Western Michigan University
Advanced Rocketry Club (ARC)

NASA SLI 2020 Project Proposal

September 18, 2019

4601 Campus Drive
Kalamazoo, MI 49008

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Acronyms

AGL……………… Above Ground Level

AIAA………………American Institute of Aeronautics and Astronautics

APCP……………. Ammonium Perchlorate Composite Propellant

ARC……………… Advanced Rocketry Club

ARMADLO………..Advanced Rover Mounted Autonomous Drill for Lunar Objectives

CAD……………….Computer Aided Design

CDR……………….Critical Design Review

CEAS……………...College of Engineering and Applied Sciences

CFD………………..Computational Fluid Dynamics

CFR………………..Code of Federal Regulations

CG………………… Center of Gravity

CP………………….Center of Pressure

CT…………………. Communications/Telemetry

DBF…………………Design-Build-Fly

ESC…………………Electronic Speed Controler

FAA………………… Federal Aviation Administration

FEA………………….Finite Element Analysis

FPV…………………..First Person View

FRR…………………. Flight Readiness Review

GPS…………………. Global Positioning System

HPR…………………. High Power Rocketry

HS…………………….High School

IMU…………………...Internal Measurement Unit

LV……………………. Launch Vehicle

LVT……………………Launch Vehicle Team

MSDS…………………Material Safety Data Sheet

MT…………………......Mission Team

NAR…………………...National Association of Rocketry

NFPA…………………National Fire Protection Association

PDR…………………..Preliminary Design Review

PLAR…………………Post Launch Assessment Review

PPE………………........Personal Protection Equipment

SET……………… ….Student Engagement Team

SLI……………………Student Launch Initiative

SMT………………….Social Media Team

STEM………………..Science Technology Engineering and Math

TOF………………….Time of Flight

TOLS……………......Three Oaks Launch Site

TRA…………………...Tripoli Rocketry Association

UAV………………….Unmanned Aerial Vehicle

WMU……………..….Western Michigan University

1 General Team Information

The Western Michigan University ARC team consists of 45 active members of multiple majors and class standings. To effectively distribute the workload, the members are split into subgroups focusing on specific parts of the design and build processes. The specific breakdown of the team structure is shown in Figure 1.2. The subgroups will collaborate to ensure that ARC fulfills the SLI competition requirements. Within each subgroup, a lead has been chosen to direct the activities of the subgroup as well as remain in close communication with the project lead and other subgroup leads. These student leaders will ultimately create a network to communicate with advisors and facilitate consistent progress toward competition goals. The advisors and student leaders are shown in section 1.1.

1.1 Advisors / Student Leaders

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1.1.1 NAR / TRA Advisors

ARC is working with Michiana Rocketry (MR) #721, who will host the team's test launches and help with periodic reviews concerning rocket design and construction methods. The Michiana Rocketry Club operates the Three Oaks Launch Site. TOLS is equipped with high power 1010 launch rails, extreme high power 1515 launch rails, and an FAA waiver up to 12,000 ft. AGL. TOLS is less than an hour drive from our base of operations and is equipped with the necessary tools and personnel for successful test flights. In addition, ARC has a local contact, Jay Calvert of Impulse Buys, that offers propulsion system insight during our testing and design phases as well as provides the team with discounts on rocket motors. However, at the time of submission no MR members were willing to commit to ARC advising. As a result, ARC lead Jay Krebs has been chosen to be the team mentor. Krebs is a level 2 TRA certified member with more than 2 level 2 flights (all with staged recovery, flight electronics and avionic use). ARC will still maintain the support relationship with experienced southwest Michigan certified flyers.

1.2 Organization Outline

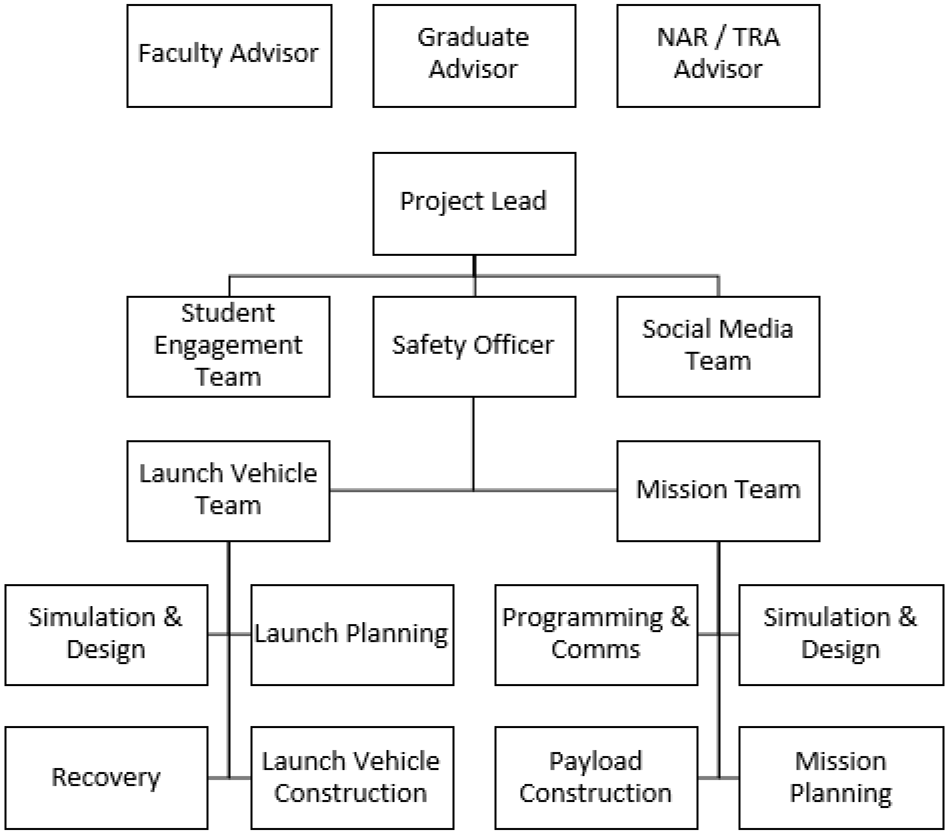


Figure 1.2

1.2.1 Launch Vehicle Team

The Launch Vehicle Team is responsible for the design, construction, testing, and delivery of the launch system. This includes material considerations, propulsion system decisions, flight simulation, mission deployment systems, and vehicle recovery systems. Simulations and vehicle evaluations will be conducted throughout the build process to ensure a successful flight. Additional focus will be given to in-flight stability to account for payload shifts throughout all flight modes. Simulations will also be used to predict the altitude of flight in accordance with SLI Handbook Vehicle Requirement 2.1. This subgroup will handle most of the hazardous materials during the build process. As a proactive safety measure, only senior members that are TRA level 2 certified will handle the construction of the propulsion and ejection systems. Any additional hazardous materials will be handled with the close supervision of the Safety Officer. This team is comprised of eighteen student members and one student team lead.

1.2.2 Mission Team

The Mission Team's key responsibility is to design, construct, and test the payload that will execute the lunar ice recovery mission. Additional responsibilities include the creation of the payload control systems, communication and launch vehicle telemetry, and the execution of the mission. To ensure each of the Mission Team's responsibilities are achieved, this team will be further divided into Mission sub-teams. These sub-teams can be seen in Figure 1.2. Some of these sub-team's responsibilities overlap, as a result close communication will be required. The programming and communication will be tasked with the programing of the control system, as well as how it will communicate with the ground crew. The control system will be essential to mission success and is therefore of the highest priority. An additional responsibility of this sub-team will be establishing a method of actively locating both the launch vehicle and mission vehicle. The simulation and design sub-team will responsible for modeling the mission system. Along with the design, this sub-team is tasked with simulation how our chosen design will function under operating conditions. This will be a mixture of finite element analysis, and computational fluid dynamics. Payload construction, another sub-team, will be working closely with the simulation and design team. Payload construction will be the team of students that manufacture the mission system's components. The final sub-team is mission planning. Mission planning is responsible for ensuring that any and all design meet mission requirements, and SLI handbook rules and regulations. This sub-team will also help coordinate launch day procedures as the ground crew. These sub-teams will be in close communication with ARC's graduate advisor. This team is comprised of sixteen student members and one team lead.

1.2.3 Safety Officer

The ARC Safety Officer is responsible for ensuring that all team members abide by all safety regulations. Furthermore, the Safety Officer will ensure that hazardous materials are handled properly, and all operations are conducted in a safe manner. To accomplish this, the Safety Officer will maintain current versions of all safety documents, create safety procedures for the build and launch of the vehicle in conjunction with the team leads, and create checklists to be followed by the team during ground tests and flights of the subscale and full-scale vehicles. The Safety Officer will create a safety contract to be followed by all members and conduct risk assessments of both build and flight hazards. Additionally, the Safety Officer will conduct regular reviews of construction, launch, and design decisions to ensure they abide by all regulations and procedures. The Safety Officer will be the primary point of contact for the Range Safety Officers at the launch sites utilized by ARC during the competition season. In addition, the Safety Officer will ensure that STEM engagement events are conducted in a safe manner.

1.2.4 Social Media Team

The Social Media Team will enable public outreach by creating an open line of communication between NASA, the public, and ARC. ARC will establish a consistent social media presence to help communicate progress of the rocket and payload to the public and SLI officials. They will document construction milestones, safety efforts, launches, periodic tests, and team member involvement. This team fulfills SLI communication requirements and facilitates long term team sustainability. Advertising our activities to current and prospective students will help facilitate continuing interest in ARC. This team is comprised of one student team member and one student team lead.

1.2.5 Student Engagement Team

The Student Engagement Team (SET) is responsible for organizing and engaging local K-12 students in STEM and rocketry focused activities and experiences. Per SLI requirements, ARC must reach 200 students in educational events that promote STEM or rocketry. In prior years, the WMU AIAA chapter (including ARC) has been proactive in educational activities within southwestern Michigan. The College of Engineering and Applied Sciences encourages involvement with local students, as such, WMU AIAA has ongoing educational activities that can be expanded. The SET is tasked with planning and enacting additional educational opportunities as well as continuing legacy activities. These activities will be documented and compiled to establish the scope of students reached through the SET's efforts. This is further discussed in section 5. This team is comprised of four student team members and one student team lead.

2 Facilities/Equipment

The WMU College of Engineering and Applied Sciences houses most of our facilities and equipment. The WMU AIAA meets in the WMU UAV lab, and many of the tools owned by the club are kept here. There are select locations in the Kalamazoo area that offer supplementary facilities and equipment. The specific locations and their equipment are discussed further below.

2.1 Western Michigan University UAV LAB

4601 Campus Dr, Kalamazoo, MI 49008 Room F-209

The UAV lab is the primary facility of ARC. The lab is available to the team 24 hours a day. The CEAS building is swipe access to students who can use the lab spaces at any time. Most of the build will be completed here. For anything that is too large or requires machinery not available in this lab, either the Student Project Lab, College Machine Shop, or the WMU Makerspace will be utilized. The UAV lab features the following:

Drill Press (x1)
Scroll Saw (x1)
Combination Belt and Disk Sander (x1)
Static Thrust Stand for Electric Motors (x1)
Small Low Speed Wind Tunnel (x1)
Soldering Station (x2)
Misc. Hand Tools
Misc. Consumables (epoxy, hardware, etc.)
PPE

Required Personnel: Team Lead(s) and/or Project Lead must be present

2.2 Western Michigan University Student Projects Lab

4601 Campus Dr, Kalamazoo, MI 49008 Room G-112

The Student Projects Lab gives the team the ability to fully fabricate any structural or payload components needed. The lab has operating hours of 9am-5pm on school days. Weekend availability is also an option if needed. The Student Projects Lab features the following equipment:

Vertical Knee Mill (x2)
Drill Press (x2)
Lathe (x1)
Combination MIG, TIG, Stick Welder (x2)
Vertical Band Saw (x3) (Wood and Metal)
Horizontal Band Saw (x1)
Paint Booth (x1)
Table Saw (x1)
Sandblasting Booth (x1)
Belt Sander (x2)
Complete Hand and Power tool Set
PPE

Required Personnel: Team Lead(s) and/or Project Lead must be present, as well as the Project Lab Supervisor.

