE ANALYSIS

Table 30 Payload Risks

Risk	Likelihood	Effect on Project	Risk Reduction Plan
Cameras do not take images	Low	Loss of science value	Test the remote relay switch circuit and make sure that

			there are redundancies in the system.
Images are blurry or are obstructed in some way	Medium	Loss of science value	Securely mount the cameras in the avionics bay and use vibration testing to determine and improve stability.
Sensors fail to send usable data to BeagleBone	Medium	Loss of science value	Rigorously test circuits in ground and flight testing.
BeagleBone fails to log data to SD Card	Low	Loss of science value	Ensure rigorous testing of all electronics and software prior to launch.
BeagleBone cannot transmit data to ground	Medium	The ground station cannot confirm the status of the quadrotor sensors and actuators without the use of a visual aid	Rigorously test transceivers in ground and flight testing.
Payload cannot receive commands from the ground	Low	The rotorcraft may drift far away from the rocket	Rigorously test transceivers in ground and flight testing.
Rotorcraft's inertial state changes faster than sensor sampling rate	Low	Loss of science value	Accurately model the quadrotors dynamics. Insure that stability is built into the design.

5.1.17.5 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.

Table 31 Quadrotor challenges

Challenge	Solutions
Proper quadrotor unfolding	A passive unfolding mechanism will be used. The propeller and wings will be deployed using springs that are preloaded against the sabot. Therefore, when the sabot is released from the rocket body tube, the quadrotor's arms are able to push the sabot apart and release the vehicle.
Bugs in autonomy control could result in catastrophic failure	Operators will be kept in-the-loop at the ground station, which will be implemented in several layers of abstraction. Not only will operators at the ground station be able to select desired waypoints, but they will also be able to fly the plane with a joystick using a HUD on the ground station computer. Furthermore, RC control will be used as an ultimate backup, which will bypass all electronics and interface with the servos via the RC receiver directly.
Uncertainties in flight conditions could pose a danger to observers	The craft will descend at a relatively low speed and between 1000 and 2500 ft during the deployed phase of flight. Furthermore, the vehicle will be designed to be inherently stable and the vehicle will remain attached to safety parachute if flight conditions are non-ideal.
Maintaining contact with the quadrotor	All link budgets will be designed with significant gain margin. Also, all links to the quadrotor will be separate: video, telemetry, and RC. This will ensure that telemetry will still be received even if, for example, the video signal fails. Finally, a set of safe modes will be designed in case contact is lost, such as orbit and return to a known "safe" location.
Maintaining structural integrity on	The vehicle's structural design will be

landing

performed with conservative safety margins, coupled with an aggressive test campaign to ensure that the airframe is capable of withstanding landing loading conditions. Furthermore, the legs of the craft will be reinforced with Kevlar in order to mitigate impact damage and vibration isolation will be used if necessary.

5.2 PAYLOAD CONCEPT FEATURES AND DEFINITION

5.2.1 CREATIVITY AND ORIGINALITY

The idea of a deploying a quadrotor with a rocket is not an entirely original idea; however, the end goal of producing a cheap and reliable rotorcraft that can take data while tracking a moving target is. Furthermore, by choosing a rocket deployment, and keeping to a \$5000 budget, it further allows for this technology to be applied to situations where time and budget are controlling factors. This quick deployment and relative low cost of operation would ideally suit the needs of search and rescue operations, reconnaissance missions, and even rapid scientific data gathering missions.

5.2.2 UNIQUENESS AND SIGNIFICANCES

By doing these experiments, we hope to demonstrate a method which can be used to validate high altitude lightning models and add to the knowledge body regarding dynamic object tracking and communication by aerial vehicles. By doing this, we hope to improve the areas of earth science and the usefulness of small UAVs in tactical situations.

5.2.2.1 TECHNICAL AND SCIENTIFIC RELEVANCE

Table 32 List of Relevant US Government SBIRs

Number	Title	Relevance to Project AI ³ R
A10-006	Missile Delivered UAV	To be completed
N131-004	Automated Target Area Threat and Route Optimization	To be completed
N131-065	Automating Unmanned and	To be completed

	Manned Sensor Performance in Demanding Tactical Environments	
S1.08	In Situ Airborne, Surface, and Submersible Instruments for Earth Science	To be completed
SB131-007	Remote Sensing for Electric and Gravity Fields	To be completed
AF131-137	Very Low Frequency Receiver front end with high sensitivity and frequency selectivity	To be completed
A13-027	Vehicle Spacing Determination and Display In Low Visibility Conditions	To be completed
A12-119	Optical Communications for Control of Unmanned Ground Vehicles	To be completed

5.2.3 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 task of deploying a quadrotor from a rocket is especially challenging. Integrating a suit of sensors into an autonomous UAV is not easy feat, especially when the craft has to implement object tracking algorithms in real-time.

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.

5.3 SCIENCE VALUE

5.3.1 SCIENCE PAYLOAD OBJECTIVES

There are two different aspects to the payload, each with their own objectives; the requirements for HALO and demonstration of object tracking/object recognition in dynamic environments during rotorcraft flight. The payload objectives relating to the HALO suite of sensors are to log atmospheric pressure, temperature and magnetic field

strength along with electric potential and VLF wave data at 5 second intervals. The payload objectives relating to improving information acquisition, processing, and transmission on and between mobile targets in an dynamic environment is to complete the flight (visually locating and tracking the rocket) solely using the software installed on the onboard processors without having to revert to back up manual control.

5.3.2 PAYLOAD SUCCESS CRITERIA

The data logging and sensors shall be deemed successful if the payload obtains and logs atmospheric pressure, temperature, and magnetic field strength along with received VLF wave, electric field strength, lightning strike count data, and images at a maximum of 5 second intervals. It shall be deemed a success regardless if the data is able to be transmitted to the ground.

Fulfilling the HALO payload requirement successfully shall also demonstrate the flexibility in the quadrotor design.

If the quadrotor successfully visually tracks the rocket, demonstrates ground target recognition, and lands in a state fit for reusability, without resorting to use of the back-up manual flight control then this will demonstrate a successful ability of a rotorcraft to tracking track moving targets while relaying information to a user (if communication to the ground is achieved).

5.3.3 EXPERIMENTAL LOGIC, APPROACH, AND METHOD OF INVESTIGATION

By using a science payload in a descending rotorcraft, atmospheric measurements presented in section 5.1.16 will be collected. The science payload will be contained inside built-in compartments in the fuselage, preventing thrashing of instruments from launch initiation to landing of rotorcraft.

To obtain such data, all the sensors will be turned on just prior to launch and measurements will be recorded at 5-second intervals during launch and decent within target area. Using a rotorcraft to carry a science payload of multiple sensors and accurately obtain such data will provide a more efficient means for obtaining such data. Additionally, the telemetry devices inside the rotorcraft will allow for safe operation of the vehicle via a pilot at the ground station. A single mission by a rotorcraft with such

science payload gathers data at varying altitudes effectively and efficiently, relative to other means of acquiring such data.

The goal of the rotorcraft is also to demonstrate the capability of a quadrotor to track a moving target in a dynamic environment. This will be achieved by having stability control on the rotorcraft such that it is able to maintain straight and level flight, perform controlled turn and land safely with no user input. Combining this with an appropriately designed user interface, this should be sufficiently automated that it can be controlled by a person with absolutely no flying experience.

5.3.4 TEST MEASUREMENTS, VARIABLES, AND CONTROLS

Testing and verification of the avionics occurs in three distinct phases: ground testing, on a commercially available quadrotor and lastly on the final quadrotor, thus enabling ground testing shall consist of validating the correct operation of all hardware and sensors in a non-critical environment. The testing on the test aircraft serves to verify that the subsystems within the avionics system work as expected in flight case and to validate changes made to the flight computer hardware and software for the purposes of the competition. The flight testing on the quadrotor is to demonstrate the avionics system is able to function correctly in its intended flight configuration and importantly, that is it capable of recovery after deployment from the rocket.

