NASA University Student Launch Initiative

University of Alabama in Huntsville 2013-2014

Proposal

November 22, 2013

Propulsion Research Center, Huntsville, AL 35805, 256.701.4665

Prometheus: Academic Research Sounding Rocket

University of Alabama in Huntsville

301 Sparkman Drive
Huntsville, AL 35899

Payloads

Name	Reqt #	Description
Landing Hazard Detection System	**3.1**	Hazard Detection Camera using onboard processor and live data feed
Microgravity Propellant Management System	**3.2.1.2**	Demonstrate the ability to control the position of a simulated propellant in a microgravity spacecraft tank, using dielectrophoresis.
Supersonic Effects on Vehicle Coatings	**3.2.2.4**	Various common external coatings will be analyzed preflight and post flight to analyze the effect of supersonic flight on rocket coatings.
Transonic Vehicle Aerodynamics	**NA**	Vehicle will collect flight data through the transonic region in order to determine Axial, Normal, and Pitching Moment Coefficients.

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Team Organization: ~17 Students

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Pheonix Missile Works: TRA#81/NAR#682

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1. Introduction

The Charger Rocket Works (CRW) team, a student organization at the University of Alabama in Huntsville, will design, build, and fly a rocket, Prometheus, for the NASA University Student Launch Initiative (USLI) Competition. The rocket will carry four payloads, three in direct support of the competition and a fourth in support of a separate NASA low-cost CubeSat launch project called the Nanolaunch 1200. The three USLI payloads are listed in Table 1.1.

Table 1.1: Payload Options

Requirement	Description
3.1	Hazard Detection Camera using onboard processor and live data feed
3.2.1.2	The payload will have a goal of demonstrating the capability to control the position of a simulated propellant in a microgravity spacecraft tank, a phenomena known as dielectrophoresis. If the liquid in the experiment behaves according to the characteristic equation, then the technology will have been verified.
3.2.2.4	Various common coatings will be analyzed preflight and post flight to analyze the effect of supersonic flight on rocket coatings.

The payload in support of the NASA Nanolaunch 1200 will be a data acquisition system that will utilize a geometrically similar scale model to obtain several aerodynamic coefficients and forces through test flights. Of primary concern are: the axial drag coefficient, base drag, and normal force. The pitching moment coefficient of the rocket is a secondary objective, as there is some difficulty in obtaining it from flight testing. The rocket will be required to collect data throughout the transonic region (Mach 0.7- 1.4) to augment current simulation techniques which may not accurately model the flow behavior through this region. A primary goal of the Nanolaunch project is to reduce the cost of launching CubeSats into orbit, so the scaled model will be constructed using 3-D printed or commercially available parts wherever possible.

Students from the Mechanical and Aerospace Engineering (MAE) department, in collaboration with students from other disciplines, will design, build, and fly the rocket as part of a two semester senior design course. In addition, students will use public relation resources to inspire younger generations and encourage them to chase a dream in the science, technology, engineering, and mathematic fields. The MAE students will be assisted by faculty and staff members from the University of Alabama in Huntsville MAE Department and Propulsion Research Center (PRC). This document outlines the long term planning required for achieving success in the USLI competition.

2. Technical Design

The 2013-2014 Charger Rocket Works rocket will be a single stage design with a drogue and a main parachute as seen in the Concept of Operations in Figure 2.1. To support the NASA Nanolaunch 1200 the outer geometry of the vehicle will be a scaled replica of the Nanolaunch 1200. The outer mold line for the geometry is being coordinated with Dr. Jonathan Jones of NASA, so that true geometric similarity can be achieved. In order to allow for many flight options, the vehicle will be designed to accommodate multiple sized standard hobby rocket motors. The vehicle body will be fabricated from standard hobby rocketry materials.

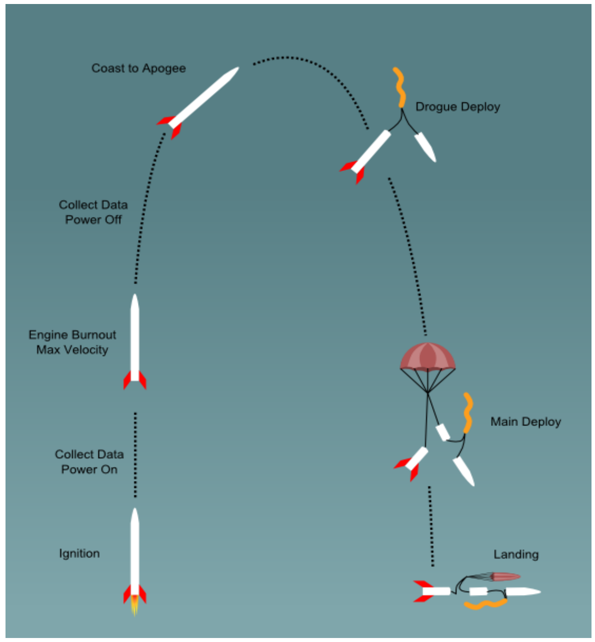


Figure 2.1 Concept of Operation Diagram

2.1. Vehicle Design

The rocket will be a scaled replica of the Nanolaunch 1200 as seen in Figure 2.1.2. The Prometheus will be 11.43 *cm* (4.5 *in*) in diameter. The overall length will be 3.04 *m* (9.98 *ft*). The vehicle will be a single stage rocket with three separate body sections. The lower section of the rocket will house the motor and main parachute and the deployable camera. The central section will house the recovery system electronics and the majority of the payload hardware. The forward section will contain the tracking hardware and the drogue parachute. In order to meet some payload objectives the rocket will also have a small compressed gas thruster or a retractable protuberance to allow the rocket to momentarily pitch approximately 10 degrees during flight and then return to straight flight. This device will be located in the forward section of the rocket. Although shown in Figure 2.1.2 the rocket designed for competition will not have an external nozzle protruding below the exit plane of the commercial solid rocket motor.

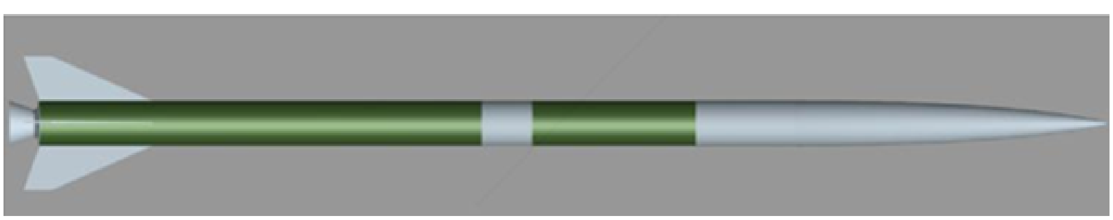


Figure 2.1.2: Nanolaunch 1200

The objective to achieve supersonic flight introduces additional design consideration over those for pure subsonic flight. The vehicle will have shock waves emanating from leading edges. This will result in high pressures and high temperatures on those surfaces. Fin flutter over a wide range of velocity must be considered. Additionally in order to use a minimum motor size, vehicle weight will be even more of a primary driver of the material selection. A variety of body materials are being considered based on their effectiveness for the design as well as cost and manufacturability. 3-D printed plastics or 3-D printed titanium will likely be used for reinforcement regardless of the final material choice for the body tube. Finite Element Modeling will be done on all body components to validate the vehicle safety margin. CAD models of the rocket will be designed to aid with the modeling and aerodynamic predictions. A Computational Fluid Dynamics package will be used to analyze the rocket design. Fin designs will be analyzed for Fin Flutter for both sub sonic and supersonic ranges.

2.2. Flight Projections

Current projected altitudes predict the rocket will fly to 5490 *m* (18,000 *ft*). This projected altitude was reached using custom developed in house code. The in house code is one degree of freedom code that takes into account the change in drag with increasing Mach as well as the change in air density with increased altitude. This result was also verified using open source rocket trajectory codes with reasonable similarities. This altitude is necessary due to the requirement to reach Mach 1.4.

2.3. Recovery

The vehicle will use a dual deployment system to safely and quickly return the vehicle to ground after launch. This will utilize a redundant system of at least two commercially available altimeters with independent power sources; the PerfectFlite Stratologger and Featherweight Raven II are currently being considered. These altimeters will be housed in their own shielded compartment to limit interference from any other electrical components which could cause a premature deployment. A drogue parachute will be deployed near apogee using a black powder charge. The drogue will be sized to allow the vehicle to descend from apogee at a high, but controlled, rate in order to minimize the drift from the launch site. A main parachute will be deployed at a predetermined altitude, through the use of a black powder charge, designated by the altimeter to slow the vehicle during the final descent. The main parachute will be sized such that the vehicle will return to the ground with a kinetic energy of less than 101 *N·m* (75 *ft·lbf*). Both the drogue chute and main parachute will be manufactured by the CRW team using which ever techniques and hardware are deemed necessary. All components of the recovery system will be thoroughly tested in accordance with all CRW health and safety plans to verify their function.

2.4. Motor Selection

The rocket will use a commercially available solid rocket motor. In order to allow for multiple test flights, the motor mounting system in the vehicle will be designed to accommodate multiple size motors. It is desired to be able to use, 54 *mm* (2.1 *in*), 75 *mm* (3.0 *in*), and 98 *mm* (3.9 *in*) motor cases with minimal changes to the vehicle. The ability to use smaller motors will offer more opportunities for test flights of the vehicle at lower cost per flight. If adaptable motor selector becomes too complicated of a problem for the design, then the efforts will be made to only accommodate 54 *mm* (3.0 *in*) and 98 *mm* (3.9 *in*) motors. A level 2 motor is being considered, but a level three may be required to accelerate the rocket with all of the required payloads to the Mach 1.4 requirement. A high impulse motor provides the fast acceleration needed to reach the required speed yet keep the rocket under the flight ceiling of 6096 *m* (20,000 *ft*).

2.5. Payload Design

As mentioned earlier the rocket will contain four independent payloads: a ground hazard detection system, propellant management in microgravity, effects of supersonic flight on coatings, aerodynamic coefficients for the Nanolaunch 1200. The majority of the data collection will take place from two key portions of the flight: as the vehicle begins to travel through the transonic and into the supersonic region, and the time immediately before and after apogee. As the rocket begins to go supersonic, the payloads for monitoring the effects of the surface coatings and those recording data for the Nanolaunch 1200 project will be recording changes in the pressure at the surface of the rocket body and pressure at the base of the rocket. An attempt to carefully pitch the rocket off its vertical trajectory will also be carried out around this time in order to determine the pitching moment coefficient from accelerometer data. As the rocket approaches and achieves apogee, the propellant management payload will be experiencing low to zero G's of acceleration, where it will be recording video of the dielectric fluid's behavior. Once the rocket has reached apogee, the drogue chute will be deployed. The camera will be deployed with the main parachute and begin monitoring the ground for landing hazards. Due to ambitious schedule of the project, and the scope encompassed by the payloads, the CRW team will implement a strategy to use additional on-campus resources for assistance during the payload development. Members from previous CRW teams will be sought for guidance and technical support. The hazard detection system algorithm will be developed through a student design project in a Computer Science Engineering course. At least one member of the current team will oversee work farmed out to other organizations.

2.5.1. **Propellant Management in Microgravity**

CRW will build on the work done for the UAH SLP rocket from 2012-2013 to study the use of dielectrophoretic forces to manage propellant storage in microgravity. This experiment is based on work conducted by James B. Blackmon as published in "Collection of Liquid Propellants in Zero Gravity with Electric Fields" in the Journal of Spacecraft and Rockets, Vol. 2, Number 3, Pages 391-398, May-June 1965. For this rocket, a redesigned payload will be developed to more thoroughly study the ability to control the position of liquid propellant using electric fields. Using the results gathered from last year's flight test, the experimental approach will be improved through the use of stronger electric fields and an improved imaging system. The payload will consist two tanks containing a fluid with a dielectric constant similar to typical propellants. One pair of electrodes will be connected to an open circuit high voltage supply to provide an electric field in the range of 10 -20 *kV* in the tank. The other tank will serve as a control volume and will have no electric field. Both tanks will have a back light and a camera to record fluid motion during flight. During flight the payload will turn on the electromagnet field and the two cameras as the rocket approaches apogee. Fluid motion will be recorded and saved to onboard memory for evaluation after recovery. The payload will include safety features to ensure that the high voltage risk to both onboard electronics and personnel is mitigated.

