Western Michigan University AIAA Advanced Rocketry Club

2019-2020 NASA USLI PDR

November 1, 2019

CONTENTS

1 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
DDM	Design Decision Matrix
ESC	Electronic Speed Controller
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
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

2 General Information

2.1 Advisors / Student Leaders

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2.2 ORGANIZATION OUTLINE

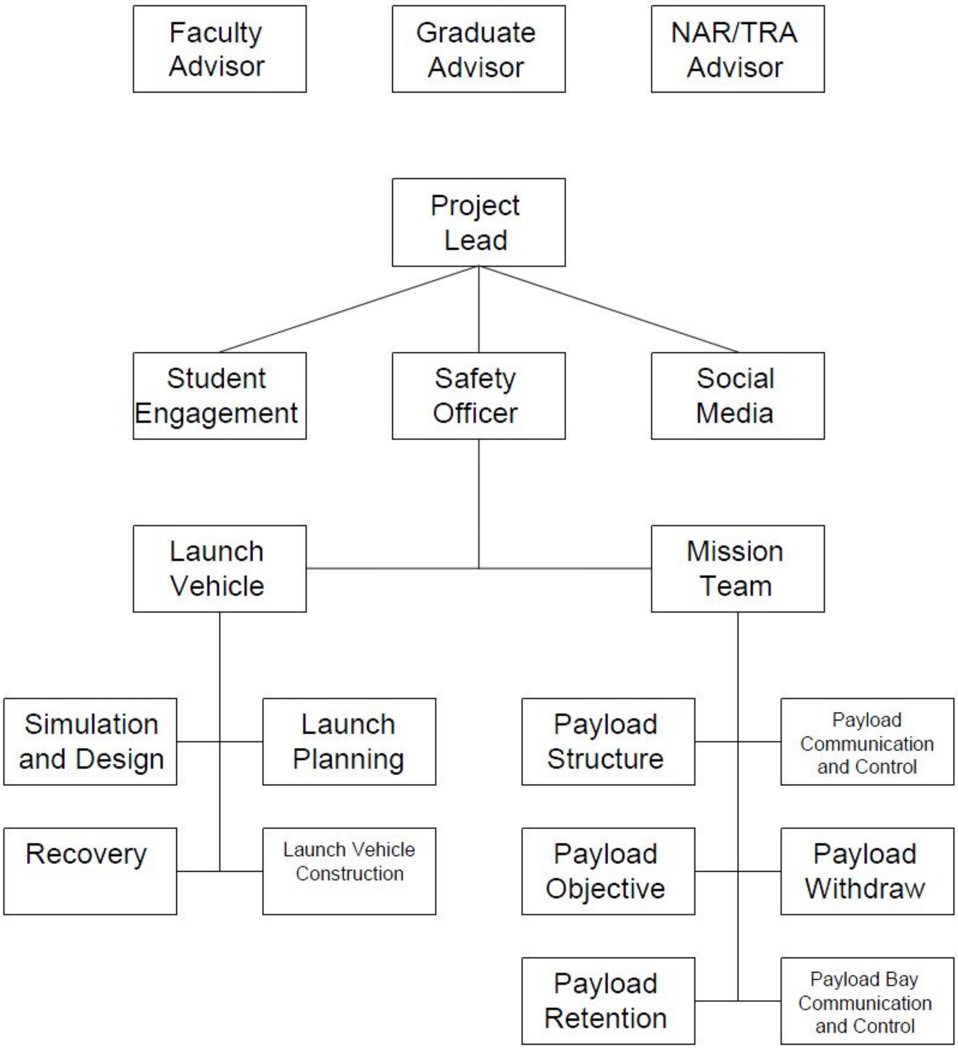

Figure 2.1: Flowchart Depicting Organization of the Teams and Sub-teams

2.2.1 Launch Vehicle Team

The Launch Vehicle Team (LVT) 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 in order to account for payload shifts throughout all flight modes. Simulations will also be used to predict the altitude of flight in accordance with Student Launch Initiative (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 Tripoli Rocketry Association (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.

2.2.2 Mission Team

The key responsibility of the Mission Team 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 team's responsibilities are achieved, this team will be further divided into sub-teams. These sub-teams can be seen in Figure 2.1. Some of these sub-teams' responsibilities overlap; therefore, close communication will be required. These teams either work on components that will remain in the rocket body after the payload is ejected or on the payload itself. The first payload team is Payload Structures. This team is responsible for the design, testing, and implementation of the mission vehicles structural components. The next payload team is the Payload Objective Team. This team is responsible for all aspects of the system that will be mounted to the mission vehicle for the recovery of simulated lunar ice. Another payload team is the Payload Communication and Control. The key responsibilities of this group are ensuring the mission vehicle has a working communication system and can be controlled at all necessary points throughout the mission. The remaining sub-teams will work on components that will remain in the rocket body after the mission vehicle exits. These sub-teams are Payload Retention, Payload Withdraw, Terrain Risk Mitigation, and Payload Bay Communication and Control. These sub-teams deal with all things necessary to prepare the mission while it is inside of the Launch Vehicle (LV), whether this is monitoring battery levels or keeping the mission vehicle restrained throughout the LV's flight. The structure of the Mission Team has changed dramatically in structure in the time since the submission of the proposal. The main reason for the changes is there was a greater number of projected members than actual members. This resulted in a restructure and increased area specialization. Members of the new sub-teams handle the design, simulation, construction, and testing of each subsystem. This team is comprised of ten student members and one team lead.

2.2.3 Safety Officer

The Advanced Rocketry Club (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 sub-scale 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 Science, Technology, Engineering, and Math (STEM) engagement events are conducted in a safe manner.

2.2.4 Social Media Team

The Social Media Team (SMT) 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 the progress of the rocket and payload to the public and SLI officials. The club 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 the club's activities to current and prospective students will facilitate continuing interest in ARC. This team is comprised of one student team member and one student team lead.

2.2.5 Student Engagement Team

The Student Engagement Team (SET) is responsible for organizing and engaging local K-12 students in STEM experiences and rocketry focused activities. Per SLI requirements, ARC must reach 200 students through educational events that promote STEM or rocketry. In prior years, the Western Michigan University (WMU) American Institute of Aeronautics and Astronautics (AIAA) Pegasus Chapter (which includes ARC) has been active in educational activities within southwestern Michigan. The College of Engineering and Applied Sciences (CEAS) encourages involvement with local students. As a result, WMU AIAA has ongoing educational activities that will be expanded throughout the coming year. 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 SETâĂŹs efforts. This is further discussed in Section 5. This team is comprised of four student team members and one student team lead.

3 Preliminary Design Review Summary

3.1 Team Summary

Team Summary	
Team Name	WMU Advanced Rocketry Club (ARC)
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Team Mentor	Jonathan Krebs, TRA #18771 Level 2
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3.2 Mission Statement

The 2019-2020 WMU ARC competing in the NASA Student Launch Initiative will deliver a controlled rover with drilling capabilities to an altitude of 4612 ft AGL. Once the payload is deployed from the vehicle, it will be controlled to a point in the field where it will extract the lunar ice before flying away to a desired location. Safety is paramount to the design in the case of unexpected problems. Redundancy in testing and simulation will mitigate risk during the mission.

3.3 Launch Vehicle Summary

The LV will be made from 139 inches of uniform 7.5 inch diameter BlueTube™. The upper body is an 18 inch section of BlueTube™and nose cone that houses the round canopy drogue parachute. The lower body consists of the lower air frame, payload bay, fins, main recovery system, and propulsive system. The body fins are a 4 split fin configuration constructed of fiberglass. The rocket will launch on a L1170FJ-P Aerotech motor in a 75mm re-loadable motor casing. The LV is projected to reach an apogee of 4635 feet. Upon apogee, there will be a single ejection charge separating the nose cone from the upper air frame (while maintain connection through a tethered shock chord) and ejecting the drogue parachute. At 550 feet, a second ejection charge will ignite, separating the upper body from the lower body entirely and initiating the lower body recovery system. The main parachute mounts externally at the bottom of the LV to allow it descend perpendicular to the ground and land on its fins. Additional vehicle characteristics are shown in Table 5.13 of Section 5.

