Rover Delivery

2017-2018 NASA University Student Launch Initiative Project Proposal

20 September 2017

Propulsion Research Center
1030 John Wright Drive NW, Huntsville, AL 35805

256-824-7209
Contents

Executive Summary ............................................................................................................. 4

1. Program overview .......................................................................................................... 5
   1.1. School Information .................................................................................................. 5
   1.2. TRA/NAR Information ............................................................................................ 5
   1.3. Team Organization .................................................................................................. 5

2. Facilities .......................................................................................................................... 7
   2.1. Charger Rocket Works Laboratory ......................................................................... 7
   2.2. Propulsion Research Center .................................................................................... 7
   2.3. UAH MAE Machine Shop ....................................................................................... 8
   2.4. Reliability and Failure Analysis Lab ....................................................................... 9
   2.5. CRW Trailer ............................................................................................................ 9
   2.6. Computing Capabilities .......................................................................................... 9
   2.7. Section 508 Compliance ........................................................................................ 10

3. Safety ................................................................................................................................ 10
   3.1. Safety Policies and Procedures .............................................................................. 10
   3.2. Safety Officer ........................................................................................................ 11
   3.3. Team Members ..................................................................................................... 12
   3.4. Hazardous Materials ............................................................................................ 12
   3.5. Purchasing and procurement ................................................................................ 14
   3.6. Workplace Analysis .............................................................................................. 14
   3.7. Inspections ............................................................................................................ 15
   3.8. Mishap Reporting and Investigation ...................................................................... 15
   3.9. Propulsion Research Center procedures ................................................................ 15
   3.10. Supervision .......................................................................................................... 16
   3.11. Buddy System .................................................................................................... 16
   3.12. Emergency Response .......................................................................................... 16
   3.13. Safety Meetings .................................................................................................... 16
   3.15. Range Safety Officer Compliance ....................................................................... 17

4. Launch Vehicle Design ................................................................................................... 17
   4.1. Requirements ........................................................................................................ 17
   4.2. Structural Design/Analysis .................................................................................... 18
Executive Summary

The Charger Rocket Works (CRW) team will design and build a rocket to carry a rover payload to an altitude of 5,280 feet above ground level (AGL). After landing safely, the rover will move 5 feet away from the rocket and deploy solar panels. This will be demonstrated prior to the Flight Readiness Review in March 2018 with a proposed budget of approximately $7,500. The current design features a two wheeled, 5 pound rover that fits inside a 6 inch diameter, 27 inch long fairing. The basic launch vehicle is 71 inch long with a nominal diameter of 4 inch and estimated dry weight of 35 pounds. The current motor configuration uses an Aerotech L1420R motor. Additionally, the team will engage local students in Science, Technology, Engineering, and Math (STEM) fields focused educational activities. The team is split into payload, launch vehicle, and management teams, with specific sub-teams to tackle technical challenges. Safety is a primary concern throughout the project and will be maintained by a safety officer coordinating with the payload and launch vehicle teams.
1. Program overview

**MAE 490 Senior Design Course Instructor**
Dr. David Lineberry  
Research Engineer  
Propulsion Research Center  
david.lineberry@uah.edu  
256.824.2888

**TRA/NAR Mentor**
Jason Winningham  
Computer Systems Engineer, Engineering Department  
jason.winningham@uah.edu  
256.824.6132  
Level 3 NAR: 9526/TRA: 13669

**Program Manager**
Nathanial L.  
nal0007@uah.edu  
502.889.0222

**Safety Officer**
Bao H.

1.1. School Information

The University of Alabama in Huntsville (UAH) is a public university located in Cummings Research Park, the second largest research park in the United States. With strong ties to both NASA Marshall Space Flight Center and private aerospace companies, UAH’s 2700 engineering students have ample opportunities to gain hands on experience in their field. UAH offers strong support for a variety of student engineering activities, including The Space Hardware Club, the NASA Moonbuggy Competition, the American Astronautical Society CanSat Competition, American Society of Civil Engineers Concrete Canoe, and the American Institute of Chemical Engineers Chem-E-Car.

1.2. TRA/NAR Information

Tripoli Birmingham is section 81 of the Tripoli Rocketry Association (TRA) and goes by the name Phoenix Missile Works (PMW). PWM flies every month between October and March in Childersburg, Alabama with a waiver of 18000 feet. Most launches feature a vendor on site to reduce shipping cost and logistics of high powered motors. The Huntsville Area Rocketry Association (HARA) is the National Association of Rocketry (NAR) Section 403. CRW will work with HARA as mentors. Currently, HARA does not have high powered launches scheduled before the competition.

1.3. Team Organization

The 2017-2018 UAH Student Launch Initiative (SLI) team includes 19 mechanical and aerospace engineering students. Team resumes are found in Appendix G. Dr. David Lineberry serves as the team's advisor and course instructor for MAE 490 Senior Design. Additionally, Jason Winningham, an Electrical and Computer Engineering department employee and TRA Level 3 flier, will serve as the team’s TRA mentor and contact. The team is organized according to Figure 1.
1.3.1. Management

Project management includes all aspects of the projects not directly related to technical design, including but not limited to: safety, budget and schedule management, communications, outreach, and project documentation. The Project Manager is Nathanial L. who is responsible for the delivery of all systems and documentation required by SLI. The Safety Officer, Bao H., is responsible for ensuring hazards are documented, Materials Safety Data Sheets (MSDS) are compiled and available, and that all procedures are conducted according to pre-approved processes. The Safety Officer will also conduct safety briefings before all construction, experimentation, and launches. A safety representative from the payload and launch vehicle teams will work with the safety officer on risk assessment and mitigation for their subteam.

1.3.2. Communications

Communications involves maintaining the team website and social media presence, as well as organizing outreach events. Spencer M. is the team’s webmaster and will be responsible for posting updates, including design documents, presentations, and Milestone Review Flysheets to the website. Amanda S. will serve as the team photographer and assist with generating posts for Facebook, Instagram, and Twitter. Amanda S. and Nathanial L. are the points of contact for outreach opportunities.

1.3.3. Payload

The payload team is being led by Andrew M. and is responsible for delivering the payload portion of the mission. The team will design, fabricate, and test all portions of the payload. Major sections of work include mechanical structures and interfaces, electrical systems, and mission software.
1.3.4. Launch Vehicle

The launch vehicle team is led by Davis H. and is divided into three subteams. The upper airframe team is responsible for delivering the nosecone, upper body tube, and coupler for the rocket. The upper airframe team will work closely with the recovery and payload teams to ensure their designs are easily integrated into the launch vehicle. The lower airframe team is responsible for the lower body tube, fins, motor, and motor retention. This team will also maintain the simulations for the flight of the vehicle. Lastly, the recovery team is responsible for the main and drogue parachutes, the avionics, and the tracking system.

2. Facilities

For the design, manufacturing, and testing of the system, the team will have access to several in-house facilities including the Charger Rocket Works Laboratory, the Propulsion Research Center (PRC), the UAH Mechanical and Aerospace Engineering (MAE) Machine Shop, the UAH Wind Tunnel, and the Reliability and Failure Analysis Lab. The capabilities of each facility are outlined in the following sections.

2.1. Charger Rocket Works Laboratory

The Charger Rocket Works Laboratory is a general workspace used by the team located in the Propulsion Research Center on campus. The laboratory houses several pieces of equipment such as drill presses, a jig saw, a chop saw, and a belt sander in addition to payload and avionics workstations, a recovery work station, and a propulsion work station. The avionics work station includes a soldering station, electrical testing equipment, and basic electronic components. A self-closing hazardous material storage locker is also located in the laboratory for safe storage of epoxies and chemicals. All propellant is stored in bunkers outside of the laboratory. This space will serve as the team’s primary manufacturing and assembly location so all rocket components and supplies will be stored in the laboratory. This lab is also available round-the-clock to students.

2.2. Propulsion Research Center

The UAH Propulsion Research Center (PRC) is an on campus facility which has experience with liquid, gel, hybrid, electric, and solid propulsion system testing. They also work with combustion analysis, optical measurement, cryogenic systems, advanced diagnostic techniques, Computational Fluid Dynamic (CFD) modeling, verification and validation, and related technologies. The PRC also has state-of-the-art test stands and data acquisition systems with a test cell that allows the team to perform static rocket motor testing and ejection charge separation testing. This will help the team to validate their design calculations and vendor supplied data to decrease some of the risks associated with launch operations. All propellants, black powder, and e-matches are stored in the PRC dedicated Magazine for Department of Transportation Class 1.3 Propellant. This Magazine is a restricted area which can only be accessed by authorized and trained personnel.
2.3. UAH MAE Machine Shop

The UAH MAE Machine shop which is located in the Olin B. King Technology Hall is a round-the-clock facility which supports the College of Engineering students for the fabrication of multidisciplinary projects. The machine shop is available for all students under the supervision of trained and machine certified students to allow students to learn in a hands-on way. The CRW team members who have the appropriate training may use both the CNC and manual machines within the shop. To receive this training, the students must complete a semester training course. Within the shop there are strict dress codes enforced including long pants, closed toed shoes, short sleeves, and safety glasses at all times while on the shop floor.

The machine shop contains a variety of CNC and manual machines which will be used by the team throughout the system production. The following capabilities will be accessible to team members throughout the academic year:

- **CNC Lathe and Mills**: Two HAAS three axis CNC mills (models VF-1 and TM-1) and a HAAS CNC lathe (model TL-1) will provide the team with the ability to manufacture complex part geometries.

- **Manual Lathes and Mills**: Various manual lathes and mills are available with digital readouts for accuracy.

- **Rapid Prototyping Machine**: There are two rapid prototyping machines (3D printers) which use Computer Aided Design (CAD) drawings to produce precise models of components. This allows the team to use an iterative design approach for smaller components. These parts are mostly printed out of ABS Plastic. There are few environmental hazards associated with these machines and the operating expenses are minimal which allows the team to quickly turn around sub-scale and system components.

- **Composite Material Production**: The machine shop is capable of producing both fiberglass and carbon fiber layups in sections up to 48 x 48 x 72 inch through both wet and dry processes. Cures are then performed at room temperature or vacuum bags within the shop’s oven.

- **Saws**: Table saws, vertical band saws, and horizontal band saws are all available for use in the machine shop. The table saws also include an automatic braking system to stop the rotation of the saw blade in less than five milliseconds to prevent injuries.

- **Welding**: Gas Metal Arc Welding, Gas Tungsten Arc Welding, Metal Inert Gas, Tungsten Inert Gas oxyacetylene brazing, and Shielded Metal Arc Welding are all available for team use with the provided safety materials.
2.4. Reliability and Failure Analysis Lab

The Reliability and Failure Analysis Lab which is located in the Von Braun Research Hall on campus allows the students to investigate possible failure mechanisms of each component through both mathematical modeling and physical testing. The lab also allows the team to perform structural loading tests prior to flights to prevent structural failure. The facility also includes an autoclave, thermal shock and vibration chamber, cyclic corrosion chamber, servo-hydraulic tension compression fatigue test machine, accelerometer calibration station, and a modal exciter which will be available for students to use. In the event that the students will need larger composite structures, this facility works in tandem with the MAE machine shop to provide composite manufacturing facilities. This facility is open for student use with permission during standard business hours.

2.5. CRW Trailer

The team will use a mobile launch trailer which was fabricated by a previous MAE 490 Senior Design Course. The trailer has an adjustable launch rail which is hydraulically raised and lowered, as well as hydraulic stabilizing legs. This mobile trailer will be used at the launch fields for all team launches. The launch rail supports both 1010 and 1515 sized rail guides. Previously, operating procedures and safety assessments were completed during the senior design course.

2.6. Computing Capabilities

Several software programs will be available to the team in the Olin B. King Technology Hall computer labs. Engineering students have round-the-clock access to Olin B. King Technology Hall. Software such as MATLAB, MathCAD, and Nastran/Patran will allow the team to solve complex mathematical problems throughout the finite element analysis process. CAD software such as Solid Edge will allow the team the ability to create accurate models of the system and its components. These files can also be used for machining and rapid prototyping. Flight simulation software such as RockSim and Open Rocket allow the team to simulate various flight profiles to ensure the rocket will meet design requirements. Microsoft Office and Adobe Professional Package will primarily be used by the team to create and edit required documents for the SLI competition. The System Tool Kit (STK) will allow the team to simulate mission systems and how those systems will integrate. The STK software also allows the team to generate, report, graph, and vary qualitative and quantitative metrics for iterative design processes. Both Nastran/Patran will allow the team to solve complex fluid dynamics problems and perform structural analysis. The team is using GanttProject to track the program schedule and deliverables. Atmel Studio will be used for programming and debugging the microcontroller on the payload. Table 1 below outlines the available programs:

Table 1 below outlines the available programs:
Table 1: Available Software Programs

<table>
<thead>
<tr>
<th>Software Programs</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adobe Professional Package</td>
<td>PDF Editing</td>
</tr>
<tr>
<td>Asana</td>
<td>Calendar Software</td>
</tr>
<tr>
<td>Atmel Studio</td>
<td>Embedded system programming</td>
</tr>
<tr>
<td>MathCAD</td>
<td>Mathematical Programming</td>
</tr>
<tr>
<td>MATLAB</td>
<td>Mathematical Programming</td>
</tr>
<tr>
<td>Microsoft Office</td>
<td>Document Writing</td>
</tr>
<tr>
<td>Nastran/Protran</td>
<td>Finite Element Analysis</td>
</tr>
<tr>
<td>Open Rocket</td>
<td>Flight Simulation</td>
</tr>
<tr>
<td>RockSim</td>
<td>Flight Simulation</td>
</tr>
<tr>
<td>Simulink</td>
<td>Modeling Software</td>
</tr>
<tr>
<td>Solid Edge</td>
<td>CAD Modeling</td>
</tr>
<tr>
<td>SubVersion</td>
<td>Document Version Control</td>
</tr>
<tr>
<td>System Tool Kit (STK)</td>
<td>Mission System Simulation</td>
</tr>
</tbody>
</table>

2.7. Section 508 Compliance

Section 508 of the Rehabilitation Act requires that Federal agencies’ electronic and information technology will be accessible to all potential users, including individuals with disabilities. These standards were developed to ensure that electronically delivered information could be available to as many people as possible. As part of the SLI competition, CRW will create and maintain a team Web presence. Section 508 compliance can be ensured by consulting resources when developing the website to promote maximum accessibility to the widest range of users.

3. Safety

CRW expects that the rocket and payload will be manufactured with potentially hazardous materials and processes. CRW have developed a communication program and various hazard mitigation procedures to ensure the health and safety of all persons. These programs and procedures meets and exceed the safety requirements of all governing bodies.

3.1. Safety Policies and Procedures

The safety plan takes into account the safety of all team members when conducting tests, experimenting, or machine work. If by some chance, there is an accident, the team will follow the proper and necessary procedures to ensure the wellbeing of the affected member(s). The team will also ensure that the necessary precautions are followed to reduce any further risks.
The safety of all personnel, test facilities, equipment, property, environment, air space, and the general public are all of importance to the team. This policy shall be the foundation upon which the participation in the SLI competition shall be based.

Table 2: Safety Objectives

<table>
<thead>
<tr>
<th>Objective and Requirements of the CRW</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prioritize the safety and health of team and personnel</td>
<td>Safety Officer will define and implement proper hazard control procedures. All members will define and implement the health and safety program.</td>
</tr>
<tr>
<td>Identify all hazards associated with any operations and facilities</td>
<td>Safety Officer will conduct an initial risk assessment and hazard analysis that will be updated as necessary to adhere for workplace changes. Members will review these assessments and propose recommendations for such revisions. Throughout the project time, the team shall be proactive in identifying any hazards that may arise.</td>
</tr>
<tr>
<td>Preventative and control of team exposure to identified hazard materials</td>
<td>Safety Officer will designate, implement, and ensure compliance will all hazard practice. Safety Officer will review the hazard practices and propose revisions if necessary.</td>
</tr>
<tr>
<td>Training of members in safe work environments, manufacturing processes, hazard recognition, and emergency response</td>
<td>Safety Officer will specify and document all appropriate work practices and emergency response procedures for all hazardous situations. All members will familiarize themselves with plans, procedures, and working documents.</td>
</tr>
</tbody>
</table>

3.2. Safety Officer

The Safety Officer shall work alongside the program manager, senior engineers, course instructor, team mentor, and any other appropriate UAH and PRC faculty members to ensure that the safety plan is comprehensive and implemented fully. The Safety Officer shall inform all members of safety plan and all members shall adhere to the safety plan. The Safety Officer is the primary person responsible for any and all risk assessments, hazard mitigation, and the definition and documentation of all hazard procedures. This person is also responsible for ensuring that all aspects of the team safety plan are implanted and
followed. The other members will support the Safety Officer by assisting in the development of the risk and hazard mitigation and verify being followed.

3.3. Team Members

All members are responsible for ensuring the safety and wellbeing of all other members during any and all testing, experimentation, and machining. The team has organized responsibilities detailing the obligation for the safety of all personnel.