5.3.4.1 PHASE ONE

First, the HALO sensors and single-board computer will be configured and tested in a laboratory setting to ensure that our software can properly read data from the sensors. We will attempt to read data from each sensor individually, and verify that the expected readings are produced. Tests at this stage include reading data from the Langmuir probes, and verifying that our stereo vision cameras and software can produce depth images of sufficient accuracy.

Next we will integrate the sensors together to identify any interferences within the sensing system. Example conflict to test for include noise on the EMF sensors caused by currents flowing to the other sensors, and the effect of the processor time spent performing computer vision operations on the sampling rate achievable on the other sensors.

5.3.4.2 PHASE TWO

The team will assemble and fly the 3D Robotics Arducopter Quad C, a commercially available quadrotor which uses the Ardupilot flight controller. This testing will enable team members to practice flying a quadrotor and become familiar with the Ardupilot software. Stumbling blocks likely to be encountered at this learning stage will be easier to resolve using a well-documented product with a large online user community, than if we were to immediately start with our custom design.

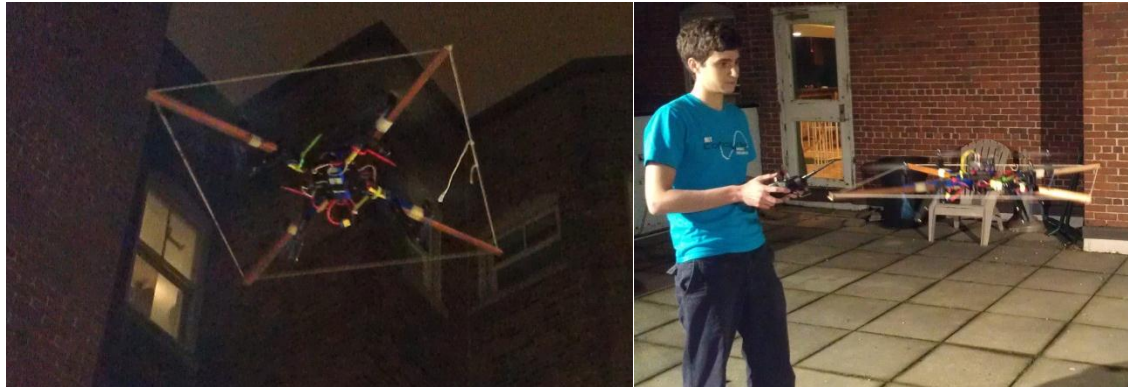


Figure 68 - Flight tests of the 3D Robotics Quadrotor

5.3.4.3 PHASE THREE

After the avionics performance has demonstrated adequate performance on the 'Test Aircraft', the avionics and propulsion systems shall be migrated to our custom-built airframe. The first flight testing shall be to determine the control gains required for stable flight of the rotorcraft. For the purposes of these tests, the equipment not essential for flying (i.e. everything but flight computer, telemetry link and GPS/IMU) shall be replaced by appropriate ballasting to minimize the risk of damage to components.

Once adequate control gains have been determined, a series of flight tests shall be undertaken to ensure that the sensor systems and data logging systems, as well as the imaging systems, still function as desired. These flights will also determine if the propulsion system's duration and thrust are sufficient to maintain steady-level flight for at least 10 minutes. Further testing representative of flight scenarios shall also be undertaken, including point-to-point flying based on user inputs at a ground station. Drop tests from a tethered weather balloon shall also be used to simulate rotorcraft deployment to ensure the rotorcraft/Avionics is capable of recovering from the post deployment dive. The rotorcraft will be unpowered (propulsion system off) due to safety reasons for these tests; the lithium polymer propulsion battery will be replaced by ballast to mitigate the risk of the lithium polymer battery exploding due to damage if the rotorcraft were to crash. Gliding should be sufficient to test all avionics. A test section of

the rocket body tube will be hung from a balloon platform attached to the weather balloon.

The rotorcraft will be packed into the sabot, and the sabot will be placed in the body tube and connected to a radio controlled remote triggering/dropping device. The balloon will be raised and tethered at an altitude of approximately 200 ft; this altitude should be sufficient for full rotorcraft deployment, while restricting the safety radius needed to be cleared of personnel on the ground to a reasonable value. Then the sabot will be dropped under drogue parachute, and the rotorcraft will deploy. These tests shall be performed with ballast instead of non-essential electronic components. This ballast will be placed in such proportions and arrangements to maintain the center of mass of the rotorcraft, providing sufficiently accurate mission conditions for the rotorcraft.

5.3.5 RELEVANCE OF EXPECTED DATA

The data collected is vital for the analysis of the systems and subsystems in determining any necessary changes to the design of the rotorcraft, or to any instruments and power devices. Accuracy of the data is also significant in that variations in the state of the craft can lead to system instability..

Effectively, all data on the stability lift and drag forces for the propellers, arms, and the assembled body must be accurate to determine the necessary attitude of the vehicle to achieve specific tasks, such as steady-level flight, and landing.

The various measurements of the atmosphere will be gathered, organized and analyzed to study changes in the atmosphere with changes in altitude, changes in amount of atmosphere between the payload and ground, and changes in level of atmosphere between the payload and space. This will provide real data, to contrast to theoretical data predicting such qualities of the atmosphere based on location, altitude, and density of the air.

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.

5.3.6 ACCURACY AND ERROR ANALYSIS

Accurate data provides information about atmospheric conditions to people, giving realistic data for the analysis and design of different potential aerial mechanisms. Such

data will also allow for scientific groups to consider the protection necessary for instruments of varying sensitivity to cosmic electromagnetic radiation, that are planned on being deployed at varying altitudes. Devices and forces can be greatly affected by variables such as pressure, temperature, relative humidity, solar irradiance, and UV radiation; appropriate knowledge of such variables can allow for proper preparation for objects entering such conditions. A minimal sampling time interval was chosen to reduce the likelihood of recording outlier values as nominal data by increasing the sampling size taken over a specific range of parameters and independent variables. To confirm the accuracy of the sensors, all sensors will be calibrated based on the methods outlined in section 5.1.13.2.2. During the experiment at least two hall sensors and two Langmuir probes will be use simultaneously. This adds redundancy to the data collection system and allows each sensor to verify it neighbor's output.

5.3.7 PRELIMINARY EXPERIMENT PROCESS PROCEDURES

- Individually test all sensors for temperature, pressure, relative humidity, solar irradiance, and UV radiation (primary and back-up sensors).
 - o Pressure can be tested in a wind tunnel with a known dynamic pressure
 - o Temperature probes can be tested at room temperature, and outside ambient temperature, which will range from 30 °F to 60 °F, at time of anticipated testing
- Determine mass of all instruments, avionics, and power devices
- Estimate mass of rotorcraft body materials
- Identify a suitable propulsion system and battery for device powering
- Using computational software, Excel and MATLAB, verify calculations for expected parameters and requirements of the rotorcraft.
- Using CAD software, model rotorcraft with appropriate dimensions and parts.
- Use flight simulation software to determine flight patterns of rotorcraft
- Develop mission success criteria

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

5.4 SAFETY AND ENVIRONMENT (PAYLOAD)

5.4.1 IDENTIFICATION OF SAFETY OFFICERS

Please refer to safety officer information in previous sections.

5.4.2 SAFETY ANALYSIS

Please refer to payload safety analysis information in previous sections.

5.4.3 ANALYSIS OF FAILURE MODES AND MITIGATIONS

Please refer to payload failure mode analysis in previous sections.

5.4.4 PERSONAL HAZARDS

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

5.4.4.1 SAFETY CHECKLIST

Please refer to system safety checklist information in rocket/vehicle section.

5.4.4.2 SAFETY PERCAUTIONS

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:

- Avoid standing in the plane of the propeller when rotorcraft propulsion system is on.
- Do not try to catch the rotorcraft during landing.
- 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.
- Take extreme caution around the rotorcraft in the case of a crash. The pack may explode if damaged.
- Never discharge a lithium polymer battery at more than the published discharge rate. The pack may explode if discharged too quickly.

5.4.4.3 TOOL USE INJURY POTENTIALS AND MITIGATIONS

Please refer to this item in the rocket/vehicle section.