3.4 Payload Summary

The leading design of the WMU ARC payload is a deployable drone. We will be refering to our payload as SubZero. This drone will be outfitted with a forward brush similar to that of a vacuum cleaner. This brush will be activated when the drone reaches the target location. This mechanism gives our mission system the ability to retrieve larger amounts of sample material than conventional methods. The system will also be equipped with a first person viewing system to ensure safe remote operations. The applications of the system in the real world scenario this competition is simulating would mass ice gathering for lunar base operations.

4 Changes Made

4.1 Launch Vehicle Changes

The launch vehicle has undergone iterative design to achieve the presented final design. Specific attention to implementation cost and complexity was taken into account when designing as team experience in complex construction methods is limited and the ARC budget is relatively small. The main parameters changed were the vehicle length, vehicle weight, fin setup, and recovery system setup. Initial proposal vehicle length was 109 inches, the final length is 139 inches. The main motivation for this change was to return vehicle stability to a similar region as initial design after the following vehicle dimension changes were made. The vehicle also decreased in weight from 39.625 pounds to 37.68 pounds. This arose from both a decrease in predicted mission system weight and a decrease in ballast weight. The fins of the rocket were increased from the 3 to 4 per fin set. The decreased weight and increased length decreased the stability beyond what was deemed acceptable by the team. The ballast weight required was already near the allowed limit and the shifting center of pressure by adding additional fins resulted in acceptable stability. The initial system staged the parachute deployment in the same order, but kept the upper body tether to the lower body for the entirety of the descent. The separation has many benefits, mainly alleviating tangle and main parachute deployment concerns. Additional reasoning for design choices made between proposal for entry and PDR are further discussed in section 5.

4.2 Payload Changes

Payload sections of the team have made dramatic changes from the initial proposal, in both the structure of the team and the primary design of the mission vehicle (MV). These changes include the removal of all terrestrial movement devices such as out initial hub mounted wheels. When analyzing alliterative MV designs it was identified that the benefits of on ground travel were greatly outweighed by the weight and complication it added to the MV. In addition it was identified that in the real world application this competition could be simulating is the recovery of large amounts of lunar ice for use in lunar bases. As a result we have increased the priority of more than required amounts of sample recovery. Another component that has changed is the addition of a GPS tracker in the nose cone section of the rocket in addition to the one located in the aft electronics bay. This new GPS tracker was added to locate the forward section of the rocket that will now be detaching from the main body components. Any additional minor changes made to specific subsystems can be found following payload sections.

In addition to design changes the payload team has also undergone a restructuring. This restructuring will increase component specialization, while promoting member to follow through all aspects of components life span. Starting with the research and design phase, continuing to the manufacturing and testing, and finishing with the analysis of total component performance. This new specialization will increase members understanding and experience in all aspects of a design and build scenario. From an organizational viewpoint this will increase member retention, and new member acquisition because members will have the opportunity to find out what phase of the design and build process appeals to them the most.

4.3 Project Plan Changes

The overall content of the team project plan remains the same as what was previously presented and explained in the proposal. The only change is a delay in all acquisitions of materials and components. This shift is a result of our primary source of funding also being delayed. At this time we have secured this funding and is available for use. In the following Project Plan section exact length of delays have been presented, in addition to all timelines that will slip back as a result. These slips have affected the construction and testing of our small scale system. At this time it is not expected that this delay will have a dramatic affect on our Project.

5 Launch Vehicle

5.1 Selection, Design, and Rationale of Launch Vehicle

Mission success of the launch vehicle is contingent upon safe deployment of payload within competition regulations. As such, the team's specific criteria for determining launch vehicle success acknowledges USLI requirements in addition to acknowledging prerequisite componential performances. When making construction and design decisions, choices must be made that maximize the launch vehicle's ability to fulfill the success criteria. For component design decisions, the parameters most important to success are defined. Potential design pros and cons are then defined and scored based on its effectiveness to fulfil those success parameters on a scale of 1-5, with increasing score correlating to increasing viability. The scores for all parameters are summed and then compared across alternative design choices. However, the highest viability score is not immediately selected for implementation. Given ARC's budgetary constraints , a final analysis for the top alternatives is conducted with percent of total budget taken into consideration. Specifically, final viability score is divided by the percent of total budget. This is to prevent exceedingly expensive design implementations in cases where a slightly less viable but more cost effective designs could yield a similar probability of success.

5.1.1 Mission Statement and Success Criteria

The launch vehicle will reach an apogee between 3,500 and 5,500 feet, safely recover to the ground, and activate payload deployment systems. Through the duration of flight and landing loads will be limited to withstandable forces to maintain the functionality of all components. Upon landing in the predetermined orientation, the payload drawer will extend allowing the payload to begin its ice retreival mission. The mission will be considered a success when the following requirements are met:

Launch Vehicle Success Criteria

1. LV reaches a minimum of 3,500 feet AGL, while remaining below 5,500 feet AGL.
2. Initial recovery system deploys and maintains connection to lower body
3. Lower body separates from upper body and main recovery system deploys.
4. Lower body lands in the predetermined orientation.
5. Payload deployment system is intact and actuates successfully.

5.2 Airframe Subsystem

The launch vehicle's main goals, as outlined by the success criteria, are broadly speaking to deliver and deploy the payload, and safely return to ground. Every step in the design and construction process must be made in an effort to maximize its ability to complete those goals and fulfill the LV success criteria. The design bottleneck, as decided by the team, was placed on the airframe dimensions. That is to say, that rather than design an airframe and cater mission system parameters to fit within, airframe dimensions were designed to accommodate preliminary mission designs. Of course, mission system dimensions could change throughout the design phase, so the upper bound of dimensions was chosen as the design point. This is how the diameter of 7.5 inches was decided.

5.2.1 Airframe Material

The airframe will be constructed of BlueTube 2.0 ™in two main pieces of 85 inches and 18 inches. BlueTube 2.0 allows for strength to withstand launch loads while maintaining low costs and weight. The cost-to-strength ratio was very important in the decision process, as at the time of designing the airframe constitute approximately 8% of the total predicted budget and approximately 11% of awarded budget. As this lower price point when compared to other materials, BlueTube affords the team the opportunity to build back-up airframes in the event of a launch vehicle failure or construction mistake.

Material consideration for the airframe is a prerequisite decision for many of the airframe decisions. Such a decision dictates range of withstand-able loads, overall weight range, and project costs to name a few. As such, this decision was made very early in the design process.

The airframe is of constant diameter throughout the length of the launch vehicle. The constant diameter eliminate the additional construction procedures of making couplers or transitions between diameter changes. The ability to provide ample room for various payload sizes is very important to the launch vehicle team. Balancing maximum airframe diameter with availability and strength of the material is of the utmost importance. Following these considerations, viability analysis was conducted with respect to:

- Material Strength: Ability to withstand launch/landing forces over multiple flights.
- Material Weight: Overall weight contribution from airframe material.
- Availability: Ease of acquisition from vendors.
- Ease of Construction Methods: Complexity of methods required to construction airframe geometries using the material.