2.5.2. **Environmental effects of supersonic flight on vehicle paint/coatings**

Supersonic flight places the rocket and its paint/coatings under severe friction. This friction causes high temperatures and large forces on the paint/coatings. The effects of supersonic flight on the coatings will be evaluated by observing the condition of the surface before and after the flight. Temperature sensors will be placed on the inside of the rocket body normal to the different surface coatings to measure any temperature changes experienced by the different surfaces as the heat is conducted through the rocket body.

A variety of common paints and coatings suitable for rocketry will be painted on the rocket. The surface coating will be analyzed before the flight using an optical microscope or scanning electron microscope and afterwards to evaluate the results of the supersonic flight.

2.5.3. **Hazard Detection Camera System**

A camera and live data feed from the descending rocket will be designed to analyze the ground and detect potential hazards. This payload will be deployed from the rocket with the main parachute and attached in such a way to be the lowest descending part of the rocket to capture the clearest images of the ground. A camera stabilization system involving the use of gyroscopes may be required to obtain clear images. The team will work with a computer science engineering design team to develop the analysis software. Potential hazards are considered to be water, trees, rough terrain or other objects potentially damaging to the rocket or its payload. Early ideas for detection methods include analyzing color, comparing sequential frames to determine roughness or terrain, or analyzing patterns in the images for known hazardous shapes. The data analysis will be performed by an onboard processor with the results transmitted in real-time to a ground station.

2.5.4. **Aerodynamic Coefficients for the Nanolaunch 1200**

This payload revolves around the acquisition of the necessary data from actual rocket flights to calculate several coefficients experimentally. Unlike many experiments where the payload is separate from the rocket, this payload and the rocket flight are tied together. This project has the requirement that the rocket have complete geometric similarity to the Nanolaunch 1200. For the Prometheus flight test, the payload will consist of an array of sensors that will measure the vehicle acceleration, orientation of the vehicle, position in space relative to the launch site, pressure at several points on the vehicle surface, and skin temperature. The payload will also include a device to disturb the rocket off its vertical trajectory while in flight. This payload will allow the analysis team to calculate several aerodynamic coefficients including the axial drag coefficient, pitching moment, and normal force. Design considerations will have to be made in order to allow for the separation of the vehicle's sections during the recovery. Either independent DAQ systems for the upper and lower sections or a wiring harness that allows for the separation of the sections will be used.

2.6. Primary Requirements

The requirements are divided into Vehicle, Recovery, Payload, and additional requirements in support of the Nanolaunch 1200. The requirements are split into a minimum capability needed to successfully complete the mission and a desired capability that enhances the results.

2.6.1. **Vehicle Requirements**

Mission Parameter	Desired Capability	Minimum Capability
Nanolaunch 1200 Geometric Similarity	Complete Geometric Similarity	Geometric Similarity
Nanolaunch 1200 CG/CP Similarity	CG/CP Similarity through entire flight	CG/SP similarity at burnout for final test configuration

Motor Adaptivity	Ability to accommodate multiple standard hobby rocket Motor Sizes	Ability to accommodate multiple length motor cases for single standard motor size.
Materials	Standard hobby rocketry body materials	Standard hobby rocketry body materials
Dual Deployment	Dual deploy	Dual deploy
Structural Safety Margin	4	1.5
Flight Perturbation Device	In flight displacement from straight level flight	In-flight displacement from straight level flight
Target Altitude	Not exceed 18,000 ft. above ground level	Not exceed 20,000 ft. above ground level
Successful Subscale Launch	Multiple successful subscale launches prior to FRR in its final flight configuration with actual payload	Successful subscale launch prior to FRR in its final flight configuration
Recoverable and Reusable	Capable of being launched multiple times on the same day without repairs or modifications	Capable of being launched again on the same day without repairs or modifications

2.6.2.**Payload Requirements**

Mission Parameter	**Desired Capability**	**Minimum Capability**
High Voltage Dielectric Test	Increased voltage from previous experiments	Same voltage as previous experiments
Microgravity	Experience several seconds of low g to run experiment	Experience a second of low g to run experiment
Coatings and Paint	Eight different coatings or paints for analysis	Four different coatings or paints for analysis
Preflight Post flight surface analysis	Electron Scanning Microscope images of the surface before and after flight	Optical microscope analysis of the surface before and after flight
Hazard detection camera	Hang a stabilized camera below the rocket on decent	Hang a camera below the rocket on decent
Live Data Feed	Images returned in real time with hazards marked	Data on if the ground below is clear of hazards
Recoverable and Reusable	Capable of being launched multiple times on the same day without repairs or modifications	Capable of being launched again on the same day without repairs or modifications

2.6.3.**Recovery System Requirements**

Mission Parameter	**Desired Capability**	**Minimum Capability**
Recovery System Redundancy	Redundant systems for parachute deployment	Redundant systems for parachute deployment
Air Braking System	Deploys after data collection to reduce vehicle apogee	Not Required

Custom Parachute	A custom parachute system designed by the team	A custom parachute system designed by the team

2.6.4.**Additional Nanolaunch 1200 project requirements**

Mission Parameter	Desired Capability	Minimum Capability
Surface Pressure Measurements	10 sensors	4 sensors
Base Pressure Measurement	5 sensors	3 sensors
Pitot Probe	Single Sensor on Nose of Vehicle	Single Sensor on Nose of Vehicle
Acceleration Measurement	Redundant Acceleration measurements in all three normal directions	2 Three Axis Accelerometers
Vehicle Orientation Measurement	Redundant Orientation measurements	2 Three axis gyroscopes
High Speed Data	1000 Hz during flight	200 Hz
Data Storage	Real time data streaming to ground station, with onboard backup	Onboard storage only
Altitude Measurement	Barometric based Altimeters	Barometric based Altimeters

2.7. Technical Challenges

The technical challenges that will require strategic planning and critical thinking to overcome were divided into two sections, the vehicle and payload. The vehicle challenges were quantified based on maintaining structural integrity throughout the flight, examples include: vehicle stability loss due to fin flutter or pitching during flight, ensuring redundant recovery systems are in place, and preventing fin and body damage upon landing. The payload challenges were quantified based on survivability of the electronics under the extreme temperatures and G loading experienced during flight. Additional payload challenges include maintaining GPS tracking; live data feed, and post processing of all of data to extrapolate the aerodynamic coefficients.

2.7.1.**Vehicle Challenges**

Risk	**Probability**	**Impact**	**Mitigation**
Fin flutter	Average	Loss of Vehicle Stability Structural Damage	Increased fin Stiffness Analysis Subscale Testing
Over Pitching of the rocket during flight	Average	Imbalance Launch Rail Complications Loss of vehicle stability	Proper Balancing, Proper Rail Configuration Analysis Predictions to ensure Vehicle can return to stable flight after pitching Subscale testing
Recovery System Deployment Failure	Average	Electrical failure, Parachute Failure	Proper Packing, Redundancy Electronics Ground Testing

Structure Failure	Low	Damage from flight or landing, Design Failure	Factor of safety, Finite Element Analysis
Adaptive Motor Mount Failure	Average	Loads not transferred to body tube Motor ejected from vehicle	Finite Element Analysis Subscale testing Ground Testing

2.7.2.**Payload Challenges**

Risk	**Probability**	**Impact**	**Mitigation**
High G Load (Payload)	Average	DAQ system fails and launch data is lost. Requires DAQ system reevaluation and re-launch causing project delay.	Keep G load down by using longer slower burning motors. Pick High G components for DAQ system.
High G Load (Avionics)	Average	Avionics system fails and rocket fails to deploy recovery system. Vehicle impacts ground at terminal velocity.	Keep G load down by using longer slower burning motors. Pick High G components for avionics system.
Size Constraints	Low	Failure to fit all required components into Rocket Structure and payload will be downsized	Set size restraints on payload teams that insure sufficient space for internal payloads.
High Temperature	Low	Avionics or DAQ fail due to high temperature loads.	Ensure electronics are not in direct contact with high temperature surfaces.
Data failure	High	Loss of ability to record data during flight; inaccurate data	Completion of successful testing prior to launch; ensure that test data and predicted results are in agreement; check all connections during preflight checklist
Power loss to one or more systems	Average	Incomplete or total loss of data collected; possible destruction of rocket due to improper altimeter function	During preflight checkouts require that batteries have adequate capacity and are fully charged
Wire separation	Average	Loss of avionics power; avionics sensors unable to communicate with the rest of the rocket; improperly deployed recovery system	Ensure proper solder joints and connections; check wire connections with a multimeter during preflight checklist
GPS lock failure or loss of signal	Average	Possible loss of the rocket	Test GPS abilities and RF capabilities before use

3. School and Team Information

3.1. School Information

The University of Alabama in Huntsville (UAH) is a public university located in the Northeastern section of Alabama on the edge of Cummings Research Park, the 2nd largest research park in the United States. UAH enrolls over 7,500 students annually, of which nearly half are science and engineering majors. It also has the highest average incoming freshman ACT score among Alabama's public universities. The university has a history of providing outstanding support for student led teams in design-build competitions which has led to a track record of success in many of these competitions including: NASA University Student Launch Initiative, NASA Moonbuggy Competition, NASA Microgravity University, ASCE Concrete Canoe, NASA CANSAT, SAE Mini-Baja, and many others.

3.2. Team Information

The students on the CRW team are participating in the USLI program through a two-semester senior design course, MAE 490/493 Rocket Design. The team will consist of approximately 20 senior design students from the MAE department and 5 additional students from CPE or EE departments to support the payloads. The CRW team will be supported by UAH faculty and staff. The faculty advisor will be Dr. Robert Frederick, who has been a part of the UAH family for over 20 years. He is currently a professor in the UAH MAE Department and is currently the Director of the UAH Propulsion Research Center. Dr. David Lineberry will be the course instructor and this year will be his third year as the Rocket Design course instructor. Dr. Lineberry is a Research Engineer at the UAH Propulsion Research Center. Mr. Amit Patel is a Graduate Research Assistant for the Propulsion Research Center and will be functioning as a safety officer.

3.3. Organizational Structure

To meet the difficult assignment of designing, fabricating, and testing the Prometheus system the MAE 490 course students have created an organization chart in order to distribute the workload. The team organization described in the following sections will ensure the team and sub-teams are interacting across a broad range of design tasks. The team has been divided up based on task types. Four general areas were found, Analysis, Design/Hardware, Avionics/Payload, and System Integration. A layout of the team can be seen in Figure 3-1.