5.4.4.4 SAFETY CODES

Please refer to this item in the rocket/vehicle section.

5.4.4.5 HAZARDS RECOGNITION

Please refer to this item in the rocket/vehicle section.

5.4.5 ENVIRONMENTAL CONCERNS

- All waste materials will be disposed of using proper trash receptacles
- Consideration of environmental ramifications will be made regarding applicable activities
- The following list of materials has been identified as potentially hazardous:
 - Aeropoxy 2032 Epoxy Resin
 - Aeropoxy 3660 Hardener
 - Lithium Polymer Batteries

6 SAFETY PLAN

6.1 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 operations involving hazardous materials or closely supervise them all usage of hazardous materials.

6.2 HAZARD RECOGNITION AND ACCIDENT AVOIDANCE

Students will be briefed on hazard recognition and accident avoidance at points in time that are relevant to associated hazards. MIT's EHS (Environmental Health and Safety) 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 is 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.

6.3 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 spoils
 - 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: 10
 - 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

6.4 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.

6.5 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.

6.6 COGNIZANCE OF FEDERAL, STATE, AND LOCAL LAWS REGARDING 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.

6.7 PURCHASING AND HANDING 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).

6.8 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 that we are not in commerce, travelling with them via car requires no special permits other than a NAR/TRA certification.

6.9 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.

7 PROJECT PLAN

7.1 BUDGET PLAN

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. Please refer to sections 9.1 and 9.2 for the full detailed budget.

Table 33 Project budget summary

System Cost Summary		
System	Sub-System	Cost
Rocket	Propulsion	530
	Airframe-Body	430
	Airframe-Fairing	70
	Avionics	700
	Payload Support Equipment	141
	Recovery	450
SPRITE	Propulsion	28.80
	Airframe	200
	Avionics, Power, Communications	366.74
	Cameras and IR sensors	400
	Recovery	115
HALO/SMD	Avionics	825
	Power	15
Total Rocket Cost		4271.54
Support	Ground Station	2000
	Testing	2500
	Spares	4000
	Team Support	6000
Total Project Cost		18771.54

7.2 FUNDING PLAN

To meet the budget needs set forth in the initial proposal, the MIT Rocket Team has reached out to three main sponsors. The largest percentage of funding will be provided by the Massachusetts Institute of Technology department of Aeronautics and Astronautics, in their support of undergraduate projects. The Massachusetts Institute of Technology Edgerton Center and NASA's Science Mission Directorate Grant will provide further funding to the MIT Rocket Team. A breakdown of financial contribution can be seen in Table 34, and a budget summary is shown in Table 33 Project budget summary.

Table 34 Funding Sources

Funding Sources	
Sources	Contribution
MIT Aero-Astro Department	\$7,000
MIT Edgerton Center	\$5,000
MIT RT Savings	\$5,000
Total	\$22,000

7.3 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.

Table 35 Milestones and projected dates

Task	Date
USLI Telecom	4-Oct
Web Presence	22-Oct
PDR	29-Oct
Scale Launch	Dec
Ejection Test	Jan
CDR	14-Jan
Full Scale Launch	Feb
DAQ Test	March
FRR	18-Mar
Full Scale Launch	March
Travel	17-Apr

Launch Day	20-Apr
PLAR	6-May

A Gantt chart has been created to organize the list of tasks that each subgroup must accomplish, and ensure that all tasks are completed before the various USLI milestones. A larger version can be found in Appendix VI. Task and milestone descriptions are listed on the left hand side. Tasks are depicted by bars which display the expected task start and end date. Milestones dates are represented by rhombuses. Extra time was margined to the tasks of machining, apparatus assembly, and data collection due to possible delays in material delivery, re-machining, and equipment scheduling.

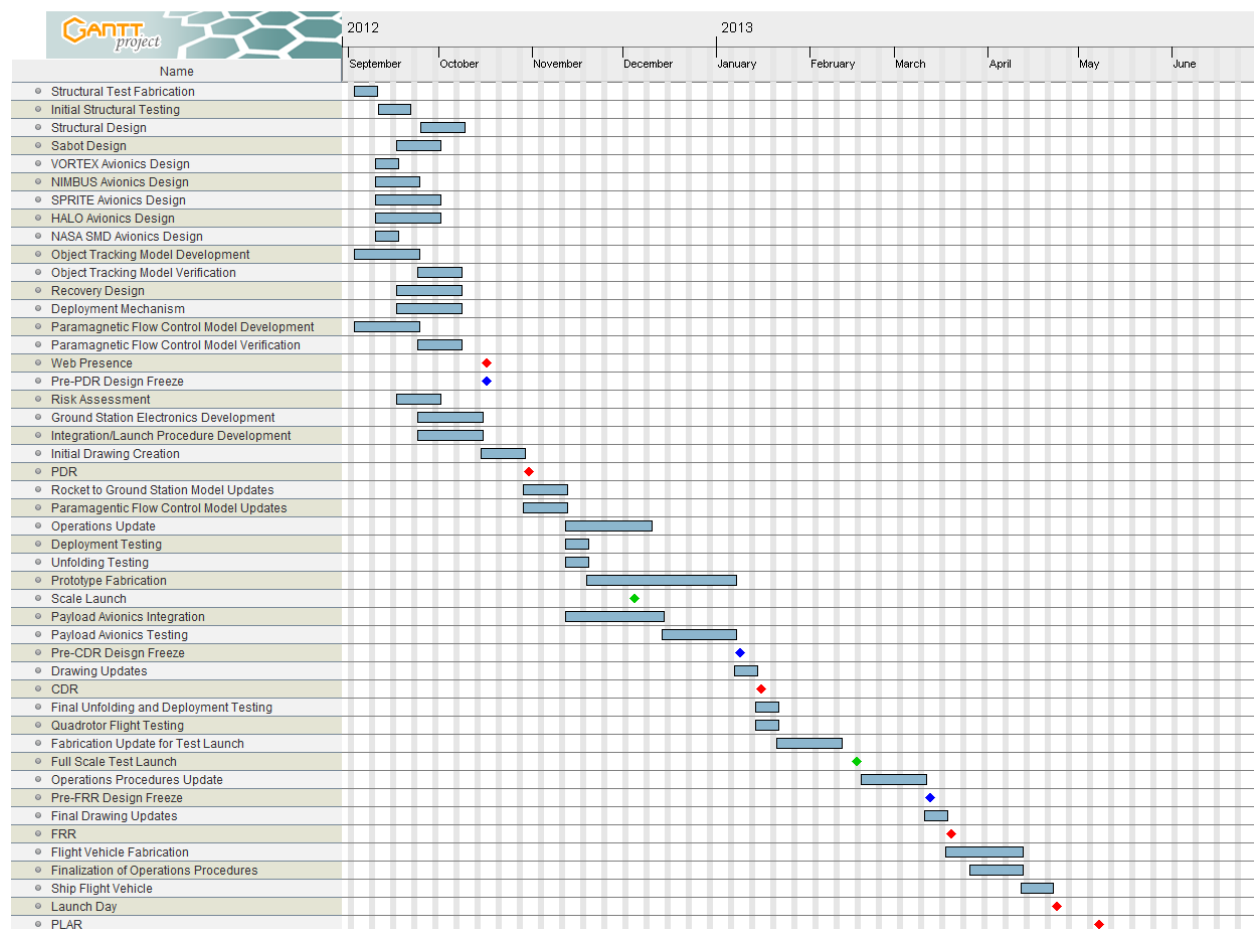


Figure 69 Project timeline

7.4 COMMUNITY SUPPORT PLAN

7.4.1 EXPERTISE

The MIT Rocket Team has reached (and will continue to) out rocket enthusiasts via networking events, on/off campus event, local rocket launches, and campus advertising.