Material		**BlueTube 2.0**		**Fiberglass**		**Composite/Multi-Material**	
Parameter	Weight	Score	Viability	Score	Viability	Score	Viability
Material Strength	4	5	20	8	32	9	36
Material Weight	5	8	40	6	30	7	35
Availability	3	8	24	7	21	6	18
Ease of Construction Methods	2	7	14	9	18	5	10
Total Viability		98		101		98	

Table 5.1: Airframe Material Design Decision Matrix

Material	BlueTube 2.0		Fiberglass	
	% of Budget	Total Viability	% of Budget	Total Viability
	5	98	24	101
Cost Effectiveness Score	1960		420	

Table 5.2: Airframe Material Cost Effectiveness Matrix

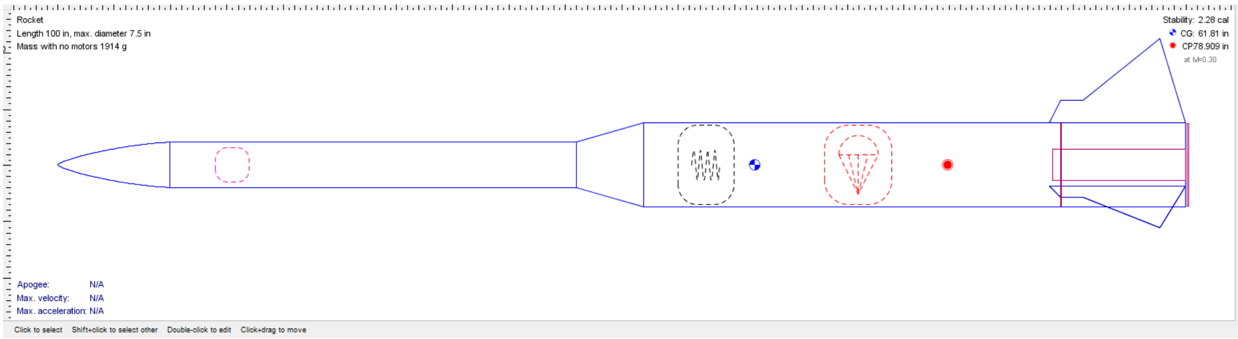


Figure 5.1: Tapered Diameter

5.2.2 Airframe Geometry

As previously mentioned, the airframe diameter was directed to provided as much room as possible for the payload and mission systems. The team discussed three ways to provide these spaces: constant diameter, tapered diameter, and forward mounted payload bay. These configurations were explored as each provided noticeable benefits to some aspect of the payload delivery.

5.2.2.1 Constant Diameter Constant diameter airframe provides the easiest construction process of all the geometries. In addition, ARC has the most experience with constructing and manufacturing constant diameter airframes. Another benefit is the airframe space available for all other components excluding the payload. This would include extra area for telemetry, controls, and recovery systems. However, the excessive diameter in areas where it is unneeded adds extra material and in turn, extra weight.

5.2.2.2 Tapered Diameter Tapering the diameter to decrease after the payload bay allows for elimination of excess weight and drag at the forward or upper body sections of the airframe. This requires verification of aerodynamically and structurally stable diameter relative to the lower body. That is to say that when designing a tapered rocket additional care must be taken when analyzing structural integrity of the smaller section as well as the transition/coupler. All things that are very achievable in the scope of the design and construction phase, but steps that are not required of a constant diameter airframe. Another consideration of the tapered geometry is the decrease in weight, specifically in the forward section, resulting in a center of gravity that shifts backward compared to constant diameter. The configuration of having the payload in the lower body already provides stability concerns, shifting the center of gravity backward would either require excessive ballasting or external aerodynamic bodies.

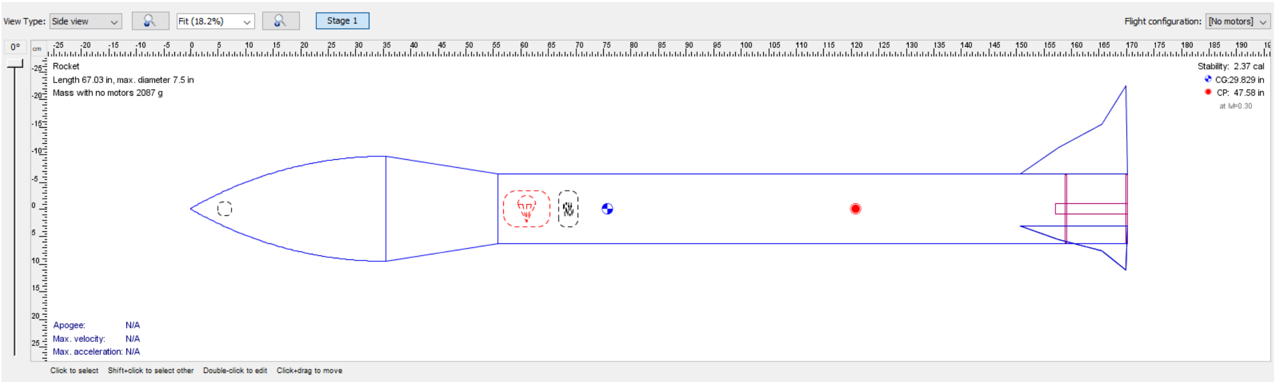


Figure 5.2: Forward Mounted Payload Bay

5.2.2.3 **Forward Mounted Payload Bay** A forward mounted payload address the same concerns as the tapered diameter airframe, but also provides solutions to the center of gravity concern as the center of gravity now shifts forward. There is however, that at certain body lengths and payload weights that shift reaches a sort of "over-correction' point. Where stability again begins to suffer from the non-uniform geometry. ARC also holds the concern that such geometry would be challenging to construct. Team members experience with constructing inverted transitions and payload bays is limited.

The 3 airframe geometries discussed all attempt to solve similar structural and functional problems in regards to payload delivery. As a result, those problems and the geometries ability to solve them have been chosen as the decision criteria for evaluating viability. Specifically:

- Stability Influence: Measure of geometry's influence on stability in reference to standard constant diameter.
- Ease of Construction Methods: Measure of the complexity of methods required to construct/manufacture the geometry.
- Weight: Measure of geometry's influence on launch vehicle's loaded weight.

Geometry		**Constant Diameter**		**Tapered Diameter**		**Forward Mounted Payload Bay**	
Parameter	Weight	Score	Viability	Score	Viability	Score	Viability
Stability Influence	3	7	21	6	18	3	9
Weight	4	6	24	5	20	7	28
Base of Construction Methods	2	8	16	7	14	6	12
Total Viability		61		52		49	

Table 5.3: Airframe Geometry Design Decision Matrix

The DDM demonstrates the forward mounted payload bay's ability to address the main three design concerns. However, it scores poorly on ease of construction methods. The manifestation of this concern however is not enough to prevent it from achieving the highest viability score. What remains is the cost effectiveness analysis to determine weather the increased complexity of construction makes financial sense.

Cost effectiveness analysis confirms that the additional complexities that arise from the forward mounted payload bay do not justify the benefits from the geometry.The same material was used to not provide any bias or advantages to a preferred geometry. A constant diameter bay, while still challenging in some areas, remains effective and cheap.

5.2.3 Aerodynamic Bodies

The airframe geometry and material are only pieces of the whole in terms of the launch vehicle. While the aforementioned aspects heavily influence the center of gravity of the launch vehicle, the aerodynamic bodies heavily influence the center of pressure. Together, these components generate the stability of the launch vehicle. Which is why many aspects of the two systems should and were designed parallel to each other. Final decisions in one aspect influence the other and the structural decisions made took into account the following aerodynamic body decisions.

5.2.3.1 **Nose Cone** The nose cone is limited by the upper body diameter. For many manufacturers, 7.5 inch diameter hardware is either the max size component they sell or above. This limits some freedom in parameter decisions. Specifically in terms of the nose cone geometry. After this was discovered, ARC prioritized nose cone material decisions first. As this would inevitably limit the geometric decision, effectively making the choice for the team.