The Program Manager shall work with the Safety Officer to ensure the safety plan is implemented effectively and that all team members are abiding by the safety plan.

The Safety Officer shall work with the team members to develop and implement the safety plan, review and approve all standard operating procedures, and facilitate any and all trainings for members in terms of safe procedures for all design, testing, manufacturing, and launch activities.

The team leads shall develop the standard operating procedures for all testing and launch operations in conjunction with their appropriate subsections; assist in the facilitation of any training for members on safe procedures for any and all design, testing, manufacturing, and launching activities.

All team members shall follow all safety plans, procedures, and regulations that are provided to them; identify hazardous work conditions and file the appropriate documentation; hold all other team members responsible for following all safety protocols; and actively offer recommendations for improving the safety protocols as necessary.

3.4. Hazardous Materials

3.4.1. Communication Program

It is the duty of the Safety Officer to provide all team members with the appropriate information and safety training prior to using hazardous materials at the beginning of a work assignment and any that are brought into the work area during the work session. This information and training shall be in compliance with the requirements given in 29 CFR Part 1910.1200(h). Any methods that will limit chemical exposure will also be incorporated into the written standard operating procedures, hazardous operation procedures, and emergency procedures.

The information and training will be part of a Communication Program that will be presented to the team prior work sessions. The Communication Program will identify all stored hazardous materials and those used in all the project facilities and operations. The Safety Officer will collect MSDS’s for these products and ensure that all materials are correctly labeled. The Safety Officer will provide all team members with the correct information and training to be able to alleviate present hazards. This communication program is to ensure compliance with the

The identification on the materials on any MSDSs must match those that are kept in the CRW Inventory of Hazardous Materials (Appendix D) and the identification that is displayed on the on container labels. All team members are responsible for ensuring that these labels are displayed in accordance with the OSHA regulations. Any transferring of chemicals to containers for storage or transportation must also follow the same labeling procedure. A printed copy of each MSDS shall be kept in the PRC by the Safety Officer. The MSDS must be easily accessible by all team members for reference and any emergencies.

3.4.2. Inventory

The Safety Officer will keep documentation 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 compiled at the beginning of the project and will be updated throughout for any materials that will be procured. Appendix D lists all of the current hazardous materials that are expected to be used for the project.

3.4.3. Prevention and Control

In order to mitigate and eliminate any potential hazards, the CRW team will use a multi-level hazard reduction sequence comprised of engineering and administrative controls, safe procedures for hazardous operations, and personal protective equipment. A detailed Risk Assessment is included in Appendix A.

3.4.3.1. Control

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. Instead it will be used in conjunction with engineering and administrative controls if they alone do not eliminate all possible hazards, or during emergencies when the aforementioned engineering controls are no longer feasible.

Any minor risk remaining after all mitigation and controls is designated as residual risk. The CRW team leadership may, with the consent of the Team Mentor and Course Instructor, accept this risk based on risk assessment results and other factors pertaining to the SLI competition. However, residual risk that violates basic health and safety standards are not acceptable. Any accepted risk will be communicated to the entire team.
3.4.3.2. 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 conducting any hazardous operations are to take place and will be notified of any hazards which present themselves. This notification shall come from both procedural documentation and from direct communication. Written procedures with emphasis on 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 an accident occurs. First aid kits are also present in each of the work areas, along with Automated External Defibrillators (AEDs).

3.4.3.3. Equipment

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 required to complete purchases and maintained in the laboratory.

3.5. Purchasing and procurement

All motors shall be purchased from licensed vendors approved by the NAR or TRA certified members. The team mentor will purchase and handle the black powder and electric matches for ejection charges. All motors and energetic materials will be stored in the propellant bunker as described in the facilities section.

3.6. Workplace Analysis

The team shall identify any and 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. 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 Project 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.
3.7. **Inspections**

The Safety Officer and team leads shall inspect the work place areas and document these inspections. Any discrepancies between the safety requirements and observed conditions shall be recorded along with the personnel responsible for the corrective measures. All corrective measures shall be tracked by the Safety Officer. Scheduled inspections for fire and other explosive hazards will be conducted in accordance with UAH policies and procedures.

3.8. **Mishap Reporting and Investigation**

If any mishap occurs, it shall be promptly reported to the Safety Officer, Program Manager, and Course Instructor. 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.

3.9. **Propulsion Research Center procedures**

The PRC 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, PRC 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 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 B.
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, Project Manager, and Course Instructor as per UAH’s Non-Employee Accident Report Form. Any other affected CRW team members and UAH staff will be notified to ensure that all required documentation is completed. The team 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 team members in order to prevent any further mishaps from occurring.

3.10. Supervision
For tests, PRC and College of Engineering staff will be present to supervise, ensuring all safety measures are followed. The Team Mentor will provide assistance to help ensure rocket launches are well within all provided safety regulations. The Safety Officer will ensure that all policies and procedures are implanted and followed.

3.11. Buddy System
Team members will not work individually when conducting potentially hazardous operations. This goes beyond the requirements outlined in the Supervision section and states that at least two members of the team will be present for all hazardous activities. A safety review/briefing will be conducted prior to any test. The Safety Officer will ensure that every member is aware of the appropriate information pertaining to these tests.

3.12. Emergency Response
If CPR 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 B.

3.13. Safety Meetings
The Safety Officer will provide a safety briefing to the whole CRW team every two weeks 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.

The CRW team will adhere to all pertinent state and federal regulations throughout the duration of the project. The Federal Aviation Association (FAA), NAR, TRA, Code of Federal Regulations (CFR), National Fire Protection Association
(NFPA), and Department of Transportation, are the primary creators of regulation pertaining to amateur rocketry. All regulations can be found in Appendix C.

3.15. Range Safety Officer Compliance

The CRW team understands that at any launch site the Range Safety Officer (RSO) will review the rocket to determine that it adheres to all safety regulations. The RSO may determine the launch of any rocket unsafe and remove any team from the program if they cannot comply with the results of the safety inspection.

4. Launch Vehicle Design

The Launch Vehicle’s primary constraint is the space required to store the payload throughout the flight. Additionally, the team chose to make the rocket as efficient as possible and not rely on the largest motor possible. These requirements made the team choose a 6 inch diameter payload fairing on a 4 inch diameter body tube with a combined length of about 5 feet. The final configuration will be traded and decided on by the PDR deadline.

4.1. Requirements

There are six primary requirements dictated by NASA SLI that CRW will follow for a successful and safe launch:

1. Design a reusable rocket capable of withstanding multiple launches
2. Design a system to be prepared and launched within 3 hours of the FAA waiver opening
3. Design a payload that will deploy from the rocket on the ground, rove at least 5 feet, and deploy a set of foldable solar cell panels
4. Deliver the payload to an altitude of 5,280 feet
5. Descend under a dual-deploy system resulting in a landing impact under 75 foot-pound
6. Use a tracking system that transmits a landing location back to the ground station of every non-tethered component to the ground station

In addition to the requirements from the competition, there are four requirements the team is choosing to impose upon itself:

1. Use a motor with a total impulse below the maximum allowable impulse
2. Fly two subscale rockets to contrast difference component options
3. Engage at least 400 participants in STEM outreach
4. Design a unique and nice-looking rocket
4.2. Structural Design/Analysis

The key structural design driver for the launch vehicle is the size and mass of the payload. The payload requires a large bay that is 6 inches in diameter and 18 inches long. The motor required to lift the vehicle will be in a 4 inch diameter body tube to minimize mass and drag of the airframe, with a six inch diameter fairing. The launch vehicle will feature a dual deploy recovery system, deploying drogue at apogee and main during descent. The necessary structural components and load paths are shown in a component configuration cutaway view (Figure 2).

![Rocket Components and Load Path](image)

The airframe and the 6 inch to 4 inch transition coupler must sustain the maximum thrust of the motor and the weight and G-loading from the payload. The nose cone, payload bay, airframe, and weight will all be made of G12 fiberglass, while the fins will be G10 fiberglass due to the materials' light weight, high stiffness, and ability to handle large compressive strain. All bulk plates will be made of 6061-T6 aluminum due to the large shear modulus and ability to withstand ejection charges. Some components including fin brackets and the boat tail will be made from 3D printed ABS plastic due to ease of manufacturing complex geometries, and a lack of significant load. All of these structures will be analyzed with hand calculations as well as FEA through PATRAN/NASTRAN to ensure they will withstand all load cases with sufficient margin. The launch vehicle will be primarily assembled with steel and aluminum fasteners. All fasteners will be secured with vibration-resistant security to ensure all components stay attached throughout flight.

The dual deploy recovery system will feature recovery harnesses connecting the lower airframe, coupler, upper airframe, and payload bay which will be 0.5 inch Kevlar chord. Each harness will be connected to a forged eye-bolt.
4.3. Manufacturing

The fiberglass and Kevlar components will be purchased through a commercial supplier to ensure the material is strong, consistent, and reliable. The aluminum and ABS parts will be created in house on a Haas VF-1 CNC mill and FORTUS 3D printer respectively.

4.4. Simulation, Stability, and Propulsion

OpenRocket, an open source rocket simulation tool, was used with preliminary design dimensions and estimated masses to simulate various motors and perform trajectory analysis. OpenRocket was also used to calculate center of pressure (CP), apogee, and stability for different configurations. The rocket must be designed to have a minimum static stability margin of 2.0 when the forward rail button loses contact with the rail to fulfill the NASA SL static stability requirement.

The vehicle will be designed for the target altitude of 5,280 feet. A commercially available barometric altimeter will be used to during launches to measure official altitudes and fulfill the competition requirements. For the proposal design, a mass estimate of 35 pounds was used based on cumulative rocketry experience and the rough size of the rocket.

For the preliminary design and simulation, three different motors were selected and used for different sizing and thrust flexibility options moving forward with the project. These are the Aerotech L2500ST, L2200G, and L1420R motors. The primary difference between these with respect to the mission are the dimensions of the motor casing and total impulse. The L2500ST will pose difficulties in mounting the fins due to its larger diameter. The L2200G and L1420R both use the same motor casing, giving the choice of more power if the L1420R is chosen. All three contain solid ammonium perchlorate composite propellant (APCP) and are in the “L” impulse range (2,560.01-5,120.00 Newton·seconds). These motors are compared in Table 3.

<table>
<thead>
<tr>
<th>Table 3: Motor Simulation Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Motor Design</strong></td>
</tr>
<tr>
<td>Apogee</td>
</tr>
<tr>
<td>Stability</td>
</tr>
<tr>
<td>CG</td>
</tr>
<tr>
<td>Diameter</td>
</tr>
<tr>
<td>Length</td>
</tr>
<tr>
<td>Propellant Weight</td>
</tr>
<tr>
<td>Total Impulse</td>
</tr>
<tr>
<td>Max Acceleration</td>
</tr>
<tr>
<td>Velocity off the Rail</td>
</tr>
<tr>
<td>Burn Time</td>
</tr>
</tbody>
</table>
4.5. Recovery

A proper recovery system will ensure that the rocket and payload descend in a controlled and safe manner. This prevents possible damage to structures, making the rocket reusable. Thus the recovery system must be analyzed carefully and tested extensively before performing any test flights. As a pre-caution, redundancy will be built into the recovery system account for potential component failures.

4.5.1. Parachutes

The Charger Rocket Works team will use a dual deploy parachute recovery system in accordance with USLI requirements. This means that both a drogue parachute and a main parachute will be used to recover the rocket. The drogue chute is to be released at apogee and provide the initial drag force to slow the rocket’s descent. Slowing the initial descent of the rocket allows for the main parachute to undergo less force from the sudden change in acceleration that comes from opening a large chute at high velocity. A load analysis will be performed on the shock cord to confirm that the forces are within the material limits. The length of cord needed will also be determined to safeguard against improper deployment and possible entanglement. After falling to a pre-determined altitude above ground level, the main parachute will then be released for the final descent. The deployment altitude will be chosen to ensure that there is sufficient time for the parachute to open and achieve the desired falling velocity while also minimizing the opportunity for drift in the trajectory. The desired velocity will be low enough to obtain a kinetic energy upon impact less than the SL allowable amount of 75 pound-foot. The team plans to use the same parachute choices as the previous year’s team due to their proven reliability and similar mass estimates. For the drogue parachute this will be a 24 inch Fruity Chutes Drogue Parachute; the main parachute will be a SkyAngle C-3 XXL. These two parachutes can be seen in further detail in Table 4.

<table>
<thead>
<tr>
<th>Parachute</th>
<th>Brand</th>
<th>Model</th>
<th>Load Capacity (lbs)</th>
<th>Surface Area (ft²)</th>
<th>Expected Cd</th>
<th>Suspension Line Length (in)</th>
<th>Net Weight (oz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main</td>
<td>SkyAngle</td>
<td>CERT-3-XXL</td>
<td>60-129.8</td>
<td>129</td>
<td>2.92</td>
<td>120</td>
<td>64</td>
</tr>
<tr>
<td>Drogue</td>
<td>Fruity Chutes</td>
<td>Drogue Chute</td>
<td>N/A</td>
<td>3.02</td>
<td>1.5</td>
<td>28</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Table 4: Parachute Comparison Specification

In order to release the parachutes at the appropriate time during flight commercial altimeters will be used. The current design features StratoLogger altimeters due to previous experience with them. The drogue chute will be deployed by two black powder charges located 180° apart from each other on the avionics bay. An electronic match will set off the primary charge and the secondary charge will follow to guarantee separation from the body tube. The main chute will be deployed in a similar fashion using two black powder charges. These charges will be located
between the avionics bay and the upper body tube in the same configuration as the drogue chute charges between the avionics bay and lower body tube. The main chute charges will fire once the rocket has fallen to the desired altitude determined by the onboard altimeter. The recovery systems will be tested extensively on the ground to obtain accurate charge sizes that will separate the body tube properly. Precautions will be taken to make sure there is enough margin in charge size to account for less than ideal orientations which may make deployment more difficult.

4.5.2. Tracking

A GPS device will be used to track the rocket’s location throughout recovery operations. For tracking, the team plans to use a tracker previously designed in house with proven flight heritage. The GPS tracker has proven to be reliable and will save the team several hundred dollars while also reducing lead time on necessary hardware. The tracker will transmit its location to ground station via radio. A laptop will be connected to a second radio which will receive the radio transmission as location coordinates. The device will be shielded and isolated to ensure that it stays in working condition while causing or experiencing interference throughout launch and recovery operations. Ground testing will be performed in order to verify the robustness of the sensor and its associated housing. Tests will also be performed to confirm transmission distance and accuracy of reported location coordinates.

4.6. System Verification

A subscale rocket will be launched before the CDR and the flight data will be recorded and included in the CDR. This will ensure a successful flight of the conceptual design before moving to a full scale flight.

Flight tests are important to practice launch preparation and recovery procedures and to quantify system performance. As such, the team is actively searching for locations, dates, and other organizations through which the designs can be tested via flight. The team will mainly be going through Phoenix Missile Works\(^1\). Phoenix Missile Works is part of the Tripoli Rocketry Association (Tripoli Birmingham) and is located outside Talladega, Alabama. The waiver for launches at this location is 18,000 feet and the tentative launch dates are as follows: October 21\(^{st}\) – TBD, November 18\(^{th}\), December 16\(^{th}\), January 20\(^{th}\), February 17\(^{th}\) – 18\(^{th}\), and March 10\(^{th}\). The team is also looking into various other locations such as Manchester, Tennessee and Hardin County, Kentucky, in hopes of allowing for additional flights if necessary.

One of the main aspects of the rocket design is that it be reusable. This is defined as being able to be relaunched on the same day as the initial launch occurs. This will be accomplished by using simplistic and common parts for the design if possible. This includes items such as pop-rivets, screws, bolts, and other such items.

\(^{1}\) phoenixmissileworks.com
For the most unique and complex parts, such as parts that must be machined or are not readily available, multiple copies will be made before hand and kept in case of one becoming damaged or breaking. These items include fins, mounting brackets, or other various parts that are not commonplace.

4.7. Anticipated Challenges & Solutions

When designing a rocket and its payload there are several challenges that could arise. Several of these challenges will not be known until after the fabrication process begins. Once these challenges are known, testing and/or research must be done to determine a resolution to the given problem. There are a few challenges that have already been determined at this stage of the design.

The most significant non-technical challenge that the team will face is staying on schedule to meet the competition requirements. To be able to meet these strict scheduling requirements the team has assigned a set of smaller sub-teams that are each responsible for specific components of the launch vehicle or payload. In addition, these sub-teams will have set milestone and delivery dates for each of their assigned components. If a sub-team needs additional help, personnel can be temporarily reassigned to aid the team in need. Hence, the team organization is dynamic and flexible based on schedules, abilities, and the needs of other teams. The ability to move team members from one position to another is one of CRW’s greatest strengths.

4.7.1. Airframe

The first, and most obvious challenge is the aerodynamic forces being exerted on the launch vehicle. The effects of these forces can vary greatly depending on the velocity of the vehicle. The stages that cause the most concern are the main launch phase and deployment of the main parachute. Determining the loads at these points is a crucial step in the design process to ensure that the launch vehicle and the payload it holds can withstand the intense jolts and vibrations experienced by the rocket during these stages of the mission. Testing the structure against the calculated forces it will experience is vital to building a rocket that can both survive its mission and be reused in later missions.