7.4.2 EQUIPMENT/SUPPLIES

The MIT Rocket Team has strong ties with the Department of Aerospace Engineering and the MIT Space Systems Laboratory. Often mechanical tools, equipment, or fasteners can be borrowed from department facilities upon permission. The Space System Laboratory is a great resource for the team in obtaining electrical hardware or electrical measurement systems. The team will work hard to continue the excellent relationship between the students and the faculty members in charge of these labs and resources. Machining and assembly of the apparatus will respectively take place in the AeroAstro machine shop and the Gelb work area. These locations are normally open to students from 9:00am to 5:00pm; however, specific work in the Wright Brothers Wind Tunnel will require extra assistance from AeroAstro personal. The availability of AeroAstro members and equipment will have to be scheduled near the beginning of the spring semester.

7.4.3 MONETARY DONATIONS

In the beginning of winter the team contacts companies and organizations and ask whether or not they would like to sponsor out team's activities for the year.

7.4.4 SERVICES

The team is in the process of expanding the list of testing facilities that out members have access to. The executive members of the team are currently in contact with faculty members regarding the potential use of the Aerospace Blast chamber.

7.4.5 ADVERTISEMENTS

The MIT Rocket Team makes full use of the advertisement opportunities available on the MIT Campus. These include multimedia ads, flyers, posters, updates on official campus wide social media networks, and ads in the school newspaper. We are looking forward to contacting local news organizations once larger events in the community are

scheduled, such as our Winter MIT Rocket Launch Event. Images of advertisements can be found in section 7.4.5.

7.4.6 PARTNERS WITH SCHOOLS

Partnerships exist with the MIT Rocket Team and the rocket organization from Boston University. There exists an ongoing project where the team has agreed to build a rocket to house their custom hybrid engine upon completion of testing. We are also looking to open up communication with Harvard University as they have a few new programs which focus on rocketry in the local area.

7.4.7 PARTNERS WITH INDUSTRY

The team plans to further its partnership with the local aerospace company Aurora Flight Sciences. Last year we gave presentations, demos, and lab tours to a TARC group which was lead by the General Manager of the Cambridge branch of Aurora. We plan to email the general manager to set up future event such as these and to also seek the possibility of monetary sponsorships or potential project opportunities.

7.5 MAJOR PROGRAMMATIC CHALLENGES AND SOLUTIONS

The current major programmatic challenge is that the team lack experienced members. Yet, because of the large influx of new members this problem can be overcome through teaching the basic principles (including hands-on work) of high power rocketry to new members throughout the academic year.

7.6 PROJECT SUSTAINABILITY PLAN

7.6.1 ACQUIRING AND MAINTAINING PARTNERSHIPS

7.6.2 ENGAGING STUDENTS IN ROCKETRY

Engaging students in rocketry is discussed in much greater detail in the outreach plan section; however, the team

7.6.3 PARTNERS IN INDUSTRY/COMMUNITY

In addition to our partners at the MIT Museum and Aurora Flight Sciences the team is trying to expand the number of partners in the local community. Our path forward involves increasing our community involvement through public events.

7.6.4 RECRUITMENT OF STUDENTS

Like all official MIT student organizations the MIT Rocket Team has a large recruitment drive in the beginning of the year which brings in 10 to 15 new members. Team membership is open throughout the year and members are encouraged to invite their friends/peers over for meetings or build sessions.

7.6.5 FUNDING SUSTAINABILITY

As long as the team remains active it has a stable and guaranteed source of funding. The largest portion comes from the Department of Aerospace Engineering which gives the team around \$10,000 annually. If financial needs still aren't met then the team seeks out funding from MIT sources such as GEL, and FinBoard.

7.7 OUTREACH PLAN AND EDUCATIONAL ENGAGEMENT

7.7.1 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.

7.7.2 CURRENT SCHEDULE

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

The following table lays out these activities:

Table 36 Outreach Events

Event	Date	Approximate Number of
-------	------	-----------------------

		Middle School Students
MIT Splash Weekend	Nov 17th	30-40
MIT Museum	Winter	20
Boston Museum	Winter	30
MIT Spark Weekend	Spring	30-40
Science on the Streets	Winter	20
MIT Museum	Spring	20
Rocket Day @ MIT	Spring	15

7.7.3 ROCKET DAT AT THE 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 demonstration²³
- 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.

7.7.4 ROCKET DAY AT THE MIT MUSEUM

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

As with the Museum of Science, SEDS members have had successful experiences with presenting at the MIT Museum in the past. We have gotten in touch with a member of museum staff who has hosted us previously, and are currently working on securing a date and duration for the event. The team has recently met with the staff of the MIT museum and has begun to outline and schedule some potential activities.

7.7.5 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).

On November 17th 2012 the team taught a total 75 middle school and high school students in the areas outlined in Figure 70 Splash List of Classes.

Manage Your Classes				
Below is a summary of the classes you have registered to teach for Splash! 2012. Please look through the information carefully; e-mail the directors if you believe there is a problem with your time or room assignment. Also, e-mail the directors immediately if you need to cancel a class.				
6359: SPACE »	Delete	View	Detailed Status	Create web page
Directors' review status: Accepted				View Students
Document uploads: There are 0 documents associated with this class.				Manage Documents
(Co-)Teachers:	Leonard Tampkins			Modify Coteachers
Section I	Room: 2-136	30 / 30 students	E-mail students	
Status: Accepted	Time: Sat 11:05am-12:55pm	(view list)		
6360: Satellites and Spacecraft »	Delete	View	Detailed Status	Create web page
Directors' review status: Accepted				View Students
Document uploads: There are 0 documents associated with this class.				Manage Documents
(Co-)Teachers:	Leonard Tampkins			Modify Coteachers
Section I	Room: 2-139	30 / 35 students	E-mail students	
Status: Accepted	Time: Sat 4:05pm-5:55pm	(view list)		
6358: Design and Build a Rocket »	Delete	View	Detailed Status	Create web page
Directors' review status: Accepted				View Students
Document uploads: There are 0 documents associated with this class.				Manage Documents
(Co-)Teachers:	Leonard Tampkins			Modify Coteachers
Section I	Room: 17-110 (Meet in Lobby 7)	15 / 15 students	E-mail students	
Status: Accepted	Time: Sat 10:05am-10:55am	(view list)		

Figure 70 Splash List of Classes

7.7.6 LAB TOURS AND ROCKETRY WORKSHOPS

The team invites local rocket groups (such as TARC groups) to participate in a workshop where students can not only learn about rockets, but also build and launch in at MIT.

7.7.7 WORK WITH MASSACHUSETTS AFTERSCHOOL PARTNERSHIP (MAPS)

The MAPS specializes in organizing afterschool programs for K to middle school students. The executive members of the team have contacted MAPS in hopes of creating a better outreach activity plan or other outreach ideas/activities.

7.7.8 SCIENCE ON THE STREET

As the USLI launch takes place during the Cambridge Science Festival the team will not be able to participate in the Cambridge city wide rocket day. However, the same group that runs this event told us that they were interested in having the MIT Rocket Team participate in the monthly Science on the Street events.

8 CONCLUSION

For its entry into NASA's University Student Launch Initiative, the MIT Rocket Team has chosen to develop a simplified flight control interface to use in conjunction with a Unmanned Aerial Vehicle to be deployed at 500 ft by a custom designed and fabricated carbon fiber rocket. The team's main goal in completing this challenge is to develop a method that will allow for a significant reduction in the skill and training needed for the successful operation of a rotorcraft. With this in mind the MIT Rocket Team anticipates that in the near future rotorcraft flight systems similar to the one being developed will be used on a greater scale than before for a wide variety of missions ranging from search and rescue, to reconnaissance and even rapid scientific data acquisition.

With these applications in mind, the MIT Rocket Team has developed a rocket capable of deploying a rotorcraft designed to fold up for storage inside of it. Furthermore, the team has designed a flight mission that will simulate a tracking and reconnaissance mission, while simultaneously completing the HALO experiment mission goals. During the flight mission, the rotorcraft will be used to visually locate the drifting rocket, while also gathering, transmitting, and storing all of the scientific data as mentioned in the HALO requirements. By completing both of these tasks, the MIT Rocket Team will prove the effectiveness of the flight system while performing the tasks for which it has been developed. To facilitate this mission, software is being written to perform these tracking methods autonomously. To make this a possible low cost, but robust system, off the shelf autopilot system will take in GPS coordinates and IMU attitude data in real time from the flight control system.