Much like the airframe, there are a standard set of nose cone materials in high power rocketry: fiberglass, plastic (of varying types), and composite. Initial research has shown that at relatively large diameters, off-the-shelf composite components were fairly unattainable. In addition, carbon-fiber (as an example of a composite material) imposes an RF shielding effect on transmitters. This is unacceptable as the upper body, and specifically the nose cone, will house telemetry/tracking systems as the unit descends independently. The structural benefits of a composite nose cone are not important enough to justify the sacrifices that are forced upon the launch vehicle. Plastic nose cones are relatively very easy to acquire, especially in the higher diameter ranges. Similarly, plastic nose cones (regardless of specific type of plastic) are light. This would help decrease overall launch vehicle weight, however, this is unneeded. Regardless of the airframe material used, the launch vehicle reaches an apogee within the required range. Additionally, nose weight is desired to increase launch stability of the vehicle. Fiberglass nose cones are also abundant and cheap from large HPR part manufacturers. The considerations of the nose cone material are:

- RF Transparency
- Weight
- Weight

Geometry		**Constant Diameter**		**Tapered Diameter**		**Forward Mounted Payload Bay**	
Parameter	Weight	Score	Viability	Score	Viability	Score	Viability
Stability Influence	3	7	21	6	18	3	9
Weight	4	6	24	5	20	7	28
Base of Construction Methods	2	8	16	7	14	6	12
Total Viability		61		52		49	

Table 5.4: Airframe Geometry Decision Matrix

Fiberglass is RF transparent, heaviest of the 3 materials, and strong. The viability analysis shows that fiberglass nose cone dramatically outperforms the other materials in the context of this launch vehicle. However, cost effectiveness must be analyzed.

Material		**Fiberglass**		**Plastic**		**Composite**	
Parameter	Weight	Score	Viability	Score	Viability	Score	Viability
RF Transparency	5	8	40	5	25	1	5
Weight	4	4	16	7	28	6	24
Material Strength	2	7	14	4	8	8	16
Total Viability		70		61		45	

Table 5.5: Nose Cone Material Design Decision Matrix

Material	**Fiberglass**		**Plastic**	
	% of Budget	Total Viability	% of Budget	Total Viability
	5	70	2.5	61
Cost Effectiveness Score	1400		2440	

Table 5.6: Nose Cone Material Cost Effectiveness Matrix

The fiberglass nose cone continues to outperform the other materials in all metrics.

5.2.3.2 **NOSE CONE GEOMETRY** The shape of the nose cone has aerodynamic implications for the launch vehicle. Unlike the materials of the nose, there are more standard geometries of HPR nose cones: conical, ogive, elliptical, Von Karman, and Haack. There are more commonly used geometries, but these are not easily acquired as off-the-shelf components and therefore were not considered. The different geometries optimize the aerodynamic characteristics for different flight characteristics and trade off the level of optimization for price.

CONICAL Conical nose cones are the cheapest geometry as they are the easiest to manufacture. However, there are limited aerodynamic benefits of this geometry. Conic shapes perform similarly at all Mach number regimes, which is negative when designing down drag in an understood Mach regime.

OGIVE Ogive nose cones operate in a similar manner to conical cones. They are easy to produce but they are blunted in nature than the conical cones that allow for a decrease in drag. In addition, the curvature increase compressive strength allowing it to withstand greater launch forces. However, it performs similarly poorly across Mach regimes.

ELLIPTICAL Elliptical geometries are in some cases also cheaply manufactured nose cones. The increase in manufacturing costs is relatively small, while the decreased drag at small Mach numbers is large when compared to conical or ogive. The bluntness of the shape decrease drag and are popular in subsonic regimes. This applies specifically to this launch vehicle as the predicated airspeed is in the range of 0.5 Mach.

Haack Large HPR retailers often stock Haack series nose cones, albeit at a lower rate than common geometries like conical or ogive. Haack series nose cones perform very well in subsonic regimes and also have performance increases in the transonic range when compared to the previously mentioned geometries. The performance increase at transonic regimes is unnecessary. While they are often produced by HPR manufacturers, Haack series nose cones fiberglass at 7.5 inches are less prevalent.

Von Karman Of all the previously mentioned geometries, Von Karman outperforms them in drag reduction in the relevant range. Drag reduction and stability increasing weight are the most important factors of the nose cone geometry. For the same length, Von Karman has a large volume and drag reduction. When paired with fiberglass material, the Von Karman nose cone satisfies all nose cone requirements.

Geometry		**Conical**		**Elliptical**		**Haak**		**Von Karman**	
Parameter	Weight	Score	Viability	Score	Viability	Score	Viability	Score	Viability
RF Transparency	3	7	21	7	21	7	21	7	21
Weight	4	4	16	4	16	4	16	4	16
Aerodynamic Profile	5	7	35	5	25	6	30	9	45
Total Viability		72		62		67		82	

Material	**Fiberglass**		**Plastic**	
	% of Budget	Total Viability	% of Budget	Total Viability
	4	72	2.5	82
Cost Effectiveness Score	1800		3280	

Table 5.7: Nose Cone Material Cost Effectiveness Matrix

5.2.4 Propulsion

With the airframe material and size chosen, the weight range of the launch vehicle can be considered. The propulsion system must be catered to achieve an apogee that is within USLI requirements. As ARC currently owns an AeroTech 75 mm 5120 reloadable motor casing, the team plans on selecting a motor from the classification. The most important characteristic of the motor is its ability to bring the LV to an acceptable apogee. The teams participation in the competition is contingent on the ability to reach an apogee within the required range. This is wholly dependent on the motors total impulse. However, the total impulse of the motor does not necessarily correlate to the weight of the motor. Motor weight is a large portion of the overall weight of the LV, and as a result, has a large impact on the stability. This results in the follwing two design decision criteria:

- Installed Apogee: The apogee reached at current LV parameters.
- Stability Impact: The ability of the motor to maintain an LV stability of above 2 calibers.

Based on accessibility,brand requirement, and USLI restrictions, the motors available for purchase are limited. The following DDM analyzes a few possible motor choices.

Unlike other design decision, these alternatives are the exact same price. The cost effectiveness analysis would support the output of the DDM, in this case, confirming the superiority of the L1170FJ-P.

Motor		L1170FJ-P		L1420R-P		L2200G-PS	
Parameter	Weight	Score	Viability	Score	Viability	Score	Viability
Installed Apogee	5	9	45	5	25	2	18
Stability Impact	4	6	28	7	35	7	35
Total Viability		73		60		53	

Table 5.8: Motor Design Decision Matrix

5.3 Recovery Subsystem

The LV employs standard order of deployment for its recovery systems. Specifically, drogue deployment at apogee through the upper body and main parachute deployment from the lower body at a specified altitude (550 feet). However, due to the nature of payload deployment, the specific methods of implementation have been altered. The drogue deployment at apogee is executed by a redundant altimeter system signalling apogee. The main altimeter is an AltusMetrum EasyMini set for apogee backed up by a PerfectFlite StratoLogger with an apogee delay of one second. Each system is connected to independent ejection charges to be able to address failures at all steps of the ejection process. A similar pair of altimeters make up the deployment system of the main parachute as well. However, there are notable differences in the deployment systems. At main parachute ejection, the upper body and lower body will separate as the shear pins are broken. The upper body will pull the main parachute from the lower body with a deployment bag. At this point, the upper and lower body are independent under their own recovery systems. This is minimize risk of tangling or spinning of either recovery system at main deployment. The separation of the two bodies lowers the weight under the main parachute, further decreasing the speed of descent. A slower descent will trade off drift distance, but will decrease risk of hard landing or bouncing on touch-down. All independent descending bodies have telemetry/tracking systems.