Structurally speaking, one of the weakest points on the launch vehicle are the fins. When designing the fins, they must be designed such that they can withstand the forces exerted on them and not break off at any point during flight. A failure of the fins could be detrimental to mission success. To ensure that the fins are designed properly, the team must spend a significant amount of time investigating and researching the forces placed on fins of varying geometries. This can be done with wind tunnel testing and computational fluid dynamics. Once testing is completed the team can decide which fin design will give the best performance.

The weight of the rocket is always a challenging constraint. The current configuration has a dry weigh 35 pounds, with about 14% of that weight being the
payload. Add 7 to 10 pounds depending on the motor selected, weight quickly becomes a driving factor. The weight affects motor selection, which is restricted by the diameter of the selected body tube. Weight also affects drogue chute and main chute selection. A heavier rocket will require bigger, heavier parachutes. All of these factors also affect the apogee of the rocket. The weight of the system must be traded against component robustness for all design decisions. The team will utilize rocket simulation software to keep track of the vehicle's status as the design process progresses.

Finding the rocket upon landing can also be a challenge. Where the rocket will land is typically unpredictable and is likely a significant distance from the launch site. Finding the rocket is made especially difficult if it happens to land in a wooded area or an area of low visibility. To combat this, a GPS tracker will be placed in the nose cone of the launch vehicle. This tracker should be tested in a variety of environments to ensure that obstacles will not block the GPS signal.

4.7.2 Payload Integration

The initial challenge of the payload is the size. The selected payload for the competition is a rover that deploys foldable solar cells. The initial design used a larger body tube to accommodate the anticipated size of the rover. After some discussion, it was decided that a smaller body tube would be used and a fairing would be placed just below the nose cone to house the rover. This allows for a reduction in the overall weight of the vehicle.

The rover must be able to reliably deploy from the launch vehicle once it has landed. If the rover cannot leave the launch vehicle it will not be able to deploy the solar cells it carries. The main challenge with this is that there is no way to predict what terrain the launch vehicle will land on. Because of this a deployment system should be designed such that it can account for multiple terrains and landing conditions.

Care must be taken to ensure that the rover and its software are properly designed to accomplish the task specified in the Student Launch Handbook. This will require someone with a working knowledge of robotics and computer programming. Because of the varying terrain mentioned previously, the rover should be designed with a high ground clearance, good traction to avoid slipping, and a collision avoidance system. Once the rover is manufactured it must be tested with the designed software to ensure that it operates as expected and completes the tasks on hand. A significant amount of testing and debugging will be done so that the rover performs the assigned tasks effectively and efficiently.

Additionally, the mechanical and electrical components have a limit of how much force they can withstand. These forces must be accounted for and taken into consideration with the overall design. The payload and all electronics in the avionics bay must be properly secured so that they are not damaged during flight. A
stress analysis can be performed to ensure that the components can endure the forces they will face. In the case of any mechanical failures the system should be designed such that it minimizes dangers to personnel.

4.7.3. Subscale

In order to gain familiarity with the fundamentals of model rocketry, safety procedures, launch day preparation, and testing, CRW will conduct a sub-scale rocket launch is tentatively scheduled for October 2017. Because of the dimensional flight constraints, the sub-scale model will not fly a functional payload. It will, however, have the properly scaled, fully functioning tracking and recovery systems. The subscale flight is designed to simulate the same applied forces as the full-scale model, with similar center stability margin. The motor will be selected so that the forces on the subscale model will be like those experienced by the full-scale model. Sub-scale flight simulations will then be verified and adjusted accordingly based on the vehicle’s flight data. These adjustments can then be applied to the full-scale simulations.

5. Payload

The team has selected the rover payload for this year’s competition. The concept is a two wheeled rover with a stabilizing tail. Each wheel will have its own motor, which will be controlled by a microcontroller unit (MCU) mounted on a custom designed printed circuit board (PCB). This PCB will also host several sensors and the radio for remote commands. An extensive ground testing campaign will be conducted to ensure the rover completes its mission during the competition.

5.1. Design

5.1.1. Structure

The rover structure will be designed around a central chassis upon which all rover components will be attached. Material and geometry trades will be completed to ensure that the chassis will have sufficient strength to withstand all mission conditions. Additionally, consideration will be given to the mounting of all components such as printed circuit boards, cameras, antenna, solar panels, and electric motors. The other major component which may require machining are the rover wheels. Material and geometry trades will be completed to ensure that the wheels will have sufficient strength to withstand all mission conditions. Additionally, focus will be given to factors such as weight and traction. Minor components such as brackets and fasteners will be designed and traded to find the most appropriate solution.

5.1.2. Circuit

The rover electrical system will be centralized around a custom printed circuit designed using Eagle PCB or DesignSpark PCB design software. The printed circuit board manufacturing will be outsourced to a reputable PCB manufacturer. Upon receipt of the PCB, the surface mount components will be soldered to the PCB to form the complete circuit card assembly (CCA). The PCB shall be designed to
accommodate an Atmel microcontroller, a regulated DC power supply, various sensors, and all data/power input/outputs.

Multiple options for PCB manufacturers were researched with the benefits provided by each company compiled below in Table 5. To ensure faster shipping and better customer service, companies were only examined if they were located in the United States. All of the manufacturer’s considered provide free gerber file analysis software. Ultimately, Advanced Circuits was selected because many members of the team have experience with their services which include student discounts on two layer PCBs. Additionally, Advance Circuits’ experts offer round-the-clock support which will be useful for the duration of this project.

![Table 5: Printed Circuit Board Manufactures and Benefits](image)

<table>
<thead>
<tr>
<th>Company</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced Circuits</td>
<td>Located in USA, offers free PCB Artist software as well as FreeDFM for exporting Gerber files, 1 - 5 day turnaround for simpler boards, offers student discounts, provides instant online quotes as well as 24 - hour tech support, space and flight approved, relatively low prices.</td>
</tr>
<tr>
<td>Custom Circuit Boards</td>
<td>Located in USA, turnaround as fast as 24 hours, 35 years of experience, specialize in products for aerospace industry as well as students, online quotes.</td>
</tr>
<tr>
<td>Express PCB</td>
<td>Located in USA, offers free design software, library of user-created content, offers a deal of 3 boards for $41.</td>
</tr>
<tr>
<td>Pad2Pad</td>
<td>Located in USA, offers free design software, provide instant quotes from Gerber files, provide boards for companies including NASA, Boeing, Amazon, and Google.</td>
</tr>
</tbody>
</table>

As of this proposal, it is very likely that the microcontroller unit (MCU) will be supplied by Atmel. Atmel provides several unique MCU options suited for various situations. Data on each MCU’s benefits, applications, and hardware parameters are compiled in Table 6.
A final decision on which device family will be used will be determined once further trade studies have been conducted and more information regarding the rest of the payload’s operation has been obtained. Top candidates from Atmel seem to be the tinyAVR, the AVR XMEGA, and the megaAVR. The tinyAVR is a nice option because of its small size and uses in motor control. However, if more processing power or storage space is required, the other options will be considered. The megaAVR family of Atmel MCUs may be useful in creating some sort of touch screen interface, if that were desired and/or required.

### 5.1.3. Sensors

While exact sensors have not yet been chosen, the team has decided that there are two mission critical sets of data. The first set of data is location of the rover with respect to the rocket. This data is important to ensure that the rover travels beyond the 5 ft distance requirement outlined in the SLI requirements. This data can be gathered through the use of GPS, integration of accelerometer data, or direct wheel RPM measurement. The second set of data is collision avoidance data. It was determined that this data could be gathered through the use of ultrasonic sensors, a mechanical collision detector, or another range finding sensor. Trade studies will be conducted to determine which option is most suitable for the rover for both sets of data. The rover will also include a radio for receiving the remote start command and for telemetry transmission. The team is currently considering various Xbee radio modules as they are easy to configure and the team has past experience with them. A final selection will be made by PDR.

### Table 6: Microcontroller Unit Trade Study

<table>
<thead>
<tr>
<th>Device Family</th>
<th>Benefits</th>
<th>Applications</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-bit tinyAVR</td>
<td>Small</td>
<td>General</td>
<td>0.5 - 16 KB Flash</td>
</tr>
<tr>
<td></td>
<td>Powerful</td>
<td>Lighting</td>
<td>6 - 32 pins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Basic motor control</td>
<td>≤ 20 MHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.0 MIPS/MHz</td>
</tr>
<tr>
<td>AVR XMEGA</td>
<td>Xtreme</td>
<td>General</td>
<td>8 - 384 KB Flash</td>
</tr>
<tr>
<td></td>
<td>8-bit</td>
<td>Lighting</td>
<td>32 - 100 pins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LCD</td>
<td>≤ 32 MHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.0 MIPS/MHz</td>
</tr>
<tr>
<td>megaAVR</td>
<td>More peripherals / options</td>
<td>General</td>
<td>4 - 256 KB Flash</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lighting</td>
<td>28 - 100 pins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LCD</td>
<td>≤ 20 MHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.0 MIPS/MHz</td>
</tr>
<tr>
<td>32-bit AVR UC3</td>
<td>Very efficient</td>
<td>General</td>
<td>16 - 512 KB</td>
</tr>
<tr>
<td></td>
<td>32-bit</td>
<td></td>
<td>48 - 144 pins</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>≤ 66 MHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.5 MIPS/MHz</td>
</tr>
</tbody>
</table>
5.1.4. Software

Embedded software will be needed to enable the rover to achieve the stated mission objectives. Consequently, the system’s microcontroller shall be programmed using C within Atmel Studio. The software shall be designed to handle all sensor inputs, signal outputs, radio communications, data collection, and more. Several members of the payload team have programming experience including C which will prove invaluable to the success of the rover. Although software flow will depend heavily on the final rover design, it is known that programming will be needed to release the rover from the launch vehicle. After release from the launch vehicle, the rover will need to analyze various sets of sensor data to determine when to drive the electric motors. Once the rover reaches its final resting spot, the software will need to actuate the deployment of the solar panels.

5.2. Manufacturing

5.2.1. Structure

Depending on material selection, the parts of the rover may be manufactured in a variety of ways. The team has access to the UAH rapid prototyping facility which is home to a large variety of additive and subtractive manufacturing technologies. Metal components will most likely be machined using the CNC Mill, manual mill, CNC lathe, manual lathe, or other subtractive methods. Plastic components may be additively manufacturing or injection molded.

5.2.2. Electronics

PCB manufacturing will be outsourced to a PCB manufacturer. PCB components shall be soldered onto the board by members of the team. All wiring harnesses and interconnects shall be assembled by members of the team.

5.3. Testing

5.3.1. Software unit testing

As electrical components are assembled, the software will be tested to ensure all components function as expected. Triggering the rover will require a radio communication system which is capable of maintaining a link throughout the flight mission. A mathematical link budget along with range testing will ensure that the payload and ground station are capable of the necessary slant range. As drivers for the various sensors are written, they will be tested individually for functionality and calibrated using known inputs.

5.3.2. Structural testing

Structural testing will be necessary to ensure the payload will not come apart or be damaged by forces associated with launching the rocket. Crush tests, drop tests, thermal tests, and impact tests will be performed to accompany simulations for safety. These will simulate possible modes of failure during launch as closely as possible.
UAH has laboratory equipment necessary for each test. Successful tests will provide data about our rover and assure all possible failures will not be devastating to any key components.

5.3.3. Full system test
As the final rover and rocket are finished, fit tests will be performed. This will allow integration teams to adjust the rover clamshell packing as necessary to best stabilize the payload. The apparatus will then go through ejection tests in a number of possible rocket landing orientations to ensure the rover will eject without fail. Tests will also be performed in a number of terrains to ensure the rover will not become stuck in any unfavorable conditions. The rover software will be tested on the ground and during test flights. An analysis of each test will be conducted and the software reiterated to correct any noted deficiencies.

5.4. Integration
Trade studies will be performed on various structural, software, and electrical components of the rover. Structurally, this would include designing the parts so that all of the components fit together. This may include adding screw holes where needed and making sure that all of the components can fit on the chassis. The electrical integration would include communication with the various components and taking analog versus digital measurements. During the trade studies, the sub-components will be selected such that they can be integrated in a manner that will allow the rover to perform as intended by the requirements.

5.5. Anticipated Challenges & Solutions
5.5.1. G-loading on circuits during powered ascent and landing
For smaller components G loading will not be an issue since the solder joints will be strong enough to constrain the part movement. Calculations will be done to ensure that the solder will hold everything together during powered ascent and landing. Any of the components that are large will be potted or conformal coated in order to deal with g-loading.

5.5.2. Reliable deployment from rocket
There may be an issue of trying to get the rover out of the rocket once it lands on the ground. When the rover is being pushed out, it would be possible for it to turn at an angle where the wheels get stuck against the inside of the rocket. A solution for this would be to place the rover inside of a container. An issue that might arise from this is not being able to get the container opened once it is outside of the rocket. A solution for this would be to use clamshell packing so it can be opened easily once it is outside of the rocket.

5.5.3. Obstacles/Terrain for Rover Movement
There would be potential for there to be water puddles. This issue would be resolved by making sure the electronics were potted and making sure the wheels...
that are chosen are appropriate for a wet environment. The rocket could land next to a tree or some other big obstacle that obstructs the rover from traveling the required five feet. A solution to this would be to have the rover programmed and designed so that it could move in any direction rather than just the forward direction.

![Figure 3: Rover Integration into Rocket](image)

6. Outreach

Local education and outreach is a programmatic goal of this year’s CRW team. Many of the team members were inspired by STEM mentors and events to pursue an engineering degree. The team will reach over 200 students by partnering with various professional engineering societies, engineering competitions, and UAH. Several team members are also members of professional societies like the American
Institute for Aeronautics and Astronautics, the Society of Women Engineers, and the American Society of Mechanical Engineers. These organizations regularly host outreach events, and the CRW team will participate with hands on activities related to rocketry. These could include stomp and water rockets, as well as guided builds of Estes kits. One competition CRW has supported in the past is First Lego League. The team plans to support this competition again as judges and referees, and will conduct a rocketry activity during the lunch break. Lastly, the CRW team will participate in UAH led activities, such as Discovery Days and various STEM Days. Discovery Days allow current UAH students to share their experiences and design projects with prospective students. One currently planned STEM day is the Girl’s Science and Engineering Day. The CRW team can help young girls to assemble model rockets and then launch them while explaining what exactly the girls are doing and how it can be applied on a larger scale. For all planned outreach activities, photographs will be taken (if allowed), and feedback will be collected from participants and educator to improve future efforts.

Table 7: Possible Outreach Opportunities with Proposed Activities

<table>
<thead>
<tr>
<th>Opportunity</th>
<th>Date</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Girl’s Science and Engineering Day</td>
<td>September 23, 2017</td>
<td>Build and launch model rockets</td>
</tr>
<tr>
<td>FIRST Lego League Qualifier Round</td>
<td>November 18, 2017</td>
<td>Sensor activity</td>
</tr>
<tr>
<td>Bob Jones High School Engineering</td>
<td>TBD</td>
<td>GPS Tracking</td>
</tr>
<tr>
<td>Class</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discovery Day</td>
<td>TBD</td>
<td>Present material that has been worked on to show</td>
</tr>
<tr>
<td>FIRST Lego League Alabama State</td>
<td>TBD</td>
<td>Sensor activity</td>
</tr>
<tr>
<td>Competition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FIRST Robotics High School team</td>
<td>TBD</td>
<td>Circuit boards, sensors</td>
</tr>
<tr>
<td>North Alabama Regional Science Fair</td>
<td>TBD</td>
<td>Rocket Demo</td>
</tr>
<tr>
<td>Science Olympiad</td>
<td>February, 2018</td>
<td>Radio demo, circuit build</td>
</tr>
</tbody>
</table>

7. Project Plan

A well thought out project plan is necessary to ensure the proper resources, including personnel, parts, and facilities, are available when needed. Time and money must be budgeted to ensure all program requirements are met. The Program Manager is responsible for keeping the project schedule and budget up to date as the project progresses.

7.1. Schedule

The team has adopted an aggressive schedule driven by local high powered launch dates. The PMW holds monthly launches starting in October. The team plans to launch the subscale rocket at the October launch and have the full vehicle ready for the January launch. This gives two opportunities to simulate the whole mission with the payload (launches in January and February) and allows for some schedule creep. Design phases include trade studies, simulations, and prepping for fabrication. The design phases also include acceptance testing for individual components. Fabrication phases include manufacturing, assembly, and integration.
of components and subsystems. Ground testing includes all subsystem and system testing that can be accomplished outside of a flight. The team is able to push for such an aggressive schedule due to previous experience in High Powered Rocketry and rover design.