Once the preliminary design has been completed the team will move into the fabrication and testing stage. With a goal of creating a strong and light launch vehicle, the MIT Rocket Team has chosen a four-ply carbon fiber layup as the main material for a large percentage of the rocket. The MIT Rocket Team has great skill working with composite

materials, and for the past six years all rockets produced by the team have been fabricated out of fiberglass and/or carbon fiber. The development of a rotorcraft however is a new task for the MIT Rocket Team and the added complexities of designing an aircraft that could fit within a 6 in body tube has been no easy task. However, the Team has developed a simple and unique method to fold the arms of the rotorcraft allowing for a sufficiently large craft to reliably perform all necessary tasks. In the following months the MIT Rocket Team will transition from design work to testing and fabrication. With this transition, the team is committed to completing all tasks necessary to stay on the competition schedule. To help facilitate this task, the team has developed detailed schedule, and planning meetings are held on a weekly basis to ensure that all tasks are being completed on schedule.

9 APPENDIX

9.1 ROCKET MASTER EQUIPMENT LIST

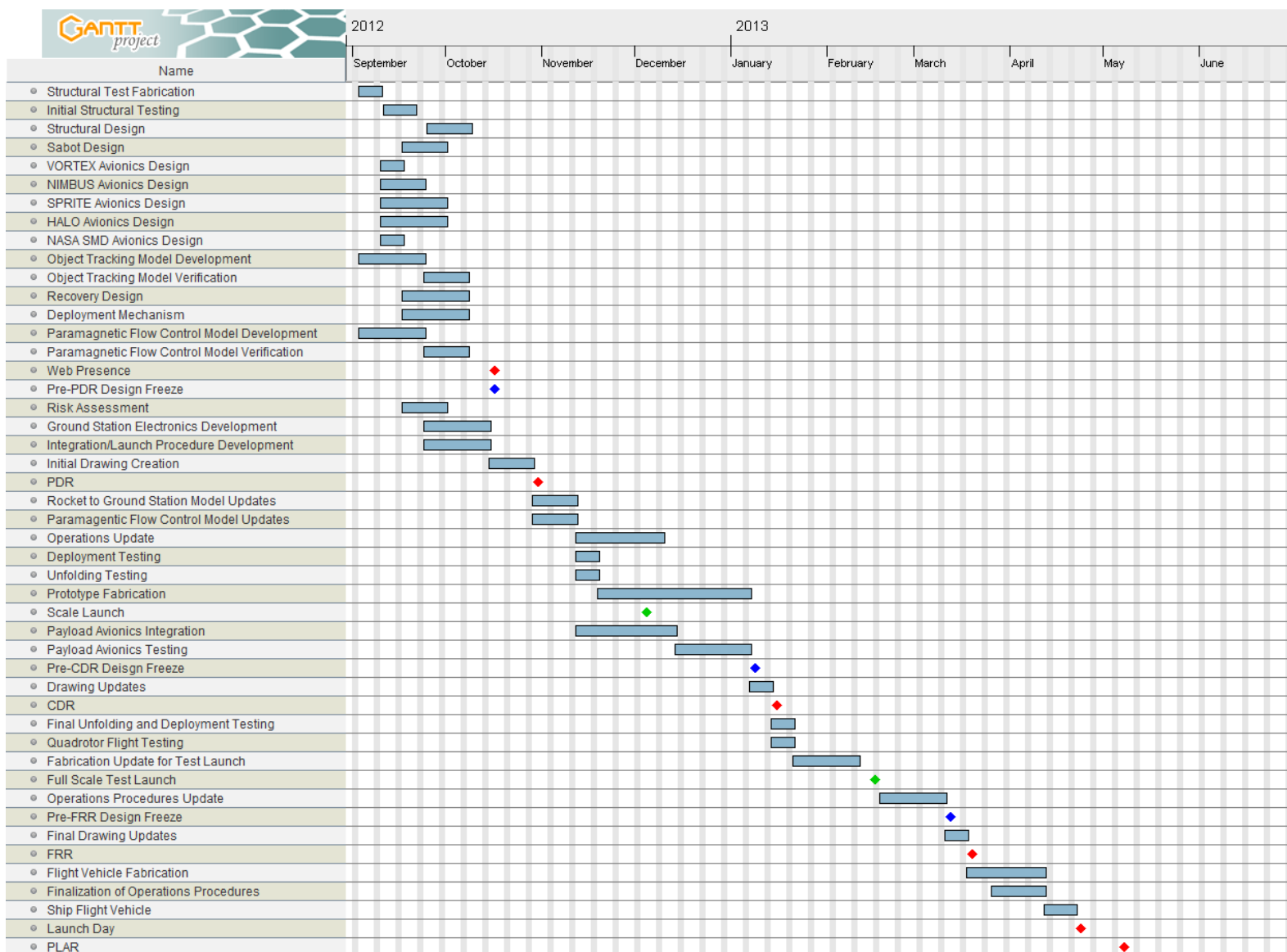
Master Equipment List				Updated on 10/28/12											
ID #	Subsystem	Item name	Usage Certainty	Description (Vendor, part #, etc.)	Cost/Item	Mass kg/Item	# Item	Location	Total Cost (\$)	Cost Marg	Margined Cost	Total Mass (kg)	Mass Measure	Mass Margin	Margined Mass
R01-01	Propulsion	Motor		Cessaroni L1115-P	\$347.00	2.394	1		247.00		247.00	2.394	0%		2.39
R01-02		Casing		Pro75-4G	\$305.00	2.01	1		305.00		305.00	2.01	0%		2.01
R01-03		Igniter		[comes with motor]	\$0.00	0	1		0.00		0.00	0	0%		0.00
Add rows above this row, do not delete this row															
Total									552.00	20%	552.00	4.404		20%	4.40
Allocation									600.00	20%	720.00	4.45		20%	5.34
R02-01-01	Airframe-Body	Stage Body: lower			\$91.00	0.90	1		91.00		91.00	0.9			0.95
R02-01-02		Stage Body: upper			\$109.00	1.02	1		109.00		109.00	1.02			1.02
R02-02		Bulkhead			\$10.00	0.09	1		10.00		10.00	0.0854			0.09
R02-03		Casing Spacing Ring			\$10.00	0.07	3		30.00		30.00	0.21			0.21
R02-04		Rail Guide		railbuttons.com	\$1.25	0.05	2		2.50		2.50	0.1			0.10
R02-05		Adhesive			\$2.00	0.03	20		40.00		40.00	0.6			0.60
R02-06		Fin			\$8.00	0.24	4		32.00		32.00	0.96			0.96
R02-07-01		Coupler			\$9.00	0.21	1		9.00		9.00	0.21			0.21
R02-08		Avionics Tube			\$20.00	0.17	1		20.00		20.00	0.167			0.17
R02-09		Avionics Plate			\$10.00	0.32	1		10.00		10.00	0.32			0.32
R02-10		Eye Nut		3274741	\$6.59	0.15	1		6.59		6.59	0.15			0.15
R02-12		Payload Support Bulkhead			\$50.00	0.61	1		50.00		50.00	0.61			0.61
R02-13		Motor Mount Tube			\$15.00	0.08	1		15.00		15.00	0.08			0.08
R02-14		Motor Retention Plate			\$10.00	0.05	1		10.00		10.00	0.05			0.05
R02-15		Avionics Bolt Doubler			\$10.00	0.08	1		10.00		10.00	0.08			0.08
R02-16		Inserts		91732A355	\$0.43	0.02	4		1.72		1.72	0.08			0.08
R02-19		Threaded Rod		9880AA496	\$3.63	0.16	1		3.63		3.63	0.16			0.16
R02-21		Access Door Nutplates		94579A100	\$0.12	0.00	16		1.96		1.96	0.048			0.05
R02-22		Access Door Bolts		92196A148	\$0.04	0.00	16		0.64		0.64	0.048			0.05
Add rows above this row, do not delete this row															
Total									445.09	20%	445.09	5.88		20%	5.88
Allocation									500.00	20%	600.00	5.90		20%	7.08
R03-01	Airframe-Fairing	Fairing Body			\$94.45	0.68	1		94.45		94.45	0.68			0.68
Add rows above this row, do not delete this row															
Total									94.45	20%	94.45	0.68		20%	0.68
Allocation									100.00	20%	120.00	0.7		20%	0.84
R04-01		Altimeter		Perfect Flight Stratologger	\$85.55	0.050	1		85.55		85.55	0.05			0.05
R04-02		Altimeter		Feather Weight Raven	\$155.00	0.025	1		155.00		155.00	0.025			0.03
R04-03		Battery		9v Battery	\$2.67	0.050	2		5.33		5.33	0.1			0.10
R04-04		Tracking Transmitter		bigredbee.com	\$85.00	0.010	2		170.00		170.00	0.02			0.02
R04-05		Kapton Tape			\$10.00	0.020	1		10.00		10.00	0.02			0.02
R04-06		Battery Holder		Digikey BHHV-PC-ND	\$3.30	0.050	3		9.90		9.90	0.15			0.15
R04-07		Bolts		92196A148	\$0.04	0.01	8		0.32		0.32	0.064			0.06
Add rows above this row, do not delete this row															
Total									430.10	20%	430.10	0.429		20%	0.43
Allocation									1,000.00	20%	1,200.00	0.9		20%	1.08
R05-01	Payload Support Equipment	Sabot Half			\$23.50	0.440	2		47.00		47.00	0.88			0.88
R05-02		Hard Point Half			\$20.00	0.240	4		80.00		80.00	0.96			0.96
R05-03		Stringer		94435A355	\$6.45	0.050	4		25.80		25.80	0.2			0.25
R05-04		Eye-Bolt: Sabot Holder		30671530	\$5.44	0.075	3		16.32		16.32	0.225			0.23
R05-05		Tubular Nylon			\$10.00	0.050	1		10.00		10.00	0.05			0.05
R05-06		Sabot Hard Point Brace			\$5.00	0.040	4		20.00		20.00	0.16			0.16
		Phenolic Tube			\$47.50	0.563	2		95.00		95.00	1.125			1.13
Add rows above this row, do not delete this row															
Total									294.12	20%	294.12	3.6		20%	3.60
Allocation									300.00	20%	360.00	3.7		20%	4.44
R06-01	Recovery	Main Chute		Rocketman 14ft Standard	\$155.00	1.020	1	http://www.the-rocketman.com/ct	155.00		155.00	1.02			1.02
R06-02		Main Chute Deployment Bag		TAC-9A	\$35.00	0.510	1	http://www.giantleaprocketry.com	35.00		35.00	0.51			0.51
R06-03		Drogue Chute		Rocketman 4ft Ballistic Mach 1	\$60.00	0.230	1	http://www.the-rocketman.com/ct	60.00		60.00	0.23			0.23
R06-04		Drogue Chute Protector		Wildman 30"x30" chute protector	\$18.00	0.080	1		18.00		18.00	0.08			0.08
R06-05		Shock Cord		McMaster #3510711	\$10.00	0.400	1		10.00		10.00	0.4			0.40
R06-06		Quicklink			\$5.00	0.010	4		20.00		20.00	0.04			0.04
R06-07		Charge+Wiring		Wildman WMOI	\$1.69	0.010	4		6.78		6.78	0.04			0.04
R06-08		Shear Pin		97263A081	\$0.05	0.002	4		0.20		0.20	0.008			0.01
R06-10		Black Powder		PowderInc: GMD5: P120080927.16.06-5	\$2.00	0.005	1		2.00		2.00	0.005			0.01
R06-11		Charge Released Locking Mechanism		http://fruitychutes.com/Recovery_1ether_Manual.pdf	\$85.00	0.020	1		85.00		85.00	0.02			0.02
R06-12		Shear Pin Insert		91732A203	\$0.46	0.002	4		1.82		1.82	0.008			0.01
R06-13		Recovery Locknut		90631A011	\$0.10	0.002	8		0.80		0.80	0.016			0.02
Add rows above this row, do not delete this row															
Total									394.60	20%	394.60	2.377		20%	2.38
Allocation									400.00	20%	480.00	2.4		20%	2.88
Allocation									2,900.00		3,480.00	18.05			21.66