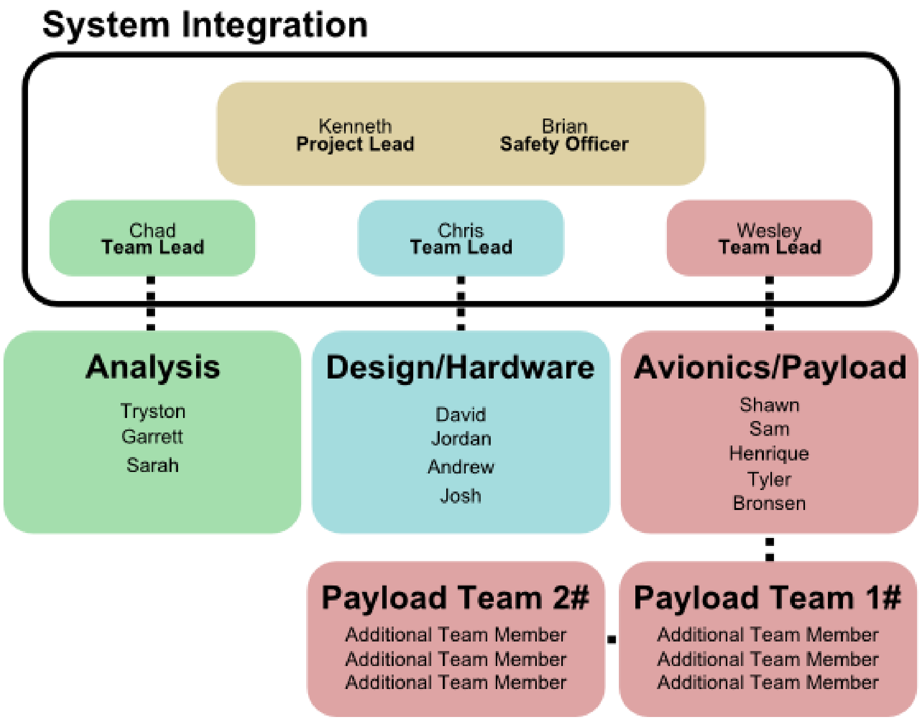


Figure 3-1: Team Organization

3.4. Analysis Team

The analysis team is responsible for pre-flight predictions and post-flight data analysis. This covers advanced analysis for other teams. The Analysis Team Lead is responsible for coordinating this function between the other teams. Once analysis request from the other teams have been given to the analysis team it is the team leads job to assign them to the appropriate analysis team member.

3.5. Design/Hardware Team

The design/hardware team is responsible for all final designs, CAD modeling, finite element analysis, and the actual physical construction process. This team will acquire the needed materials and be the primary source responsible for manufacturing components. The design/hardware team lead is responsible for coordinating with the avionics/payload team to insure the rocket structure matches the required payload specifications to measure the require data.

3.6. Avionics/Payload Team

The avionics/payload team is responsible for all of the internal components of the rocket. DAQ and avionics are both handled by the team as well as the separate recovery electronics. The avionics/payload team lead is responsible for keeping the avionics/payload team on track and assigning task to team members.

3.7. Payload Team 1

Payload team 1 is responsible for the design and fabrication of the dielectrophoresis payload. Additional team members will be identified for this payload team to help support the Propellant Management in Microgravity payload. Payload team 1 will fall under the leadership of the Avionics/Payload team lead.

3.8. Payload Team 2

Payload team 2 is responsible for the design and fabrication of the landing zone hazard assessment system. Computer Science Engineering students will be brought on as additional team members to collaborated with for Payload 2. Payload team 2 will fall under the leadership of the Avionics/Payload team lead.

3.9. Project Lead and System Integration

The Project Lead is responsible for keeping the entire team on track. The budget is managed by the project lead and all purchases have final approval through the project lead. Document editing and submission will primarily happen through the project lead with assistance from the safety officer. The Project Lead is also the System Integration (SI) lead and is responsible for keeping the SI team on track. The System Integration team is responsible for making the final call on all major decisions and for being the primary method that all of the teams stay on the same page

3.10. Safety Officer

The Safety Officer will manage all working documents (MSDS, evacuation routes, safety reviews, incident reports, and test operation procedures), ensure that all test procedures are followed correctly, and give pre-launch safety reviews. The Safety Officer will perform all pre-flight checklists and ensure the entire rocket and all components are flight ready before launch. The safety officer will also function as the test engineer.

4. Facilities

The CRW team will have the ability to access several local facilities for the purposes of manufacturing the final sub scale Nanolaunch vehicle. These facilities include the Charger Rocket Works Laboratory, the Propulsion Research Center, the UAH MAE Machine Shop, the UAH Wind Tunnel, and the Reliability and Failure Analysis Lab. These allow for fabrication, assembly, and testing all in-house on the UAH campus. The capabilities of these facilities are detailed in the following sections:

4.1. Charger Rocket Works Laboratory

The Charger Rocket Works Laboratory is a workshop located in the Propulsion Research Center. The workshop is equipped with two drill presses, a chop saw, a jig saw, a belt sander, a dust & particulate air filtration system, a self-closing hazardous materials storage locker, payload and avionics work stations, an assembly area, and three laptop computers. The workshop also contains a whiteboard for collaborative activities. All electrical work, simple manufacturing activities, and the final assembly will be completed in this workshop. Additionally, all rocket components and supplies will be stored in this room. More complex manufacturing will be conducted in the UAH MAE Machine Shop (see section 4.3).

4.1.1. **Payload and Avionics Work Station**

The payload and avionics work station has a stock of basic electrical components, shadow boards for tool storage, soldering station, and electronics diagnostic equipment. The station is intended for non-structural fabrication.

4.1.2. **Recovery Work Station**

The recovery work station has the parachutes, drogues, shock cord, and ancillary hardware accumulated from past years of CRW participation in USLI. There are also sections of past airframes available for testing various configurations of recovery system packaging. The Propulsion Research Center also has a test cell area which allows for safe parachute deployment testing on school property.

4.1.3. **Propulsion Work Station**

The propulsion work station contains the motor cases, enclosures, and adapters remaining from past years of CRW participation in USLI. There is a student built vertical thrust stand equipped with a 1000 lbf load cell and data acquisition card (DAQ) that transmits thrust data to a dedicated laptop for recording and analysis. This stand is shown in Figure 4-1.

Figure 4-1: CRW Static Test Stand

4.2. Propulsion Research Center (PRC)

The PRC is a research center located on the campus of UAH. The Center has experience with liquid, gel, hybrid, electric, and solid propulsion system testing, as well as experience with combustion analysis, optical measurement, cryogenic systems, advanced diagnostic techniques, CFD modeling, verification and validation, and related technologies. The PRC has a state of the art propulsion laboratory which includes a hot-fire propulsion test stand and data acquisition system. The stand has a rocket test cell as shown in Figure which will allow the CRW team to perform static testing on rocket motors and ejection charges. During these tests, the team will have the capability to obtain temperature, thrust curve, pressure, and acoustic data sets for all systems tested. The data acquisition system used by the PRC also has the capability to obtain data through a variety of other instrumentation. All propellants, black powder, and e-matches are stored in the PRC dedicated Magazine for DOT Class 1.3 Propellant.

Figure 4-2: Propulsion Research Center Test Stand

4.3. MAE Machine Shop

The MAE Machine Shop at UAH is located inside the western wing of Olin B. King Technology Hall. The machine shop supports UAH College of Engineering students during the fabrication process of design projects. The purpose of the shop is to teach students how to run equipment such as lathes, mills, band saws, Computer Aided Manufacturing (CAM), and numerically controlled machines (CNC) as well as other basic machining tools as part of the design process. UAH employs an experienced machinist who has an office inside the machine shop. This machinist works to ensure the safety of all students by providing training and supervision. The facility is access controlled to ensure that only experienced students can operate the machinery.

The machining capabilities of the UAH MAE machine shop are as follows:

1) CNC lathe and mill

The machine shop features several CNC machines, such as the HAAS 3 and 4 axis CNC mills, and a CNC lathe. This allows for the fabrication of more complex parts that would otherwise be unfeasible to create using traditional machining methods.

2) Manual lathe and mill

The machine shop also has several manual mills and lathes. These machines are equipped with digital readouts that have the capability to be used with either English or Metric units.

3) Rapid Prototyping machine

The rapid prototyping machine located in the MAE Machine shop is a Stratasys Fortus 360 with a build envelope of 16 X 14 X 16". This machine uses CAD drawings to produce highly precise models of prototypes and other small components from common engineering polymers such as Acrylonitrile Butadiene Styrene (ABS). The printing process uses Formative Deposition Modeling (FDM), which is an additive fabrication methodology in which a thin bead (0.005-0.013”) of a molten thermoplastic material is extruded in individual layers according to a computer controlled path in order to construct a physical model from the virtual one. This particular process combines an ability to construct detailed, functional parts (including pre-assembled assemblies) that exhibit excellent thermoplastic material properties in a process with few environmental hazards or constraints while requiring minimal operating expense.

4) Composite materials production

The machine shop offers the capability to fabricate parts using several different composite materials such as fiberglass, Kevlar, and woven & unidirectional carbon fiber. These materials can be laid up in sections up to 48 X 48 X 72" utilizing either wet or dry processes. For the wet processes, lay ups can be performed using vacuum bagging and autoclave curing with a maximum temperature of 650^{0}F. The machine shop also has 4-axis CNC milling capability for manufacturing molds and tooling in addition to a selection of Nomex, honeycomb, and Rohacell filler materials.

5) FARO Arm

The FARO arm is an articulated device with 6 degrees of freedom. It has precise encoders at each joint. It permits the user to encode precise digital location information describing a physical part in order to create a CAD or other virtual model. This particular machine is accurate to approximately 0.0008” within its 48" spherical radius for coordinate measuring machine probing and better than 0.005" for the laser line digitizer which allows the "painting" of a 3 dimensional complex shape with reflected laser light to generate a virtual copy of a surface.

6) Saws

The machine shop has a table saw, a vertical band saw, and a horizontal band saw. The table saw is a Sawstop brand table saw with an automatic braking system to stop rotation of the saw blade in less than five milliseconds in order to prevent operator injury. All saws can be used to cut material to desired length in preparation for machining or for the final product.

7) Welding

The machine shop has the facilities to perform GMAW (Gas Metal Arc Welding), MIG (metal inert gas), GTAW (Gas Tungsten Arc Welding), TIG (Tungsten Inert Gas) oxyacetylene brazing, and SMAW (Shielded Metal Arc Welding, informally known as stick welding). All necessary safety equipment required for welding is available in the shop.

4.4. UAH Wind Tunnel

Sub-scale aerodynamic models of the rocket can be tested in the UAH MAE subsonic wind tunnel. This variable speed wind tunnel has a test section which is 0.3 m tall, 0.3 m wide, and 0.61 m long (1 ft. x 1 ft. x 2 ft.). At the highest fan speed, the tunnel test section velocity will reach 50 m/sec (160 ft./sec or 110 miles/hour). The test section is followed by a diverging section, which reduces the air speed to an acceptable velocity before it exits the tunnel. The wind tunnel can be seen in Figure 4-3.

Figure 4-3: UAH Wind Tunnel

4.5. CRW Trailer

The CRW Trailer stores the team's student-built launch rail. There is a bench for field assembly, shadow boards for tool storage, racks for storing rockets during transport, and tie downs for securing canopies and tables. The launch rail stand has been modified recently to support both 1010 and 1515 rail guides.

4.6. Computing Capabilities

The CRW lab has access to two Dell laptop computers, and a Dell XPS ballistic armored laptop for field activities. The team also will have access to three desktop computers in the Propulsion Research Center. All of these computers use a Windows OS and feature the Solid Edge CAD package, MathCAD, MATLAB, RockSim 9.0, Microsoft Office 2007, and the Adobe Professional package. The computers are openly accessible 24 hours a day.

4.6.1. **Analysis Software**

A number of analysis software packages are available to aid in preflight and post flight analysis. MATLAB and MathCAD are both available to use for mathematical programming. Solid Edge and Pro/E are both available for CAD modeling. ESI ACE + Fastran are available for Computational Fluid Dynamics (CFD) analysis. Open Rocket is available for trajectory and flight analysis. System Tool Kit (STK) is a software package design to simulate the systems of a mission and how to integrate them which will also be available to the CRW team. This tool kit allows the user to generate, report, graph, and vary thousands of qualitative and quantitative metrics, as well as their expected locations and movements at each stage of the mission, model limitations including geometric, line of sight and field of view, work in time domain and set event triggers.