**Project Phase Cycle**

<table>
<thead>
<tr>
<th>Project Life-Cycle Phases</th>
<th>Pre-A</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept Study &amp; Proposal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concept &amp; Technology Development</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preliminary Design &amp; Technology Completion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final Design &amp; Fabrication</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>System Assembly, Integration &amp; Test</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Launch Operations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Closeout</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Key Decision Points</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposal Submission, 9/20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Awarded Proposal, 10/6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preliminary Design Review, 11/03</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Critical Design Review, 1/12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flight Readiness Review, 3/5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Launch Readiness Review, 4/4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLAR, 4/27</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Project Life-Cycle Reviews</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>September</td>
<td>October</td>
<td>November</td>
<td>December - January</td>
</tr>
<tr>
<td></td>
<td>2017</td>
<td>2017</td>
<td>2017</td>
<td>2017</td>
</tr>
<tr>
<td>Timeline</td>
<td>April - March</td>
<td>April - March</td>
<td>April - March</td>
<td>April 8 - April 17</td>
</tr>
<tr>
<td></td>
<td>2017</td>
<td>2018</td>
<td>2018</td>
<td>2018</td>
</tr>
</tbody>
</table>

*Figure 5. Project Phase Cycle*

### 7.2. Budget

The project budget summary is shown in Table 8. Table 9 lists the components necessary to build two rovers. The budget allows for two rovers for the purpose of redundancy; therefore, if a part malfunctions a backup will be available. Also, as shown in the table, budgeting for this redundancy only results in a 36% increase in the payload cost and a 3.7% increase in overall cost. This increase is acceptable considering the amount of time that would be saved by not having to order a replacement part if one were to malfunction.

Table 10 lists the components necessary to manufacture two subscale and two full-scale launch vehicles. Two subscale vehicles are planned to be built in order to give more people on the team hands-on experience with building rockets. This is also done to reduce the likelihood that a subscale launch day will be unsuccessful, since two subscale models can be launched on a given launch day. Two full-scales are allowed for the purpose of redundancy, similar to the payload subsystem. Six subscale motors and six full-scale motors are also included. This is done to allow for thrust stand testing and multiple launches. Due to the availability of local launches...
and the fact that the competition is held in Huntsville, team members will provide their own transportation. This implies the travel costs will be eliminated.

**Table 8: Summary of Budget**

<table>
<thead>
<tr>
<th>Budget Summary</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch Vehicle Budget</td>
<td>$5,706.78</td>
</tr>
<tr>
<td>Payload Budget</td>
<td>$1,013.63</td>
</tr>
<tr>
<td>Miscellaneous, Taxes, and Shipping</td>
<td>$750.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$7,470.41</strong></td>
</tr>
</tbody>
</table>

**Table 9: Payload Budget for Components Needed for Two Rovers**

<table>
<thead>
<tr>
<th>Item</th>
<th>Vendor</th>
<th>Price</th>
<th>Quantity</th>
<th>Total Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kapton Tape</td>
<td>Amazon</td>
<td>$9.00</td>
<td>1</td>
<td>$9.00</td>
</tr>
<tr>
<td>Flash memory</td>
<td>Digkey</td>
<td>$5.81</td>
<td>2</td>
<td>$11.62</td>
</tr>
<tr>
<td>Batteries</td>
<td>Amazon</td>
<td>$21.00</td>
<td>2</td>
<td>$42.00</td>
</tr>
<tr>
<td>Wires</td>
<td>McMaster-Carr</td>
<td>$10.74</td>
<td>1</td>
<td>$10.74</td>
</tr>
<tr>
<td>MOLEX connectors</td>
<td>Digkey</td>
<td>$0.50</td>
<td>20</td>
<td>$10.00</td>
</tr>
<tr>
<td>Solder</td>
<td>Amazon</td>
<td>$3.00</td>
<td>1</td>
<td>$3.00</td>
</tr>
<tr>
<td>6061 Aluminum</td>
<td>McMaster-Carr</td>
<td>$93.09</td>
<td>1</td>
<td>$93.09</td>
</tr>
<tr>
<td>Battery Holders</td>
<td>Digkey</td>
<td>$1.13</td>
<td>4</td>
<td>$4.52</td>
</tr>
<tr>
<td>ABS</td>
<td>Technical Training Aids</td>
<td>$165.00</td>
<td>1</td>
<td>$165.00</td>
</tr>
<tr>
<td>9-axis IMU</td>
<td>Digkey</td>
<td>$10.63</td>
<td>2</td>
<td>$21.26</td>
</tr>
<tr>
<td>Ultrasonic sensor</td>
<td>Digkey</td>
<td>$3.95</td>
<td>2</td>
<td>$7.90</td>
</tr>
<tr>
<td>PCB</td>
<td>Advanced Circuits</td>
<td>$33.00</td>
<td>2</td>
<td>$66.00</td>
</tr>
<tr>
<td>DC Motor</td>
<td>Digkey</td>
<td>$38.00</td>
<td>2</td>
<td>$76.00</td>
</tr>
<tr>
<td>ATxmega128A3U-AU</td>
<td>Microchip</td>
<td>$6.65</td>
<td>2</td>
<td>$13.30</td>
</tr>
<tr>
<td>Switch</td>
<td>Digkey</td>
<td>$2.50</td>
<td>2</td>
<td>$5.00</td>
</tr>
<tr>
<td>Camera</td>
<td>BuryMobius</td>
<td>$7.80</td>
<td>2</td>
<td>$15.60</td>
</tr>
<tr>
<td>MOSFETs</td>
<td>Amazon</td>
<td>$0.72</td>
<td>12</td>
<td>$8.64</td>
</tr>
<tr>
<td>Xbee Pro 60mW</td>
<td>Digkey</td>
<td>$37.95</td>
<td>2</td>
<td>$75.90</td>
</tr>
<tr>
<td>Fasteners</td>
<td>McMaster-Carr</td>
<td>$45.00</td>
<td>1</td>
<td>$45.00</td>
</tr>
<tr>
<td>Yagi Antenna</td>
<td>Bany Network: USA</td>
<td>$137.06</td>
<td>1</td>
<td>$137.06</td>
</tr>
<tr>
<td>LEDs</td>
<td>Digkey</td>
<td>$9.25</td>
<td>4</td>
<td>$37.00</td>
</tr>
<tr>
<td>Solar cell</td>
<td>Digkey</td>
<td>$2.15</td>
<td>4</td>
<td>$8.60</td>
</tr>
<tr>
<td>Heat shrink</td>
<td>Amazon</td>
<td>$8.00</td>
<td>1</td>
<td>$8.00</td>
</tr>
<tr>
<td>Various capacitors, resistors, inductors</td>
<td>Digkey</td>
<td>$10.00</td>
<td>3</td>
<td>$30.00</td>
</tr>
</tbody>
</table>

For Two Rovers: $1,013.63

For Single Rovers: $744.76
7.3.  Funding
The project funding will come from the Alabama Space Grant Consortium (ASGC) and the UAH Propulsion Research Center (PRC). Once the project proposal has been approved by NASA, a funding proposal will be sent to the ASGC. On acceptance, the UAH PRC will match the funding of the ASGC. The university will also provide support through facilities and overhead use.

7.4.  Sustainability
The CRW team recognizes the importance of building a program that can deliver quality hardware to the SLI competition year after year. CRW is a critical part of UAH's plans to deliver quality engineering education, as is evidenced by this news article on last year's team. As a premier student program at UAH, the CRW team receives a great deal of resources from the university. This includes dedicated manufacturing and assembly facilities and support of faculty such as Dr. Lineberry

---

and Jason Winningham. These resources will continue to be available for future teams to utilize. In return, the team supports the recruiting efforts of the university by presenting at engineering open houses and engaging with potential students. Building interest in the SLI competition this early ensures that by the time students take senior design, they are motivated to push themselves and represent the university. This year, the team is implementing a Subversion server for document revision control. In addition to improving project management, this will allow future teams easier access to old documents and designs to learn from.
Appendix A: Risk Analysis and Hazard Controls

Table 1 lists Risk Assessment Criteria (RAC). Table 2 and Table 3 define the parameters used in Table 1. Table 4 contains the Risk Analysis and Hazard Controls. Table 5 contains Hazard Mitigation.

<table>
<thead>
<tr>
<th>Probability</th>
<th>Severity</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Catastrophic</td>
<td>1A</td>
<td>2A</td>
<td>3A</td>
<td>4A</td>
</tr>
<tr>
<td>A - Frequent</td>
<td>Critical</td>
<td>1B</td>
<td>2B</td>
<td>3B</td>
<td>4B</td>
</tr>
<tr>
<td>B – Probable</td>
<td>Marginal</td>
<td>1C</td>
<td>2C</td>
<td>3C</td>
<td>4C</td>
</tr>
<tr>
<td>C – Occasional</td>
<td>Negligible</td>
<td>1D</td>
<td>2D</td>
<td>3D</td>
<td>4D</td>
</tr>
<tr>
<td>D - Remote</td>
<td></td>
<td>1E</td>
<td>2E</td>
<td>3E</td>
<td>4E</td>
</tr>
<tr>
<td>E - Improbable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 1: RAC**

**Table 2 Level of Risk and Level of Management Approval**

<table>
<thead>
<tr>
<th>Level of Risk</th>
<th>Level of Management Approval/Approving Authority</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Risk</td>
<td>Highly Undesirable. Documented approval from the MSFC EMC or an equivalent level independent management committee.</td>
</tr>
<tr>
<td>Moderate Risk</td>
<td>Undesirable. Documented approval from the facility/operation owner’s Department/Laboratory/Office Manager or designee(s) or an equivalent level management committee.</td>
</tr>
<tr>
<td>Low Risk</td>
<td>Acceptable. Documented approval from the supervisor directly responsible for operating the facility or performing the operation.</td>
</tr>
<tr>
<td>Minimal Risk</td>
<td>Acceptable. Documented approval not required, but an informal review by the supervisor directly responsible for operating the facility or performing the operation is highly recommended. Use of a generic JHA posted on the SHE Webpage is recommended.</td>
</tr>
</tbody>
</table>

**TABLE 3 Severity Definitions – A condition that can cause:**

<table>
<thead>
<tr>
<th>Description</th>
<th>Personnel Safety and Health</th>
<th>Facility/Equipment</th>
<th>Environmental</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – Catastrophic</td>
<td>Loss of life or a permanent-disabling injury.</td>
<td>Loss of facility, systems or associated hardware.</td>
<td>Irreversible severe environmental damage that violates law and regulation.</td>
</tr>
<tr>
<td>2 - Critical</td>
<td>Severe injury or occupational-related illness.</td>
<td>Major damage to facilities, systems, or equipment.</td>
<td>Reversible environmental damage causing a violation of law or regulation.</td>
</tr>
<tr>
<td>3 - Marginal</td>
<td>Minor injury or occupational-related illness.</td>
<td>Minor damage to facilities, systems, or equipment.</td>
<td>Mitigatable environmental damage without violation of law or regulation where restoration activities can be accomplished.</td>
</tr>
<tr>
<td>4 - Negligible</td>
<td>First aid injury or occupational-related illness.</td>
<td>Minimal damage to facility, systems, or equipment.</td>
<td>Minimal environmental damage not violating law or regulation.</td>
</tr>
</tbody>
</table>
### Table 4: Probability Definitions

<table>
<thead>
<tr>
<th>Description</th>
<th>Qualitative Definition</th>
<th>Quantitative Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A - Frequent</td>
<td>High likelihood to occur immediately or expected to be continuously experienced.</td>
<td>Probability is $&gt;0.1$</td>
</tr>
<tr>
<td>B - Probable</td>
<td>Likely to occur to expected to occur frequently within time.</td>
<td>$0.1 \geq$ Probability $&gt;0.01$</td>
</tr>
<tr>
<td>C - Occasional</td>
<td>Expected to occur several times or occasionally within time.</td>
<td>$0.01 \geq$ Probability $&gt;0.001$</td>
</tr>
<tr>
<td>D - Remote</td>
<td>Unlikely to occur, but can be reasonably expected to occur at some point within time.</td>
<td>$0.001 \geq$ Probability $&gt;0.000001$</td>
</tr>
<tr>
<td>E - Improbable</td>
<td>Very unlikely to occur and an occurrence is not expected to be experienced within time.</td>
<td>$0.000001 \geq$ Probability</td>
</tr>
</tbody>
</table>

### Table 5: Risk Mitigation

<table>
<thead>
<tr>
<th>Overall Project</th>
<th>Pre-RAC</th>
<th>Mitigation</th>
<th>Verification</th>
<th>Post-RAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>#</td>
<td>Hazard</td>
<td>Cause</td>
<td>Effect</td>
<td>Pre-RAC</td>
</tr>
</tbody>
</table>
| 1 | Project falls behind schedule | Missed deadlines | 1. Insufficient time to perform quality level work  
2. Incomplete project | 2C | 1. Assign weekly workload requirements for sub-teams  
2. Monitor progress with a schedule | 1. Weekly reports from sub-team leads on progress and schedule conflicts  
2. Track milestones with a Gantt chart. | 2E |
<p>| 2  | Project goes over budget | Improper allocation of funds | 1. Inability to order parts on time and progress falls behind schedule 2. Unable to fly subscale, full-scale, or competition launches due to lack of parts | 1. Implement a spending plan that governs parts procurement in intervals 2. Budget accordingly to allow for additional back-up components | 1. Project Manager shall monitor purchasing versus spending plan and authorize out of cycle purchases. 2. Budget shall allow for two or more replacement parts in high failure areas or single-use items |
| 3  | Parts become unavailable | Improper procurement planning | 1. Inability to follow schedule due to manufacturing delays 2D | 1. For every critical part ordered, determine and keep on record a backup supplier or buy multiples of parts whenever possible | 1. Chief Engineer shall ensure that all vendor supplied items have multiple vendors or adjust spending plan accordingly |</p>
<table>
<thead>
<tr>
<th><strong>Vehicle</strong></th>
<th><strong>Payload</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>4 Airframe Structural Failure</td>
<td>6 Data collection failure</td>
</tr>
<tr>
<td>1. Rocket body destructs 2. Unstable flight</td>
<td>1. Loss of ability to record data during flight 2. Inaccurate data</td>
</tr>
<tr>
<td>1. Ensure that loads are properly communicated throughout vehicle 2. Ensure that all joints, pins, and points of integration are strong enough to withstand the highest calculated stress</td>
<td>1. Completion of successful testing prior to launch 2. Ensure ground and flight test results match calculated results</td>
</tr>
<tr>
<td>5 Excessive fin flutter</td>
<td></td>
</tr>
<tr>
<td>#</td>
<td>Hazard</td>
</tr>
<tr>
<td>----</td>
<td>----------------------------</td>
</tr>
<tr>
<td>7</td>
<td>GPS lock failure</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Power loss to one or more systems</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Flight**

<table>
<thead>
<tr>
<th>#</th>
<th>Hazard</th>
<th>Cause</th>
<th>Effect</th>
<th>Pre-RAC</th>
<th>Mitigation</th>
<th>Verification</th>
<th>Post-RAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Weather cocking</td>
<td>Improper exit velocity or static margin</td>
<td>1. Surpasses field 2. Insufficient altitude</td>
<td>1C</td>
<td>1. Adjust CG/CP locations according to simulations 2. Design for sufficient exit velocity off the rail Design for reasonably high thrust to weight ratio;</td>
<td>1. Measure the stability margin and compare to simulation data 2. weigh the rocket and compare to vendor thrust data</td>
<td>1E</td>
</tr>
<tr>
<td></td>
<td>Unstable flight</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>----------------</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Weather cocking or Fin flutter</td>
<td>1. Safety threat to audience</td>
<td>1C</td>
<td>1. Simulate flight with software</td>
<td>1E</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Structural failure</td>
<td>2. Possible destruction of rocket</td>
<td></td>
<td>2. Test with subscale model</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Insufficient altitude</td>
<td>Improper thrust to weight ratio</td>
<td>2C</td>
<td>1. Use analytics and computer software in conjunction with ground testing to ensure proper motor choice</td>
<td>2E</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1. Fails to meet minimum competition requirement</td>
<td></td>
<td>2. Ensure that the rocket is of the proper mass</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Improper payload deployment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Exceeds altitude</td>
<td>Improper thrust to weight ratio</td>
<td>2C</td>
<td>1. Use analytics and computer software in conjunction with ground testing to ensure proper motor choice</td>
<td>2E</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1. Fails to meet technical requirements of success</td>
<td></td>
<td>2. Ensure that the rocket is of the proper mass</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Disqualification of overall competition award</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Propulsion