2.3 Western Michigan University Makerspace

1090 Arcadia Loop, Kalamazoo, MI 49008 Room 2030

The WMU Makerspace gives the team the ability to rapidly prototype vehicle components by 3-D printing composite elements or laser cutting wooden elements. The Makerspace is available to all WMU students during the hours of operation set by the WMU Innovation Club. The lab hours for this academic year have yet to be defined, but it is assumed that the lab will be available at least 30 hours a week. The Makerspace Lab features the following equipment:

3-D Printer (x2)
Laser Cutter
Soldering Station
Basic Hand Tools

Required Personnel: Makerspace Supervisor

3 Safety

The safety of our members is of the utmost importance to ARC. Throughout the construction process and test flights, there are many possibilities for injury if safety precautions are neglected. A safety manual and contract have been written by the Safety Officer. While the manual primarily applies to ARC, all members of the WMU AIAA must sign the safety contract because the materials listed within are also used by the Design-Build-Fly (DBF) and Unmanned Aerial Systems teams. Similarly, many of the FAA regulations referenced in the manual apply to both ARC and the DBF team. The safety manual in its entirety can be found in Appendix 7.2. The manual in standalone form can be found at the link in the same appendix.

3.1 NAR/TRA Personnel Protocols and Motor Handling

As stipulated in the ARC Safety Manual, only those members that have been certified by the NAR or TRA to operate Class 2 HPRs shall be permitted to purchase, handle, install, load, reload, or arm the vehicle's motor. While working with the motor and its propellant, these members will be required to wear safety glasses, dust masks, and gloves to minimize risk of injury. All members handling the motor and conducting launch operations will be responsible for abiding by the launch procedures set forth in the safety manual as well as NFPA-1127, FAA CFR Title 14 Section 101 Subpart C, CFR Title 27 Section 55, the NAR and TRA HRP safety codes, and the SLI handbook. ARC has 3 ammunition cannisters that have historically held the energetic materials. In addition, members responsible for the operation of the payload in its quadcopter configuration shall abide by the AMA handbook, FAA CFR Title 14 Section 101 Subpart E, and FAA CFR Title 14 Section 107. All members agree to follow these regulations when they sign the safety contract.

3.2 Hazard Briefings

To ensure the team's safety during the build process, the Safety Officer will brief the team on the lab safety procedures in the manual prior to the initiation of vehicle construction. Information about hazardous materials and emergency contacts will also be provided. Prior to flights, the Safety Officer will brief the team on launch safety protocols in the ARC safety manual, the handling of the motor, and the laws and regulations apparent during launches. However, all members are ultimately responsible for their own safety.

3.3 Compliance with HPR Safety Laws and Regulations

The Safety Officer will maintain physical and digital versions of current material safety data sheets and regulations. These documents will be made available to all members, who are responsible for reading and understanding these regulations as stated in the safety manual. The Safety Officer will regularly review the design of the vehicle to ensure it follows all regulations. In addition, the build and flight of the vehicle will be overseen by the Safety Officer to ensure all safety protocols are followed. The Range Safety Officer at the launch site makes the final determination of the safety of the launch vehicle, and the team will abide by that determination.

3.4 Necessary Caution Statements and Risk Assessments

Following the Occupational Safety and Health Administration's standards for safety labels, the following convention will be used in the manual, briefings, procedures, checklists, and other safety documents:

DANGER: Signifies severe risk of death or serious injury.
WARNING: Signifies moderate risk of death or serious injury.
CAUTION: Signifies risk of minor or moderate injury.

In the following risk assessments, a standard risk assessment matrix is utilized. The likelihood of a hazard occurring is defined as follows:

Value	Likelihood	Probability
A	Very Unlikely	Less than 5%
B	Unlikely	Between 5% and 25%
C	Possible	Between 26% and 50%
D	Likely	Between 51% and 89%
E	Very Likely	90% or greater

Table 3.1: Hazard probability scale.

The severity of the consequences of a hazard occurring is defined as follows:

Value	Severity	Result
1	Marginal	Negligible injuries or damage to vehicle/facilities, no impact on mission
2	Moderate	Minor injuries or damage to vehicle/facilities, minor impact on mission
3	Critical	Severe injuries or damage to vehicle/facilities, partial failure of mission
4	Catastrophic	Life-threatening injuries/death or loss of vehicle/facilities, loss of mission

Table 3.2: Hazard severity scale.

These scales are combined to produce the following risk assessment matrix:

Likelihood	Severity	1	2	3	4
A		1A	2A	3A	4A
B		1B	2B	3B	4B
C		1C	2C	3C	4C
D		1D	2D	3D	4D
E		1E	2E	3E	4E

Table 3.3: Risk assessment matrix.

The following table outlines the risks associated with the hazardous materials to be used in the build process:

Material	Hazard	Cause	Risk	Mitigation
Acetone	Fire, severe eye irritation, dizziness/drowsiness	Exposing acetone to heat source, not using PPE	3C	Wear appropriate PPE, keep acetone away from heat sources, and do not inhale fumes.
Ammonium Perchlorate	Fire or explosion, severe eye irritation, permanent organ damage	Exposing to heat source, improper handling, prolonged exposure	4C	Wear appropriate PPE, keep away from heat sources, limit exposure time, only level 2 certified members authorized to handle
Body Filler	Fire, severe eye irritation, permanent organ damage, possible carcinogen, impacts on fertility	Exposing to heat source, improper handling, prolonged exposure	4B	Wear appropriate PPE, keep away from heat sources, limit exposure time, do not inhale fumes
Cardboard	Combustible dust concentrations, aggravation of existing conditions	Post-shipment processing and handling	1B	Keep workspace well-ventilated
Enamel Paint	Fire, possible carcinogen, harmful fumes, permanent nerve damage	Exposing to heat source, inhaling fumes, overexposure	3D	Wear appropriate PPE, work in ventilated area, keep away from heat sources, limit exposure time, do not inhale fumes
Epoxies	Skin irritation, severe eye irritation, burns	Improper handling, prolonged skin contact	2D	Wear appropriate PPE

Epoxy Accelerator	Fire, headaches/dizziness/drowsiness	Exposing to heat source, prolonged fume exposure	2C	Wear appropriate PPE, keep away from heat sources
Ferrosoferric Oxide	Mild skin/eye irritation	Improper handling	1C	Wear appropriate PPE
Fiberglass	Fiberglass splinters, mild skin irritation, respiratory hazards	Handling prior to sanding, heavy sanding	2C	Wear appropriate PPE prior to and during sanding, sand in ventilated area
Igniters	Fire, airborne debris, explosion, thermal burns	Exposing to heat source, accidental ignition	4C	Wear appropriate PPE, keep away from heat sources, only level 2 certified members authorized to handle
Lead Solder	Possible carcinogen, acutely toxic, may impact fertility, organ damage	Ingestion, inhaling, prolonged exposure	4A	Wear appropriate PPE, do not ingest, do not inhale fumes, limit exposure time
Solder Flux Paste	Severe burns, severe internal burns, severe eye damage, blindness	Improper handling, ingestion	4C	Wear appropriate PPE, do not ingest, keep away from eyes
Thread Locker	Skin/eye irritation, respiratory tract irritation	Improper handling, fume inhalation	2B	Wear appropriate PPE, do not inhale fumes

Table 3.4: Risk assessment of hazardous materials used in build process.

The following table outlines the possible failure modes of the launch vehicle and their resulting impact on personnel, spectators, the vehicle/mission, and facilities:

Failure Mode	Possible Hazards	Cause	Risk	Mitigation
Safe Misfire	Fire on vehicle or immediate launch area, danger to personnel within exclusion zone	Ignition system failure, improper arming, operator error	2C	Follow launch protocols and checklists, check ignition system before use, only level 2 certified members authorized to operate ignition system, wear PPEs while motor is armed, have fire suppression equipment nearby
Catastrophic Misfire	Fire or explosion destroying vehicle or damaging immediate launch area, danger to personnel within exclusion zone	Ignition system failure, improper arming, operator error	4A	Follow launch protocols and checklists, check ignition system before use, only level 2 certified members authorized to operate ignition system, wear PPEs while motor is armed, have fire suppression equipment nearby
Insufficient thrust to clear pad	Brush fire, damage to vehicle and immediate launch area, danger to personnel within exclusion zone, danger to spectators if vehicle departs launch area	Motor incompletely ignites, design did not provide sufficient TWR	3B	Follow launch protocols and checklists, have TWR of at least 3:1 during design phase, ensure all weight changes to components are communicated to team, wear PPEs
Vehicle loses control while intact	Danger to ground personnel and spectators due to erratic trajectory, possible loss of the vehicle	Vehicle was not designed with sufficient stability, build errors compromised stability	4A	Have minimum static stability margin of 2.0 upon launch rail departure during design phase, ensure build work is completed precisely and checked by team leads, wear PPEs
Aerodynamic surface shears off	Loss of control, danger to ground personnel and spectators due to erratic trajectory, possible loss of the vehicle	Build error, insufficient strength of adhesive or mounting mechanism	4A	Ensure mounting method used can withstand flight forces, ensure build work is completed precisely and checked by team leads, wear PPEs

Motor casing fails (CATO)	Propellant expelled through sides of motor, loss of control, danger to ground personnel/spectators/facilities due to erratic trajectory, brush fires upon impact, possible loss of vehicle	Improper motor handling, motor failure	4C	Follow launch protocols and checklists, only level 2 certified members authorized to handle motor, have fire suppression equipment nearby, wear PPEs
Motor explodes	Loss of vehicle, falling debris, brush fires upon impact, danger to ground personnel, spectators, and facilities	Improper motor handling, motor failure	4A	Follow launch protocols and checklists, only level 2 certified members authorized to handle motor, have fire suppression equipment nearby, wear PPEs
Staging does not occur/is incomplete	Vehicle descent uncontrolled, damage to or loss of vehicle, danger to ground personnel/spectators/facilities	Improper build/installation of staging hardware	3B	Follow launch protocols and checklists, ensure build work is completed precisely and checked by team leads, wear PPEs
Shock cord breaks	Nose cone descent uncontrolled, damage to or loss of nosecone, danger to ground personnel/spectators/facilities	Insufficient strength of shock cord, improper installation	2A	Ensure shock cord can withstand staging forces, ensure build work is completed precisely and checked by team leads, wear PPEs
Parachute does not deploy/breaks off	Vehicle descent uncontrolled, damage to or loss of vehicle, danger to ground personnel/spectators/facilities	Insufficient strength of parachute lines, improper installation	3C	Ensure parachute can support vehicle weight, ensure build work is completed precisely and checked by team leads, wear PPEs
Parachute cord detonates improperly	Structural failure of vehicle, uncontrolled descent, damage to or loss of vehicle, falling debris, danger to ground personnel/spectators/facilities	Improper installation or arming of parachute cord	3B	Follow launch protocols and checklists, ensure build work is completed precisely and checked by team leads, wear PPEs
Parachute partially deploys/tangles	Vehicle descent faster than planned, damage to vehicle, danger to ground personnel/spectators/facilities	Improper parachute installation, unfavorable winds	2C	Follow launch protocols and checklists, ensure build work is completed precisely and checked by team leads, only launch in conditions within the parachute's tolerances, wear PPEs
Complete structural failure in flight	Falling debris, loss of vehicle, motor continues flying, danger to ground personnel/spectators/facilities, brush fires upon impact	Vehicle designed with insufficient safety margins	4A	Ensure vehicle is designed to withstand flight loads, wear PPEs
Structural failure on landing	Damage to vehicle, payload damaged or unable to deploy properly	Improper build, insufficient strength of adhesive or mounting mechanism, wear and tear, descent too fast	1D	Ensure vehicle descent rate falls within tolerable values, ensure build work is completed precisely and checked by team leads, ensure payload is well-restrained
Vehicle does not land in proper orientation for payload deploy	Structural failure on landing, payload damaged or unable to deploy properly	Improper parachute installation, unfavorable winds	1B	Follow launch protocols and checklists, ensure build work is completed precisely and checked by team leads, only launch in conditions within the parachute's tolerances, ensure payload is well-restrained
Payload release system fails	Payload unable to deploy properly	Build error, hard landing	1C	Ensure build work is completed precisely and checked by team leads, ensure payload is well-restrained

Table 3.5: Risk assessment of launch vehicle failure modes.

3.5 Adherence to Safety Determinations

By signing the safety contract, all members of ARC have agreed to the following:

- Each member complies with the determinations of all safety inspections conducted before a flight or face removal from the competition.

- The Range Safety Officer has the final say on the vehicle's safety and has the right to deny the vehicle's launch on that basis.

- The team mentor is ultimately responsible for the safe flight of the vehicle. Therefore, no vehicle will fly until the design and construction have been reviewed by the mentor and are found to comply with all established regulations and safety guidelines.