4.7. Reliability and Failure Analysis Lab (RFAL)

The Reliability and Failure Analysis Lab is a facility located on the UAH campus in Von Braun Research Hall that investigates possible failure mechanisms of a part through mathematical modeling and physical testing. The facility is equipped with an autoclave, thermal shock and vibration chamber, cyclic corrosion chamber, servo-hydraulic tension/compression/fatigue test machine, accelerometer calibration station, and a modal exciter. These facilities will allow the team to perform critical structural testing prior to flight and will help the team prevent structural failure during flight. RFAL also contains facilities for composite structure manufacture, and the necessary equipment to cure large composite structures.

4.8. Section 508 Compliance

Section 508 of the Rehabilitation Act requires that Federal agencies' electronic and information technology be accessible to all potential users, including individuals with disabilities. The accessibility standards associated with Section 508 were developed to ensure that electronically delivered information is available to as many people as possible. As part of the USLI competition, Charger Rocket Works must create and maintain a team Web presence. Section 508 compliance can be ensured by consulting Section 508 resources when developing the website in order to promote maximum accessibility to the widest range of users.

5. Safety

The CRW safety plan is the method by which the Safety Officer, Project Manager, and Team Leads can ensure that all members are conducting all tests and experiments safely. If any type of mishap occurs, all CRW team members follow the proper procedures to ensure the well-being of all affected members and ensure that proper measures are taken to reduce any future risks.

5.1. Management, Leadership, and Employee Participation Policy

Of vital importance to the CRW team are the safety of all personnel, property, test facilities, the environment, airspace, and the general public. This policy shall be the foundation upon which participation in the SLP competition will be based.

5.2. Goals and Objectives

The CRW team will implement all safety policies and procedures to meet the goals and objectives spelled out in Table 5.1.

Table 5.1: Safety Plan Goals and Objectives

Goals and Objectives of the CRW Safety Plan	
Goal	**Objectives**
Demonstrate a complete team commitment to safety and health.	• Definition and implementation of proper hazard control procedures by all leadership personnel. • All CRW team members assist with the creation and proper implementation of the health and safety program.
Identify all hazards associated with CRW	• CRW team leadership will conduct an initial risk assessment and hazard analysis to be updated as necessary by workplace changes.

operations and facilities.	• All CRW team members will review the initial assessments and propose recommendations on any revisions.
Prevent or control CRW team member exposure to identified hazards.	• CRW team leadership will designate, implement, and ensure compliance with all necessary hazard mitigation. • All CRW team members will review the hazard mitigation and propose necessary revisions.
Train all CRW team members in safe work and manufacturing processes, hazard recognition, and emergency response.	• CRW team leadership will specify and document all appropriate work practices and emergency response procedures for hazardous situations. • All CRW team members will be familiar with all plans, emergency procedures, and working documents.

5.3. Team Leadership Roles

The CRW personnel who shall maintain an active role in the team safety plan include: the Program Manager, Safety Officer, Team Leads, and all involved UAH and PRC faculty members. This group's expertise will be used for all risk assessment, hazard analysis, and for the definition and documentation of all hazard mitigation procedures. The Safety Officer has the ultimate responsibility for the safety of all members throughout the duration of the project, and is responsible for the implementation of all aspects of the CRW safety plan. All other CRW leadership shall demonstrate their commitment to the health and safety plan through the conduction of any necessary inspections and through the verification of proper hazard mitigation by all team members.

5.4. Team Member Involvement

The goal of CRW is to foster cooperation and collaboration between all members, regardless of whether or not they hold management positions within the team. Ensuring the safety and well-being of all CRW members during all testing and experimentation requires a team effort, as does the completion of all necessary documentation. The Project Proposal, Preliminary Design Review (PDR), Critical Design Review (CDR), Flight Readiness Review (FRR), and all other milestone documents will be divided up amongst all team members whenever it is practical or feasible to do so. Any design or safety concerns of the team members will be referred to their respective Team Lead, who will bring said issue to the Systems Integration team if it is deemed necessary. Team Leaders and the Systems Integration Team are expected to see that closure of each issue is obtained in a manner consistent with all design and safety parameters set forth. Recommendations will be requested from team members to resolve any issues at hand, and any feedback regarding the decisions made is desired. The safety responsibilities of all team members are shown below in Table 5.2.

Table 5.2: Safety Responsibilities

Personnel	Safety Program Responsibilities
Program Manager	• Ensure that any and all safety documents are available to all team members. • Work with Team Safety Officer to ensure that all team members are following their safety plans.

Team Safety Officer	• Work with Team Leads to develop and implement Safety Plan. • Review and approve all Standard Operating Procedures. • Facilitate training for Team Leads on safe procedures for all design, testing, manufacturing, and launching activities.
Team Leads	• Develop Standard Operating Procedures for all testing and launch operations pertaining to their subsystem. • Facilitate training for team members on proper equipment and power tool operation before their use.
Team Members	• Follow all safety plans, procedures, and regulations. • Identify any hazardous work conditions and file appropriate documentation. • Ensure that fellow team members are following all safety protocols. • Offer recommendations for improving safety protocols.

5.5. Training

A CPR/AED and First Aid training is made available for members of the CRW to encourage and properly educate about safety. These tests will be encouraged for all members and mandatory for Red Team (see below) members. A White/Blue/Red card system is in place for the MAE workshop. To enter the shop requires a basic safety class which earns the White card. The Red card requires more advanced training and grants the holder the ability to operate a number of the machines in the shop with supervision from a Blue Card holder. A Blue card requires a comprehensive course that covers how to safely operate the machines in the workshop and grants the user the access to the machine shop and to act as supervisor to those operating under a Red card.

5.6. Material Hazard Communication Program

The Hazard Communication Program will identify all stored hazardous materials and those used in all project facilities and operations. The Safety Officer shall collect Material Safety Data Sheets (MSDSs) for these products and ensure that they have been correctly labeled. The Safety Officer shall also provide all CRW team members with the proper information and training to effectively mitigate any hazards present. This program shall serve to ensure compliance with the Occupational Safety and Health Administration (OSHA) regulation, 29 CFR Part 1910.1200, Hazard Communication. Hazardous materials shall be defined as any chemical which is classified as a physical hazard, health hazard, simple asphyxiant, combustible dust, pyrophoric gas, or any other hazard defined as such.

The product identifiers listed on any MSDSs must match those kept in the CRW Inventory of Hazardous Materials (see Appendix D) and the identifier displayed on the container labels. All CRW team members are responsible for ensuring that these labels are displayed in accordance with the appropriate OSHA regulations. Any chemicals transferred to containers for storage or transportation must also be labeled in this manner. A printed copy of each MSDS shall be kept in the Propulsion Research Center (PRC) by the Safety Officer. These MSDSs must be easily accessible by all CRW team members for reference, and for any emergency response purposes.

For hazardous chemicals present at the beginning of a work assignment, and any that are subsequently introduced into the work area, it shall be the duty of the Safety Officer to provide all CRW team members with the appropriate information and training in order for their safe use. This information and training shall comply with the requirements given in 29 CFR Part 1910.1200(h). Methods to mitigate chemical exposure shall also be incorporated into written standard operating procedures, hazardous operations procedures, and emergency procedures whenever possible.

5.7. Hazardous Materials Inventory

The Safety Officer shall maintain an inventory of all the hazardous materials stored and used in the CRW facilities and operations. All materials will be identified in the same manner as the MSDS. The inventory will be updated at the onset of each semester. Appendix D lists all of the current hazardous materials expected to be used throughout the project.

5.8. Purchasing and Procurement

All motors and energetic materials will only be purchased from licensed vendors by NAR or TRA certified members within CRW. Those motors and energetic materials will be stored in the propellant bunker as described in section 4.2.

5.9. Workplace Analysis

The CRW team will work to identify all hazards within the workplace for the duration of the project. This information will come from a combination of surveys, analyses, workplace inspections, mishap investigations, and collection of all health and safety data reports. These reports will include: reports of spills and releases of chemicals to the environment, facilities-related incidents related to partial or complete loss of a system function, and any reports of hazards by CRW members.

All hazards identified that pose an immediate threat to the life or health of any CRW members will be immediately brought to the attention of the Safety Officer, the Program Manager, and PRC faculty members to ensure that proper action to correct the hazard is taken. All of the current safety plans and any other working documents or procedures will immediately be reviewed by PRC faculty members.

5.10. Inspections

Inspections of work areas will be performed and documented each semester by the CRW team leadership. Any discrepancies between the safety requirements and the observed conditions will be recorded along with the personnel tasked for implementing the corrective measures. All corrective measures will be tracked to closure by the Safety Officer. Scheduled inspections for fire and other explosive hazards will be conducted in accordance with UAH policies and procedures.

5.11. Employee Reports of Hazards

All members of the CRW team are encouraged to report any hazardous conditions and analyze and prevent any apparent hazards. All CRW team leadership will ensure that reprisal-free reporting occurs, and will use safety training and all project life cycle reviews to incorporate all CRW team members into hazard prevention activities.

5.12. Mishap Reporting and Investigation

If any mishap occurs, it shall be promptly reported to the affected team lead and the Safety Officer, who will ensure the required procedures are carried out for any fire, hazardous material release, or other emergency. All of the CRW team leadership will be immediately notified of the incident by the Safety Officer, who will also submit all subsequently required documentation.

The Safety Officer shall then conduct an investigation into the cause(s) of the mishap and what actions must be taken to rectify the situation and ensure no future incidents occur. A safety meeting will then be conducted with all CRW team members to ensure they are aware of any and all potential safety problems and hazards.

5.13. Hazard Prevention and Control

5.13.1. **Appropriate Controls**

In order to mitigate or eliminate any potential hazards, the CRW team will use a multi-level hazard reduction sequence comprised of engineering controls, administrative controls, and personal protective equipment. Engineering controls involve designing the facility, equipment, or process in a way to reduce or eliminate any potential hazards. Administrative controls include: standard operating procedures (SOPs), work permits, training and safe work practices, exposure limits, alarms, signs and other warnings, and the use of a buddy system. Personal protective equipment will never be used as the sole avenue for mitigating risk and preventing hazards. It is to be used in conjunction with the engineering and administrative controls if they alone do not eliminate any possible hazards, or during emergencies when the aforementioned engineering controls would no longer be feasible.

Any risk remaining after all mitigation and controls is designated as residual risk. The CRW team leadership may, as a group, accept this risk based on risk assessment results and other factors pertaining to the SLP competition. However, residual risk that violates basic health and safety standards may not be acceptable. Any accepted risk will be communicated to the rest of the CRW team.

5.13.2. **Hazardous Operations**

Hazardous operations involve materials or equipment that, if used or handled improperly, pose a high risk of resulting in loss of life, serious injury or illness to personnel, or damage to systems, equipment, and facilities. All CRW personnel will be notified before the conduction of any hazardous operations is to take place and will be notified of any hazards which present themselves. This notification shall come from both procedural documentation, and from real-time communication, if necessary. Written procedures with emphasis on the safety steps will be developed before any hazardous operations commence to ensure that all regulatory requirements have been met.

General workshop safety rules are posted in all workshops and each tool or machine will display the proper operating procedures. It is required that more than one person be in the workshop to offer assistance if something does go wrong. First aid kits are also present in each of the work area AED locations.

5.13.3. **Protective Equipment**

The Occupational Safety & Health Administration (OSHA) requires the use of the personal protective equipment (PPE) at the workplace. The use of PPE is meant to reduce employee exposure to hazards when engineering and administrative controls are not effective in reducing these exposures to acceptable levels. Employers are required to determine if PPE should be used to protect their workers. The Safety Officer for CRW will be responsible for educating team members on the proper implementation for protective gear. CRW team members are required to wear appropriate PPE to perform hazardous activities. The requirements for PPEs will be based on the MSDS of the materials required to complete a task and the assessment of hazards that exist in the work environment. PPEs will be provided and maintained in the laboratory and all USLI related work spaces and will be taken to all field activities. The Safety Officer as well as Propulsion Research staff will monitor the proper use of the PPE. The expected PPE for the project includes but is not limited to:

1. Safety Glasses
2. Face Shields
3. Lab Coats
4. Hearing Protection
5. Work Gloves
6. Welding Protective Equipment (sleeves, face shield, etc.