9.2 QUADROTOR BILL OF MATERIALS

MIT Rocket Team USLI 2012-2013 CDR Version: Final

System	Short Name	Full Name	Part Number	Supplier	URL	Quantity	Cost Each(USD)	Cost Total	Mass Each(g)	Mass Total(g)	Width (cm)	Height (cm)	Length (cm)	ready to order?	date ordered	date received
Flight Control	ArduCopter Kit*	3DR ArduCopter Quad-C Frame + M 3D Roboti			https://store.3drrobotics.com/	1	449.99	449.99		0				yes		
	*ArduPilot Mega 2.5					1		0		0	4.064		6.109			
	*ESC					4		0		0						
	*Motor					4		0		0						
	*Propeller					4		0		0						
	*Power Distro Board					1		0		0						
	*GPS					1		0		0						
	Motor Battery	Turnigy 2650mAh 3S	T2650.3S.20	Hobby Kin	http://www.hobbyking.com/	1	11.44	11.44	225	225	13.7	4.3	1.7	no		
	Sonar	XL-MaxSonar-EZO		3D Roboti	http://store.3drrobotics.com/	1	44.95	44.95		0				no		
	3DR Radio	3DR Radio Telemetry Kit - 915 Mhz		3D Roboti	https://store.3drrobotics.com/	1	74.99	74.99		0				no		
								0		0						
Propulsion (Full Scale)	CCW Propeller	Wooden 13x4.5R prop	9329000078	Hobby Kin	http://www.hobbyking.com/	2	7.2	14.4	40	80						
	CW Propeller	Wooden 13x4.5 prop	9329000077	Hobby Kin	http://www.hobbyking.com/	2	7.2	14.4	40	80						
	Motor	Turnigy Aerodrive SK3	SK3-4240-620	Hobby Kin	http://www.hobbyking.com/	4	33.28	133.12	336	1344	4.2	4.2	7			
								0		0						
Science Payload	Single Board Computer	PandaBoard ES		PandaBoa	http://pandaboard.org/	1	161.64	161.64	81.5	81.5	11.43		10.16	no		
	Xbee Pro	Xbee Pro 60mW Wireless WRL-08742		SparkFun	https://www.sparkfun.com/products/10422.html	1	37.95	37.95		0				no		
	MAX232	IC DUAL EIA-232 DRV	296-6940-5-ND	Digikey	http://www.digikey.com/	5	0.83	4.15		0				no		
	External DIP Switch	SWITCH SPST GOLD S	CT2064ST-ND	Digikey	http://www.digikey.com/	2	0.95	1.9		0	1.143	0.9779	1.234	no		
	5V Regulator	IC REG LDO 5V 1.5A	T 296-13996-5-ND	Digikey	http://www.digikey.com/	2	0.8	1.6		0				no		
	9V Battery	ENERGIZER LS22		Amazon	http://www.amazon.com/	3	7.95	23.85	34.4	103.2				no		
	Lightning Detector		LD4-R1-A	Hobby Bo	http://www.hobbyking.com/	1	32.5	32.5		0				no		
	3 Axis Magnetometer	HMC5883L	SEN-10530	SparkFun	https://www.sparkfun.com/products/10422.html	1	14.95	14.95		0	1.8		1.8	no		
	Natural Radio Receive Explorer	E202		Sistel (Italy)	http://www.sistel.it/	1	311	311		0				no		
	Atmosphere Sensor	BMP085 Barometric		391 Adafruit	http://www.adafruit.com/	1	19.95	19.95		0				no		
	Langmuir Probe					1		0		0				no		
	EMF Sensor					1		0		0				no		
	JPEG Color Camera	LinkSprite LS-Y201	SEN-10061	Sparkfun	https://www.sparkfun.com/products/10422.html	4	49.95	199.8		0	3.2	3	3.2	no		
								0		0						
Reserve Parachute	Accelerometer with F	ADXL345				1		0		0						
	Boarduino	DC Boarduino (Arduino)	72	Adafruit	http://www.adafruit.com/	1	17.5	17.5		0	7.5	1	2	no		
	Barometer					1		0		0				no		
	9V Battery	ENERGIZER LS22		Amazon	http://www.amazon.com/	1	7.95	7.95	34.4	34.4				no		
	5V Regulator	IC REG LDO 5V 1.5A	T 296-13996-5-ND	Digikey	http://www.digikey.com/	1	0.8	0.8		0				no		
	Parachute					2		0		0				no		
	Tube					2		0		0				no		
	Explosive					2		0		0				no		
Air Frame	Trigger					2		0		0				no		
	Arm (not including Motor and prop)			In House Build		4			114.5	458				no		
	Arm Block			In House Build		1			215.76	215.76				no		
	Avionics Trays			In House Build		1			185.43	185.43				no		
Totals:								1578.83		2807.29						
							USD			grams						