- Failure to comply with any safety requirements will result in the team being denied launch of the vehicle.

4 Technical Plan

4.1 Mission Systems

Upon release of the 2019-2020 SLI handbook, ARC immediately began brainstorming ideas for the ice recovery systems. ARC prioritized the payload's ability to complete the missions above all other design parameters. As a result, the launch vehicle as well as the communication and telemetry characteristics are products of the payload design. To start the preliminary design process the team took an in-depth look into what was required of a mission vehicle. This led to four key design requirements:

1. Ability to exit launch vehicle after descent
2. Ability to traverse all types of terrain in travel to dig sites
3. Ability to extract simulated lunar ice
4. Ability to travel on ground ten linear feet after ice extraction

These four design requirements guided the design of Advanced Rover Mounted Autonomous Drill for Lunar Objectives mk.1 (ARMADLO). ARMADLO is an expanding bipropeller quadcopter. In addition to the propellers ARMADLO has two hub driven wheels, and one low resistance skid plate. This combination of ground and aerial vehicle can affect each mode of flight. The pair of hub driven wheels must carry the additional weight of the quadcopter motors. Ideally, the low resistance skid plate will alleviate any resistive forces caused by the propellers or motors during ground travel. Additionally, the front asymmetrical mount wheels may affect the flight center of gravity. Preliminary models addressed this concern through strategic placement of the drill and skid plate assembly. These two propulsion systems give ARMADLO two forms of travel: aerial which utilizes the four bi-propellers, and terrestrial movement through its wheels and skid plate. These features satisfy design requirements 1, 2, and 4. Another feature of ARMADLO mk.1 is a self-contained auger system for lunar ice recovery. This auger is mounted on the skid plate and is angled in such a way that when a solenoid is energized it extends to meet the ground. This auger satisfied our last identified design requirement. ARMADLO mk.1 also features compressible suspension for storing in the launch vehicle, along with a full first-person view system for the piloted portions of the missions.

4.1.1 Mission System Construction

ARMADLO mk.1 will be primarily constructed out of Lexan and carbon fiber sheet. It will also feature an assortment of electronics such as: a flight controller, GPS, first person view camera, barometer, time of flight sensor, internal measurement unit, and electronic speed controller to list a few. To help fit ARMADLO into the tightest rocket body possible the four booms will expand after exiting the launch vehicle. This will be achieved by connecting both port booms with a spring, and the same on the starboard side. While in launch configuration, both forward booms will be pulled tight together against the force of the springs. A small servo will be used to pin the two together while in the launch vehicle. A similar configuration will be utilized for the two aft booms as well. Once safely out of the launch vehicle, the servo's pinning the forward and aft booms together will retract, springing them back to flight orientation. Figure 4.1.1a and 4.1.1b show the rough preliminary design of ARMADLO mk.1.

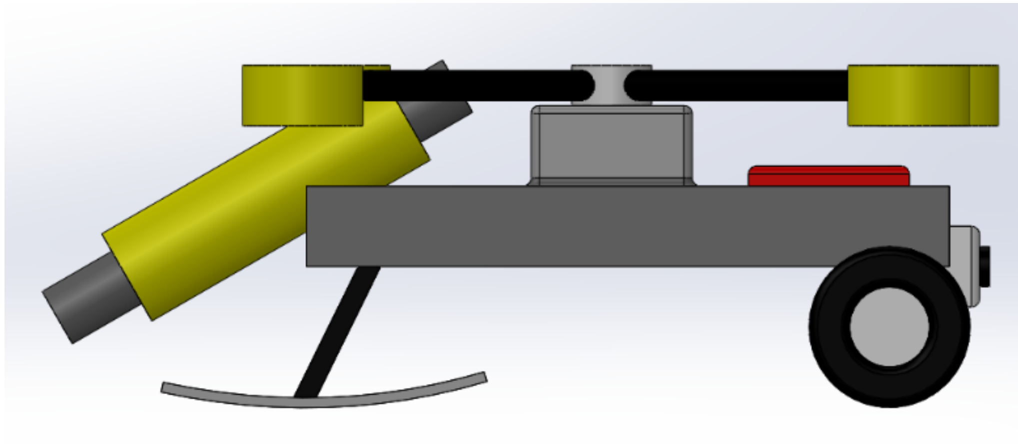


Figure 4.1.1a Side View

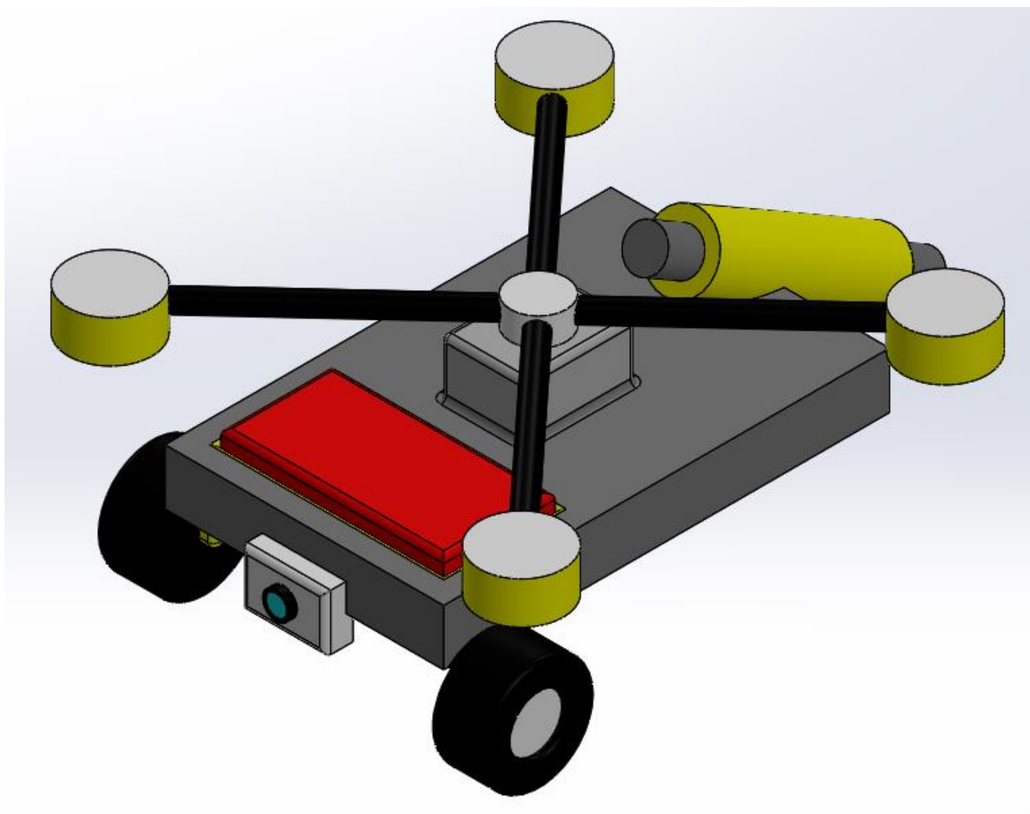


Figure 4.1.1b ARMADLO mk.1 Iso View

4.1.2 Mission Procedures

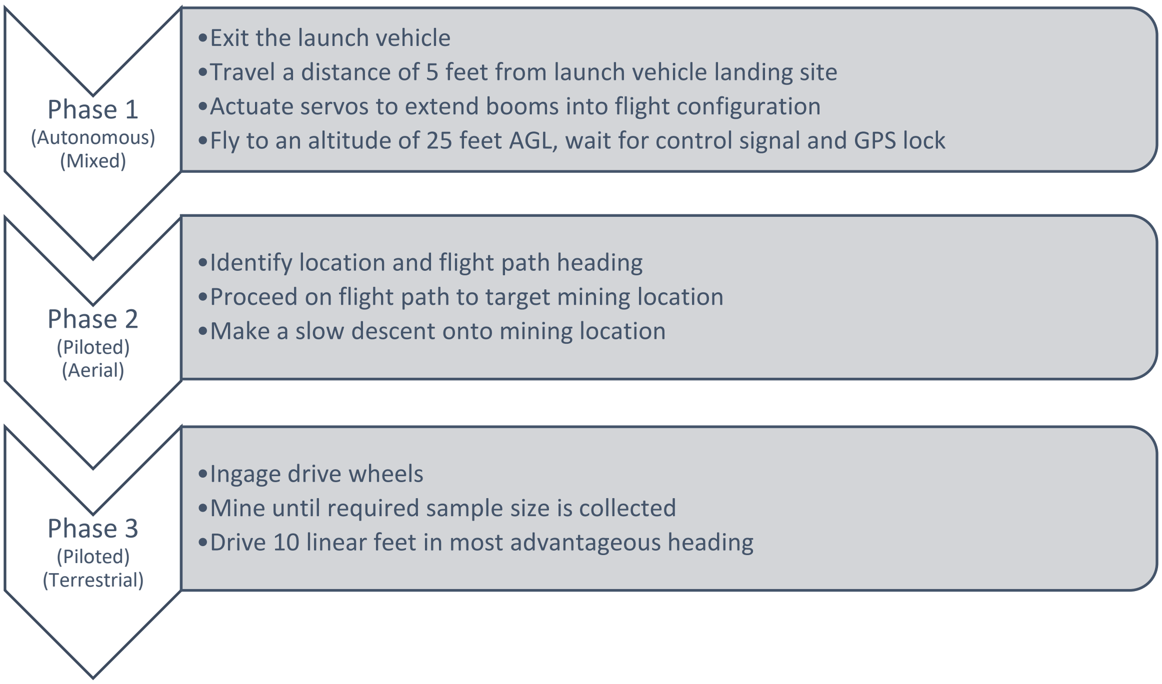


Figure 4.1.2

4.2 Launch Vehicle

As previously mentioned, designing a payload that could achieve mission success was the first and most important phase of design. Preliminary designs yielded the need for a payload section of at least 6 inches in diameter. For ease of construction, the launch team selected a uniform airframe with a diameter of 7.5 inches. Allowing for a single material purchase and space margins in the payload section allowing for small dimensional changes in the mission system construction/design phases. The OpenRocket model of the launch vehicle is shown in Figure 4.2a. This preliminary design of the launch vehicle is known as the BlueWhale. The airframe is 109 inches of blue tube, with a 30-inch ogive plastic nose cone. The blue tube airframe keeps the total body weight low despite the extremely long and wide geometry, but still provides a very structurally sound body tube. Fiberglass fins were chosen over wood to ensure there were no structural bottlenecks during the boost phase. The split fins aid in the stability of BlueWhale, moving the center of pressure forward along the body. This setup helps alleviate the stability penalty of housing our payload and mission deployment systems in a more aft position in the airframe than other conventional rocket designs. The reasoning behind the mission systems location is discussed in further detail below. The center of gravity and center of pressure are located 82.87 and 99.68 inches from the nose, respectively. This results in launch vehicle stability of 2.24 calibers.

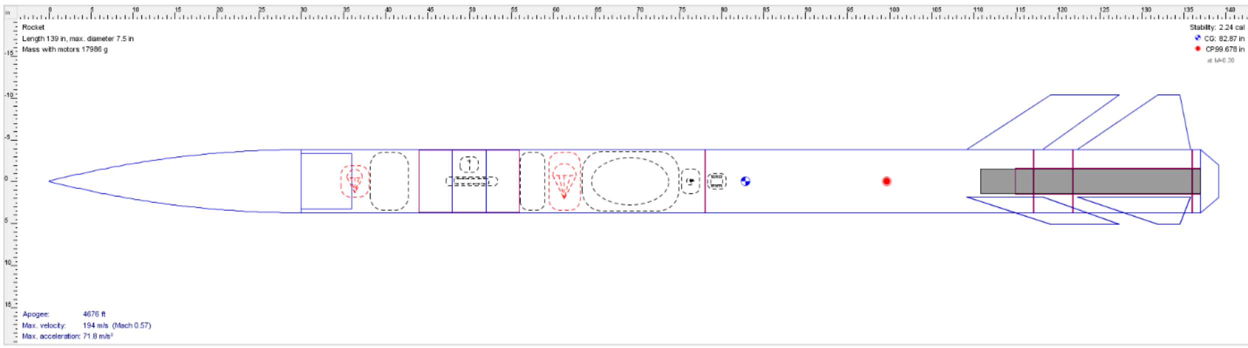


Figure 4.2a

The BlueWhale houses a L1170FJ-P motor. ARC possesses Aerotech 75/5120 motor hardware. Financially, it makes sense to purchase reloads that would fit this case to minimize motor costs and maximize funds available for test launches. Simulated launches in this configuration result in a predicted apogee of 4676 feet. This is right in the middle of the allowed apogee window, which gives a large enough safety margin to account for launch condition inconsistencies and weight changes in the construction phase. The thrust curve of the L1170 and the simulated flight are shown in Figures 4.2b and 4.2c, respectively.