5.14. Propulsion Research Center Procedures

The Propulsion Research Center affords the members of CRW the ability to perform numerous types of ground tests for propulsion, recovery, and other critical rocket subsystems. The facility is available for various research purposes including: externally sponsored research projects, Propulsion Research Center staff and Graduate Student research projects, and selected Undergraduate projects. Below is a list of safety protocols that all users of the PRC facilities must follow:

UAH Propulsion Research Center- Facility Usage Policy

1. All PRC Test operations are under the authority of the PRC Director and UAH campus safety practices.
2. All personnel involved in testing are UAH employees, UAH students under PRC supervision, customers with an active contract with UAH, or those with other formal arrangements agreed to in writing by the University.
3. All tests involving pressures over 100 psi, high voltage, combustion, or other sources of possibly injury require a Standard Operating Procedure (SOP), reviewed and signed by the test Red Team (see below), and approved by the PRC Director.
4. The tests are conducted by a designated Red Team who has at least one UAH staff member and has at least two members who are Red Cross Safety and CPR/AED Certified.
5. After any major test anomaly, all PRC test operations are automatically suspended until a determination of the basic cause of the incident is determined and all active SOPs are reviewed in light of the findings of the incident before resuming testing. A verbal report of the incident will be given to the V.P. of Research and a representative of Campus Safety within 24 hours of the incident.
6. If the need to evacuate the Johnson Research Center becomes apparent due to inclement weather, fire, or any other hazards, all CRW members will follow the evacuation plan provided in Appendix A.

All pertinent procedures from the UAH Emergency Procedures Handbook will be followed in the event of any mishap or injury. Any mishap or injury will be reported to the Safety Officer and the affected Team Lead as per UAH's Non-Employee Accident Report Form. Any other affected CRW Team Members and University staff will be notified to ensure that all required documentation is completed.

The Safety Officer will then work to determine the cause(s) of the mishap and ensure that the proper corrective action is taken. A debrief of the incident will be provided to all CRW members in order to prevent any further mishaps from occurring.

5.15. Supervision

For tests, PRC and MAE staff will be present to supervise to ensure all safety measures are followed. A NAR/TRA mentor will help ensure rocket launches are safe and offer pointers to take safety beyond what is in the regulations. No test or launch will be performed without consultation and supervision from experienced staff or mentor.

5.16. Buddy System

No test will be undertaken by a single individual. All tests must not only have supervision but more than one person working on the test. A safety review will be conducted prior to any test. The safety officer will ensure that every member is aware of the appropriate information pertaining to any tests.

5.17. Accountability

All CRW team members will be held accountable to perform all assigned tasks in a safe and healthful manner, for identifying and reporting any apparent safety issues or non-compliances, and following all other provisions of the CRW safety plan. As stated earlier, any apparent safety issues shall be brought to the attention of the affected team lead(s), who will report the issues to the safety officer and the project manager if deemed necessary. Any issues that cannot be resolved by the CRW team will be brought to the appropriate faculty members. If disciplinary action is required, it may only be administered by faculty members.

5.18. Emergency Response

If cardiopulmonary resuscitation is required, certified personnel will administer the required aid using the AED machines located in each of the facility used by CRW. Any first aid certified CRW team member may also administer general first aid if it is required. If this basic first aid is not sufficient, the appropriate emergency procedures shall be followed to notify emergency responders. All CRW team members will be aware of the proper fire and tornado evacuation routes as depicted on the Johnson Research Center Emergency Evacuation in Appendix A.

5.19. Periodic Safety Meetings

The Safety Officer will provide a safety briefing to the whole CRW team on a biweekly basis with information on any mishaps that may have occurred, any upcoming safety hazards that will affect the majority of the team, and safety information on any upcoming tests or launches.

5.20. State and Federal Regulations

The CRW team will agree adhere to all pertinent state and federal regulations throughout the duration of the project. The Federal Aviation Association (FAA), National Association of Rocketry (NAR), Department of Transportation (DOT), and Tripoli Rocketry Association (TRA) are the primary creators of regulation pertaining to amateur rocketry. All regulations can be found in Appendix B.

5.21. Vehicle Safety and Environment

Further details on the specific failure modes of the launch vehicle will be available in later submissions once a final vehicle design has been identified. Regardless of the final vehicle design, all manufacturing and launch procedures will be conducted in accordance with any and all pertinent state and federal regulations in order to ensure maximum safety to all persons involved. Special care will also be taken to ensure no unnecessary damage to the environment occurs throughout the manufacturing process and during the launch. Appendix B contains a list of all current regulations the CRW team has agreed to abide by. Further regulations, operator manuals, and MSDS's will be made available as they are required.

6. Educational Engagement

The engagement plan will consist of local school outreach, innovative campus wide involvement, active STEM (Science, Technology, Engineering and Mathematics) participation, and sponsored interest events.

6.1. Outreach to local schools

Members from the Charger Rocket Works will visit local schools to inform the younger generation of the SLI competition. Team members will provide examples of the immense skill set that is built when operating with such a large organization structure as in the competition. Examples of the skill set are as follows: excellent critical thinking skills, efficient time management, and teamwork. The team will provide information regarding local engineering events to promote CRW events. The team will challenge the students with hands on rocket activities forcing the students to think outside the box. The activities will include basic physics problems and building miniature water rockets to promote science and engineering involvement in the local schools. Students will have a chance to get their hands on actual rocket hardware as seen in Figure .

Figure 6-1: UAH Students assisting Rocket Camp Students

6.2. Campus wide involvement

Students will be able to innovatively stay up to date with the progress CRW is making during the fall and spring semesters by following CRW on its website, Facebook, Twitter, Google+, YouTube and blogs on UAH's website. This allows students interested in supporting USLI by coming to launches or other planned events. Major events on campus will be used to increase student awareness of the USLI competition and CRW. CRW is working with other disciplines in the university to become involved in USLI.

CRW has already actively participated in the UAH Open House on several occasions to promote possible UAH undergraduates to pursue a degree in an engineering related field. CRW set up a booth displaying past rockets' sections and payloads to demonstrate the type of work that was completed at the PRC as seen in Figure 6.2. The UAH Open House Event took place on October 19th and November 9th from 8:00 am to 12:00 pm.

Figure 6-2: Girls' In Science and Engineering Day Outreach

6.3. STEM Events

CRW intends to participate in STEM Outreach Events over the Fall 2012 and Spring 2013 semesters. STEM Outreach Events are designed to stimulate interest in students that are in grades K-12 in the local area to pursue careers in STEM fields. Each event will include visual and interactive aids that students can safely investigate, a presentation that explains what CRW does and why, and a demonstration. Events will be planned and scheduled by the Outreach Coordinator. The Outreach Coordinator will collect feedback on STEM Outreach Events to submit to the NASA MSFC Academic Affairs Office.

CRW has already participated in the largely publicized Girls and Science Engineering Day at UAH. The event focused on sparking science and engineering career paths for grades 3 through 5. 5 team members played active roles in the event. The team diversified with two members working the rocketry presentation booth, seen in Figure , displaying past rockets and payloads similar to the UAH Open House

Event, while the remaining 3 worked as team leaders for the event providing assistance wherever needed. The event took place on November 16 from 8:00 am to 12:45 pm.

Figure 6-3: Campus Engineering Open House

6.4. Sponsored Interest

CRW seeks sponsored interests to fund or support research activities. Sponsored interests are corporations, groups, or individuals that are able and willing to provide monetary or product support that will further the goals and progress of CRW. All team members are representatives of CRW and UAH. Team members are made aware of potential sponsored interests. Similar to the STEM Outreach Events, team members will present CRW's project and technical plan and explain the team's goals and how sponsored interests can fund or support research activities.

7. Project Plan

7.1. Project Schedule

A high level Gantt chart was developed to give a guideline of when major milestones will be met. This also informs the customer when reports will be submitted. The System Integration team will be responsible for ensuring that deadlines and major milestones are met. Later datelines are given as a range to accommodate weather delays in launches and other unexpected schedule delays. A Technology Readiness Level chart has been provided to show the current state of the project as can be seen in Figure .

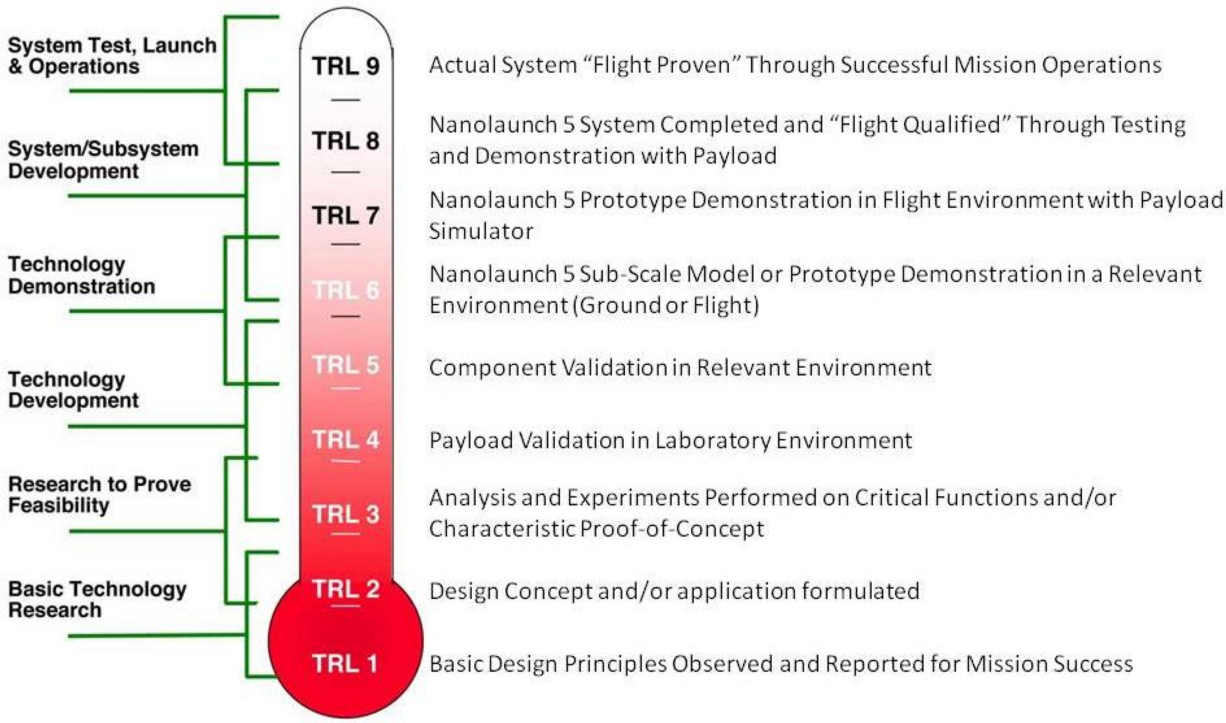


Figure 7-1: Technology Readiness Level Chart

TRL levels 1-2 are early planning stages where steps are being taken to understand the problem fully. TRL levels of 2-3 are research into feasible ways of solving the problem. 3-5 are early development stages where design work is being prototyped and validated. TRL of 5-7 are actual system demonstrations where several systems are interacting in simulations of actual environments expected. 7-9 is the last stage which involves the actual launch.