5.3.1 Parachutes & Shock Chord

The relatively low ceiling of USLI inherently prevents any dramatic drifting of the descending body or payload. As a result, the impact of different parachutes is fairly minimal. However, it is important that parachute size is adequate for the launch vehicle weight to ensure safe descent. Through use of the following formula, required parachute diameter is calculated.

$$\mathrm{D} = \sqrt{(8 * m * g)/(\pi * \rho * C_d * v^2)} \quad (5.0)$$

Air Density: $\rho = 1.22 kg/m^3$
Acceleration of Gravity: $g = 9.8 m/s^2$
Drag Coefficient (1.5 for dome parachute): C_d
Descent Velocity: $v = m/s$
Mass of LV: $m = kg$

$$\text{Parachute Diameter: } D = m$$

To prevent any bouncing or hard landings in the recovery configuration, a landing velocity of <8m/s is established. Vehicle mass is set as the lower body weight, as the lower body will be the only mass under main parachute, which is 8.528kgs or (18.8$pounds$). With these values the required main parachute size is determined to be:

$$D = 2.15m$$

The drogue and main parachute must be of the correct size to allow the launch vehicle to descend at an acceptable rate of speed. Too slow and the body will spend too long in the air and possibly drift too far. Too fast and the landing could be too hard or could break the shock chord. In addition to size, the weight of the material and chord must be taken into account. Recovery system weight is non-trivial in regards to vehicle stability and total weight. These considerations provide the two design parameters of the parachutes:

- Parachute Weights
- Descent Speed

Previous ARC competition rockets utilized in-house fabricated parachutes. The most recently fabricated main parachute is a dome parachute of 92$inches$ (or 2.34$meters$). While this is above the calculated required parachute diameter, it allows for an even slow descent speed. A slower speed will limit possibility of bouncing or hard landing. Under the ARC fabricated parachute, and taking lower body separation into account, the lower body hits ground at 3.87m/s. Similiarly, ARC constructed a corresponding drogue parachute for a LV of similar weight. This drogue parachute is 36$inches$, under this parachute the LV descends at 21.9m/s. At this rate the deceleration at main ejection and drift distance is manageable. While these parachutes fulfills design parameters of the main parachute, it is important to analyze alternatives.

Other parachute options include toroidal,cruiciform, and flat circular. The shapes correlate to different coefficients of drag, and in turn different descent speeds. In addition, the amount of material required to achieve similar descent speeds vary between the options. These options are compared against the existing ARC parachutes on the previously mentioned design paramters, of course still taking into account the cost of the new shapes.

Shape		**Toroidal**		**Cruciform**		**Flat Circular**	
Parameter	Weight	Score	Viability	Score	Viability	Score	Viability
Parachute Weight	3	6	18	8	24	5	15
Descent Speed	5	2	10	3	15	2	10
Total Viability		28		39		25	

Table 5.9: Parachute Shape Design Decision Matrix

The toroidal scores low in descent speed because at standardized weight it slows the LV too much. It scores moderately in parachute weight because it is able to achieve slow descent speed at smaller sizes (and therefore weights). The cruciform shape is able to achieve acceptable descent speeds at relatively low weights when compared to the other options. The flat circular is not able to achieve acceptable descent speeds unless a large amount of material is used. The cruciform performs very similar to dome parachutes, much like the ARC parachutes. With this fact taken into account, the ARC parachutes are more cost effective as no material or build time is required to achieve effective descent characteristics.

Utilizing Equation (5.3.1) and a desired descent speed of around 20 m/s, a drogue diameter of $.787 meters$ or $31 inches$ is desired. The descent speed encompasses many other parameters of the parachutes. Equation (5.3.1) is a function of parachute drag coefficient, which in turn is a function of parachute geometry. Similarly, the weight design parameter effectively includes material consideration. The maximum force on the shock chord is upon initial release, where acceleration is the greatest. Simulations have shown apogee deployment acceleration to be $9.8 m/s^2$ and main deployment acceleration to be $70.8 m/s^2$. The force on the chord at these events follows $F = ma$, resulting in:

Max Force on Drogue Ejection: $F_{max} = 179 Newtons$
Max Force on Main Ejection: $F_{max} = 1293 Newtons$

Tubular nylon is the standard shock chord material used in HPR. The specific width of the tubular nylon affects the tensile strength and therefore its ability to withstand ejection loads. Tensile strength would logically be the most important parameter of the shock chord. However, tensile strength of commonly supplied materials (like tubular nylon) have very high tensile strengths. Tensile strength must be coupled with elastic properties to not only minimize ejection loads on chord, but loads on the rest of the launch vehicle and payloads due to large deceleration. Another consideration is heat resistance, as the shock chord is the most exposed to ejection gases. Materials like Kevlar address that concern. These parameters ake up the decision criteria for shock chords.

- Tensile Strength: Ability to withstand ejection loads.
- Elasticity: Ability of chord to minimize snatch loads.
- Heat Resistance: Ability of chord to withstand ejection gases.

Material		**Tubular Nylon**		**Kevlar**	
Parameter	Weight	Score	Viability	Score	Viability
Tensile Strength	3	7	21	6	18
Elasticity	3	7	21	5	15
Heat Resistance	4	5	20	7	28
Total Viability		62		61	

Table 5.10: Shock Chord Material Design Decision Matrix

Tubular nylon outperforms the kevlar in two of three metrics. Considering ARC already owns a supply of one inch tubular ylon, the DDM confirms the choice to use tubular nylon.

5.3.2 Ejection/Deployment

As previously mentioned, all ejection/deployment systems involve redundancy. Electronic systems have two of each component with different hardware to eliminate hardware failure across all systems. E-match and energetic also have single redundancy, with the backup system using 10% more black powder than the main. This minimize the possibility of an ejection attempt not creating enough pressure to deploy a recovery system. Using the following tables and equation,and using 200 pounds-force as the baseline for required deployment forces, the required amount of pressure for recovery deployment can be determined.

$$G = C * D^2 * L \qquad (5.1)$$

G = Black Powder [Grams] C = Charge Coefficient D = Airframe Diameter [Inches] L = Airframe Length to be Pressurized [Inches]

Airframe Diameter	**100 lbf**	**150 lbf**	**200 lbf**	**250 lbf**
2.6"	19 psi	28 psi	38 psi	47 psi
4.0"	8 psi	12 psi	16 psi	20 psi
6.0"	2.5 psi	5.3 psi	7.0 psi	8.8 psi
7.5"	2.3 psi	3.4 psi	4.5 psi	5.7 psi

Table 5.11: Force on Airframe due to Pressure

C	**Psi**
.002	5
.004	10
.006	15
.0072	18
.008	20

Table 5.12: Charge Coefficient at Varying Pressures

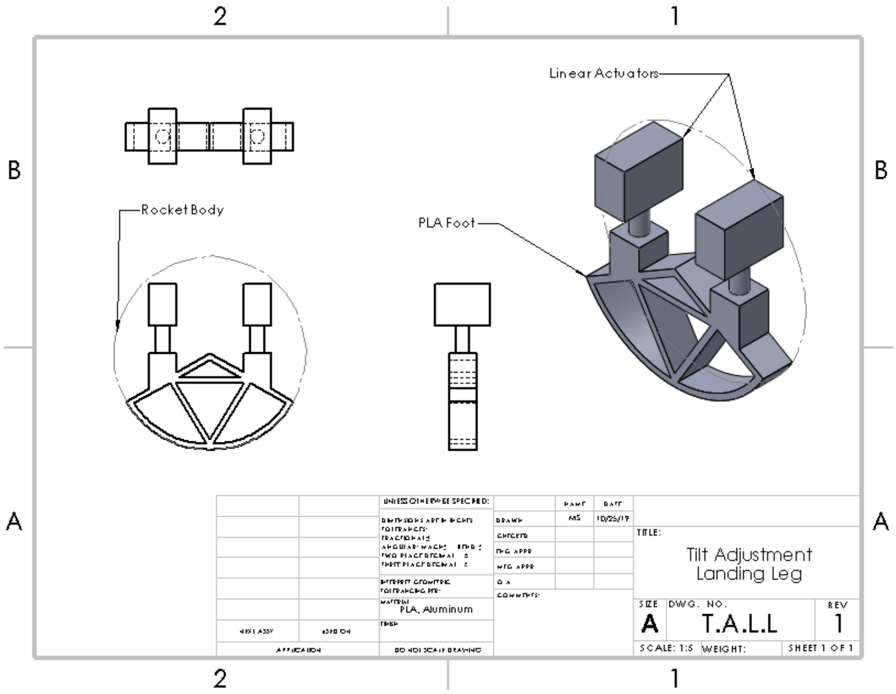
Table 5.11 shows that a pressure of at least 4.5 psi is required to impart 200 pounds of force on the recovery system. Table 5.12 shows that a charge coefficient of .002 is required to achieve chamber pressure of 5 psi. The upper body pressure chamber length is 18 inches and the lower body chamber length is 25. inches. Using these values in equation 5.1 yields a black powder mass of 2.025 grams on drogue deployment and 2.98 grams on main deployment. The redundant ejection systems utilize a 10% increase in black powder mass for safety, resulting in 2.2275 grams for drogue ejection and 3.28 grams for main ejection.