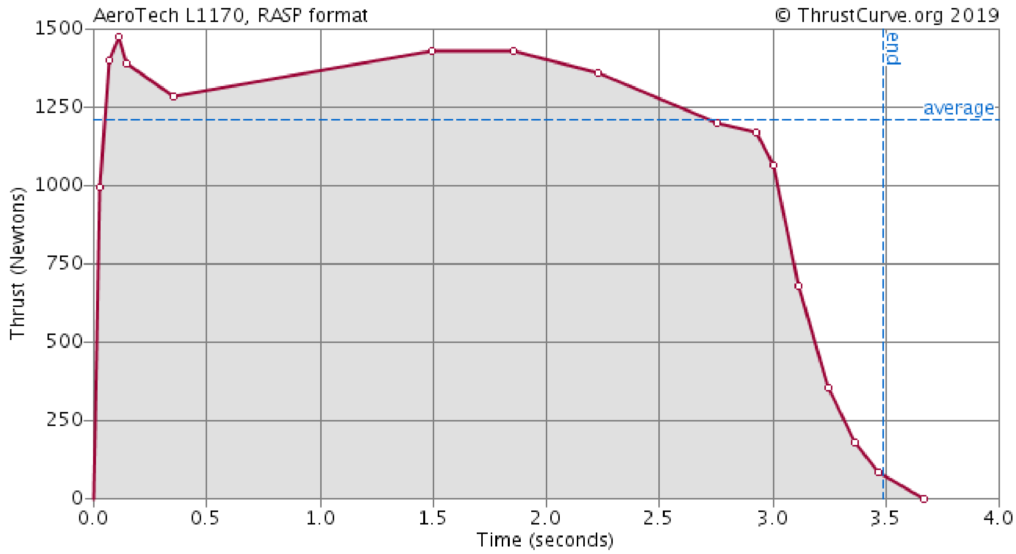


Figure 4.2b

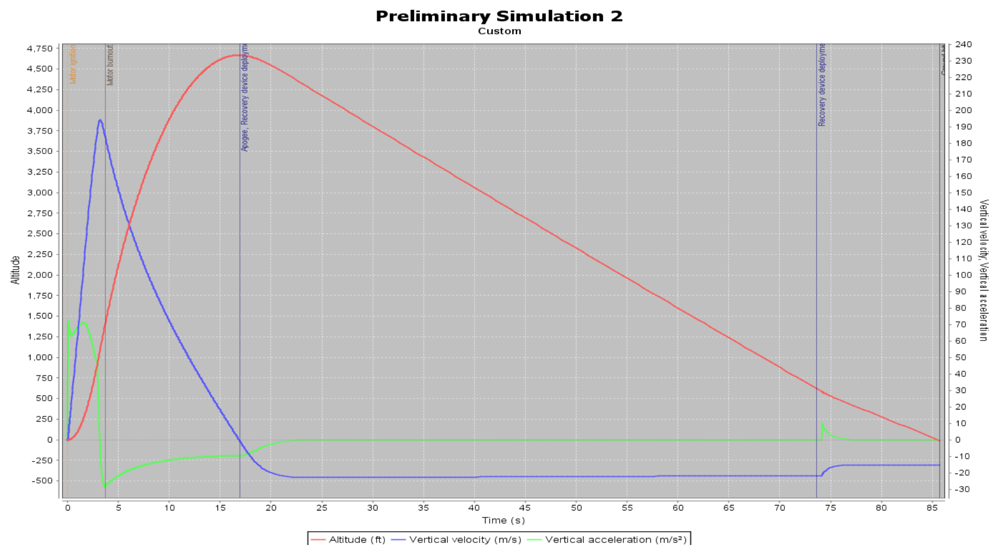


Figure 4.2c

4.2.1 Airframe Construction

The airframe will be constructed out of 72 inch and 48 inch precut sections of blue tube, 4 inch section used for the avionics bay, and 12 inches used for airframe coupling. All blue tube and black anodized aluminum for the boat tail trasistion section will be qcuired from Always

Ready Rocketry. The aft fins are precut fiberglass D-09 geometry fins, and the fore fins are of custom precut fiberglass all of which will be purchased from PublicMissiles. The blue tube motor mount will be sustained by 3 wooden centering rings. The ogive nose cone is polycarbonate acquried from LocPrecision. Carbon fiber shaving reinforced epoxy will be used to adhere and fillet all attached components. This includes centering rings, fins, bulkeads, and avionics/electronics bays. Figure 4.2.1 shows premilinary 3D model of the launch vehicle.

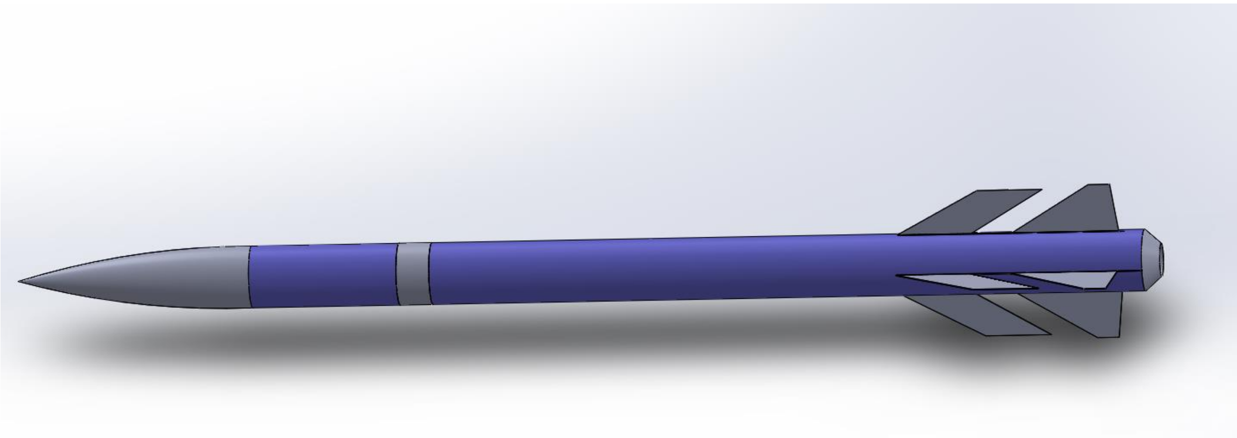


Figure 4.2.1

4.2.2 Recovery

The rocket is expected to reach apogee 4676 feet, and then the first stage will deploy. The desire to place the payload in the lower airframe caused some issues and recovery system staging. ARC addressed this challenge with the current arrangement of the drogue and main parachutes inverse of what most rocket designs. Previous ARC rockets have employed this reversed recovery with success. Recovery of the rocket occurs in a four-phase process, as shown in Figure 4.2.2. In phase A, a black powder charge will ignite which will then deploy the drogue parachute. This will slow the launch vehicle down until it reaches an altitude of 500 feet. For Phase B, a second charge will ignite, which will eject the electronics bay and the main parachute. The main parachute will have a harness point near the base of the rocket. This point will run half of the lines of the main parachute on the external body of the rocket, as shown by the redline in phase A and B. Phase C represents the ejection of the main parachute. This will cause the rocket to pivot parallel to the ground and will slowly descend the launch vehicle to the ground. The anchor point for the main parachute is located between two of the fins to ensure consistency of landing orientation, which will directly affect the deployment system. Phase D represents the mounted landing of the rocket in the correct orientation allowing for the easiest payload deployment.

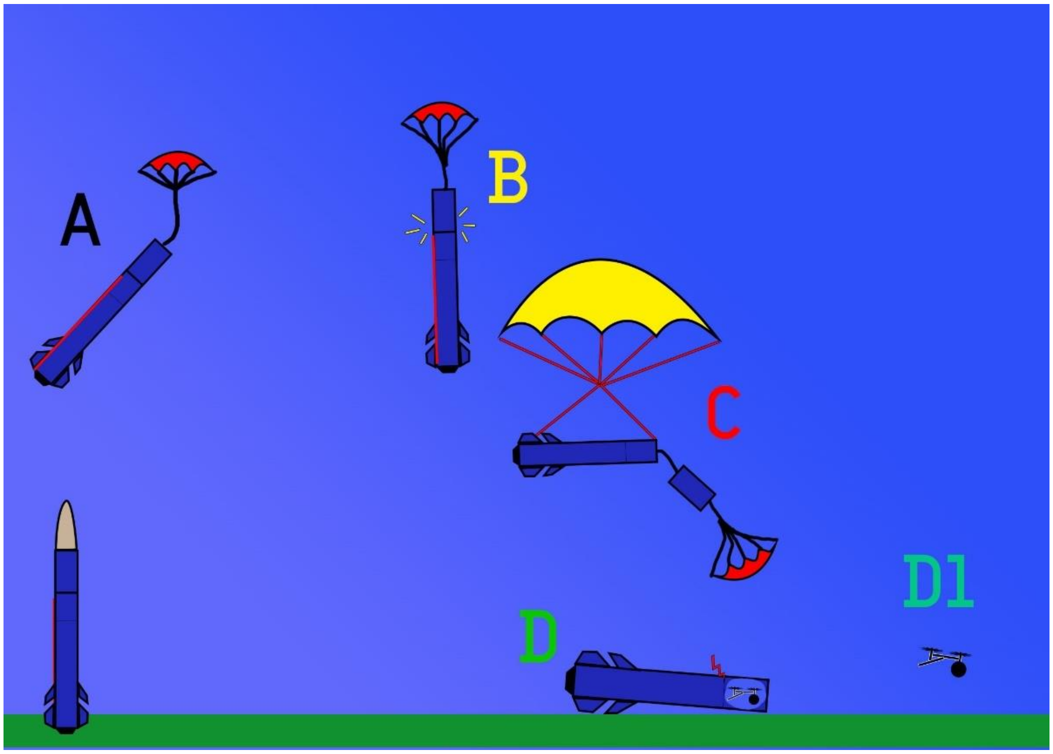


Figure 4.2.2

4.2.3 Deployment

The deployment of the payload will happen once the rocket lands in flight phase D. The landing orientation of the rocket is important due to the nature at which the ARMADLO vehicle exits the rocket body. The ARMADLO is held in place by a mechanical clamp during all flight phases, as required by the SLI handbook. The clamp is securely fastened to a bulkhead behind the drone and connected to main body telemetry and control. Once the rocket lands, release of the clamp will be signaled by the ground crew. The ARMADLO will deploy and exit the main body of the rocket. This is what is shown as phase D1 in Figure 4.2.2.

5 Student Engagement Plan

Student engagement has been a goal of the university and AIAA for many years. WMU invites students to visit the College of Engineering and Applied Sciences, and AIAA prepares activities to show the types of work aerospace engineers may do. Efforts to expand these events have been a point of focus for AIAA in the last two years. These expansion efforts have focused on events at high schools in the area and social media outreach, directed at high school students, about club activities. ARC's involvement in NASA SLI has reignited the club's outreach efforts. Described below are the details of ARC's current and planned outreach efforts.

5.1 Current Projects

5.1.1 Air Zoo Science Innovation Hall of Fame (SIHOF)

A local air and space museum, the Kalamazoo Air Zoo, annually hosts an event awarding local educators for their excellence in promoting the STEM field. WMU AIAA participates by strengthening and developing bonds with the present educators to extend their STEM program's reach. Through collaborations with these educators, AIAA and ARC have created multiple opportunities for student engagement events. ARC will continue to participate in this event to promote sustainable engagement with the community.

5.1.2 Western Michigan University Campus Day/STEM Summer Camp/etc.

Throughout the summer and academic year, WMU invites groups of students to tour the CEAS. The students will often visit labs and participate in educational activities. These activities vary in terms of group size and age; however, the activities are catered to the specific audience. WMU AIAA and ARC have a list of activities made for all age groups. For students in middle school or younger, DBF has the students build paper model airplanes and talk about aerodynamics, and ARC has stomp rocket models and discussions about the rocket's flight. For students in upper middle or high school, ARC has model rockets and simulations to talk about the dynamics of rocket flights. The WMU UAV lab has a full-scale research flight simulator that is often used to show how specific physical characteristics of flight vehicles affect the flight in real time.