<table>
<thead>
<tr>
<th>#</th>
<th>Hazard</th>
<th>Cause</th>
<th>Effect</th>
<th>Pre-RAC</th>
<th>Mitigation</th>
<th>Verification</th>
<th>Post-RAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>Propellant does not ignite or chuffs</td>
<td>Poor vendor-supplied component selection</td>
<td>1. Rocket does not take off or does not reach sufficient altitude</td>
<td>2C</td>
<td>1. Use appropriate and tested ignition systems</td>
<td>1. Verify selected hardware is appropriate in accordance with vendor specifications</td>
<td>2E</td>
</tr>
<tr>
<td>15</td>
<td>Propellant over pressurizes or burns through the casing</td>
<td>Poor vendor-supplied component selection</td>
<td>1. Destruction of booster airframe structure 2. Destruction of transition piece</td>
<td>2C</td>
<td>1. Use certified motor 2. Have backup rocket</td>
<td>1. Verify the chosen motor is certified. 2. Design plan will included two rocket production efforts</td>
<td>2E</td>
</tr>
<tr>
<td>16</td>
<td>Motor dislodges from proper position</td>
<td>Structural Failure</td>
<td>1. Ejection of motor from the rocket 2. Inability to separate payload</td>
<td>2C</td>
<td>1. Use motor retention 2. Compress ion testing on vehicle</td>
<td>1. Flight testing 2. Ensure motor tube was not deformed from the testing.</td>
<td>2E</td>
</tr>
</tbody>
</table>

### Table 6: Hazard Mitigation

**Chemical Handling:** 3M Scotch-Weld Structural Plastic Adhesive, DP-8005, Black

<table>
<thead>
<tr>
<th>#</th>
<th>Hazard</th>
<th>Cause</th>
<th>Effect</th>
<th>Pre-RAC</th>
<th>Mitigation</th>
<th>Verification</th>
<th>Post-RAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>Eye contamination</td>
<td>Direct contact with eyes</td>
<td>Corrosive burns</td>
<td>2D</td>
<td>1. Safety glasses with side shields or indirect vented goggles.</td>
<td>1. MSDS Section 8</td>
<td>2E</td>
</tr>
<tr>
<td></td>
<td>Hazard</td>
<td>Cause</td>
<td>Effect</td>
<td>Pre-RAC</td>
<td>Mitigation</td>
<td>Verification</td>
<td>Post-RAC</td>
</tr>
<tr>
<td>-----</td>
<td>-------------------------</td>
<td>--------------------------------------------</td>
<td>-------------------------------</td>
<td>---------</td>
<td>------------------------------------------------</td>
<td>--------------</td>
<td>----------</td>
</tr>
<tr>
<td>18</td>
<td>Eye Irritant</td>
<td>Exposure to vapor during curing, or to dust created by cutting, grinding, sanding, machining</td>
<td>Moderate Eye Irritation</td>
<td>2C</td>
<td>1. Safety glasses with side shields or indirect vented goggles. 2. Local exhaust ventilation for cutting, grinding, sanding, or machining.</td>
<td>1. MSDS Section 8 2. SOP</td>
<td>2E</td>
</tr>
<tr>
<td>19</td>
<td>Skin and Respiratory Irritant</td>
<td>1. Direct contact with skin. 2. Exposure to vapor during curing, or dust created by cutting, grinding, sanding, machining</td>
<td>Severe Skin and Respiratory Irritation</td>
<td>2C</td>
<td>1. Gloves/protective clothing to prevent skin contact and Respiratory Protection 2. Exposure time limitations</td>
<td>1. MSDS Section 8 2. SOP</td>
<td>2E</td>
</tr>
<tr>
<td>20</td>
<td>Gastrointestinal irritant</td>
<td>Ingestion</td>
<td>Gastrointestinal irritation</td>
<td>2D</td>
<td>1. Safe work practices</td>
<td>1. SOP</td>
<td>2E</td>
</tr>
<tr>
<td>21</td>
<td>Combustible liquid and vapor</td>
<td>1. Vapor may ignite. 2. Reaction to strong Oxidizing Agent</td>
<td>Fire/Explosion</td>
<td>1D</td>
<td>1. Ventilation/Avoid Proximity with Flame 2. Safe work practices.</td>
<td>1. SOP 2. MSDS Section 5</td>
<td>1E</td>
</tr>
</tbody>
</table>

**Chemical Handling: Acetone**

<table>
<thead>
<tr>
<th></th>
<th>Hazard</th>
<th>Cause</th>
<th>Effect</th>
<th>Pre-RAC</th>
<th>Mitigation</th>
<th>Verification</th>
<th>Post-RAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>Skin irritant and permeator</td>
<td>Direct contact with skin</td>
<td>Mild Irritation</td>
<td>3C</td>
<td>1. Gloves and protective clothing</td>
<td>1. MSDS Section 8</td>
<td>3E</td>
</tr>
<tr>
<td>#</td>
<td>Hazard</td>
<td>Cause</td>
<td>Effect</td>
<td>Pre-RAC</td>
<td>Mitigation</td>
<td>Verification</td>
<td>Post-RAC</td>
</tr>
<tr>
<td>----</td>
<td>-------------------------</td>
<td>------------------------------------------------------------------------</td>
<td>----------------------</td>
<td>---------</td>
<td>-----------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>23</td>
<td>Eye irritant</td>
<td>Direct contact with eyes or eye contact with vapor.</td>
<td>Moderate to Severe Irritation</td>
<td>2C</td>
<td>1. Splash goggles with side shields or indirect vented goggles. 2. Local eyewash station</td>
<td>1. MSDS Section 8 2. MSDS Section 4</td>
<td>2E</td>
</tr>
<tr>
<td>24</td>
<td>Respiratory irritant</td>
<td>Inhalation</td>
<td>1. Mild irritation. 2. At high concentrations: can harm the nervous system.</td>
<td>2C</td>
<td>1. Respiratory Protection. 2. exposure time limitations</td>
<td>1. MSDS Section 8 2. SOP</td>
<td>2E</td>
</tr>
<tr>
<td>25</td>
<td>Flammable / Slightly explosive</td>
<td>1. Liquid/Vapor presence with acids, oxidizing materials, open flames and sparks</td>
<td>Fire/Explosion</td>
<td>1D</td>
<td>1. Ventilation/ Avoid Proximity with Flame. 2. Safe work practices</td>
<td>1. SOP 2. MSDS Section 5</td>
<td>1E</td>
</tr>
</tbody>
</table>

**Chemical Handling: Alcohol, Isopropyl**

<table>
<thead>
<tr>
<th>#</th>
<th>Hazard</th>
<th>Cause</th>
<th>Effect</th>
<th>Pre-RAC</th>
<th>Mitigation</th>
<th>Verification</th>
<th>Post-RAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>26</td>
<td>Eye Irritant</td>
<td>Direct contact with eyes or eye contact with vapor.</td>
<td>Mild Irritation</td>
<td>3D</td>
<td>1. Safety glasses with side shields or indirect vented goggles. 2. Local eyewash station</td>
<td>1. MSDS Section 8 2. MSDS Section 4</td>
<td>2E</td>
</tr>
<tr>
<td>27</td>
<td>Skin Irritant, Sensitizer, Permeator</td>
<td>Direct contact with skin</td>
<td>Mild Irritation</td>
<td>3C</td>
<td>1. Gloves and protective clothing</td>
<td>1. MSDS Section 8</td>
<td>2E</td>
</tr>
<tr>
<td></td>
<td>Hazard</td>
<td>Cause</td>
<td>Effect</td>
<td>Pre-RAC</td>
<td>Mitigation</td>
<td>Verification</td>
<td>Post-RAC</td>
</tr>
<tr>
<td>---</td>
<td>-------------------------------</td>
<td>------------------------------------</td>
<td>---------------------------------------------</td>
<td>---------</td>
<td>-----------------------------------------------</td>
<td>---------------------</td>
<td>----------</td>
</tr>
<tr>
<td>28</td>
<td>Respiratory Hazard</td>
<td>Inhale large quantities</td>
<td>Irritation</td>
<td>3C</td>
<td>1. Respiratory Protection. 2. exposure time limitations</td>
<td>1. MSDS Section 8  2. SOP</td>
<td>E</td>
</tr>
<tr>
<td>29</td>
<td>Highly flammable and explosive</td>
<td>1. Presence of heat, open flames, oxidizing materials and sparks</td>
<td>Near Invisible Flame/Fire or Explosion</td>
<td>1B</td>
<td>1. Ventilation Avoid Proximity with Flame. 2. Safe work practices</td>
<td>1. SOP  2. MSDS Section 5</td>
<td>E</td>
</tr>
</tbody>
</table>

**Chemical Handling: Ammonium Perchlorate, Hobby Rocket Motor**

<table>
<thead>
<tr>
<th></th>
<th>Hazard</th>
<th>Cause</th>
<th>Effect</th>
<th>Pre-RAC</th>
<th>Mitigation</th>
<th>Verification</th>
<th>Post-RAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>Skin irritant</td>
<td>Direct contact</td>
<td>1. Irritation. 2. prolonged exposure can cause ulcerations and burns</td>
<td>3C</td>
<td>1. Gloves and protective clothing 2. exposure time limitations</td>
<td>1. MSDS Section 8  2. SOP</td>
<td>E</td>
</tr>
<tr>
<td>31</td>
<td>Eye Irritant</td>
<td>Direct contact with eyes</td>
<td>Mild Irritation</td>
<td>2D</td>
<td>1. Safety glasses with side shields or indirect vented goggles. 2. Local eyewash station</td>
<td>1. MSDS Section 8  2. MSDS Section 4</td>
<td>E</td>
</tr>
<tr>
<td>#</td>
<td>Hazard</td>
<td>Cause</td>
<td>Effect</td>
<td>Pre-RAC</td>
<td>Mitigation</td>
<td>Verification</td>
<td>Post-RAC</td>
</tr>
<tr>
<td>----</td>
<td>-----------------------</td>
<td>-----------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
<td>---------</td>
<td>---------------------------------------------------------------------------</td>
<td>----------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>33</td>
<td>Flammable and Explosive</td>
<td>Presence of open flames, sparks, shocks, heat, reducing agents, combustible materials, organic materials</td>
<td>1. Fire/Explosion 2. Personnel injury by burns or impacts</td>
<td>1C</td>
<td>1. Safe work practices 2. Training/Personnel certification; performed by or under supervision of Level 2 certified NAR Mentor</td>
<td>1. MSDS Section 5 2. NAR High Power Safety Code</td>
<td>1D</td>
</tr>
</tbody>
</table>

**Chemical Handling: Black Powder, Loose**

<table>
<thead>
<tr>
<th>#</th>
<th>Hazard</th>
<th>Cause</th>
<th>Effect</th>
<th>Pre-RAC</th>
<th>Mitigation</th>
<th>Verification</th>
<th>Post-RAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>34</td>
<td>Accidental Detonation</td>
<td>Sources of friction, impact, heat, low level electrical current, and electrostatic or RF energy</td>
<td>Detonation may cause severe physical injury, even death; Facility/equipment damage (unlikely due to small quantities in use)</td>
<td>1B</td>
<td>1. Safe work practices 2. Impervious rubber gloves; clothing must be metal-free AND non-static producing</td>
<td>1. SOP 2. MSDS</td>
<td>1D</td>
</tr>
</tbody>
</table>
## Ejection Charge Handling

<table>
<thead>
<tr>
<th>#</th>
<th>Hazard</th>
<th>Cause</th>
<th>Effect</th>
<th>Pre-RAC</th>
<th>Mitigation</th>
<th>Verification</th>
<th>Post-RAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>Accidental ignition</td>
<td>Sources of heat or low level electrical current</td>
<td>1. Bystander injury 2. Facility or equipment damage</td>
<td>2C</td>
<td>1. Isolate ejection charge from strong electric fields and heat sources 2. Safe work practices and personnel certification</td>
<td>1. HOP 2. Certificates of completion for training</td>
<td>2E</td>
</tr>
<tr>
<td>36</td>
<td>Accidental release of projectile</td>
<td>Failure of ejection charge retention system</td>
<td>1. Injury to personnel 2. Facility or equipment damage</td>
<td>2C</td>
<td>1. Large safety factor designed into retention system 2. Written test procedures; safe work practices</td>
<td>Conduct test in blast-proof test cell; 2. Supervision by Level 2 certified NAR Mentor</td>
<td>2E</td>
</tr>
</tbody>
</table>

## Motor Handling

<table>
<thead>
<tr>
<th>#</th>
<th>Hazard</th>
<th>Cause</th>
<th>Effect</th>
<th>Pre-RAC</th>
<th>Mitigation</th>
<th>Verification</th>
<th>Post-RAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>Accidental ignition</td>
<td>Sources of heat or low level electrical current</td>
<td>1. Bystander injury 2. Facility or equipment damage</td>
<td>2C</td>
<td>1. Isolate ejection charge from strong electric fields and heat sources 2. Safe work practices and personnel certification</td>
<td>1. HOP 2. Certificates of completion for training</td>
<td>2E</td>
</tr>
<tr>
<td>#</td>
<td>Hazard</td>
<td>Cause</td>
<td>Effect</td>
<td>Pre-RAC</td>
<td>Mitigation</td>
<td>Verification</td>
<td>Post-RAC</td>
</tr>
<tr>
<td>----</td>
<td>----------------------------------------------------</td>
<td>----------------------------</td>
<td>---------------------------------------------</td>
<td>---------</td>
<td>----------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>38</td>
<td>Motor retention system failure</td>
<td>Poorly Attached to vehicle</td>
<td>1. Uncontrolled motor movement</td>
<td>2C</td>
<td>1. Large safety factor designed into retention system</td>
<td>1. Conduct test in blast-proof test cell; 2. Supervision by Level 2 certified NAR Mentor;</td>
<td>2E</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. Injury to personnel and facility or equipment damage</td>
<td></td>
<td>2. Written test procedures; safe work practices</td>
<td></td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>Blades on a Lathe or Milling Machine</td>
<td>Improper use</td>
<td>1. Injury to or loss of hand, limb</td>
<td>2C</td>
<td>1. Safe work practices</td>
<td>1. SOP 2. Supervision by experienced personnel</td>
<td>2E</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. Damage to equipment or facilities</td>
<td></td>
<td>2. Training and qualification</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>Shrapnel from Lathe or Milling Machine</td>
<td>Metal shavings ejected from machinery</td>
<td>1. Laceration or eye injury</td>
<td>2C</td>
<td>1. Safe work practices and Protective Equipment</td>
<td>1. SOP 2. Supervision by experienced personnel</td>
<td>2E</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. Facility or equipment damage</td>
<td></td>
<td>2. Training and qualification</td>
<td></td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>Injury from Sanding and Grinding</td>
<td>Improper use of tool or equipment failure</td>
<td>1. Skin Abrasion</td>
<td>3C</td>
<td>1. Safe work practices and PPE</td>
<td>1. SOP 2. Supervision by experienced personnel</td>
<td>3E</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. Facility or equipment damage</td>
<td></td>
<td>2. Training and qualification</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Probability</td>
<td>1 Catastrophic</td>
<td>2 Critical</td>
<td>3 Marginal</td>
<td>4 Negligible</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------</td>
<td>----------------</td>
<td>------------</td>
<td>------------</td>
<td>--------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A - Frequent</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B - Probable</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C - Occasional</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D - Remote</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E - Improbable</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7: Compilation of post-RAC severities

- 42: Soldering/Electrical Tool Injury
- Improper use of tool or in use in unsafe conditions
- 1. Skin Burns
- 2. Damage to Components
- 3. Fire
- 4B: 1. Safe work practices and PPE
- 2. Training and qualification
- 3. Assigned solder station in workspace
- 1. SOP
- 2. Supervision by experienced personnel
- 3. HOP
- 4E
Appendix B: Propulsion Research Center Evacuation Plan
Appendix C: Applicable Laws and 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.

(c) 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 0 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 may 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.

3. 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


   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
4. **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-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 D: Material Safety Data Sheets
AeroTech Division, RCS Rocket Motor Components, Inc.

Material Safety Data Sheet & Emergency Response Information

Prepared in accordance with 29 CFR § 1910.1200 (g)

Section 1. Product Identification

Model rocket motor, high power rocket motor, hobby rocket motor, composite rocket motor, rocket motor kit, rocket motor reloading kit, containing varying amounts of solid propellant with the trade names White Lightning™, Blue Thunder™, Black Jack™, Black Max™, Redline™, Warp-9™, Mojave Green™, Metalstorm™, Metalstorm DM™ or Propellant X™. These products contain varying percentages of Ammonium Perchlorate, Strontium and/or Barium Nitrate dispersed in synthetic rubber with lesser amounts of proprietary ingredients such as burn rate modifiers and metal fuels. Rocket motor ejection charges contain black powder.

Section 2. Physical Characteristics

Black plastic cylinders or bags with various colored parts, little or no Odor

Section 3. Physical Hazards

Rocket motors and reload kits are flammable; rocket motors may become propulsive in a fire. All propellants give off varying amounts of Hydrogen Chloride and Carbon Monoxide gas when burned, Mojave Green propellant also produces Barium Chloride.

Section 4. Health Hazards

Propellant is an irritant in the case of skin and eye contact, may be extremely hazardous in the case of ingestion, and may be toxic to kidneys, lungs and the nervous system. Symptoms include respiratory irritation, skin irritation, muscle tightness, vomiting, diarrhea, abdominal pain, muscular tremors, weakness, labored breathing, irregular heartbeat, and convulsions. Inhalation of large amounts of combustion products may produce similar but lesser symptoms as ingestion.