5.3.2.1 SEPARATION Separation of the lower body requires a shearable retention system for the connection of the upper and lower body sections. This is most commonly achieved through the use of shear pins. This type of separation configuration was also the basis of the most recent ARC competition LV. As the lower body separation configuration greatly benefits the landing characteristics, ARC plans to mirror this design. Many HPR component vendors sell nylon shear pins for this purpose. 3 nylon shear pins require 64.24 pounds of force to shear all the pins. As previously calculated, the largest amount of separating force on the LV prior to main deployment is 179 Newtons or 40 pounds. This leaves a 37.7% safety margin. In addition, the main ejection forces are planned to reach 200 pounds. Easily shearing the pins for a successful ejection.

5.3.3 LANDING LEG SYSTEM

Due to the unpredictability of the landing site's surface material and terrain, the Tilt Adjustment Landing Leg (TALL) is designed to reorient the nose of the rocket so that the payload can deploy unimpeded. TALL consists of a rounded-wedge shaped printed PLA foot, and two linear actuator arms connected to the on board Raspberry Pi computer for payload deployment. For the duration of the flight, TALL will be stored inside the rocket directly behind the payload vehicle bay; with the outer curve of the foot fitting flush inside a cutout to the rocket body's outer surface. Using the main parachute for orientation, the rocket will land horizontally;with two rear fins and TALL pointing "down" towards the ground. After contact with the ground, TALL will extend its foot out from the side of the rocket body in order to push the nose up to an angle of at minimum 0°.

Although the basic design for TALL has been planned, there still are a lot of variables that need to be accounted for. Due to the power requirements and potential geometric/ mechanical limitations of the linear actuators, further testing needs to be done to prove the design. One alternative option is to use a loaded spring system to mechanically deploy the foot upon landing instead. This could be done by releasing the springs via a smaller servo motor, and locking the telescoping arms in place once deployed. However, although it would be a simpler process than using electronic actuators, it would not be possible to finely tune the extension distance once deployed. If the spring is under loaded, it won't have enough force to lift the rocket to a positive angle. Inversely, if the spring is over loaded, it could exert enough force to damage either the rocket body or the landing leg, or even launch and/or topple the rocket off of its proper landing side.



5.4 Mission Performance Predictions

The collection of the aforementioned design decisions make up ARC's preliminary launch vehicle design. The following information summarizes the physical characteristics of the vehicle, describes expected flight performance, and the methods use to achieve these summaries.

5.4.1 Flight Profile

5.4.1.1 **Target Altitude** Through rigorous simulation and use of Monte Carlo perturbation simulation, ARC's official target altitude is **4635 feet**.

5.4.1.2 **General Characteristics** OpenRocket was used to both model the LV and simulate its flight.

The center of gravity and center of pressure at located 87.918 and 105 inches from the nose cone, respectively. This results in a loaded stability of **2.3 calibers**. The upper body and all internal components weight **3.517 kilograms**. The lower body and components (not including the payload) weight is **6.18 kilograms**. The preliminary predicted payload weight is **2.5 kilograms**. The Aerotech L1170FJ-P has a loaded motor weight is **4.99 kilograms** and burnt weight is **2.19 kilograms**.

5.4.1.3 **Flight & Simulations** The target altitude was decided upon after various flights conditions were simulated. Wind conditions of 0-20 mph were simulated with use of the Monte Carlo simulation method. The Monte Carlo simulation applied perturbations to the simulation parameters to provide a range of results that represent non-ideal performances.

General LV Characteristics	
Stability	2.3
Weight (Loaded)	17.4 kg
Weight (Burnt)	14.6 kg
Length	139 in
Diameter	7.5 in
Number of Fins	8(Split 4)
Predicted Apogee	4635 ft
Flight Time (Upper Body)	~112 s
Flight Time (Lower Body)	~130 s

Table 5.13: General Launch Vehicle Characteristics

These apogees were averaged, with heavier weight applied to the lower wind conditions, to achieve the final target apogee.

The baseline flight simulated the LV at OpenRocket standard flight parameters (specifically an average wind speed of 5 mph and 10% turbulence and speed variation). The performance of this baseline flight is very indicative of the other simulations. The following tables represent that major flight characteristics of the wind-varied simulations.

[redacted]	Wind Speed (mph)	[redacted]	[redacted]		
Characteristic	[redacted]	Apogee (ft)	Drift (Upper) (ft)	Drift (Lower) (ft)	Flight Time (s)
[redacted]	0	4776	6	6	130
	5	4667	10	125	111
	10	4621	320	680	156
	15	4596	50	1430	154
	20	4523	130	1850	152

Table 5.14: Wind Varied Simulations

Using the baseline simulation, the kinetic energy of the independent bodies can be found. The entire launch vehicle descends under drogue at **17.678 m/s**. This results in a LV descent kinetic energy of **2718.85 joules**. After separation the upper and lower body descend at **8.23 m/s** and **4.88 m/s**, respectively. This results in upper body descent kinetic energy of **119.1 joules** and a lower body descent kinetic energy of **103.35 joules**.

5.4.2 Launch & Propulsion

As previously mentioned, the Aerotech L1170FJ-P motor provides adequate thrust-to-weight ratio while achieving an apogee within the required range. While the resulting flight fulfills all design requirements, the loads imparted on the LV by the propulsive system must be confirmed to be endurable.

As shown in Figure 5.1, the thrust of the of the motor maxes out at 1473 Newtons (or 331 lbf), resulting the peak boost acceleration of 74.9 m/s^2. Under whole launch vehicle weight,

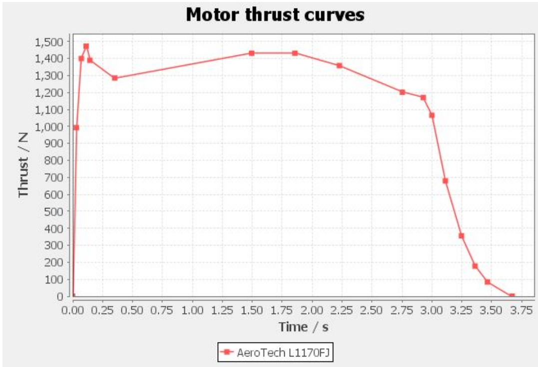


Figure 5.3: L1170 Thrust Curve

Specimen #	Specimen Comment	Inner Diameter in	Outer Diameter in	Platen Separation in	Area in^2	Modulus ksi	Load At Yield lbf
1		3.002	3.128	9.00000	0.60662	559.60219	2974.13082
2		3.002	3.128	9.00000	0.60662	607.10291	3211.11207
3		3.002	3.128	9.00000	0.60662	574.09091	3052.63859
Mean		3.002	3.128	9.00000	0.60662	580.26534	**3079.29383**
Std. Dev.		0.000	0.000	0.00000	0.00000	24.34486	120.71828

Specimen #	Stress At Yield MPa	Peak Load lbf	Peak Stress psi	Energy To Peak ft*lbf	Break Load lbf	Elongation at Peak in	
1	33.80322	2974.13082	4902.72798	14.11096	1504.89966	0.11156	
2	36.49669	3211.11207	5293.38147	20.93077	1607.34466	0.13095	
3	34.69552	3052.63859	5032.14469	18.27847	1534.46427	0.11815	
Mean	34.99848	3079.29383	**5076.08472**	17.77340	1548.90286	0.12022	
Std. Dev.	1.37205	120.71828	198.99895	3.43785	52.72665	0.00986	

Figure 5.4: BlueTube Strength Table

this results in compressive loads of 1303.26 Newtons (or 292 lbf). According to Always Ready Rocketry's BlueTube strength test, shown in Figure 5.2, this is far below the compressive yield stress of BlueTube.