5.2 Planned Projects

5.2.1 East Kentwood HS Aerospace Club

Two teachers of East Kentwood High School host an Aeronautics and Astronautics club. During a college fair at the school, ARC was approached by these teachers to host on-site activities for each of their clubs. WMU AIAA DBF and ARC have communicated interest in working with the two clubs. ARC activities will include small scale rocket launches, a rocketry basics course, and lessons on the history of rocketry and how rockets are used today. There are about 20 students per club, and ARC intends on extending the rocketry lessons beyond the student clubs.

5.2.2 WMU Rocket Day

ARC is in communication with the university about hosting a small-scale launch day on Parkview Campus. This event would be reminiscent of the East Kentwood activities ARC has planned but executed on the WMU campus. ARC owns launch stands and motors for smaller rocket launches and is acquiring additional materials to scale up the size of the event. In addition to the launch, ARC plans on setting up booths with various premade rocket set-ups of varying quality to teach the students which physical characteristics of the rocket affect flight the most. In the summer months, ARC students have worked closely with the CEAS Director of Outreach and Engagement to gauge interest in such an event.

5.3 Evaluation Criteria

Per SLI regulations, ARC must reach 200 students with outreach events. A count of students participating in each event, method of event (hands-on activity, lesson, or demonstration), and quality of event according to participants will be documented. These criteria are discussed in detail below.

5.3.1 Student Count

To ensure certainty of the number of students reached, ARC will have a sign-in sheet for WMU hosted activities and tours. This information will be checked against the records of the attending group's organizers. It will then again be referenced against the surveys filled out by the participants or schools. This ensures a triple-checked, accurate representation of the students who participated in the event. For on-site activities, a similar process will be used. However, ARC will forgo the use of a sign in sheet and directly acquire data from hosting school or participants.

5.3.2 Method of Event

The planned and current outreach events vary in nature. The lesson and teaching events yield a vastly different experience than that of a demonstration or build activity. ARC will state what type of event was used and the specific format in the final report of engagement. At this time, there are five distinct formats planned: in person launch or build events, WMU CEAS hosted STEM tours and activities, WMU CEAS hosted lessons and teaching events, on-site lessons and teaching, and digitally prepared educational material.

5.3.3 Quality of Event

It is a priority to present high quality educational events. The SET has a "quality over quantity" mindset when it comes to preparing outreach events. However, it is the participants opinion of the event that deems it effective or not. As such, the SET has created an online survey that will be distributed at the event to enable participants and the school administration to evaluate the SET's work. In addition to the recording of the student count and event method, participant feedback will be recorded. This will aid in the correction of SET shortcomings in the 2019-2020 SLI timeframe and help future ARC teams improve outreach efforts. The link to the survey can be found in the appendices.

6 Project Plan

6.1 Project Schedule

ARC has developed a project schedule with sub-teams in mind. SLI milestones, per the SLI handbook, were also taken into consideration when determining safe margins for task completion. The milestones ARC has chosen to be schedule cornerstones are listed in Table 6.1.

Project Milestone	Date
SLI Teams Acceptance	October 3rd (10/3)
Social Media Presence Established	October 24th (10/24)
Preliminary Design Review	November 1st (11/1)
Three Oaks Test Launch 1	December 18th (12/18)
Critical Design Review	January 10th (1/10)
Test Flight Deadline/Flight Readiness Review	March 2nd (3/2)
Post Launch Assessment Review	April 27th (4/27)

Table 6.1

A Gantt chart was created to align the individual construction and design goals with the rest of the sub-teams. This will allow ARC to monitor team progress toward the milestones. The Gantt charts are presented below, with the sub-team tasks color coded and the critical team tasks in green. Larger and more detailed charts are located in appendix 7.3.2

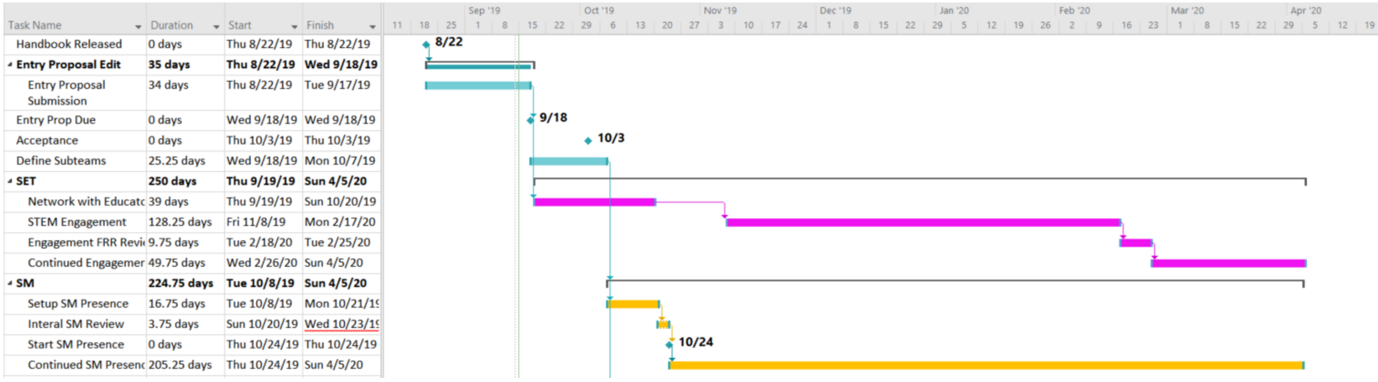


Figure 6.1a

Figure 6.1a shows the non-build teams and their pertinent tasks. SET and SM have ongoing tasks that are not affected by the various build milestones. As such, the team activities begin right away and continue to, and-beyond, launch week. The specific tasks are listed on the left.

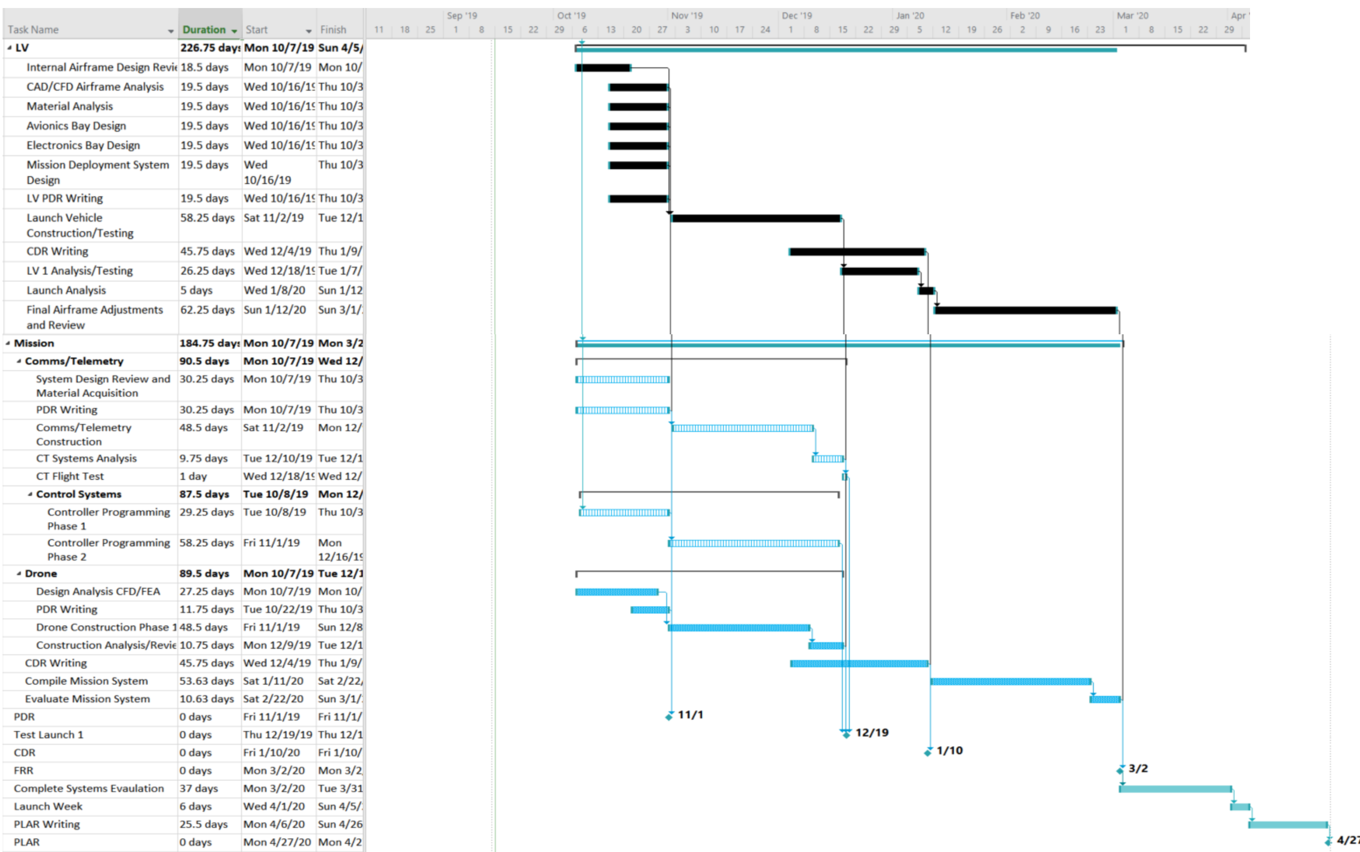


Figure 6.1b

Figure 6.1b shows the timeline for the Launch Vehicle and Mission sub-teams. Design review phase beings team tasks, contingent on acceptance. ARC experience and team evaluations puts this process at a month, ending before PDR. At PDR, launch vehicle, mission, and mission team divisions will have preliminary design paths determined. Testing and analysis will happen for the following months leading to the first test flight, which is currently scheduled for December 18th.

6.2 Project Budget

WMU AIAA ARC Expense Overview	
Team	Budget
Student Engagement Team	$384.65
Social Media Team	N/A
Safety Team	$250.00
Mission Team	$775.09
Launch Vehicle Team	$1,719.66
Team Travel	$1,045.00
Total:	$4,174.40

Table 6.2

Table 6.2 above illustrates an overview of ARC's projected expenses broken down by the five different subgroups, and team travel. For a detailed itemized breakdown reference appendix 7.1. The following will be a brief description of expenses.

SET: SET's budget goes directly into the purchase of materials needed to complete the many STEM and rocketry activities planned. An example would be the purchase of "Stomp Rockets" an easy to use pressure-based launch systems. These "Stomp Rockets" will be used to demonstrate and explain rocket stability, as well as basic pressure to force conversions.

SMT: SMT does not have any expected expenses currently. All social media tools ARC expects to use are free.

ST: ST's budget will be used to pay for the many PPE ARC requires to operate safely. Portions of ST's budget may also be used for specialized safety training such as a Red Cross first aid course, or CPR course. Training like this would help ARC ensure the safety of all members.

MT: MT's budget will pay for any construction needs of the mission vehicle. These expenses will be a mixture of raw material purchase, and any manufacturing that is not possible in ARC's many available lab spaces.

LVT: LVT's budget accounts for all expenses needed for both the construction and testing of the launch vehicle. As a result of both responsibilities LVT's budget is much larger than any other subgroups. The primary factor is the cost of multiple rocket motors for the test launches projected.

Travel: Travel expenses represent all costs projected for both team travel to competition, and local events.

6.3 Project Funding

The primary source of ARC's funding is through the WMU CEAS Excellence Fund. The Excellence Fund is awarded throughout WMU CEAS student organizations based on need and STEM outreach completed in the name of the university. AIAA has been applying for and receiving this aid for the past 21 years. ARC, as a part of WMU AIAA, receives part of this aid. Based on past awards and AIAA's request for funding (2019-2020), it is expected for ARC to receive an award of $3,500. Along with the funding from the CEAS, ARC also fundraises. In years past this has resulted in at least $250.00 in additional funding. ARC is also in talks with local companies in the aerospace industry for additional sponsorships. One specifically is Jedco Aerospace, a company in which a few of ARC's members have interned. ARC will also continue to explore sponsorship opportunities throughout the coming months. As a result, the team expects to gain an additional $500.00 from industry sponsorship. With all award amounts, fundraising, and sponsorships taken into consideration ARC expects to have at least $4,250.00 in available funds. These funds are just $75.00 over projected budget. A breakdown is shown below in Table 6.3. One additional source of funding ARC is currently applying for is the Michigan Space Grant Consortium, a grant available to university students participating in "Hands on NASA – oriented experiences for students". This is not currently in the funding breakdown because ARC has never applied for this grant, and the amount that could be awarded varies. Possible awards range from $100.00 to $5000.00.