An overview Gantt chart can be seen in Figure 7-2. The Preliminary Design Review (PDR) will be at a TRL level of a 4-5 due at the beginning of the spring semester. The Critical Design Review (CDR) will be at a TRL of 6-7 due at the end of the February of 2014. The Flight Readiness Review (FRR) will be a TRL level of 8-9 due in the middle of April 2014. The Post Launch Assessment Review (PLAR) will be the final delivery and will be due at the beginning of June. The full Gantt chart can be seen in Appendix E: Gantt Chart.

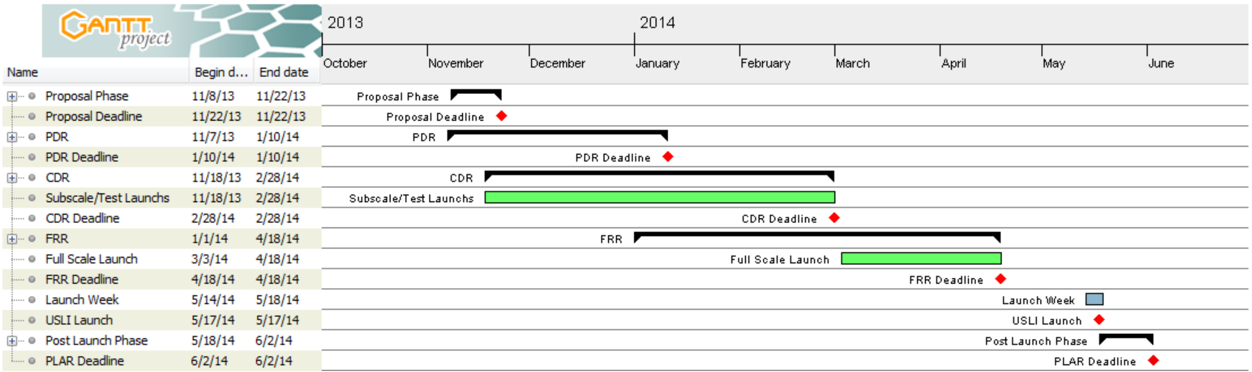


Figure 7-2: Overview Gantt Chart

7.2. Budget

Charger Rocket Works has received $5,000 from the customer which represents the current funding. The Charger Rocket Works team will work towards acquiring more resources to keep the fiscal health of the team balanced. The team's current balance sheet shows a positive $5,000.00. The CRW management team intends to submit a proposal for additional funding to Alabama Space Grant Consortium (ASGC) for an additional $25,000 to cover the cost of travel to the launch in Utah.

7.3. Programmatic Challenges

With any project, there will be obstacles and challenges that will have to be faced during the course of the program. Figure 7-3, Table 7.1, and Table 7.2 identify expected programmatic challenges, their risk level, the possible impact of the challenge, and mitigation steps to be taken. Examination of the challenges during the initial planning phase will reduce their impact during later stages of the project, and allows the team to build extra time into the schedule to overcome these issues. As with all publically and privately funded projects the current economic climate drives the availability of funding. The financial management team at Charger Rocket Works has worked on a plan to mitigate the loss or delay of funding.

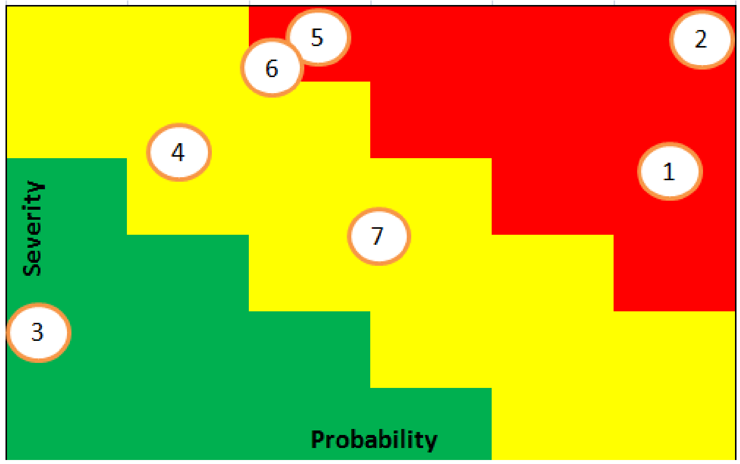


Figure 7-3: Program Risk Chart

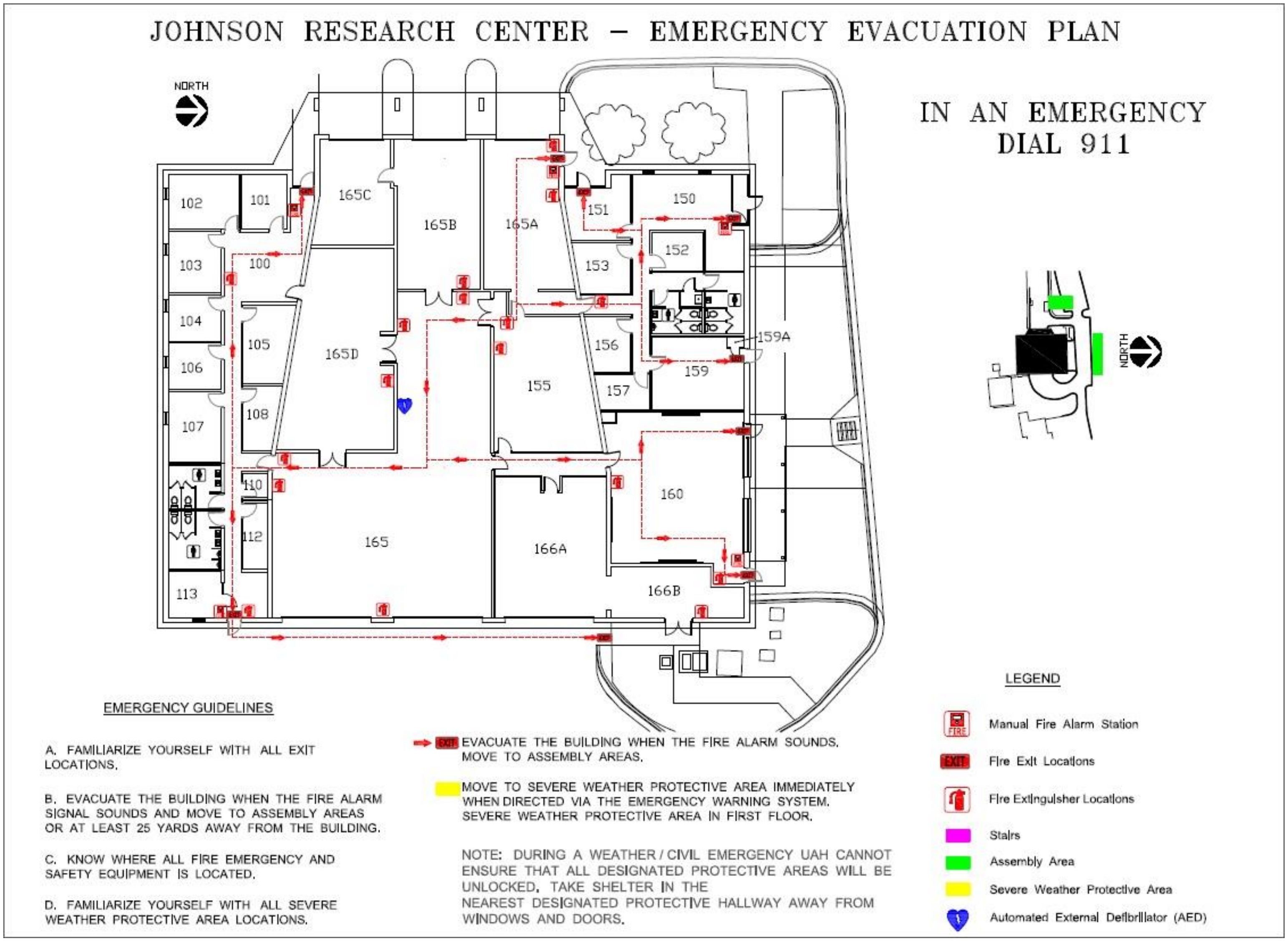
Table 7.1: Programmatic Challenges

Financial Challenges				
Reference Number To Figure 7-3	Risk	Probability	Impact	Mitigation
1	Delayed Funding	High	If funding is delayed then CRW may encounter delays with purchase orders or reimbursements with travel expenses.	Use of financial reserves, re-delegation of current balance for immediate needs, executing procurement activities well ahead of project schedule
2	Funding Loss	High	If funding is cut for this project, CRW will have a reduced budget to use for the overall competition.	Reevaluation of current financial standing, determination of alternative financial support methods
3	Overspending	Low	Loss of resources required for later project stages, inability to build full scale rocket due to lack of money	Developing budget estimates for each project stage. This budget will contain hard financial limits for each stage
4	Vehicle Failures	Average	Unanticipated purchase of components and supplies, overspending due to replacement of critical components and hardware	Reevaluation of current budget, re-delegation of surpluses from one area to the impact area, use of emergency funds

Table 7.2: Schedule Challenges

Schedule Challenges				
Reference Number To Figure 7-3	Risk	Probability	Impact	Mitigation
5	Purchase Orders are Delayed	High	If parts are delayed in shipping CRW may have to push back deadlines in team schedule.	The Program Manager will push team to beat deadlines by an average of one week in order to mitigate loss of time.
6	Team Falls Behind Schedule	High	During the year team members may fail to meet project deadlines.	The team will reevaluate its current standing with the schedule and work to mitigate the loss of time.
7	Team Conflicts	Average	Stress levels may increase throughout the year as team members strive to meet NASA's demanding schedule. This may cause conflicts among team members.	A team charter will be created in order to direct workflow and outline the decision making process. This will serve as a way to resolve conflicts.

Appendix A: Johnson Research Center Evacuation Plan



Appendix B: State and Federal Regulations

6.1.6a FAA Regulations, CFR, Title 14, 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.

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.

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.

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

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

(a) At any altitude where clouds or obscuring phenomena of more than five-tenths coverage prevails;

(b) At any altitude where the horizontal visibility is less than five miles;

(c) Into any cloud;

(d) Between sunset and sunrise without prior authorization from the FAA;

(e) Within 9.26 kilometers (5 nautical miles) of any airport boundary without prior authorization from the FAA;

(f) In controlled airspace without prior authorization from the FAA;

(g) Unless you observe the greater of the following separation distances from any person or property that is not associated with the operations:

(1) Not less than one-quarter the maximum expected altitude;

(2) 457 meters (1,500 ft.);

(h) Unless a person at least eighteen years old is present, is charged with ensuring the safety of the operation, and has final approval authority for initiating high-power rocket flight; and

(i) Unless reasonable precautions are provided to report and control a fire caused by rocket activities.

101.27 ATC notification for all launches.

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

(a) The name and address of the operator; except when there are multiple participants at a single event, the name and address of the person so designated as the event launch coordinator, whose duties include coordination of the required launch data estimates and coordinating the launch event;

(b) Date and time the activity will begin;

(c) Radius of the affected area on the ground in nautical miles;

(d) Location of the center of the affected area in latitude and longitude coordinates;

(e) Highest affected altitude;

(f) Duration of the activity;

(g) Any other pertinent information requested by the ATC facility.

6.1.6b NAR High Power Rocket Safety Code

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. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.

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 a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of NFPA 1127.

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 the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 and clear that area of all combustible material 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, occupied 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, or 1000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams, and a maximum expected altitude of less than 610 meters (2000 feet).

11. **Launcher Location**. My launcher will be 1500 feet from any occupied 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.