Section 5. Primary Routes of Entry

Skin contact, ingestion, and inhalation.

Section 6. Permitted Exposure Limits

None established for manufactured product.

Section 7. Carcinogenic Potential
None known.

**Section 8. Precautions for Safe Handling**

Disposable rubber gloves are recommended for handling Mojave Green propellant. Keep away from flames and other sources of heat. Do not smoke within 25 feet of product. Do not ingest. Do not breathe exhaust fumes. Keep in original packaging until ready for use.

**Section 9. Control Measures**

See section 8.

**Section 10. Emergency & First Aid Procedures**

If ingested, induce vomiting and call a physician. If combustion products are inhaled, move to fresh air and call a physician if ill effects are noted. In the case of skin contact, wash area immediately and contact a physician if severe skin rash or irritation develops. For mild burns use a first aid burn ointment. For severe burns immerse the burned area in cold water at once and see a physician immediately.

**Section 11. Date of Preparation or Revision**

March 22, 2012

**Section 12. Contact Information**

AeroTech Division, RCS Rocket Motor Components, Inc.
2113 W. 850 N. St.
Cedar City, UT 84721
(435) 865-7100 (Ph)
(435) 865-7120 (Fax)
Email: customerservice@aerotech-rocketry.com
Web: http://www.aerotech-rocketry.com

Emergency Response: Infotrac (352) 323-3500
Material Safety Data Sheet
Isopropyl alcohol MSDS

Section 1: Chemical Product and Company Identification

Product Name: Isopropyl alcohol
Catalog Codes: SLI1153, SLI1579, SLI1906, SLI1246, SLI1432
CAS#: 67-63-0
RTECS: NT8050000
TSCA: TSCA 8(b) inventory: Isopropyl alcohol
C#; Not available.
Synonym: 2-Propanol
Chemical Name: isopropanol
Chemical Formula: C3-H8-O

Contact Information:
Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77306
US Sales: 1-800-901-7247
International Sales: 1-281-441-4400
Order Online: ScienceLab.com
CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300
International CHEMTREC, call: 1-703-527-3887
For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

<table>
<thead>
<tr>
<th>Name</th>
<th>CAS #</th>
<th>% by Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isopropyl alcohol</td>
<td>67-63-0</td>
<td>100</td>
</tr>
</tbody>
</table>

Toxicological Data on Ingredients: Isopropyl alcohol: ORAL (LD50): Acute: 5045 mg/kg [Rat], 3000 mg/kg [Mouse], 6410 mg/kg [Rabbit], DERMAL (LD50): Acute: 12800 mg/kg [Rabbit].

Section 3: Hazards Identification

Potential Acute Health Effects:
Hazardous in case of eye contact (irritant), of ingestion, of inhalation. Slightly hazardous in case of skin contact (irritant, sensitizer, permeator).

Potential Chronic Health Effects:
Slightly hazardous in case of skin contact (sensitizer). CARCINOGENIC EFFECTS: A4 (Not classifiable for human or animal.) by ACGIH, 3 (Not classifiable for human.) by IARC. MUTAGENIC EFFECTS: Not available. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Classified Reproductive system/toxin/female, Development toxin [POSSIBLE]. The substance may be toxic to kidneys, liver, skin, central nervous system (CNS). Repeated or prolonged exposure to the substance can produce target organs damage.

Section 4: First Aid Measures
Eye Contact:
Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Cold water may be used. Get medical attention.

Skin Contact:
Wash with soap and water. Cover the irritated skin with an emollient. Get medical attention if irritation develops. Cold water may be used.

Serious Skin Contact: Not available.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention if symptoms appear.

Serious Inhalation:
Evacuate the victim to a safe area as soon as possible. Loosen tight clothing such as a collar, tie, belt or waistband. If breathing is difficult, administer oxygen. If the victim is not breathing, perform mouth-to-mouth resuscitation. Seek medical attention.

Ingestion:
Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. Loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention if symptoms appear.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: Flammable.

Auto-Ignition Temperature: 399°C (750.2°F)

Flash Points: CLOSED CUP: 11.667°C (53°F) - 12.778 deg. C (55 deg. F) (TAG)

Flammable Limits: LOWER: 2% UPPER: 12.7%

Products of Combustion: These products are carbon oxides (CO, CO₂).

Fire Hazards in Presence of Various Substances:

Explosion Hazards in Presence of Various Substances:
Risks of explosion of the product in presence of mechanical impact: Not available. Explosive in presence of open flames and sparks, of heat.

Fire Fighting Media and Instructions:
Flammable liquid, soluble or dispersed in water. SMALL FIRE: Use DRY chemical powder. LARGE FIRE: Use alcohol foam, water spray or fog.

Special Remarks on Fire Hazards:
Vapor may travel considerable distance to source of ignition and flash back. CAUTION: MAY BURN WITH NEAR INVISIBLE FLAME. Hydrogen peroxide sharply reduces the autoignition temperature of Isopropyl alcohol. After a delay, Isopropyl alcohol ignites on contact with dioxgenyl tetrafluoroborate, chromium trioxide, and potassium tert-butoxide. When heated to decomposition it emits acrid smoke and fumes.

Special Remarks on Explosion Hazards:
Secondary alcohols are readily autoxidized in contact with oxygen or air, forming ketones and hydrogen peroxide. It can become potentially explosive. It reacts with oxygen to form dangerously unstable peroxides which can concentrate and explode during distillation or evaporation. The presence of 2-butane increases the reaction rate for peroxide formation. Explosive in the form of vapor when exposed to heat or flame. May form explosive mixtures with air. Isopropyl alcohol + phosphene forms isopropyl chlorofomate and hydrogen chloride. In the presence of iron salts, thermal decomposition can occur, which in some cases can become explosive. A homogeneous mixture of concentrated peroxides + isopropyl alcohol are capable of detonation by shock or heat. Barium perchlorate + isopropyl alcohol gives the highly explosive alkyl perchlorates.
It forms explosive mixtures with trinitromethane and hydrogen peroxide. It produces a violent explosive reaction when heated with aluminum isopropoxide + crotonaldehyde. Mixtures of isopropyl alcohol + nitroform are explosive.

Section 6: Accidental Release Measures

Small Spill:
Dilute with water and mop up, or absorb with an inert dry material and place in an appropriate waste disposal container.

Large Spill:
Flammable liquid. Keep away from heat. Keep away from sources of ignition. Stop leak if without risk. Absorb with DRY earth, sand or other non-combustible material. Do not touch spilled material. Prevent entry into sewers, basements or confined areas; dike if needed. Be careful that the product is not present at a concentration level above TLV. Check TLV on the MSDS and with local authorities.

Section 7: Handling and Storage

Precautions:
Keep away from heat. Keep away from sources of ignition. Ground all equipment containing material. Do not ingest. Do not breathe gas/fumes/vapor/spray. Avoid contact with eyes. Wear suitable protective clothing. In case of insufficient ventilation, wear suitable respiratory equipment. If ingested, seek medical advice immediately and show the container or the label. Keep away from incompatibles such as oxidizing agents, acids.

Storage:
Store in a segregated and approved area. Keep container in a cool, well-ventilated area. Keep container tightly closed and sealed until ready for use. Avoid all possible sources of ignition (spark or flame).

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Provide exhaust ventilation or other engineering controls to keep the airborne concentrations of vapors below their respective threshold limit value. Ensure that eyewash stations and safety showers are proximal to the work-station location.

Personal Protection:
Splash goggles. Lab coat. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Vapor respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits:
TWA: 983 STEL: 1230 (mg/m3) [Australia] TWA: 200 STEL: 400 (ppm) from ACGIH (TLV) [United States] [1999] TWA: 980 STEL: 1225 (mg/m3) from NIOSH TWA: 400 STEL: 500 (ppm) from NIOSH TWA: 400 STEL: 500 (ppm) [United Kingdom (UK)] TWA: 999 STEL: 1259 (mg/m3) [United Kingdom (UK)] TWA: 400 STEL: 500 (ppm) from OSHA (PEL) [United States] TWA: 980 STEL: 1225 (mg/m3) from OSHA (PEL) [United States] Consult local authorities for acceptable exposure limits.

Section 9: Physical and Chemical Properties

Physical state and appearance: Liquid.
Odor:
Pleasant. Odor resembling that of a mixture of ethanol and acetone.
Taste: Bitter. (Slight.)
Molecular Weight: 90.1 g/mole
Color: Colorless.

pH (1% soln/water): Not available.

Boiling Point: 82.5°C (180.5°F)

Melting Point: -88.5°C (-127.3°F)

Critical Temperature: 235°C (455°F)

Specific Gravity: 0.78505 (Water = 1)

Vapor Pressure: 4.4 kPa (@ 20°C)

Vapor Density: 2.07 (Air = 1)

Volatility: Not available.

Odor Threshold:
22 ppm (Sittig, 1991) 700 ppm for unadapted panelists (Verschuren, 1983).

Water/Oil Dist. Coeff.: The product is equally soluble in oil and water; log(oil/water) = 0.1

Ionicity (in Water): Not available.

Dispersion Properties: See solubility in water, methanol, diethyl ether, n-octanol, acetone.

Solubility:
Easily soluble in cold water, hot water, methanol, diethyl ether, n-octanol, acetone. Insoluble in salt solution. Soluble in benzene. Miscible with most organic solvents including alcohol, ethyl alcohol, chloroform.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Heat, Ignition sources, incompatible materials

Incompatibility with various substances: Reactive with oxidizing agents, acids, alkanes.

Corrosivity: Non-corrosive in presence of glass.

Special Remarks on Reactivity:
Reacts violently with hydrogen + palladium combination, nitroform, oleum, COCl₂, aluminum trisopropoxide, oxidants
Incompatible with acetaldehyde, chloride, ethylene oxide, isocyanates, acids, alkaline earth, alkali metals, caustics, amines, crotonaldehyde, phosgene, ammonia. Isopropyl alcohol reacts with metallic aluminum at high temperatures. Isopropyl alcohol attacks some plastics, rubber, and coatings. Vigorous reaction with sodium dichromate + sulfuric acid.

Special Remarks on Corrosivity: May attack some forms of plastic, rubber and coating.

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Absorbed through skin. Dermal contact. Eye contact. Inhalation.

Toxicity to Animals:
WARNING: THE LC50 VALUES HEREUNDER ARE ESTIMATED ON THE BASIS OF A 4-HOUR EXPOSURE. Acute oral toxicity (LD50): 3600 mg/kg [Mouse]. Acute dermal toxicity (LD50): 12800 mg/kg [Rabbit]. Acute toxicity of the vapor (LC50): 16000 8 hours [Rat].

Chronic Effects on Humans:
CARCINOGENIC EFFECTS: A4 (Not classifiable for human or animal.) by ACGIH, 3 (Not classifiable for human.) by IARC.
DEVELOPMENTAL TOXICITY: Classified Reproductive system/toxin/female, Development toxin [POSSIBLE]. May cause damage to the following organs: kidneys, liver, skin, central nervous system (CNS).

p. 4
Other Toxic Effects on Humans:
Hazardous in case of ingestion, of inhalation. Slightly hazardous in case of skin contact (irritant, sensitizer, permeator).

Special Remarks on Toxicity to Animals: Not available.

Special Remarks on Chronic Effects on Humans:
May cause adverse reproductive/teratogenic effects (fertility, fetotoxicity, developmental abnormalities(developmental toxin)) based on animal studies. Detected in maternal milk in human.

Special Remarks on other Toxic Effects on Humans:
Acute Potential Health Effects: Skin: May cause mild skin irritation, and sensitization. Eyes: Can cause eye irritation. Inhalation: Breathing in small amounts of this material during normal handling is not likely to cause harmful effects. However, breathing large amounts may be harmful and may affect the respiratory system and mucous membranes (irritation), behavior and brain (Central nervous system depression - headache, dizziness, drowsiness, stupor, incoordination, unconsciousness, coma and possible death), peripheral nerve and sensation, blood, urinary system, and liver. Ingestion: Swallowing small amounts during normal handling is not likely to cause harmful effects. Swallowing large amounts may be harmful. Swallowing large amounts may cause gastrointestinal tract irritation with nausea, vomiting and diarrhea, abdominal pain. It also may affect the urinary system, cardiovascular system, sense organs, behavior or central nervous system (somnolence, generally depressed activity, irritability, headache, dizziness, drowsiness), liver, and respiratory system (breathing difficulty). Chronic Potential Health Effects: May cause defatting of the skin and dermatitis and allergic reaction. May cause adverse reproductive effects based on animal data (studies).

Section 12: Ecological Information

Ecotoxicity: Ecotoxicity in water (LC50): 100000 mg/l 96 hours [Fathead Minnow]. 64000 mg/l 96 hours [Fathead Minnow].

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The product itself and its products of degradation are not toxic.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:
Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: CLASS 3: Flammable liquid.
Identification: Isopropyl Alcohol UNNA: 1219 PG: II

Special Provisions for Transport: Not available.

Section 15: Other Regulatory Information

Federal and State Regulations:
Appendix E: Black Powder Handling

Goex Powder, Inc.

Material Safety Data Sheet

MSDS-BP (Potassium Nitrate)

Revised 3/17/09

PRODUCT INFORMATION

<table>
<thead>
<tr>
<th>Product Name</th>
<th>Black Powder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trade Names and Synonyms</td>
<td>N/A</td>
</tr>
<tr>
<td>Manufacturer/Distributor</td>
<td>GOEX Powder, Inc. (DOYLINE, LA) &amp; various international sources</td>
</tr>
<tr>
<td>Transportation Emergency</td>
<td>800-255-3924 (24 hrs – CHEM TEL)</td>
</tr>
</tbody>
</table>

PREVENTION OF ACCIDENTS IN THE USE OF EXPLOSIVES

The prevention of accidents in the use of explosives is a result of careful planning and observance of the best known practices. The explosives user must remember that he is dealing with a powerful force and that various devices and methods have been developed to assist him in directing this force. He should realize that this force, if misdirected, may either kill or injure both him and his fellow workers.

WARNING

All explosives are dangerous and must be carefully transported, handled, stored, and used following proper safety procedures either by or under the direction of competent, experienced persons in accordance with all applicable federal, state and local laws, regulations, or ordinances. ALWAYS lock up explosive materials and keep away from children and unauthorized persons. If you have any questions or doubts as to how to use any explosive product, DO NOT USE IT before consulting with your supervisor, or the manufacturer, if you do not have a supervisor. If your supervisor has any questions or doubts, he should consult the manufacturer before use.

HAZARDOUS COMPONENTS

<table>
<thead>
<tr>
<th>Material or Components</th>
<th>%</th>
<th>CAS NO.</th>
<th>TLV</th>
<th>PEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium nitrate</td>
<td>70.76</td>
<td>007757-79-1</td>
<td>NE</td>
<td>NE</td>
</tr>
<tr>
<td>Charcoal</td>
<td>8-18</td>
<td>N/A</td>
<td>NE</td>
<td>NE</td>
</tr>
<tr>
<td>Sulfur</td>
<td>9-20</td>
<td>007704-34-9</td>
<td>NE</td>
<td>NE</td>
</tr>
<tr>
<td>Graphite(^1)</td>
<td>Trace</td>
<td>007782-42-5</td>
<td>15 ppmct (TWA)</td>
<td>2.5 mg/m(^3)</td>
</tr>
</tbody>
</table>

N/A = Not assigned NE = Not established

\(^1\) Not contained in all grades of black powder.

P.O. Box 639, Doxline, LA 71023-0639, (318) 392-9300
www.goexpowder.com
<table>
<thead>
<tr>
<th>PHYSICAL DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiling Point</td>
</tr>
<tr>
<td>Vapor Pressure</td>
</tr>
<tr>
<td>Vapor Density</td>
</tr>
<tr>
<td>Solubility in Water</td>
</tr>
<tr>
<td>Specific Gravity</td>
</tr>
<tr>
<td>PH</td>
</tr>
<tr>
<td>Evaporation Rate</td>
</tr>
<tr>
<td>Appearance and Odor</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HAZARDOUS REACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instability</td>
</tr>
<tr>
<td>Incompatibility</td>
</tr>
<tr>
<td>Hazardous decomposition</td>
</tr>
<tr>
<td>Polymerization</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FIRE AND EXPLOSION DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flashpoint</td>
</tr>
<tr>
<td>Auto Ignition Temperature</td>
</tr>
<tr>
<td>Explosive temperature (5 sec)</td>
</tr>
<tr>
<td>Extinguishing media</td>
</tr>
<tr>
<td>Special fire fighting procedures</td>
</tr>
</tbody>
</table>
### Unusual fire and explosion hazards

Black powder is a deflagrating explosive. It is very sensitive to flame and spark and can also be ignited by friction and impact. When ignited unconfined, it burns with explosive violence and will explode if ignited under even slight confinement.

### HEALTH HAZARDS

#### General
Black powder is a Division 1.1 Explosive, and detonation may cause severe physical injury, including death. All explosives are dangerous and must be handled carefully and used following approved safety procedures under the direction of competent, experienced persons in accordance with all applicable federal, state and local laws, regulation and ordinances.