Funding Breakdown		
Source	Amount	
CEAS Excellence Fund	$	3,500.00
Industry Sponsorship	$	500.00
Team Fundraising	$	250.00
Total:	$	4,250.00
Project Costs:	$	4,174.40
Difference:	$	75.60

Table 6.3

6.4 ARC Sustainability

It is important to ARC that it maintains a consistent number of members. However, ARC sustainability is not only a function of its size. Member and lead competence, student interest, and public awareness are all valuable to continuing ARC success. Therefore, placing team-wide priority on these values will allow ARC to exist into the future.

6.4.1 Member Competence

Knowledge of rocketry and the various payload systems is required to build successful missions regardless of the competition in which the team decides to participate. To this end, current team leaders perform weekly lessons over the information pertaining to each sub-team. For example, the mission team has the ARC experts in control systems give lessons on system modeling and control loops. ARC's payload design and construction lead has flight controller and drone lessons at regular intervals. The launch vehicle team has in-depth lessons created on rocket stability and materials selection. This has been an important element of team stability in the last two years of ARC's existence. Often the knowledge that can be applied to the team is taught in upper level classes. Because of this, it was important that pertinent knowledge is passed down to the members that will sustain the team. In terms of new member competence, the social media team leads help in the HPR certification of new members. This helps younger members to learn the basics of HPR which will eventually be applied to ARC.

6.4.2 Student Interest

While member competence is important, that competence is rendered useless if ARC does not sustain an adequate number of members. Efforts to maintain student interest in ARC is a requirement for the team's existence. WMU hosts multiple events to advertise the various student organizations on campus. Multiple events, including Bronco Bash, CEAS Passport Day, and Involvement Zone, incentivize current WMU students to explore student organizations. While organization participation is voluntary, ARC, and the WMU AIAA as a whole, has enthusiastically participated in these events. The information provided at these events yields most of the new member recruitment. This has always sustained ARC. In addition to these events, ARC has extended recruitment efforts outside of WMU. In the last year, ARC has participated in high school outreach events to promote STEM careers. Such activities double as advertisements for HPR and the activities of ARC. Targeting prospective and incoming students as well as current students allows ARC two potential streams of incoming members.

6.4.3 Public Awareness

As previously mentioned, high school outreach activities have become a regular occurrence for ARC. Through these activities, local schools have become aware of ARC's efforts in rocketry. Currently, ARC exists as one of two organizations in West Michigan that are active in HPR. The only other is the Michiana Rocketry TRA/NAR group, which works closely with ARC. Local schools, educators, and even the general public are now aware of HPR on a scale that has not been seen in recent years. This increased publicity is due, in part, to WMU's ability to advertise to a large area. However, as previously mentioned, ARC's outreach activities have played a role as well.

7 Appendices

7.1 ARC Detailed Budget

Student Engagement Team					
Name	Notes:	Vendor	Price	# Per	Total
Avian Rocket 24pc	Bulk rocket pack for outreach and community events	Apogee	$195.56	1	$195.56
A-8 3 Rocket Motors 24pc	Motors for outreach rockets	Apogee	$80.11	1	$80.11
Sky Complete Launch System	Launch system for outreach rockets	Apogee	$26.98	1	$26.98
Stomp Rocket Kits	Stop Rockets to teach rocket stability	Amazon	$21.00	2	$42.00
Estimated Shipping Costs	Cost for shipping, and hazard shipping on components	N/A	$40.00	1	$40.00
				Student Engagement Team Total:	$384.65

Table 7.1a

Social Media Team					
Name	Notes:	Vendor	Price	# Per	Total
N/A	N/A	N/A	N/A	N/A	N/A
				Social Media Team Total:	N/A

Table 7.1b

Team Travel					
Name	Notes:	Vendor	Price	# Per	Total
Travel to Competition	Gas, and Tolls for 2 Cars	N/A	$150.00	2	$300.00
Competition Lodging	Air BNB for Nights	Air BNB	$135.00	5	$675.00
Travel to Test Launch	Gas for 2 Test Launches	N/A	$10.00	2	$20.00
Travel to Engagement Events	Travel to all of the engagements around the area	N/A	$5.00	10	$50.00
				Team Travel Total:	$1,045.00

Table 7.1c

Launch Vehicle Team					
Name	Notes:	Vendor	Price	# Per	Total
Altimeter	Easy Mini	Apogee	$92.00	2	$184.00
Airframe	7.5 x 72 Blue Tube	ARR	$162.00	1	$162.00
Rail Buttons	15 x 15 Rail Aerodynamic (2pc)	Apogee	$11.17	1	$11.17
Tail Cone	Tail Cone for 75mm w/ Retainer	ARR	$51.00	1	$51.00
Motor Tube	G12 Fiberglass 75mm	Madcow	$27.00	1	$27.00
Centering Rings	G10 Fiberglass 7.5 to 75mm (2 per)	Apogee	$26.00	2	$52.00
Nose Cone	LOC Plastic nose cone	Madcow	$87.95	1	$87.95
ARR 3 Fin Slots	in 7.5 tube	ARR	$15.00	1	$15.00
Fins	Public Missiles Fiberglass Fin	Madcow	$20.19	3	$60.57
Coupler	7.5 ARR Coupler	ARR	$26.96	1	$26.96
Motor	L1170 Black Max	Wildman	$279.99	3	$839.97
Bulk Head Disk	Fiberglass Bulk Heads	Apogee	$13.01	4	$52.04
Other Electronics, Misc.	etc..	N/A	$150.00	1	$150.00
				Launch Team Total:	$1,719.66

Table 7.1d

Mission Team					
Name	Notes:	Vendor	Price	# Per	Total
Aluminum Sheet	H14 AL 12 x 12 x .125	Amazon	$18.25	1	$18.25
Carbon Fiber Plate	3 K Carbon Fiber 7.87 x 11.811 x .118	Amazon	$32.99	1	$32.99
Lexan Sheet	Polycarbonate 12 x 12 x .118	Amazon	$8.85	1	$8.85
Drive Motors	Motors controlling on ground movement	TBD	$25.00	2	$50.00
Tank Tracks	Tracks used for ground movement	TBD	$30.00	2	$60.00
Speed controller	Controller for ground movement	TBD	$20.00	2	$40.00
Drivetrain	Drivetrain for ground movement	TBD	$10.00	2	$20.00
Flight Motors	Motors for aerial movement	TBD	$20.00	4	$80.00
Propellers	Propellers for aerial movement	TBD	$5.00	4	$20.00
Stand-offs	Stand off for creating the structure of the rover	TBD	$15.00	1	$15.00
Flight Controller	Controller for aerial movement	TBD	$20.00	1	$20.00
Logic Board	Programing rover systems	TBD	$50.00	1	$50.00
Receiver	Receives Signal from control	TBD	$10.00	1	$10.00
FPV System	Camera, Receiver, Transmitter	TBD	$35.00	1	$35.00
Machining	Machining of Carbon & AL	TBD	$200.00	1	$200.00
Maintenance and Repair	Repair needs of Craft	TBD	$40.00	1	$40.00
Msc..	Nuts, Bolts, Different Consumables	TBD	$75.00	1	$75.00
				Mission Team Total:	$775.09

Table 7.1e

7.2 Safety Documents

College of Engineering and Applied Sciences

Western Michigan University

AIAA

SHAPING THE FUTURE OF AEROSPACE

ARC SAFETY MANUAL

2019 - 2020

TABLE OF CONTENTS

1. Preface

This safety manual has been created in order to ensure a safe working environment for all rocketry team members and compliance with regulations for the design and operation of high-powered rockets. The protocols presented in this manual are derived from several regulations that govern the design, build, and flight of high-powered rockets. This manual is intended to group the most important information for all members to know in one place and is NOT a comprehensive document. All members will have access to the regulations in full, and each member is responsible for reviewing them. While the Safety Officer and team leadership will monitor the design, construction, and operation of the vehicle, the ultimate responsibility for safety lies with each team member. Therefore, all members should become familiar with the contents of this manual, the safety data sheets for all hazardous materials, and all supplemental regulations provided herein. In addition, all members must sign a safety contract acknowledging their familiarity with and willingness to abide by all safety protocols presented in this manual and in supplemental sources.

1.1 Working Definitions

Per the standards established by the Occupational Safety and Health Administration, the following terminology will be utilized for instructions regarding hazardous situations within this manual and in future materials (handouts, briefings, etc.):

- Danger: Signifies severe risk of death/serious injury if not heeded.
- Warning: Signifies moderate risk of death/serious injury if not heeded.
- Caution: Signifies a risk of minor/moderate injury if not heeded.

In addition, the following abbreviations will be utilized:

- AMA: Academy of Model Aeronautics
- ARC: Advanced Rocketry Club (the rocketry team)
- ATC: Air Traffic Control
- CEAS: College of Engineering and Applied Sciences
- FAA: Federal Aviation Administration
- HPR: High-Powered Rocket/High-Powered Rocketry
- MSDS: Material Safety Data Sheet

- NAR: National Association of Rocketry
- NASA: National Aeronautics and Space Administration
- NFPA: National Fire Prevention Association
- LV: Launch Vehicle
- PPE: Personal Protective Equipment
- SLI: Student Launch Initiative
- SPL: Student Projects Lab
- TRA: Tripoli Rocketry Association
- UAV: Unmanned Aerial Vehicle
- WMU: Western Michigan University

1.2. Safety Equipment Furnishing

The following safety equipment is furnished by WMU:

- Fire Suppression Systems
- First Aid Kit

The following safety equipment is furnished by AIAA using allotted funds:

- Safety Glasses
- Gloves
- Dust Masks
- High-Strength Soaps

All members are responsible for being aware of the locations of these items and using them as required.

2. Safety Protocols

To ensure safety during the construction, transport, and flight of the LV, all team members will observe the following safety protocols.

2.1. Lab Protocols

The following protocols are specific to construction of the launch vehicle, which will occur in the UAV lab (F-209) and SPL (G-112) at the Parkview campus. Some components may also be manufactured at the WMU Makerspace in Waldo Library.

Most of these procedures are derived from the contents of CEAS's SPL Safety and Basic User Guide. All members working in the SPL must abide by the entirety of the Safety and Basic User Guide.

1. Safety goggles must be worn in the lab whenever build work is occurring.
2. All shoes worn in the lab must have a closed toe.
3. Ties, loose clothes, long sleeves, jewelry, and gloves are not to be worn near moving machinery. Long hair must be tied back around moving machinery. In addition, rags must be kept away from moving machinery.
4. Gloves must be worn when working with hot objects, glass, sharp-edged items, or other hazardous materials.
5. When removing gloves, ensure that the glove exterior does not contact your skin.
6. Know the location of the exit, first aid kit, safety procedures, MSDSs, safety goggles, dust masks, and gloves in the lab. The nearest fire extinguisher is located in the hallway to the left of the lab as you exit.
7. No running or horseplay.
8. Keep sharp tools pointed away from your body.
9. Regularly clean Exacto blades and other sharp instruments. This minimizes the risk of infection if you cut yourself.
10. Thoroughly wash your hands for at least 20 seconds before beginning work, after handling hazardous materials or performing large sanding jobs, at regular intervals while working, and before you leave.
11. Food and drink must be kept well away from all active build areas.
12. Do NOT use fire extinguisher on a type of fire that it is not rated for.
13. Do not stand on tables or chairs. Only stand on stepstools or ladders.
14. Do not fly UAVs in the lab while build work is occurring.
15. Remain clear of the wind tunnel and propeller test device while DBF is conducting testing.

16. Keep body parts clear of the point of operation of all machinery. (e.g. keep your fingers away from the drill bit)

17. Always clean up after yourself. A disorganized or dirty workspace can lead to trip hazards, injury from a sharp object, etc.

18. Do not operate any machinery or work with any material you are unfamiliar with or have not been given permission to use.

19. Routinely check power cords to ensure they have not frayed or deteriorated.

20. Follow all necessary precautions and refer to the MSDS when working with hazardous materials.

21. Heavy sanding and painting must be conducted in well-ventilated areas. Use a dust mask for additional protection.

22. Do not directly use your hands to remove shavings from the work area. Use a brush or a small blast of air.

23. Do NOT attempt to remove foreign objects from the body or eyes. Await treatment by authorized medical personnel.

24. If chemicals contact the eye, wash in an open flow of water for at least 15 minutes and seek treatment. An emergency eye wash station is in the SPL.