6.1.6c National Fire Protection Association Regulations

NFPA 1122: Code for Model Rocketry

'Model rockets' are rockets that conform to the guidelines and restrictions defined in the NFPA 1122 document. These rockets weigh less than 1500 grams, contain less than 125 grams of total fuel, have no motor with more than 62.5 grams of fuel or more than 160 NS of total impulse, use only pre-manufactured, solid propellant motors, and do not use metal body tubes, nose cones or fins. One inconsistency with this is the CPSC definition of a model rocket motor, which by their definition must contain no more than 80NS total impulse. NFPA 1122 contains the most complete definition of a model rocket and the model rocket safety code. This is the same safety code as adopted by NAR. 'Large Model

Rockets' is a term used in the FAA FAR 101 regulations. It refers to NAR/NFPA model rockets that are between 454 and 1500 grams (1 to 3.3 pounds) total liftoff weight and contain more than 113 grams but less than 125 grams of total fuel.

NFPA 1127: Code for High Powered Rocketry

'High power rockets' are rockets that exceed the total weight, total propellant or single motor total impulse restrictions of model rockets, but otherwise conform to the same guidelines for construction materials and pre-manufactured, commercially made rocket motors. High power rockets also allow the use of metal structural components where such a material is necessary to insure structural integrity of the rocket. High power rockets have no total weight limits, but do have a single motor limit of no more than O power (40,960NS maximum total impulse) and have a total power limitation of 81,920NS total impulse. NFPA document 1127-1985 contains the most complete definition of a high power rocket and also the high power rocketry safety code. This safety code has been adopted by both the NAR and TRA. Metal bodied rockets are allowed by NFPA 1127 where metal is required to insure structural integrity of the rocket over all of its anticipated flight.

6.1.6d State of Alabama Regulations

11-47-12. Gunpowder and explosives storage.

It is the duty of the corporate authorities of every city or town to provide a suitable fireproof building without the limits of the town or city for the storage of gunpowder or other explosive material on such terms as the corporate authorities my prescribe.

13A-11-224. Keeping gunpowder or explosives in city or town

Any person who keeps on hand, at any one time, within the limits of any incorporated city or town, for sale or for use, more than 50 pounds of gunpowder or other explosives shall, on conviction, be fined not less than $100.00. The explosive material on such terms as the corporate authorities may prescribe.

6.1.6e Tripoli Rocketry Association Requirements for High Power Rocket Operation

1 Operating Clearances. A person shall fly a high power rocket only in compliance with:

a. This code;

b. Federal Aviation Administration Regulations, Part 101 (Section 307,72 Statute 749, Title 49 United States Code, Section 1348, “Airspace Control and Facilities,” Federal Aviation Act of 1958); and

c. Other applicable federal, state, and local laws, rules, regulations, statutes, and ordinances.

d. Landowner permission.

2 Participation, Participation and Access at Tripoli Launches shall be limited to the following:

2-1 HPR Fliers may access and conduct flights from the High Power Launch Area and/or Model Rocket Launch Area.

2-2 Non-Tripoli Members age 18 and over that are students of an accredited educational institution may participate in joint projects with Tripoli members. These individuals are allowed in the High Power Launch Area and/or Model Rocket Launch Area if escorted by a Tripoli member. The maximum number of non-member participants shall not exceed five (5) per Tripoli Member.

2-3 Non-Tripoli Members that are members of a Named Insured Group may participate in joint projects with Tripoli members. These individuals are allowed in the High Power Launch Area and/or Model Rocket Launch Area if escorted by a Tripoli member. The maximum number of non-member participants shall not exceed five (5) per Tripoli Member.

2-4 Tripoli Junior Members that have successfully completed the Tripoli Mentoring Program Training may access and conduct flights from the High Power Launch Area while under the direct supervision of a Tripoli Senior member in accordance with the rules of the Tripoli Mentored Flying program. The Tripoli Senior member may provide supervision for up to five (5) individuals that have successfully completed the Tripoli Mentoring Program Training at a time in the High Power Launch Area.

2-5 Children younger than 18 years of age may conduct flights from the Model Rocket Launch Area under the direction of a HPR Flier.

2-6 Attendance by Invited Guests and Spectators

2-6.1 An invited guest may be permitted in the Model Rocket Launch Area and preparation areas upon approval of the RSO.

2-6.2 An Invited Guest may be allowed in the High Power Launch Area if escorted by a HPR Flier. A HPR Flier may escort and be accompanied by not more than five (5) non-HPR fliers in the High Power Launch Area. The HPR flier escort is required to monitor the actions of the escorted non-HPR fliers, and the escort is fully responsible for those actions and for the safety of those escorted.

2-6.3 Spectators, who are not invited guests, shall confine themselves to the spectator areas as designated by the RSO and shall not be present in the High Power Launch Area or Model Rocket Launch Area.

Referenced Publications

The following documents or portions thereof are referenced within this code. The edition indicated for each reference is the current edition as of the date of the NFPA issuance of this document.

3-1 NFPA Publications. National Fire Protection Association, I Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101

NFPA 1122, Code for Model Rocketry.

NFPA 1125, Code for the Manufacture of Model Rocket Motors.

NFPA 1127, Code for High Power Rocketry

3-2 Government Publications. Superintendent of Documents, U.S. Government Printing Office, Washington DC 20402.

Federal Aviation Administration Regulations, from the Code of Federal Regulations. Federal 7/31/2012

Hazardous Substances Act, from the United States Code (re. Airspace Control)

3-3 TRA Publications. Tripoli Rocketry Association, Inc., P. O. Box 87, Bellevue NE 68005.

Articles of Incorporation and Bylaws

High Power Rocketry Safety Code

Tripoli Motor Testing Committee (TMT), Testing Policies

Appendix A - Additional Tripoli Rulings

A-1 NFPA 1127 was adopted by the Tripoli Board of Directors as the Tripoli Safety Code. (Tripoli Report, April 1994, Tripoli Board Minutes, New Orleans, 21 January 1994, Motion 13.) Since this adoption, the code has gone through some revisions. Such is the way with codes – they are constantly undergoing change to improve and update them when safety prompts, or when the federal regulations change or are reinterpreted

A-2 All Tripoli members who participate in Association activities shall follow the Tripoli Certification Standards.

A-3 Any Board action(s), with regard to safety, made previous to or after publication of this document shall be a part of the Tripoli Safety Code.

A-4 Increased descent rates for rocket activities conducted at the Black Rock Desert venue are acceptable if needed to insure a controlled descent to remain inside the FAA approved Dispersion Area.

A-5 A rocket motor shall not be ignited by using:

a. A switch that uses mercury.

b. “Pressure roller” switches

Appendix C: Risk Mitigation

Overall Project			
Risk	**Probability**	**Impact**	**Mitigation**
Project falls behind schedule	Average	Missed deadlines, insufficient time to perform quality level work; incomplete project	Have weekly milestones; Have weekly progress reports by sub-teams; Track progress with a schedule; have a manager to make sure schedule is maintained
Project goes over budget	Average	Inability to order parts on time, progress falls behind schedule, unable to fly subscale, full-scale, or competition launches due to lack of parts	Ensure the budget is planned out for several months; if at any given time the budget does not have enough money for the rest of the project then an active fundraising plan shall be implemented; never allow the budget to become depleted past a certain level
Parts become unavailable	Low	Unable to finish completion of the rocket by a launch day; inability to follow schedule due to manufacturing delays	For every critical part ordered, determine and keep on record a backup supplier; buy multiples of parts whenever possible

Vehicle			
Risk	**Probability**	**Impact**	**Mitigation**
Airframe Structural Failure	Low	Rocket body destructs due to insufficient structural strength; unstable flight;	Ensure that loads are properly communicated throughout vehicle; ensure that all joints, pins, and points of integration are strong enough to withstand the highest calculated stress
Unsuccessful dart and boost separation	Low	Unstable dart flight; inability to reach minimum altitude	Extensive ground testing; include condition of transition part into preflight checklist
Excessive fin flutter	Average	Unstable flight; loss of fin; air frame structural failure	Proper material selection; preflight analytical prediction of flutter; proper alignment of fins
Nosecone Failure	Low	Rapid increase of dart coefficient; inability of the dart to fly or separate as designed;	Design the nose cone with a large safety factor; use analytical predictions to determine expected loads; perform impact testing

Payload			
Risk	**Probability**	**Impact**	**Mitigation**
Data failure	High	Loss of ability to record data during flight; inaccurate data	Completion of successful testing prior to launch; ensure that test data and predicted results are in agreement; check all connections during preflight checklist
Power loss to one or more systems	Average	Incomplete or total loss of data collected; possible destruction of rocket due to improper altimeter function	During preflight checkouts require that batteries have adequate capacity and are fully charged
Wire separation	Average	Loss of avionics power; avionics sensors unable to communicate with the rest of the rocket; improperly deployed recovery system	Ensure proper solder joints and connections; check wire connections with a multimeter during preflight checklist
GPS lock failure or loss of signal	Average	Possible loss of the rocket	Test GPS abilities and RF capabilities before use

Flight			
Risk	**Probability**	**Impact**	**Mitigation**
Weather cocking	High	Surpasses field; insufficient altitude	Adjust CG/CP locations
Unstable flight	Low	Safety threat to audience; insufficient altitude; possible destruction of rocket	Simulate flight with software; test with subscale model; wind tunnel testing
Insufficient altitude	High	Fails to meet minimum competition requirement; improper payload deployment	Use analytics and computer software in conjunction with ground testing to ensure proper motor choice; ensure that the rocket is of the proper mass
Exceeds altitude	High	Fails to meet technical requirements of success; disqualification of overall competition award	Use analytics and computer software in conjunction with ground testing to ensure proper motor choice; ensure that the rocket is of the proper mass

Propulsion			
Risk	**Probability**	**Impact**	**Mitigation**
Propellant does not ignite or chuffs	High	Rocket does not take off; insufficient altitude	Use appropriate and tested ignition systems
Propellant over pressurizes or burns through the casing	Low	Destruction of booster airframe structure; destruction of transition piece; inability to launch rocket	Inspect motor grains for irregularities; assemble per manufacturer instructions; perform a ground test of a replica of the flight motor
Motor dislodges from proper position	Average	Ejection of motor from the rocket; ejection of the motor up through the rocket body causing substantial structural damage and failure; inability to launch the rocket	Use of proper and testing and retention methods

Appendix D: Hazardous Materials Inventory and Risk Analysis

Work Task	Potential Hazard	Hazard Ranking	Hazard Controls
Chemical Handling: 3M Scotch-Weld Structural Plastic Adhesive, DP-8005, Black, Part A (Epoxy)	• Corrosive eye burns in direct contact • Moderate eye irritation from exposure to vapor during curing, or to dust created by cutting, grinding, sanding, machining • Severe skin and • Respiratory irritation. Gastrointestinal irritation from ingestion • Combustible liquid and vapor • Vapor may travel long distance along ground or floor to source of ignition and flash back • Hazardous in contact with strong acids, strong oxidizing agents, heat, sparks and/or flames • Fire	• Rating: Potentially Hazardous Operation • Probability: Low • Severity: Moderate to Severe	• Engineering: local exhaust ventilation for machining processes • Administrative: MSDS; SOP; safe work practices; exposure time limitations; training • PPE: safety glasses with side shields or indirect vented goggles; gloves; protective clothing to prevent skin contact if appropriate • Respiratory Protection: not usually required; Residual Risk: accepted

Work Task	Potential Hazard	Hazard Ranking	Hazard Controls
Chemical Handling: 3M Scotch-Weld Structural Plastic Adhesive, DP-8005, Black, Part B (Epoxy)	• Moderate eye irritation from exposure to vapor during curing, or to dust created by cutting, grinding, sanding, machining • Moderate skin irritation • Respiratory irritation from inhaling vapor or dust • Gastrointestinal irritation from ingestion • Contains a carcinogenic chemical • Hazardous in contact with strong acids, strong oxidizing agents • Fire	• Rating: Potentially Hazardous Operation • Probability: Low • Severity: Mild to Severe	• Engineering: local exhaust ventilation for cutting, grinding, sanding, or machining; shop exhaust ventilation • Administrative: MSDS; SOP; safe work practices; exposure time limitations; training • PPE: safety glasses with side shields; gloves (butyl rubber, nitrile rubber, polyethylene, or polyvinyl alcohol); protective clothing to prevent skin contact, if appropriate to task • Respiratory Protection: not usually required; NIOSH approved air-purifying respirator with organic vapor cartridge and particulate prefilter, when ventilation is inadequate • Residual Risk: accepted