The fins and the nose cone also experience launch loads, in the form of aerodynamic forces. Both of these components are made of fiberglass, whose material properties allow it to withstand compressive loads easily. In the case of the fins, high dynamic pressures result in large shearing forces. This is somewhat mitigated by the tabbed nature of the fin construction, however, fiberglass's ability to withstand the shear must be confirmed. The baseline flight simulation shows a max velocity of 199 m/s at an altitude of 340 meters. According to the Standard Atmosphere, air density at 340 meters is 1.1855 kg/m^3. Using Equation 5.2 the max dynamic pressure on the fins is 19800.5 kPa (2872 psi).

$$Q = (1/2) * \rho * v^2 \tag{5.2}$$

According to SubsTech material properties, fiberglass can withstand 4500 psi of shear stress. Proving that tabbed fiberglass fins can survive all expected flight loads.

6 Payload Criteria

6.1 Payload Objectives and Success criteria

Payload Mission Objectives

1. MV will remain connected with GS and Controller at all times throughout mission
2. Payload Bay will remain connected throughout entire mission
3. All separable LV components will have GPS tracking at all times
4. FPV system will be utilized to remotely pilot MV to target locations
5. Payload Objective system will recover at least a 50 mL sample of simulated lunar ice
6. MV will remain retained inside LV until specifically controlled by GS
7. MV will operate portions of the mission in an autonomous mode

Payload Mission Success Criteria

1. MV will have established connection by time of release
2. Payload Bay will remain connected at all times
3. All components will be recoverable and reusable
4. MV will collect a sample of at least 20 mL

6.2 System-Level Design Alternatives

6.2.1 Payload Structures

The design for our payload requires a structure to connect all payload subsystems and keep them that way for the duration of the mission. Before we could start brainstorming our payload, we initially had to consider criteria to follow. Upon reading the rules, it was concluded to be in our best interest to pursue some form of airborne capable vehicle. As illustrated by images and tables below, all iterations the chassis has seen constant revision.

The Mk 1 was the team's initial concept for payload structure design. This is the only version that implemented wheels and a ski for terrestrial locomotion. A camera was also considered as it was previously unclear how close a pilot could get from where the payload would be deployed in the field. Being the smallest of the three designs, it is also the lightest of the bunch. Having the thinnest frontal area, aerodynamics are better for this model than the others. This iteration did have a well balanced CG, with the battery offsetting the weight of the auger (potential method for sample extraction). Adaptability was not designed into the Mk 1 concept. Unfortunately, electronics for the on board control system weren't thought of, so many changes would have to be had to do so.