25. In case of significant contact with a chemical requiring use of a shower, proceed to the SPL and use the chemical shower. Disrobe in part or in whole if your clothes are contaminated. Short-term embarrassment is better than severe injury.

26. Do not work if you are in a hurry or excessively tired. This may result in careless mistakes that cause injury.

27. ALWAYS ASK if you are unsure how to proceed.

28. Obey ALL posted signs, warnings, and special instructions.

29. If you see or suspect a safety issue, whether in design, construction, or procedure, BRING IT FORWARD. It is better to be safe than sorry.

IN CASE OF LIFE-THREATENING OR SERIOUS EMERGENCY:

- Dial 911 and WMU Public Safety (269-387-5555)

- Request an ambulance and describe location in detail
- Stay on the line and describe the situation
- Guide emergency personnel to the victim upon arrival
- Notify appropriate academic department office

IN CASE OF EMERGENCY THAT MAY REQUIRE PROFESSIONAL CARE:

- Contact a local health center or hospital

IN CASE OF MINOR EMERGENCY, USE FIRST AID KIT

2.2. Motor Handling

The competition vehicle for this academic year utilizes a motor that lies within the criteria for a Level 2 HPR certification. To ensure compliance with NFPA 1127 requirements and in the interest of general team safety, only team members with a Level 2 certification or above shall engage in the purchase, loading/reloading, installation, handling, and arming of the LV's motor. The only other parties who shall handle the motor and its related elements are authorized personnel at the launch sites.

2.3. Launch Protocols

The following launch protocols will be followed by all team members. Several protocols are adopted from other high-powered rocketry codes which the team must abide by. This is a general list of protocols and is not comprehensive of all safety codes.

1. Members shall abide by ALL instructions and determinations of the Range Safety Officer at the launch site up to and including denial of launch.

2. Only members with Level 2 certification or above (or other authorized launch site personnel) shall conduct flights and handle the motor.

3. The team mentor is ultimately responsible for the safe flight and recovery of the LV.

4. Fire suppression devices and first aid kits shall be kept nearby during launch.

5. The LV shall be launched such that it does not endanger those on the ground, surrounding facilities, or air traffic. Appropriate distance from surrounding areas shall be maintained.

6. The LV shall not be launched into clouds, when visibility is obscured at ground level or flight altitudes, between sunset and sunrise, within 10

miles of a reported thunderstorm, in the presence of lightning, or when wind speeds exceed 20 mph.

7. The LV shall not be recovered from trees, power lines, or other hazardous areas; this is only to be done by authorized launch site personnel.

8. An audible 5-second countdown will be used when launching, and a means to warn those on the ground will be available in the event of an anomaly.

9. The launch area shall be clear of all but essential personnel (safety and those required to safely arm/disarm the LV) when the LV is armed.

10. The LV shall not be armed unless it is in proper launch orientation.

11. In the event of a misfire, the ignition system shall be inhibited, and at least 60 seconds shall elapse prior to the next ignition attempt.

12. There shall be NO attempts to modify the motor in ANY way.

13. The LV shall not be launched if it has not been proven to be stable.

14. The LV shall not be launched within 5 nautical miles of an airport boundary or in controlled airspace without prior FAA authorization.

15. Members shall NOT participate in launch activities while under the influence of substances that affect judgment, coordination, or balance.

16. Members shall NOT smoke near the LV, as this poses a fire hazard.

17. Unless the launch site assumes this responsibility, the ATC facility nearest to the launch site must receive duration and location information regarding the flight between 3 days and 24 hours of any intended flight of a class 2 HPR.

18. An FAA waiver must be obtained prior to operation of a class 2 HPV. Detailed information about the LV must be submitted to the FAA at least 45 days prior to launch.

19. The LV shall NOT be launched if any member suspects unsafe conditions. These include design flaws, construction errors, procedural errors, or protocol violations. BRING SAFETY CONCERNS FORWARD AS THEY ARISE.

3. Hazardous Materials

The team has identified several materials that may pose a threat to personal safety during the construction process. In addition to the basic summaries presented here, all team members are responsible for reviewing the MSDS of each material prior to working with it and abiding by the precautions presented therein.

General Precautions:

1. Keep all hazardous materials away from heat and open flames.
2. No smoking near hazardous materials.
3. Tightly seal container when not in use.
4. Take precautions to avoid static discharge.
5. Avoid breathing fumes or dust from any chemicals.
6. Wear gloves, safety glasses, and dust masks while handling hazardous materials.
7. Store all materials in a well-ventilated, dry, and cool location.
8. Dispose of hazardous materials and their containers through approved waste disposal plants.
9. Ensure all materials are well out of reach of children during visits to the lab.
10. Use extinguishing methods appropriate for the type of fire (traditional combustibles, flammable liquids/vapors, flammable metals, and electrical fires).

IF MATERIAL IS INHALED: Move to source of fresh air, provide artificial respiration if needed, and consult Poison Control or a physician if feeling unwell.

IF MATERIAL IS ON SKIN/ON CLOTHES/IN HAIR: Rinse with lots of water, remove any contaminated clothing articles, and begin washing with lots of soap. In the event of extensive contact, proceed to the SPL and use the chemical shower.

IF MATERIAL IS IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses if possible and continue rinsing. In the event of extensive contact, proceed to the SPL and use the emergency eye wash station.

IF MATERIAL IS SWALLOWED: Do not induce vomiting. Rinse mouth with water and contact Poison Control or a physician.

3.1. Acetone

Acetone is a fluid that will be used during the build process to prepare rocket components for adhesion.

DANGER: Acetone is highly FLAMMABLE in both liquid and vapor form. If handled improperly, acetone causes severe eye irritation and may cause dizziness or drowsiness if handled improperly.

3.2. Ammonium Perchlorate

Ammonium perchlorate is an oxidizing solid that will be used as the LV's propellant. **ONLY MEMBERS WITH A LEVEL 2 CERTIFICATION OR HIGHER SHALL HANDLE THIS SUBSTANCE.**

DANGER: Ammonium perchlorate poses a risk of FIRE or EXPLOSION. Improper handling can result in severe eye irritation. Prolonged or repeated exposure may cause permanent organ damage.

3.3. Body Filler

Body filler (Bondo) is a substance that will be used to smooth sharp edges on the rocket body to improve aerodynamics.

DANGER: Bondo is highly FLAMMIBLE in both liquid and vapor forms. Improper handling can result in severe eye irritation. Prolonged or repeated exposure will lead to damage of the respiratory systems and sensory organs, and it may lead to liver damage. Bondo is a suspected CARCINOGEN, and it may impact fertility or the safety of unborn children.

3.4. Cardboard

Cardboard is a material created from plant fibers that will be used in the construction of the rocket due to its strength and low weight. While it poses no appreciable safety hazard in its shipped form, processing and handling can generate hazards due to a decrease in particle size.

WARNING: Cardboard can generate combustible dust concentrations in the air if small particles are generated during processing and handling. These dust particles may also aggravate pre-existing eye, skin, or respiratory conditions.

3.5. Enamel Paint

Enamel-based paint will be used to paint the LV to protect the body and add aesthetic flair.

DANGER: Enamel paint is a highly FLAMMABLE liquid and has been classified as a possible CARCINOGEN. The fumes are harmful if inhaled, and overexposure can lead to respiratory tract irritation and permanent nervous system damage.

3.6. Epoxies

Two-part epoxies of varying curing duration will be used to permanently bond parts of the rocket.

WARNING: Epoxy may cause skin irritation and severe eye irritation if handled improperly. Prolonged skin contact may result in BURNS.

3.7. Epoxy Accelerator

To speed the curing process of some epoxies, a spray-on accelerator will be applied to newly-bonded areas of the rocket.

WARNING: Epoxy accelerator is a FLAMMABLE liquid. Prolonged exposure to fumes may result in headaches, dizziness, or drowsiness.

3.8. Ferrosoferric Oxide

Ferrosoferric oxide, better known as black powder, is a powder that will be used in the LV's ejection charges and parachute deployment systems.

CAUTION: Ferrosoferric oxide may cause mild skin or eye irritation if handled improperly.

3.9. Fiberglass

Fiberglass is a strong but lightweight material that will be used in the construction of the rocket body.

CAUTION: Fiberglass splinters and mild skin irritation may result from handling fiberglass prior to sanding. In addition, fiberglass dust from sanding poses a respiratory hazard.

3.10. Igniters

To ignite the LV's SRV at launch, electric igniters will be utilized. **ONLY MEMBERS WITH A LEVEL 2 CERTIFICATION OR HIGHER SHALL HANDLE THIS EQUIPMENT.**

DANGER: Igniters are a FIRE/PROJECTION HAZARD and may cause an EXPLOSION. Thermal BURNS to the skin and eyes can result from accidental ignition.

3.11. Lead Solder

To join metal parts of the LV, particularly the electrical components, lead solder will be used.

DANGER: Lead is a suspected CARCINOGEN and is acutely TOXIC if ingested or inhaled. Lead may impact fertility and unborn children, and organ damage may result from prolonged or repeated exposure.

3.12. Solder Flux Paste

To prepare metal surfaces for soldering, a water-soluble flux paste will be used.

DANGER: Solder flux can cause SEVERE BURNS upon contact or ingestion, and severe eye damage up to and including BLINDNESS may result from contact with the eye.

3.13. Thread Locker

To ensure bolts stay firmly in position, thread lockers of varying strengths will be applied during assembly.

WARNING: Thread lockers may cause skin and eye irritation if improperly handled. Respiratory tract irritation may result from fume inhalation. Allergic skin reactions may occur in some cases.

4. Other Applicable Regulations

In addition to the procedures outlined in this manual, all members are responsible for reviewing and abiding by the following regulations:

4.1. SLI Handbook

This document outlines the requirements for NASA's SLI competition, including design considerations, mission objectives, project timelines, and safety restrictions. It is highly recommended that all members review this document to ensure a smooth design process.

4.2. NAR/TRA HPR Safety Codes

Both the NAR and TRA have created safety codes which govern all HPR launches, including certification flights, competitions like SLI, and other launch events. All members should review these documents to ensure safe launches throughout the season.

4.3. NFPA 1127

This section of the National Fire Prevention Association's codes pertains to the safe operation of HPRs and dictates who shall handle HPR motors. To adhere to this code, only members with a level 2 certification or higher will handle the LV's motor.

4.4. CFR Title 27, Section 55

This section of the Code of Federal Regulations regulates the sale, licensing, storage, and documentation of operations of explosive devices such as the LV's motor. Members who are certified for level 2 HPR are responsible for following these regulations when purchasing and handling the motor.

4.5. AMA Safety Handbook

This handbook, while primarily applicable to RC aircraft, transfers well to model rocketry, particularly in the areas of ensuring spectator safety. In addition, the handbook applies to the payload when operating in its quadcopter configuration.

4.6. FAA Regulations

CRF Title 14, Section 101, Subpart C pertains to the safe operation of amateur rockets and prescribes several restrictions on the flight of Class 2 HPRs. Requirements for notifying the FAA and Air Traffic Control about launches are stipulated within. In addition, the payload will be subject to Section 101, Subpart E and Section 107 while operating in quadcopter configuration.

5. Safety Contract

To comply with SLI requirements and ensure team safety, all members will be required to sign a safety contract. All members will confirm that they have read, understand, and will abide by this manual and other applicable regulations. They will agree to comply with all determinations made by the Range Safety Officer at the launch site and SLI personnel. In addition, they will acknowledge that, while the Safety Officer and team leadership will set standards for team safety, the ultimate responsibility for safety lies with each member.

6. Where to Find Regulations and MSDSs

This manual, applicable regulations, and MSDSs will be made available on the team's Google Drive for web access, download, and printing. In addition, the Safety Officer will maintain a physical copy of all key regulations and MSDSs in the UAV lab.

7. Essential Emergency Contact Information

The following is a list of contact information in case of emergency.