#### Carcinogenicity
None of the components of Black Powder are listed as a carcinogen by NTP, IARC, or OSHA.

### FIRST AID

#### Inhalation
Not a likely route of exposure. If inhaled, remove to fresh air. If not breathing give artificial respiration, preferably by mouth-to-mouth. If breathing is difficult, give oxygen. Seek prompt medical attention. Avoid when possible.

#### Eye and skin contact
Not a likely route of exposure. Flush eyes with water. Wash skin with soap and water.

#### Ingestion
Not a likely route of exposure. If ingested, dilute by giving two glasses of water and induce vomiting. Avoid when possible.

#### Injury from detonation
Seek prompt medical attention.

### SPILL OR LEAK PROCEDURES

#### Spill/leak response
Use appropriate personal protective equipment. Isolate area and remove sources of friction, impact, heat, low level electrical current, electrostatic or RF energy. Only competent, experienced persons should be involved in clean up procedures.

Carefully pick up spills with non-sparking and non-static producing tools.

#### Waste disposal
Desensitize by diluting in water. Open train burning, by qualified personnel, may be used for disposal of small unconfined quantities. Dispose of in compliance with Federal Regulations under the authority of the Resource Conservation and Recovery Act (40 CFR Parts 260-271).

### SPECIAL PROTECTION INFORMATION

<table>
<thead>
<tr>
<th>Protection</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventilation</td>
<td>Use only with adequate ventilation. (If required)</td>
</tr>
<tr>
<td>Respiratory</td>
<td>None</td>
</tr>
<tr>
<td>Eye</td>
<td>None</td>
</tr>
<tr>
<td>Gloves</td>
<td>Impervious rubber gloves. (If required)</td>
</tr>
<tr>
<td>Other</td>
<td>Metal-free and/non-static producing clothes</td>
</tr>
</tbody>
</table>
SPECIAL PRECAUTIONS

- Keep away from friction, impact, and heat and open flame. Do not consume food, drink, or tobacco in areas where they may become contaminated with these materials.
- Contaminated equipment must be thoroughly water cleaned before attempting repairs.
- Use only non-spark producing tools.
- No smoking.

STORAGE CONDITIONS

Store in a cool, dry place in accordance with the requirements of Subpart K, ATF: Explosives Law and Regulations (27 CFR 55.201-55.219).

SHIPPING INFORMATION

<table>
<thead>
<tr>
<th>Proper shipping name</th>
<th>Black Powder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazard class</td>
<td>1.1D</td>
</tr>
<tr>
<td>UN Number</td>
<td>UN0027</td>
</tr>
<tr>
<td>DOT Label &amp; Placard</td>
<td>DOT Label</td>
</tr>
<tr>
<td></td>
<td>EXPLOSIVES 1.1D</td>
</tr>
<tr>
<td></td>
<td>DOT Placard</td>
</tr>
<tr>
<td></td>
<td>EXPLOSIVES 1.1</td>
</tr>
<tr>
<td>Alternate shipping</td>
<td>Limited quantities of GOEX black powder (1# cans only) may be transported as “Black powder for small arms – flammable solid” pursuant to U.S. Department of Transportation 49 CFR.</td>
</tr>
</tbody>
</table>

The information contained in this Material Safety Data Sheet is based upon available data and believed to be correct; however, as such has been obtained from various sources, including the manufacturer, military and independent laboratories, it is given without warranty or representation that it is complete, accurate, and can be relied upon. GOEX, Incorporated, has not attempted to conceal in any manner the deleterious aspects of the product listed herein, but makes no warranty as to such. Further, GOEX, Incorporated, cannot anticipate nor control the many situations in which the product or this information may be used; there is no guarantee that the health and safety precautions suggested will be proper under all conditions. It is the sole responsibility of each user of the product to determine and comply with the requirements of all applicable laws and regulations regarding its use. This information is given solely for the purposes of safety to persons and property. Any other use of this information is expressly prohibited.

For further information contact: GOEX Powder, Incorporated
P. O. Box 659
Doyline, LA 71023-0659
Telephone Number: (318) 382-9300
Fax Number: (318) 382-9303
BLACK POWDER

FRICITION TEST
PA
Steel – Snaps
Fiber – Unaffected

IMPACT TEST
PA
16 Inches (10% Point)

ELECTROSTATIC DISCHARGE TEST
Bureau of Mines
  0.8 Joules (Confined)
  12.5 Joules Unconfined

STABILITY
  75°C International Heat Test – 0.31% Loss
  Vacuum Stability – 0.5 cc @ 100°C

BRISANCE – Sand Test 8 gm.

VELOCITY
In the open, trains of black powder burn very slowly, measurable in seconds per foot. Confined, as in steel pipe, speeds of explosions have been timed at values from 560 feet per second for very coarse granulations to 2,070 feet per second for the finer granulations. Confinement and granulation will affect the values.

CHEMICAL DECOMPOSITION
Use water to dissolve the potassium nitrate. By leaching out the potassium nitrate, the residue of sulfur and charcoal is non-explosive but combustible when dry – dispose separately.

SPECIAL REQUIREMENTS:
Black Powder is very sensitive to flame and spark and can also be ignited by friction and impact. When ignited unconfined, it burns with explosive violence and will explode if ignited under even slight confinement.

When dry, it is compatible with most metals. However, it is hygroscopic and when wet, attacks all common metals except stainless steel.

CAUTION: Explosives must be tested for compatibility with any material not specified in the production/procurement package with which they may come in contact. Materials include other explosives, solvents, adhesives, metals, plastics, paints, cleaning compounds, floor and table coverings, packing materials and other similar materials, situations and equipment. Explosives include propellants and pyrotechnics.
Appendix F: Team Resumes

Stephen B.
Birmingham, Alabama

Education
College: The University of Alabama in Huntsville
Bachelor of Science, Mechanical Engineering
Minor: Mathematics
Expected Graduation: May, 2018

Experience
Honda Manufacturing of Alabama, LLC
Lincoln, Alabama
January 2015-August 2016

- Quality Analysis Department, May 2016 to August 2016
  - Investigated warranty claims on vehicles with missing, incorrect, or damaged parts
  - Tested vehicle components (mainly chassis related) to understand or find more issues
    Weld 2 Department, August 2015 to December 2016
  - Used Catia V5 to design components for robot end effectors and assembly fixture equipment
  - Operated equipment/worked weld assembly processes on line
  - Installed new weld times and tip dressers and worked alongside contractors

Engineering Group of America – Lincoln, January 2015 to May 2015

- Designed Engine Assembly Training Cell to test robots and vision system: Utilized 3D modeling for stand and 2D drawings for component manufacturing
- Designed dust shield for deburring machine in Die Cast department
- Used Microsoft Excel to track overall equipment efficiency of Weld Line 1 in an effort to reduce downtime
- Designed and quoted projects for several departments of Honda Manufacturing of Alabama, LLC

Related Skills: Microsoft Office (Word, Excel, Powerpoint), MATLAB, Simulink, MathCAD, Catia V5, Solid Edge, Solid Works
Familiar with Programmable Logic Controllers, Teach Pendants, Spot Welding, MIG Welding, FANUC Robots

Honors, Organizations, and Certifications
National Society of Leadership and Success, Sigma Alpha Pi
August 2013 – August 2016
The American Society of Mechanical Engineers
August 2017 – Present
James B.
Huntsville, Alabama

**Education**
College: The University of Alabama in Huntsville
Bachelor of Science, Mechanical Engineering
Expected Graduation: May, 2018

**Experience**

**The Raytheon Company, Raytheon Missile Systems**
Tucson, AZ/Huntsville, AL
05/2016 - Present
TechStudent - Senior
- June, 2017 – present: Currently supporting internal research and development of prototype control actuation systems for advanced missile systems
- May, 2016 – May, 2017: Design engineering and production support for defensive systems intended to protect naval vessels and military installations from artillery, missiles, mortars, and other threats

**The Boeing Company, Boeing Commercial Airplanes**
Huntsville, AL
01/2016 - 04/2016
Research Assistant IV
- Contract employee through UAH Rotorcraft Systems Engineering and Simulation Center.
- Was responsible for generating detailed mechanical designs and performing stress analyses on flight hardware for the fuselage of the 777X commercial aircraft

**Parker Hannifin Corporation, Parker Aerospace Group**
Mentor, OH
05/2015 – 08/2015
Design Engineering Intern
- Main projects included: Reducing assembly defects in gas turbine fuel manifolds, reducing manufacturing costs for various products, fuel spray nozzle life assessments, and additive manufacturing support

**RadioBro Corporation**
Madison, AL
02/2015 – 04/2015
Product Engineering Intern
- Embedded systems and modeling support

**Honors, Organizations, and Certifications**

**Space Hardware Club**
2014- Present
- July, 2017 – present: Spaceport America Cup: Currently working to develop and fly one of the world’s first student-built liquid-powered rocket engines to an altitude of 30,000 feet above ground level. I’m currently the fluid systems sub-team lead and member of the avionics/simulation team.
- September, 2016 – September, 2017: Multistage Rocketry Team: Developed a multistage rocket capable of reaching an altitude of 30,000 feet above ground level.
- October, 2015 – October, 2016: Treasurer: Was responsible for managing the club’s $80,000 annual operating budget. Duties included writing grant proposals, seeking corporate sponsorship, managing all club accounts, overseeing team budgets, and handling parts/materials orders.
- October, 2015 – May, 2016: Intercollegiate Rocket Engineering Competition: Led a twelve-person team that designed, built, and flew a hybrid rocket capable of delivering a 10-pound payload to 10,000 feet.
- January – June, 2015: 2015 International CanSat Competition: Was the team lead of a five-person team that placed second in the world and first in The United States. The purpose of the competition was to build a rocket payload capable of collecting and transmitting telemetry, stabilizing around nadir using an autonomous control system, and descending through the atmosphere using autorotation.

**Active DoD Security Clearance**

**Tripoli Rocketry Association High Power Level 3 Certification**

**Advanced Manufacturing Magazine's 30 under 30**
July, 2017
- Recognized as an individual under the age of 30 making a difference in manufacturing and STEM
2017 AIAA Southeastern Regional Student Conference

- Development of a Multistage High-Power Rocket, co-author

8th Wernher Von Braun Memorial Symposium Student Poster Competition

- Using a two-tier PID control system to stabilize CanSat rotation around nadir, co-author
Brian C.
Huntsville, Alabama

Education
College: The University of Alabama in Huntsville
Bachelor of Science, Aerospace Engineering

Experience

**Boeing**
Huntsville Design Center, Huntsville Alabama
Research Assistant II
- Worked as an intern at Boeing working on the 777X program. We developed parts and processes for the aft section of the fuselage.

**CFDRC**
Hudson Alpha
Engineering Intern
- Worked as an intern at Computational Fluid Dynamics Research Corporation on NASA’s high order mesh program. I was tasked with building meshes and learning multiple meshing programs for research purposes.

Honors, Organizations, and Certifications

- Tau Beta Pi Honors Society 2015
- UAH Honors College 2014
- Honors Dean’s List 2016
- Lancers 2015
Bao H.
Huntsville, Alabama

Education
College: The University of Alabama in Huntsville
Bachelor of Science, Aerospace Engineering Expected Graduation: May 2018

Experience
University of Alabama in Huntsville January 2017 – Present
Huntsville, Alabama Research Assistant
• Fabricate and test piezoelectric tubes to support the Adaptive Structures Laboratory.

University of Alabama in Huntsville August 2016-Present
Huntsville, Alabama PASS Leader
• Supplementary Instructor for Thermodynamics

Intern at Mekong River Imaging Technologies Co. Ltd May 2015-August 2015
Ho Chi Minh City, Vietnam Intern
• Delivered and ensured product quality to customers. Kept track of product inventory in stock.

Honors and Organizations
Risk Management Officer: Judicial Chairman
Space Hardware Club: University of Alabama in Huntsville 2014 – 2015
Weather Balloon payload fabrication and launching. CanSat 2015 ground station developer.
William H.
Huntsville, Alabama

Education
The University of Alabama in Huntsville
Bachelor of Science, Aerospace Engineering

Experience

Pelham High School NASA Rover Challenge August 2012-April 2014
Pelham, AL Team Lead, Chief Engineer, Driver
- Design, manufacture, and race a human powered exploration rover
- Composite frame construction

UAH Space Hardware Club August 2014-Present
Huntsville, AL Vice President, Treasurer
- 2015 CanSat International Competition (7th in the US)
  - Alternate Team Lead, Chief Engineer
  - Develop a science payload to analyze atmosphere and take stabilized nadir video
  - Autorotation descent control and autonomous fin stability control system analysis
- 2015 Midwest High-Power Rocket Competition (2nd Place)
- Rocket Design and Fabrication Engineer
- Develop a boosted dart high power rocket
- Composite layups, aerodynamic stability control, system testing
- 2016 Battle of the Rockets Competition (2nd Place)
- Rover Chief Engineer
- Develop an autonomous rover and a rocket to deploy the rover at over 1000ft
- Design reviews, composite layups, additive manufacturing, system integration

The Boeing Company May 2016-Present
Huntsville, AL Research Assistant IV
- Boeing 777X Fuselage Stress and Strain Analysis
  - Performed stress analysis on fuselage structures through hand calculations, CATIA, SA+, IAS, and other programs
  - Performed strain analysis through Boeing G-A-G cycles
  - Created Strength Check Notes for the AFT Pressure Bulkhead Minuteman III Flight Testing, Telemetry, and Termination (FT3)
  - Designed, modeled, and created drawings of brackets and aerodynamic covers for the missile’s electronics raceway
  - Reviewed part-fit-check with the missile and created multiple revisions to ensure proper integration

Honors, Organizations, and Certifications

AIAA Regional Conference Team Division 1st Place April 2016
Paper Published through AIAA SciTech Forum January 2017
TRA Level 2 Rocketry Certification December 2015
Dashiel H.  
Huntsville, Alabama

Education  
The University of Alabama in Huntsville  
Bachelor of Science, Aerospace Engineering

Experience  
**InPro Electric, GmbH**  
Bremen, Germany  
Electrical Engineering Intern  
May – August 2017  
- Worked with Siemens Step 7 software for programming programmable logic circuits used in automated manufacturing of vehicles, specifically for Mercedes-Benz.

**University of Alabama in Huntsville**  
Huntsville, Alabama  
Research Assistant  
May – August 2016  
- Worked as a research assistant to Dr. Landrum of the MAE Dept. focusing mainly on improving a new wing design inspired by biological structures and studying flight dynamics of Monarch butterflies.

**Canvas, Inc.**  
Huntsville, Alabama  
Engineering Intern  
February – September 2016  
- Worked with Siemens Step 7 software for programming programmable logic circuits used in automated manufacturing of vehicles, specifically for Mercedes-Benz.

Honors, Organizations, and Certifications  
Secretary/cofounder of Joy of Thinking mathematics and physics club at UAH  
2016  
Member of Space Hardware Club at UAH.  
2015 – 2016  
Student member of AIAA at UAH.  
2015 – present  
Secretary of Engineering Club at Faulkner State.  
2014 – 2015  
J.E. Strickland Engineering Award  
2015  
Scholar  
Spring 2016  
Fall 2016  
Honors Scholar  
Fall 2015  
Dean’s List  
Spring 2015  
Fall 2014  
Fall 2013
Justin H.
Pulaski, TN

Education
College: The University of Alabama in Huntsville
Bachelor of Science, Mechanical Engineering  Expected Graduation: Spring, 2018

Experience
Belk  October 2016 - Present
Huntsville, AL
Sales Associate
- Improved customer service & public speaking skills
- Enhanced multitasking skills while being involved
- Assisted customers in a kind, orderly fashion
- Stock, replenish, and organize inventory with accuracy and efficiency

Sharp Motor Company  April 2014 - August 2014
Pulaski, TN  Service Representative & Mechanic
- Primary interface with customers
- Learned important agenda/time management skills by arranging appointments
- Wrote various forms of service tickets/notes
- Basic mechanic repairs and operations

Private Citizen  May 2013 - August 2013
Pulaski, TN
Labor/Construction
- Aided in the construction of a 20 ft x 60 ft x 16 ft barn
- Used general building tools and machinery (drills, welder, loaders)
- Learned basic concrete work
- Gained knowledge of basic civil structural designs

Convoy of Hope  Fall 2012
Middle Tennessee  Volunteer
- Assisted in the loading, unloading, and distribution of food and supplies to homeless
- Served underprivileged families in a non-profit setting
- Setup and operated photo studio, downloaded, and printed photos

Honors, Organizations, and Certifications
UAH IGVC (AUSVI) Group  2016
Education
The University of Alabama in Huntsville
Bachelor of Science, Aerospace Engineering  Expected Graduation: May 2018
Minor: Mathematics

Experience
U.S. Army Aviation and Missile Life Cycle Management Command (AMCOM)  January 2016 - Present
Huntsville, AL  Pathways
Engineering Intern
- Certified technician for Army and DOD calibration and repair support for legacy and next generation weapon systems
- Provide measurement data to assist lead engineers with analysis, trends, improved accuracies, root-cause failures, and corrective actions
- Report Unit Under Test (UUT) deficiencies
- Present data using MS applications (Word, Excel, etc.) and other software applications
- Trained and qualified on various testing processes, procedures, and equipment
- Submit recommendation(s) to improve efficiency and effectiveness of laboratory processes that have been recognized by organization leaders and program office
- Produce technical documents for calibration methods
- Assist lead engineers in developing calibration standards

Honors, Organizations, and Certifications

Active DOD Security Clearance  Spring
Society of Women Engineers  2014 - Present
American Institute of Aeronautics and Astronautics  Fall 2013 - Present
University of Alabama in Huntsville Academic Scholarship  Fall 2013 – Spring 2017
J. Davis H.
Huntsville, Alabama

Education
College: The University of Alabama in Huntsville
Bachelor of Science, Aerospace Engineering          Expected Graduation: December, 2018
Minor: Mathematics

Experience
NASA MSFC - ES10                              6/2017-Present
Huntsville, AL                            Intern
- Developed flat-floor based testbed for electric sail tether deployment validation. Duties included design of, data acquisition system, cold-gas thrusters, and thruster control system, as well as manufacturing, assembly, and testing of system.