9.3 SCHEDULE



9.4 CAD MODELS

9.5 MECHANICAL DRAWINGS

9.6 CIRCUIT SCHEMATICS

9.7 PCB DESIGNS

9.8 MANUFACTURING PLAN

9.9 CODE OVERVIEW

9.10 NIMBUS

NIMBUS

Mission Motivation

One Atmosphere Uniform Glow Discharge Plasma (OAUGDP) experiments have shown that it can accelerate flow and reattach boundary layers at velocities of several hundreds of meters per second. OAUGDP has not been applied to rockets for use as an active stabilization controller. Also, field testing of OAUGDP is very minimal. A control system and boundary layer measurement device will be built to test the possibility of using OAUGDP as a possible stabilization method and to acquire more field data on how OAUGDP systems perform in a dynamic environment over a range of pressures and neutral flow velocities.

In summary the team aims to:

- Study the effects of an Electrohydrodynamic (EHD) accelerated flow system on rocket flight stability

MISSION STATEMENT

The MIT Rocket Team aims to develop an inexpensive, customizable, and reusable rocket system with an EHD accelerated flow measurement and control system.

MISSION REQUIREMENTS

- The NIMBUS payload will meet the following objectives:
 - Easy integration
 - Reusable

- Powered from a low voltage source
- Safe: non-lethal currents
- Measure ability to control rocket attitude within the velocity range of _____ meters per second

PAYLOAD DETAILS

The stabilization system is a system integrated in the rocket's fiberglass nose cone that uses electrodes to accelerate the air around the nose cone. This effect reattaches the flow around the fins thereby reducing turbulent flow and improving the rocket's drag profile. Individually controlling the acceleration of the flow on each side of the fins should alter the drag profile of the fins causing the rocket to slightly change its orientation. The switching circuit for this system will be controlled by a gyroscope/tilt sensor with a fast sample rate and a fast microprocessor such as the STM32. This circuitry and power supply will be housed in the rocket avionics bay.

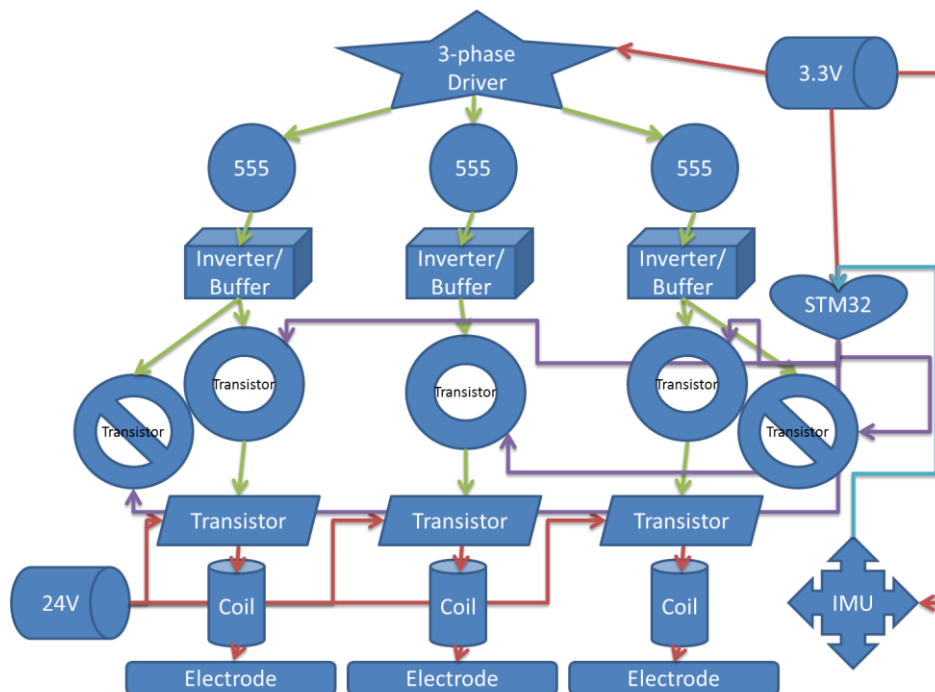


Figure 71 NIMBUS overview diagram

THEORY

“The development of the One Atmosphere Uniform Glow Discharge Plasma (OAUGDP) in a flat surface layer has made it possible to exert significant EHD body forces in the boundary layer above electrodes on aerodynamic surfaces.” (Roth, 2001) The neutral air is accelerated due to the EHD body force induced by peristaltic flow acceleration.

This acceleration is the result of using a “polyphase voltage phase supply to excite the OAUGDP at progressive voltage phases angles on successive linear electrode strips.” (J. Roth – Aerodynamic Flow Acceleration Using Electrohydrodynamic Effects) “Induced peristaltic velocities up to several hundred meters per second...may be possible.” (J. Roth – Aerodynamic Flow Acceleration Using Electrohydrodynamic Effects)

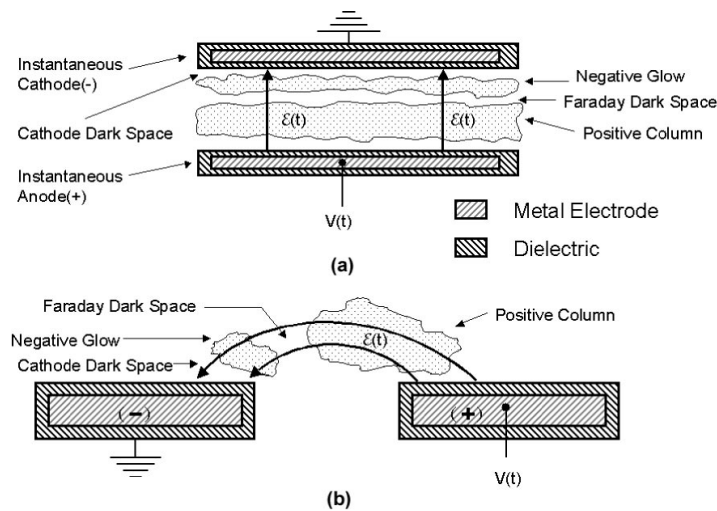


Figure 72 Electrode configuration for co-planer flat panels (J. Roth – Aerodynamic Flow Acceleration Using Electrohydrodynamic Effects)

Previous testing by _____ has observed the peristaltic acceleration using the flat-plate configuration with the following time averaged parameters: gap distance of 2 to 5 mm, volumetric power dissipation of 0.10 to 1 W/cm³, rf frequency from 3 to 10kHz, and electrode voltage of 3 to 16. These parameters play a major role in determining the initial high voltage driving source for NIMBUS. The basic flat-plate configuration used is based on the “asymmetric electrode configuration” developed by J Roth. This configuration is shown below.