IN CASE OF LIFE-THREATENING EMERGENCY:

- **911**
- **WMU DPS: (269) 387-5555**

For less severe emergencies:

Kalamazoo DPS: (269) 337-8994

Sindecuse Health Center: On WMU's main campus
(269) 387-3287
Hours: M-W, F 8am-5pm; R 9am-5pm

Bronson Methodist Hospital: 601 John St
(269) 341-7654
Hours: 24/7

Borgess Medical Center: 1521 Gull Road
(269) 266-7000
Hours: 24/7

GPS LOCATION OF PARKVIEW CAMPUS:
College of Engineering and Applied Sciences
4601 Campus Drive
Kalamazoo, MI 49008

7.2.1 ARC Team Safety Contract

2019-2020 ADVANCED ROCKETRY CLUB

MEMBER SAFETY CONTRACT

To ensure compliance with all regulations and to promote an atmosphere of safety in the ARC, all members must sign and abide by the following safety contract.

Read the following statements carefully and initial in the spaces provided to indicate your understanding of the statements and willingness to adhere to them.

- I have read and understand all the lab safety and hazardous material protocols outlined in the safety manual, and I agree to abide by them. I also understand that I must adhere to the WMU SPL Safety and Basic User Guide when completing work in the SPL.

  INITIAL: ____________

- I understand that only members who are certified by the NAR or TRA to fly Level 2 HPRs are authorized by the NFPA to purchase, handle, install, load, arm, ignite, or work with the motor in any way. If I am a member with a Level 2 certification, I understand that I am responsible for adhering to CFR Title 27, Section 55 (Commerce in Explosives) while purchasing and working with the motor.

  INITIAL: ____________

- I understand that I will be working with hazardous materials during the vehicle construction process and will follow the associated safety protocols. I am aware of the locations of all PPEs (safety glasses, dust masks, gloves, etc.), the first aid kit, and the nearest fire extinguisher. I will use appropriate PPEs when working with these materials. I am aware of the location of the MSDSs in the lab and will review them prior to beginning work. I know where to find critical contact information in case of an emergency.

  INITIAL: ____________

- I have reviewed and understand the NASA SLI rules for this competitive season. I understand that the safety manual is derived from other regulations, and I must follow those regulations in their entirety. I know where to access the key regulations (NFPA-1127, CFR Title 14 Sec 101 Subpart C, and the HPR safety codes) and understand that it is my responsibility to review these regulations.

INITIAL: ____________

- I have reviewed and understand the launch safety protocols provided in the safety manual, and I agree to follow them. I understand that these procedures are derived from other regulations, and I must follow those regulations in their entirety.

INITIAL: ____________

- I understand that range safety inspections will be completed on the LV prior to launch, and the team must comply with the determination of the inspection or risk removal from the competition.

INITIAL: ____________

- I understand that the SLI Range Safety Officer has the final say on all rocket safety issues and therefore has the right to deny launch of the LV for safety reasons.

INITIAL: ____________

- I understand that the team mentor is ultimately responsible for the safe flight and recovery of the LV and payload and will therefore review the design and build of the vehicle. I understand that the vehicle will not be flown unless the team mentor is satisfied that it meets all applicable safety regulations.

INITIAL: ____________

- I understand that if the team fails to comply with all safety regulations, the vehicle will not be permitted to fly.

INITIAL: ____________

I, _____________________________, agree to abide by all statements presented in this contract. I understand that, while the team mentors and Safety Officer will oversee operations to ensure regulations are followed, ***I am ultimately responsible for my own safety.***

Signature: ___________________________________ Date:___________________

7.2.2 Safety Document Depositories

Safety Manual Online Link:
https://drive.google.com/file/d/1Zt5k4PRTlfWy40BpVwl7amvBmYA3EDKX/view?usp=sharing

ARC MSDS Depository:

https://drive.google.com/drive/folders/1dkoXxSIiXZnXP4WbAluzCkUe7_upWYs-?usp=sharing

ARC Relevant Regulations:

https://drive.google.com/drive/folders/1dHdO_1cozUaCODgA0UqbKI61qEjT7cD8?usp=sharing

7.3 Additional Appendices

7.3.1 ARC Outreach Student Survey

9/16/2019 Western Michigan University ARC Student Survey

Western Michigan University ARC Student Survey

Please fill out the questions to the best of your ability.

* Required

1. **Name ***

2. **School ***

3. **Grade ***
   Mark only one oval.
   - ⬭ Freshman
   - ⬭ Sophomore
   - ⬭ Junior
   - ⬭ Senior
   - ⬭ Other: ____________

4. **How interested where you in a STEM field before the activity? ***
   Mark only one oval.

	1	2	3	4	5	
Greatly	⬭	⬭	⬭	⬭	⬭	Not At All

5. **How interested are you in a STEM field after the activity? ***
   Mark only one oval.

	1	2	3	4	5	
Greatly	⬭	⬭	⬭	⬭	⬭	Not At All

6. **How much do you feel you have learned? ***
   Mark only one oval.

	1	2	3	4	5	
A Large Amount	⬭	⬭	⬭	⬭	⬭	Very Little

https://docs.google.com/forms/d/1eUy8J_YKJPHz5fsKxdgreW8s9l-LmyfLtD80td-nucg/edit 1/2

7. **Were you entertained throughout the activity?** *
Mark only one oval.

	1	2	3	4	5	
Entertained The Whole Time	◯	◯	◯	◯	◯	Bored Very Often

8. **Was the activity fun and interesting?** *
Mark only one oval.

	1	2	3	4	5	
Very Fun and Intersting	◯	◯	◯	◯	◯	Not Fun or Intresting

9. **Would you like to have WMU ARC back in the future?** *
Mark only one oval.

	1	2	3	4	5	
Yes absolutely	◯	◯	◯	◯	◯	No not at all

10. **Comments or suggestions?**

____

____

____

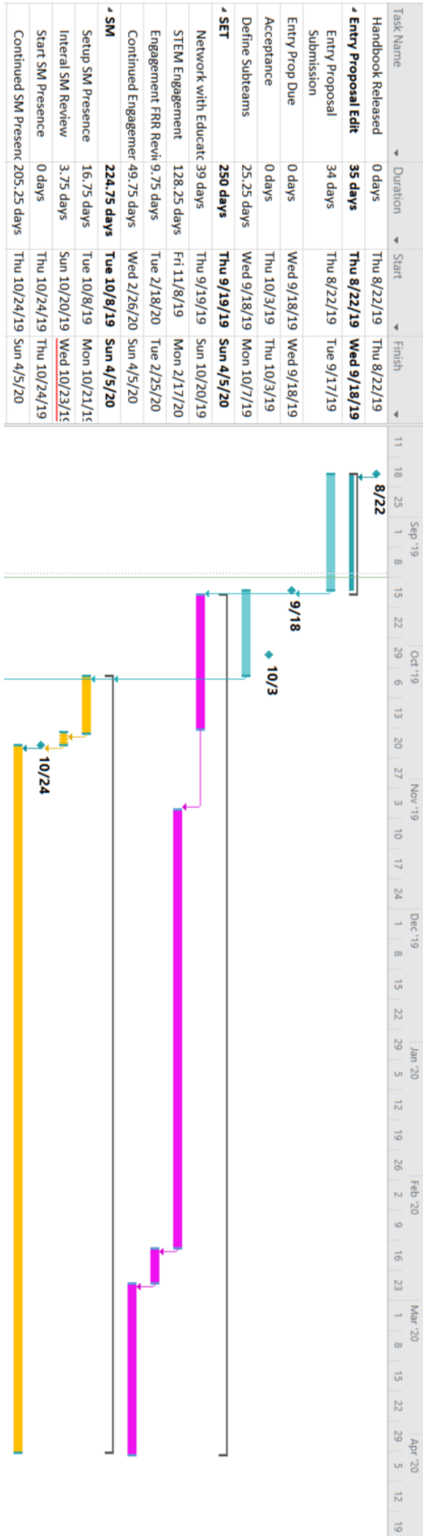
____

____

Powered by
Google Forms

Outreach Evaluation Survey:
https://docs.google.com/forms/d/e/1FAIpQLSf7uREpVL0PBcpgnPuYAIfzs9Y_JaM22pNkIgtDhzcZRx9PWQ/viewform?usp=sf_link

7.3.2 Gantt Charts



Task Name	Duration	Start	Finish
Handbook Released	0 days	Thu 8/22/19	Thu 8/22/19
Entry Proposal Edit	**35 days**	**Thu 8/22/19**	**Wed 9/18/19**
Entry Proposal Submission	34 days	Thu 8/22/19	Tue 9/17/19
Entry Prop Due	0 days	Wed 9/18/19	Wed 9/18/19
Acceptance	0 days	Thu 10/3/19	Thu 10/3/19
Define Subteams	25.25 days	Wed 9/18/19	Mon 10/7/19
SET	**250 days**	**Thu 9/19/19**	**Sun 4/5/20**
Network with Educatc	39 days	Thu 9/19/19	Sun 10/20/19
STEM Engagement	128.25 days	Fri 11/8/19	Mon 2/17/20
Engagement FRR Revi	9.75 days	Tue 2/18/20	Tue 2/25/20
Continued Engagemer	49.75 days	Wed 2/26/20	Sun 4/5/20
SM	**224.75 days**	**Tue 10/8/19**	**Sun 4/5/20**
Setup SM Presence	16.75 days	Tue 10/8/19	Mon 10/21/1
Interal SM Review	3.75 days	Sun 10/20/19	Wed 10/23/1
Start SM Presence	0 days	Thu 10/24/19	Thu 10/24/19
Continued SM Presenc	205.25 days	Thu 10/24/19	Sun 4/5/20

Task Name	Duration	Start	Finish
LV	**226.75 days**	**Mon 10/7/19**	**Sun 4/5/**
Internal Airframe Design Revie	18.5 days	Mon 10/7/19	Mon 10/
CAD/CFD Airframe Analysis	19.5 days	Wed 10/16/19	Thu 10/3
Material Analysis	19.5 days	Wed 10/16/19	Thu 10/3
Avionics Bay Design	19.5 days	Wed 10/16/19	Thu 10/3
Electronics Bay Design	19.5 days	Wed 10/16/19	Thu 10/3
Mission Deployment System Design	19.5 days	Wed 10/16/19	Thu 10/3
LV PDR Writing	19.5 days	Wed 10/16/19	Thu 10/3
Launch Vehicle Construction/Testing	58.25 days	Sat 11/2/19	Tue 12/1
CDR Writing	45.75 days	Wed 12/4/19	Thu 1/9/
LV 1 Analysis/Testing	26.25 days	Wed 12/18/19	Tue 1/7/
Launch Analysis	5 days	Wed 1/8/20	Sun 1/12
Final Airframe Adjustments and Review	62.25 days	Sun 1/12/20	Sun 3/1/
Mission	**184.75 days**	**Mon 10/7/19**	**Mon 3/2**
Comms/Telemetry	**90.5 days**	**Mon 10/7/19**	**Wed 12/**
System Design Review and Material Acquisition	30.25 days	Mon 10/7/19	Thu 10/3
PDR Writing	30.25 days	Mon 10/7/19	Thu 10/3
Comms/Telemetry Construction	48.5 days	Sat 11/2/19	Mon 12/
CT Systems Analysis	9.75 days	Tue 12/10/19	Tue 12/1
CT Flight Test	1 day	Wed 12/18/19	Wed 12/
Control Systems	**87.5 days**	**Tue 10/8/19**	**Mon 12/**
Controller Programming Phase 1	29.25 days	Tue 10/8/19	Thu 10/3
Controller Programming Phase 2	58.25 days	Fri 11/1/19	Mon 12/16/19
Drone	**89.5 days**	**Mon 10/7/19**	**Tue 12/1**
Design Analysis CFD/FEA	27.25 days	Mon 10/7/19	Mon 10/
PDR Writing	11.75 days	Tue 10/22/19	Thu 10/3
Drone Construction Phase 1	48.5 days	Fri 11/1/19	Sun 12/8
Construction Analysis/Revie	10.75 days	Mon 12/9/19	Tue 12/1
CDR Writing	45.75 days	Wed 12/4/19	Thu 1/9/
Compile Mission System	53.63 days	Sat 1/11/20	Sat 2/22/
Evaluate Mission System	10.63 days	Sat 2/22/20	Sun 3/1/
PDR	0 days	Fri 11/1/19	Fri 11/1/
Test Launch 1	0 days	Thu 12/19/19	Thu 12/1
CDR	0 days	Fri 1/10/20	Fri 1/10/
FRR	0 days	Mon 3/2/20	Mon 3/2
Complete Systems Evaulation	37 days	Mon 3/2/20	Tue 3/31
Launch Week	6 days	Wed 4/1/20	Sun 4/5/
PLAR Writing	25.5 days	Mon 4/6/20	Sun 4/26
PLAR	0 days	Mon 4/27/20	Mon 4/2