IERUS Technologies, Inc.                      4/2017-5/2017
Huntsville, AL                              Technical Intern
Operations Intern
- Designed and manufactured parts to improve CNC machine, and improved additive manufacturing capabilities.

Honors, Organizations, and Certifications
UAH Space Hardware Club                     2014-
Present
- July 2017 - Present: Spaceport America Cup - Working on the development of one of the world’s first student-built liquid-powered rocket engines which will fly to an altitude of 30,000' AGL. Serving in support roles on both the ground support/fill system and payload.
- September 2016 - September 2017: URSA Multistage Rocket Team - Chief engineer of a team of 9 that developed a 2-stage rocket capable of launching to an altitude of 30,000' AGL.
- May 2015 - July 2015: International CanSat Competition - Mechanical lead for team developing a mock-satellite which used auto-rotation to control descent after deployment from a rocket. Placed 10th internationally, and 6th in the USA.
- September 2015 - July 2016: Battle of the Rockets: Mars Rover - Rocket team lead in development of a high-power rocket vehicle which transported and deployed a rover at an altitude of 2,000' AGL. Placed 2nd in competition after 3 successful launches.
- October 2014 - June 2015: Midwest High-Power Rocketry - Led a team of 12 in development of a boosted dart rocket, which flew to 4,000'AGL and characterized the roll using both and IMU and post-processed onboard video.

- Published at AIAA SciTech 2017
- Won 1st place, AIAA Region II Student Conference, 2016 Team Technical Category - Primary Author
“Design of a Boosted Dart”
- AIAA Region II Student Conference, 2015 Team Technical Category - Primary Author

“Development of a Multistage High-Power Rocket”
- AIAA Region II Student Conference, 2017 Team Technical Category - Primary Author

Tripoli Rocketry Association Level 3 Certification
Nathanial L.
Huntsville, AL

Education
College: The University of Alabama in Huntsville
Bachelor of Science, Aerospace Engineering
Expected Graduation: May 2018

Experience
Space Hardware Club
Huntsville, Alabama
October 2013-Present
CanSat Team Member, Secretary, President
- Lead radio and ground station design, construction, and operation for CanSat Competition
- As secretary, took and distributed meeting minutes and managed internal and external communications
- As president, managed the work of 10 teams with a total budget of over $100,000.
- Grew club to its largest size in terms of members, projects, and budget

RadioBro
Madison, Alabama
June 2014-Present
Managing Director/Product Engineer
- Opened and currently managing European office
- Represent RadioBro at trade shows and with potential customers
- Designed and fabricated a small, autonomous antenna rotator using a 3-D printer
- Program manager for a BalloonSat workshop- led design of curriculum, flight electronics and software, and flight operations

NASA Marshall Spaceflight Center
Huntsville, Alabama
June 2015-August 2015
Summer Intern
- Designed and implemented motor failure detection for a hexacopter
- Integrated sensors and Arduino electrically, mechanically, and in software
- Recorded flight data, including RPM measurements, for later review
- Developed an understanding of UAV systems, controls, and policies

Honors and Organizations
Sigma Gamma Tau, Tau Beta Pi, Phi Kappa Phi 2015
Von Braun Symposium, 2nd place poster 2014
American Institute of Aeronautics and Astronautics 2014-Present
Honors College, University of Alabama in Huntsville 2013-2016
Boy Scouts of America (Eagle Scout 2012, Philmont Crew Lead 2013) 2005-2013
Chloe M.
Franklin, Tennessee

Education
College: The University of Alabama in Huntsville
Bachelor of Science, Aerospace Engineering May 2018

Experience

Jacobs ESSSA Group May 2017 - ongoing
Huntsville, AL
Solid Rocket Booster Insulation

Development
- Insulation Development and Testing for SLS Solid Rocket Boosters
- Statistical analysis and DOE for rubber formulations to determine Phase II testing materials
- Rubber Mixing and Casting for mechanical, thermal, and rheology analysis
- Inert solid propellant casting and subscale hybrid motor testing
- Design and Manufacturing of Silica Cloth Phenolic and Carbon Cloth Phenolic components

Huntsville, AL Propulsion Technology

Development
- Development, Design, Manufacturing, and Testing of a thrust stand for micro-electric propulsion. Quantified thrust levels as low as 1 micro-Newton for both static and pulsed thrusters.
- Testing of various cathode designs for an iodine fueled electric propulsion system
- Controlled the flow rate to the cathode remotely during testing

NSF Research Experience for Undergraduates June 2015-Aug. 2015
Huntsville, AL Undergraduate Research Assistant

- Acoustic testing of UAV rotors in the UAH anechoic chamber
- Determined lift and drag components of small aircraft using motion capture technology
- IMU integration with Raspberry Pi for Geotagging using UAVs

UAH Space Hardware Club Sept. 2014 – ongoing

- Vice President, management of 145 club members, three lab facilities and six teams
- One Month Project Lead, responsible for the training and mentorship of 125 new members
- NASA USIP selected team to design a balloon-borne telescope payload to actively shield X-Rays of a specific range for future NASA balloon missions
- International CanSat Competition Team, placed 2nd internationally and 1st in the U.S. This competition included the design, manufacturing, and testing of a rocket deployed payload which used passive autorotation to descend while taking stabilized video in the Earth facing direction and sending data to the ground station

Honors, Organizations, and Certifications
Tripoli Level 1 Certification Oct. 2014-ongoing
NASA Intern Poster Expo, Third Place out of 160 August 2016
Wernher Von Braun Memorial Symposium Student Poster Oct. 2015
• “Using a two-tier PID control system to stabilize CanSat rotation around nadir”
  NASA Undergraduate Student Instrument Proposal  
  April 2015 – ongoing
• Awarded $50,000 to develop active radiation shielding for a hard X-ray Detector
  which will be flying on a NASA astrophysics or solar balloon flight payload
  Alabama Space Grant Consortium Scholarship  
  Sept. 2016- ongoing
Forrest M.
Madison, AL

Education

College: The University of Alabama in Huntsville
Bachelor of Science, Mechanical Engineering
Minor: Mathematics
Expected Graduation: May, 2018

Experience

KBRwyle
May 2017 – Present
Huntsville, AL
Mechanical Engineering Intern
- Learned about the PATRIOT system and how tasks performed impact the Lower Tier Project Office (LTPO)
- Reviewed PATRIOT Technical documentation related to specifications from the Technical Data Package (TDP)
- Provided comments to specs and drawings from a mechanical engineering perspective including analysis of design, materials, and drafting.
- Responsible for defending comments and adjudicating responses
- Translated old raster style drawings into a new format for CECOM
- Used thermodynamics, heat and mass transfer, and fluid mechanics to aid in designing and optimizing a data center with Server Rack cooling issues

SAIC
Aug 2015 – May 2017
Huntsville, AL
Information Technology Intern
- Distribution and logistics of shipping and package management
- Labeling and configuration of newly acquired systems and equipment
- Tracking, scanning, and inventory of hardware and non-standard software assets in their respective databases
- Responsible for supplying hardware to SAIC’s various locations CONUS and OCONUS
- Installed printers, scanners, and other hardware
- Fulfilled and resolved user submitted requests to the TSSC

Honors, Organizations, and Certifications

University of Alabama in Huntsville Transfer Scholarship
Aug 2015 – Present
University of North Alabama Math Colloquium
University of North Alabama Academic Scholarship
Andrew M.
Huntsville, AL

Education
The University of Alabama in Huntsville
Bachelor of Science, Aerospace Engineering

Experience
UAH Propulsion Research Center
Huntsville, AL
February 2016- Present
Undergraduate Research Assistant
- Overseeing operation of Trans-sonic/Supersonic Wind Tunnel
- Researching shock wave boundary layer interaction to characterize unsteadiness
- Designing and implementing facility upgrades for test section and data acquisition
- Maintaining a safe work environment by updating safety procedures

Honors, Organizations, and Certifications
Dean’s List, UAH 2014-2017
Charger Distinction Scholarship 2014-2017
UAH Space Grant Midwest High-Power Rocketry Competition Team 2015
Charger Swing Dance Club 2016-2017
Spencer M.
Lilburn, Georgia

Education
The University of Alabama in Huntsville  Expected Graduation: May 2018
Bachelor of Science, Aerospace Engineering
Minor: Mathematics

Experience

Jacobs ESSSA Group  May 2016 to Present
Huntsville, AL  SLS Operations
Dashboard Tool Developer
- Develop Microsoft Excel dashboards to aid in managing and statusing of various vehicle requirements for the Space Launch System (SLS), saving hundreds of hours per year.
- Write user's manuals and developer's guides following a standard NASA document writing format.
- Present work to multiple audiences including SLS operations team members, Jacobs ESSSA upper management, and SLS project management.
- Valuable experience has been gained in NASA systems engineering practices and working with a large team on a large, multi-system project.
- Related Skills: Microsoft Office, Visual Basic for Applications (VBA), data analysis, technical documentation, presentation skills, teamwork, and communication.

Space Hardware Club  August 2014 to May 2015
University of Alabama in Huntsville, Huntsville, AL  Team Member
- Received hands-on experience in engineering projects including weather balloon payloads and rockets.
- Led a small team on a project with requirements decided by the team. Although the team was unable to complete the project, valuable lessons were learned.
- Related Skills: Soldering, presentation skills, leadership skills, teamwork, and communication.

Honors, Organizations, and Certifications
Sigma Gamma Tau  2017 to Present
National Space Club  2017 to Present
NASA MSFC PIV Badge  2016 to Present
Edwin F. Connors Continuous Improvement Award  2016
UAH Engineering Dean’s List  2016 to Present
UAH Honors College  2014 to Present
UAH Charger Excellence Scholarship  2014 to Present
Walter P.
Huntsville, Alabama

Education
College: The University of Alabama in Huntsville
Bachelor of Science, Aerospace Engineering  Expected Graduation: May, 2018

Experience

The University of Alabama in Huntsville  May 2017-August 2017
Huntsville, Alabama  Student Specialist III
- Ran wind tunnel experiments on heat transfer and film cooling for varying flow conditions with varying Reynolds numbers and blowing ratios. Required to perform maintenance on the wind tunnel and prepare it for future experiments.
- Used Solid Edge to design new target hardware for target plates to be tested in the wind tunnel.
- Used Solid Edge to design a new wind tunnel facility that will focus on flow visualization efforts. Talked with manufactures to obtain quotes and lead times of parts needed for the new facility.
- Related Skills: MATLAB, VBA, Solid Edge, Microsoft Office Suite

The Boeing Company  May 2016-August 2016
Huntsville, Alabama  Research Assistant IV
- Contracted through The University of Alabama in Huntsville to work for The Boeing Company on the CST-100, or Starliner, for the CCtCap program.
- Used NX 8 to design and modify components for the Starliner. Created sensor layouts that detailed installation locations and orientations on the capsule.
- Peer reviewed parts to ensure that proper procedures had been followed before sending it further through the workflow process.
- Related Skills: Solid Edge, NX 8, Microsoft Office Suite, VBA

Honors, Organizations, and Certifications
College of Engineering Dean’s List  2016-Present
Ray S.
Huntsville, Alabama

Education
College: The University of Alabama in Huntsville
Bachelor of Science, Mechanical Engineering  Expected Graduation: May 2018

Experience
The Boeing Company  August 2016 - Current
Huntsville, Alabama  Research Assistant IV
- Contracted through UAH
- Design team on three projects, CST-100, F/A18, and AV8-B.
- Used Teamcenter and NX, to design parts, transfer old drawing to CAD files, wire routing,
- Part Maintenance Technical Writing for Pac-3

Honors, Organizations, and Certifications
Pi Tau Sigma Alabama Delta Upsilon  2017
National Society of Leadership and Success  2016
Super Scholar Transfer Scholarship  2015
President’s List  2011-2016
Associate of Science Summa Cum Laude  2014
Amanda S  
Huntsville, AL

Education  
College:  The University of Alabama in Huntsville  
Bachelor of Science, Aerospace Engineering

Experience  
**Society of Women Engineers**  
April 2016 - Present  
Huntsville, Alabama  
President/Vice-President  
- Run productive meetings while helping oversee chair positions, growing UAH chapter by 50% in one year to a total of over 366 women  
- Managed $20,000 budget, including planning 11-member regional conference trip  
- Attend monthly meetings with Dean of Engineering to solicit feedback on activities  
- Help execute outside events such as First Lego League qualifying rounds

**Association for Campus Entertainment**  
January 2015 – May 2015  
Huntsville, Alabama  
Social Media Chairperson  
- Revolutionized social media presence for Association of Campus Entertainment  
- Helped manage a budget of $250,000 to put on student entertainment events  
- Scheduled and executed advertising for events during Week of Welcome, Homecoming, Spring Fling, and Late Night Breakfast  
- Initialized student feedback for events to better plan future involvement

**Space Camp/US Space and Rocket Center**  
May 2015 – August 2015  
March 2014 – December 2014  
Huntsville, Alabama  
Crew Trainer  
- Fostered love of aerospace-related topics amongst students aged 9-15  
- Responsible for ensuring team of students executes training throughout week  
- Self-taught information about U.S. space endeavors to maintain knowledge base  
- Constantly-changing schedule required flexibility in training plan

Honors, Organizations, and Certifications

Society of Women Engineers  
2012 - Present

Girl Scouts of America  
2000 - Present

Delta Zeta Sorority – Lambda Kapa Chapter  
2015 - Present

Crew Trainer of the Week  
2014

Space Camp Team of the Quarter  
2014

FIRST Lego League  
2016 – 2017  
Head referee, judge assistant, and volunteer coordinator

FIRST Robotics Competition pit support volunteer  
2016 – 2017

Professional Development Conferences:  
- Society of Women Engineers Southeast Regional Conference  
  2016, 2017  
- Delta Zeta National Conference  
  2016
Andrew W
Atlanta, Georgia

Education
The University of Alabama in Huntsville
Bachelor of Science, Aerospace Engineering Expected Graduation: May, 2018
Minor: Russian Language

Experience
AMRDEC, SSDD
Huntsville, AL
Pathways Intern
June 2017 - Present

- Aids in the development of simulation and testing scenarios, and provides supports and pre-flight and post-flight analysis support for Captive Test, Guided Test, and Live Fire Tests events.
- Performs monte-carlo simulation execution of weapon systems models, and aids in the development of documentation and technical presentations associated with these analyses.

Space Hardware Club
Huntsville, Alabama
October 2014 - May 2015
CanSat Team Member,

- Learned various engineering skills through the use of weather balloon payloads and amateur rocketry.
- Assisted with the software development of several payloads, as well as the mechanical design of a subsonic rocket
- Related Skills: C, Soldering, Composite layups, Presentation Skills, Teamwork and Communication.

Honors, Organizations, and Certifications
Active DoD Security Clearance
Student member AIAA
Honors College, University of Alabama in Huntsville
Sigma Gamma Tau
Slavic Club: Vice President
Engineering Dean List
May 2015 - Present
August 2014 - Present
April 2017 - Present
Spring 2016 - Present
Spring 2016
Eric Z.
Irmo, South Carolina

Education
College: The University of Alabama in Huntsville
   Bachelor of Science, Aerospace Engineering

Experience
   The Boeing Company            March 2016-November 2016
   Huntsville Design Center, Huntsville Alabama  Research Assistant II
   - Duties: Structure design and drawing for the 777x-9 aircraft fuselage stringers and skins, selected for advanced training, rapid promotion in responsibilities due to performance.

   TPM, Inc.                      Summer 2014 and 2015
   Columbia South Carolina        Department Assistant
   - Duties: Prepared and rendered engineering drawings, provided personal customer service delivery, utilized various computer software programs to ensure quality products

Honors, Organizations, and Certifications
College of Engineering Dean’s List  2017
Honors College                    2014-Present
Eagle Scout                       2013