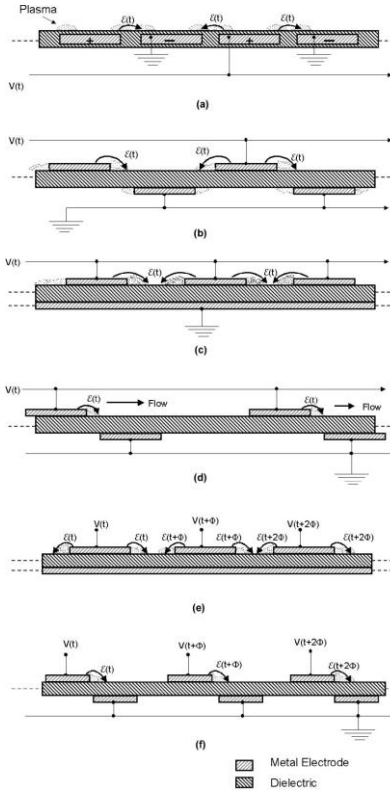


Figure 73 Asymmetric Electrode Configuration

Derived from the ion drift velocity, the governing equation for peristaltic flow acceleration gives the resulting neutral gas velocity from initial power source, material, and structural parameters.

$$E = \frac{V_0 2\pi}{NL}$$

$$v_p = \text{phase velocity (m/s)} = f_0 NL$$

$$v_{di} = \text{ion drift velocity (m/s)} = \mu E = \frac{eV_0}{M_i f_{in}} \frac{2\pi}{NL}$$

$$D = \text{air diffusion constant at } 25^\circ\text{C} = 1.76 \times 10^{-5}$$

$$k = \text{boltzmann constant} = 1.380 \times 10^{-23}$$

$$T = \text{room temperature (kelvin)} = 298.15$$

$$e = 1.6 \times 10^{-19}$$

$$\mu = \text{air mobility} = \frac{De}{kT} = 6.8441 \times 10^{-4}$$

$$f = \text{frequency (hertz)} = 2000$$

$$N = \text{number of electrodes per cycle (number of phases)} = 3$$

$$L = \text{distance between electrodes (meters)} = 0.041$$

$$v_p = 246$$

$$v_{di} = v_p$$

$$E = \frac{v_{di}}{\mu} = 3.5943 \times 10^5$$

$$V_0 = \text{applied voltage} = \frac{ENL}{2\pi} = 7.0363 \times 10^3$$

$$V_b = \text{breakdown voltage} = \frac{aPL}{\ln(Pd + b)} = 1.8610 \times 10^5$$

$$f_{min} = \frac{\mu V_0}{2\pi L} = 911.8907$$

The frequency and voltage needed to accelerate the local flow up to 246 m/s is 2 kHz and 7kV respectively. The values fall within the range of tested EHD values and meet the breakdown voltage and minimum frequency requirements.

Frequency	1-20 kHz
Voltage	1.5-9.5 kV
Electrode Gap	0.8-2.5 cm

Table 37 Confirmed characteristic parameter ranges for uniform glow discharge operation

LIST OF COMPONENTS	
Name	IMU Analog Combo Board – 5 Degrees of Freedom IDG500/ADXL335
Manufacture	Sparkfun
Vendor	Sparkfun
Part Number	SEN-11072
Cost	35.95
Dimensions	
Weight	
Input Voltage	3-16V

Gyro Range	500 degrees/second
Accelerometer Range	+/- 3g
Signals Out	Analog

Description

The IMU measures the attitude of the rocket.

Name	Atomik Ignition Coil for Venom 26cc Gas Engine
Manufacture	Atomik
Vendor	Atomik
Cost	14.99
Dimensions	
Weight	

Description

Raises the voltage level of outputted by the transformer.

Name	High Voltage Power Supply Kit
Manufacture	Images Scientific Instruments
Vendor	Images Scientific Instruments
Part Number	HVPS-01
Cost	84.95
Dimensions	
Weight	
Input Voltage	24V
Output Voltage	7-17 kV
Output Frequency	1000-2000 Hz
Maximum Current	300 mA

Description

Outputs a high voltage and high frequency signal from an low voltage DC input.

Name	LM555
Manufacture	Fairchild
Vendor	Digikey
Part Number	LM555CNFS-ND
Cost	0.43
Dimensions	
Weight	
Input Voltage	4.5-16V
Maximum Current	200 mA
Footprint	8-DIP

Description	
Timer	
Name	LM2904P
Manufacture	Texas Instruments
Vendor	Digikey
Part Number	296-9528-5-ND
Cost	0.49
Dimensions	
Weight	
Input Voltage	2-14V
Output Voltage	2-14V
Output Frequency	20 kHz
Maximum Current	800 mA
Footprint	8-SOP

Description	
3-phase brushless DC sinusoidal sensor-less fan motor driver	

Name	HV Transistor TBD
Manufacture	Fairchild
Vendor	Digikey
Part Number	LM555CNFS-ND
Cost	0.43
Dimensions	
Weight	
Input Voltage	4.5-16V
Maximum Current	200 mA
Footprint	8-DIP

Description	
Drivers the frequency of the transformer	

Name	STM32F4DISCOVERY
Manufacture	STMicroelectronics
Vendor	Digikey
Part Number	497-11455-ND
Cost	14.90
Dimensions	

Weight	
Input Voltage	3V or 5V
Gyro Range	500 degrees/second
Accelerometer Range	+/- 3g
Signals	Analog, SPI, UART, I2C, PWM

Description

Main CPU

Batteries	3.3V x 1; 24V x 1
Output Voltage Range	3.3V-7kV
Current Maximum	300mA

OPERATIONS DURING ROCKET ASCENT

During ascent the EHD flow acceleration system will turn on various rows of electrodes on various sides of the fins depending on the attitude of the rocket. The EHD flow measurement system will try to measure any induced changes in the flow velocities or local boundary layers.

BUDGET

NIMBUS

Structure	30
Avionics	250
Power	30

9.11 DESCOPE PLAN

As the nature of this project is very complex in order to ensure that the team does not run over schedule, over budget, or that deliverables are not subpar sections of the project will be descope in order of their importance. Sections will be descope once the team determines that their milestones cannot be met without sacrificing resources from more important sections.

The order at which sections will be descope is as follows:

1. NIMBUS
2. Object tracking
3. HALO

9.12 OBSERVED REGULATIONS AND SAFETY REQUIREMENTS

9.13 SIGNED DOCUMENTS

9.13.1 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

9.13.2 EDUCATIONAL ENGAGEMENT FORM

Educational Engagement Form

Please complete and submit this form each time you host an educational engagement event.

(Return within 2 weeks of the event end date)

School/Organization name:

Date of event:

Location of event:

Grade level or age range and number of participants: *(If you are able to break down the participants into grade levels: PreK-4, 5-9, 10-12, and 12+, this will be helpful.)*

Participants	Direct Interactions	Indirect Interactions
K-4		
5-9		
10-12		
12+		
Educators (5-9)		
Educators (other)		

Direct Interactions: A count of participants in instructional, hands-on activities. This includes instructor- led facilitation around an activity regardless of media (e.g. DLN, face-to-face, downlink.etc.).

Indirect Interactions: A count of participants in enrichment activities. This includes presence at STEM events, but not necessarily direct active participation.

Are the participants with a special group/organization (i.e. Girl Scouts, 4-H, school)?

Y N

If yes, what group/organization?

Briefly describe your activities with this group:

Did you conduct an evaluation of your educational engagement? If so, what were the results?

9.14 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 fiftenths 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]

§ 101.27ATC 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; 29

(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, 30

(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]

9.15 HIGH POWER ROCKET SAFETY CODE

NFPA 1127 “Code for High Power Rocket Motors”

[<http://www.nar.org/NARhpssc.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.

10 MISC SAMPLE DOCUMENTS

10.1 ADVERTISEMENTS

10.1.1 OFFICIAL 2012 DEPARTMENTAL POSTER



10.1.2 MULTIMEDIA DISPLAY



10.1.3 BRIGGS FIELD FLYER

10.1.4 MIT TECH NEWSPAPER

10.2 OUTREACH ACTIVITY

10.2.1 LESSON PLANS

10.2.2 ACTIVITY SHEETS

10.2.3 SIGN-IN SHEETS

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