Work Task	Potential Hazard	Hazard Ranking	Hazard Controls
Chemical Handling: Acetone	• Hazardous skin irritant • Slightly hazardous skin permeator • Hazardous eye irritant • Damage to respiratory system if inhaled • Damage to digestive system if ingested • For chronic exposure, is a classified reproductive system toxin for females and suspected reproductive system toxin for males, possible harm to genetic material, fertility, developing fetus; toxic to skin, liver, kidneys, central nervous system, reproductive system; target organ damage • Flammable liquid • Vapor may travel considerable distance to source of ignition and flash back • Slightly explosive in present of acids, oxidizing materials, open flames and sparks • Reactive with oxidizing agents, reducing agents, acids, alkalis • Fire	• Rating: Hazardous Operation • Probability: Moderate • Severity: Mild to Severe	• Engineering: shop exhaust ventilation; eyewash stations nearby • Administrative: MSDS; SOP; safe work practices; exposure time limitations; training; access control for females and males attempting to conceive or pregnant • PPE: indirect vent splash goggles; lab coat; waterproof boots; nitrile rubber gloves • Respiratory Protection: not usually required; NIOSH approved vapor respirator when ventilation is inadequate • Residual Risk: accepted

Work Task	Potential Hazard	Hazard Ranking	Hazard Controls
Chemical Handling: Alcohol, Isopropyl	• Hazardous eye irritant • Slightly hazardous skin irritant, sensitizer, permeant; chronic exposure may cause defatting of skin, dermatitis, allergic reaction • Hazardous to breathe large amounts • Hazardous to ingest large amounts • For chronic exposure, classified as a reproductive system toxin for females, possible harm to developing fetus; toxic to skin, liver, kidneys, central nervous system; target organ damage • Highly flammable and explosive in presence of heat, open flames and sparks • Flammable in presence of oxidizing materials • Can become explosive in contact with oxygen or air • Vapor may travel considerable distance to source of ignition and flash back • May burn with nearly invisible flame	• Rating: Hazardous Operation • Probability: Low • Severity: Mild to fatal health effects; mild to severe damage to facility/equipment	• Engineering: shop exhaust ventilation; eyewash stations nearby • Administrative: MSDS; SOP; safe work practices; exposure time limitations; training; access control for females attempting to conceive or pregnant • PPE: splash goggles; lab coat; nitrile gloves • Respiratory Protection: not usually required; NIOSH approved vapor respirator when ventilation is inadequate • Residual Risk: accepted

Work Task	Potential Hazard	Hazard Ranking	Hazard Controls
Chemical Handling: Ammonium Perchlorate, Hobby Rocket Motor	• Accidental ignition • Hazardous skin irritant; prolonged exposure can cause ulcerations and burns • Hazardous eye irritant • Hazardous if inhaled or ingested • With chronic exposure, is toxic to blood and kidneys; may damage target organs • Flammable in presence of shocks, heat, reducing agents, combustible materials, organic materials • Extremely explosive in presence of open flames andsparks, shocks, heat, reducing agents, organic materials • Slightly explosive in presence of acids • Oxidizing material • Personnel injury by burns and impacts • Facility/equipment damage • No direct exposure to chemical under normal conditions, due to containment within pre-loaded motor	• Rating: Hazardous Operation • Probability: Moderate • Severity: Mild to Severe	• Engineering: process enclosures; local exhaust ventilation • Administrative: HOP or written test procedure; safe work practices; training; personnel certification; performed by or under supervision of Level 2 certified NAR Mentor • PPE: splash goggles; lab coat; nitrile gloves • Respiratory Protection: not usually required; NIOSH approved dust respirator when ventilation is inadequate • Residual Risk: accepted

Work Task	Potential Hazard	Hazard Ranking	Hazard Controls
Chemical Handling: Black Powder, Loose	• Division 1.1 Explosive • Sources of friction, impact, heat, low level electrical current, and electrostatic or RF energy may detonate • Improper clothing may generate static, resulting in detonation • Detonation may cause severe physical injury, even death • Fire • Facility/equipment damage (unlikely due to small quantities in use)	• Rating: Hazardous Operation • Probability: Low • Severity: Moderate to Severe	• Engineering: ventilation; storage • Administrative: MSDS; HOP; safe work practices; training; personnel certification; access control; only non-sparking tools • PPE: impervious rubber gloves; clothing must be metal-free AND non-static producing • Residual Risk: accepted

Work Task	Potential Hazard	Hazard Ranking	Hazard Controls
Chemical CRW Handling: Carbon Fabric, Sized or Unsized	• Temporary mechanical irritation of eyes, skin (primarily at pressure points such as neck, wrist, waist, between fingers), upper respiratory tract • Eye and respiratory tract irritation from fumes or vapor generated by heating or curing sized product • Electrically conductive carbon fibers and dust may cause electrical short-circuits, resulting in damage to and malfunction of electrical equipment and/or personnel injury • Product or dust may aggravate pre-existing eye, skin, or respiratory disorders	• Rating: Potentially Hazardous Operation • Probability: Low • Severity: Mild to moderate	• Engineering: shop and/or local exhaust ventilation • Administrative: MSDS; SOP; safe work practices; exposure time limitations; training • PPE: safety glasses with side shields for product use or machining, grinding, or sawing cured product; loose-fitting long sleeved shirt that covers to base of neck; long pants; gloves • Respiratory Protection: not usually required; use NIOSH approved organic vapor respirator if needed for heating or curing sized product; use NIOSH approved dust respirator if needed for machining, grinding, or sawing cured product • Residual Risk: accepted

Work Task	Potential Hazard	Hazard Ranking	Hazard Controls
Chemical Handling: Fiberglass Fabric	• Mechanical skin irritant (primarily at pressure points such as neck, wrist, waist, between fingers) • Mechanical eye irritant • Mouth, nose, and throat irritation if inhaled • Mechanical stomach and intestine irritant if ingested • Fiber release during cutting or sanding	• Rating: Potentially Hazardous Operation • Probability: Moderate • Severity: Mild	• Engineering: shop exhaust ventilation and/or local exhaust ventilation • Administrative: MSDS; SOP; safe work practices; exposure time limitations; training • PPE: safety goggles or safety glasses with side shields; loose-fitting long sleeved shirt that covers to base of neck; long pants; gloves • Respiratory Protection: not usually required; NIOSH/MSHA approved disposable dust respirator, when ventilation is inadequate or irritation occurs • Residual Risk: accepted
Ejection Charge Handling: Assembly	• Accidental ignition • Skin burn • Impact injury • Chemical exposure to black powder • Bystander injury • Facility/equipment damage	• Rating: Hazardous Operation • Probability: Moderate • Severity: Moderate to Severe	• Engineering: isolate ejection charge from strong electric fields and heat sources • Administrative: HOP; safe work practices; training; personnel certification • Residual Risk: accepted

Work Task	Potential Hazard	Hazard Ranking	Hazard Controls
Ejection Charge Handling: Testing	• Failure of ejection charge retention system releases projectile • Premature combustion • Injury to personnel • Facility/equipment damage • Unauthorized entry of test cell	• Rating: Hazardous Operation • Probability: High • Severity: Moderate to Severe	• Engineering: conduct test in blast-proof test cell; large safety factor designed into retention system • Administrative: written test procedures; safe work practices; supervision by Level 2 certified NAR Mentor; controlled access; training; personnel certification • Residual Risk: accepted
Machine Use: Lathe	• Injury to or loss of hand, limb • Laceration by shrapnel • Eye injury by shrapnel • Bystander injury • Facility/equipment damage	• Rating: Hazardous Operation • Probability: Moderate • Severity: Mild to Severe	• Engineering: machine selection; shop design • Administrative: SOP; safe work practices; training and qualification; supervision by experienced personnel; controlled access • PPE: eye protection • Residual Risk: accepted
Machine Use: Milling Machine	• Injury to or loss of hand, limb • Laceration by shrapnel • Eye injury by shrapnel • Bystander injury • Facility/equipment damage	• Rating: Hazardous Operation • Probability: Moderate • Severity: Mild to Severe	• Engineering: machine selection; shop design • Administrative: SOP; safe work practices; training and qualification; supervision by experienced personnel; controlled access • PPE: eye protection • Residual Risk: accepted

Work Task	Potential Hazard	Hazard Ranking	Hazard Controls
Motor Handling: Installation	• Accidental ignition • Skin burn • Impact injury • Bystander injury • Facility/equipment damage	• Rating: Hazardous Operation • Probability: Moderate • Severity: Moderate to Severe	• Engineering: isolate ejection charge from strong electric fields and heat sources • Administrative: HOP; safe work practices; training; personnel certification; performed only by Level 2 certified NAR Mentor • Residual Risk: accepted
Motor Handling: Testing	• Motor retention system failure resulting in uncontrolled motor movement • Premature combustion • Injury to personnel • Chemical exposure to ammonium perchlorate • Facility/equipment damage • Unauthorized entry of test cell	• Rating: Hazardous Operation • Probability: High • Severity: Moderate to Severe	• Engineering: conduct test in blast-proof test cell; large safety factor designed into retention system • Administrative: written test procedures; safe work practices; supervision by Level 2 certified NAR Mentor; controlled access; training; personnel certification • Residual Risk: accepted
Tool Use: Sanding/Grinding	• Skin abrasion • Laceration by shrapnel • Eye injury by shrapnel or dust • Respiratory irritation • Bystander injury • Facility/equipment damage • Chemical exposure if material being worked is hazardous • Catastrophic failure of grinding wheel resulting in high velocity	• Rating: Potentially Hazardous Operation • Probability: Low • Severity: Mild to Severe	• Engineering: machine selection; shop design; shop exhaust ventilation • Administrative: SOP; safe work practices; exposure time limitations; training; supervision by experienced personnel • PPE: eye protection • Residual Risk: accepted

Work Task	Potential Hazard	Hazard Ranking	Hazard Controls
Tool Use: Soldering, Electrical	• Skin burn • Damage to components • Fire	• Rating: Hazardous Operation • Probability: High • Severity: Mild to Severe	• Engineering: tool selection • Administrative: SOP; safe work practices; training • Residual Risk: accepted

Appendix E: Gantt Chart

Name	Begin d...	End date
Proposal Phase	11/8/13	11/22/13
Research	11/8/13	11/12/13
Writing	11/8/13	11/22/13
Proposal Deadline	11/22/13	11/22/13
PDR	11/7/13	1/10/14
Research	11/8/13	12/1/13
Writing	11/7/13	1/10/14
PDR Deadline	1/10/14	1/10/14
CDR	11/18/13	2/28/14
Research	11/18/13	12/20/13
Writing	12/12/13	2/28/14
Subscale/Test Launchs	11/18/13	2/28/14
CDR Deadline	2/28/14	2/28/14
FRR	1/1/14	4/18/14
Research	1/1/14	2/10/14
Writing	2/5/14	4/18/14
Full Scale Launch	3/3/14	4/18/14
FRR Deadline	4/18/14	4/18/14
Launch Week	5/14/14	5/18/14
USLI Launch	5/17/14	5/17/14
Post Launch Phase	5/18/14	6/2/14
Data Analysis	5/18/14	6/2/14
PLAR Writing	5/18/14	6/2/14
PLAR Deadline	6/2/14	6/2/14