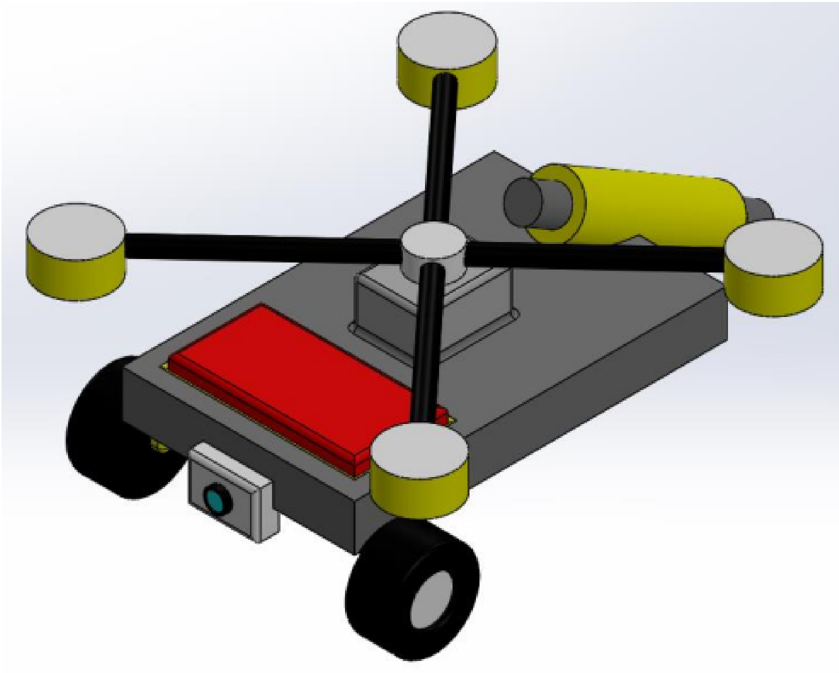


Figure 6.1: Payload Mark 1 Design

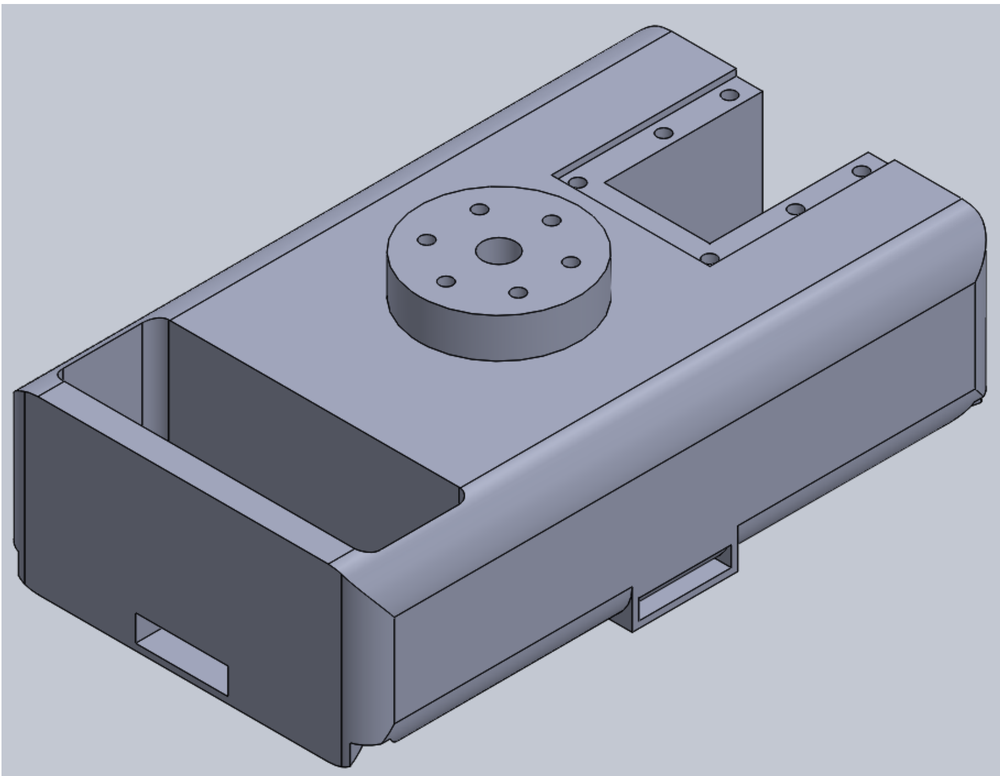


Figure 6.2: Payload Mark 2 Body

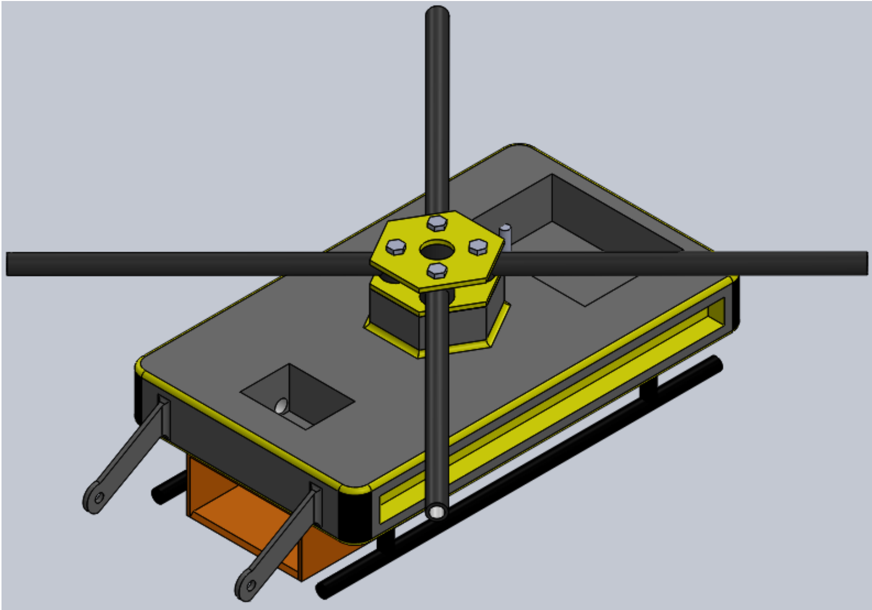


Figure 6.3: Payload Design Mark 3 Expanded

Post a QA session, a new and more in depth understanding of the rules, Mk 2 differed greatly from Mk 1. Two striking differences are the lack of camera and wheels. Weight increased as compared to the Mk 1 due to the larger chassis. With a majority of components being held internally, aerodynamics are comparable with the Mk 1. The battery and auger for sample extraction are located at opposite ends of the chassis to offset each other. Electronics are located in the center under the propeller boom mount. This layout permits a nearly centered CG. Adaptability is a new feature realized with the Mk 2. The collection mechanism was designed separately from the chassis, so a mounting region was designed in. Notches were added for restraint inside the rocket body.

Most recent is Mk 3. Similar to Mk 2, it was optimized to fit within the constraints of our rocket body and in parallel with the deployment mechanism. The volume of Mk 3 is less than that of Mk 2, thus resulting in a lower weight. Aerodynamics remains similar with a similar frontal area. Mk 3 was designed with a new collection method in mind, so a rearrangement in component placement was a necessity. This rearrangement improves the CG over previous designs. Legs were added as a method for restraining the payload. Rotor-booms are now capable of collapsing to fit within the rocket body.

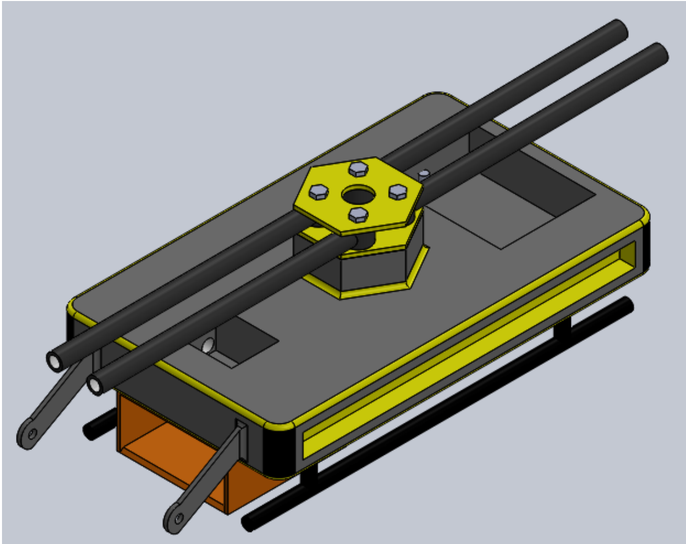


Figure 6.4: Payload Design Mark 3

Draft		**Mk 1**		**Mk 2**		**Mk 3**	
Parameter	Weight	Score	Viability	Score	Viability	Score	Viability
Weight	5	9	45	6	30	8	40
Aerodynamics	3	7	21	8	24	9	27
CG	4	7	28	8	32	9	36
Adaptability	2	4	8	8	16	10	20
Total Viability		102		102		123	

Table 6.1: Payload Structure Design Decision Matrix

Another major component in structural design is choosing materials. The decision was weighed in a matrix based on the parameters weight, tolerance, manufacturablility, durability, and cost.

6065 Aluminum was the initial material of choice due to its commonality. Unfortunately, it is the heaviest material on this list, with a density of 2.7 g/cm. It is more than capable of holding high tolerances. 6065 Aluminum is easy to machine, but would not allow for internal geometries. Durability is another parameter where this material scores high on.

Acrylonitrile Butadiene Styrene (ABS) is a common 3D printable material. It has a density between 0.9 g/cm - 1.53 g/cm. Tolerances vary depending on print environment. ABS is an easy material to work with, and allows for geometries not capable with traditional manufacturing methods. It has a high durability and is cheap and easy to access.

Polylactic acid (PLA), another 3D printable material, has a density of 1.25 g/cm. Tolerances and manufacturability compare to ABS. Compared to ABS has low durability. It is cheap and easy to access.

3D printed carbon fiber has a density around 1.34 g/cm. Tolerances and manufacturing are similar to that of ABS and PLA. Carbon fiber filaments have higher durability than other 3D printable materials. Cost is greater than that of other filaments.

Lexan is a form of polycarbonate with a density between 1.2 g/cm - 1.22 g/cm. It is able to hold tolerances comparably to 3D printed materials. Manufacturing is simple; cutting lexan layer by layer and stacking layers together with epoxy. This material costs more than PLA and ABS, but is cheaper than the other options listed.

Draft		**6065 Aluminum**		**ABS**		**PLA**		**Carbon Fiber(3D printed)**		**Lexan**	
Parameter	Weight	Score	Viability	Score	Viability	Score	Viability	Score	Viability	Score	Viability
Weight	5	6	30	10	50	10	50	10	50	10	50
Tolerance	2	10	20	8	16	7	14	8	16	8	16
Manufacturable	4	6	24	10	40	10	40	9	36	10	40
Durability	3	10	30	8	24	6	18	8	24	8	24
Cost	5	6	30	10	50	10	50	6	30	8	40
Total Viability		134		180		172		156		170	

Table 6.2: Payload Structure Material Decision Matrix

6.2.2 Payload Bay Communication and Control

In order to provide the launch vehicle with a capability to transmit its status and receive commands from the ground, the rocket body will be equipped with a communication and control system. The fundamental components of such a system are a controller on the rocket, a receiver/transmitter on the rocket, a GPS module to find the vehicle's location, a receiver/transmitter on the ground, a battery system on the rocket, and a battery monitor to track the power levels of the vehicle. The following paragraphs and figures examine the specific setups that were considered, rank them on their viability and cost-effectiveness, and justify the selection of the primary system.

6.2.2.1 Payload Bay Controller

Decision Matrix Methodology:
When performing the viability analysis, six parameters were considered: affordability, computational functionality, comm integration, hardware interface, ease of use, and total experience. Affordability measures the financial cost for acquisition of the controller, with 10 representing no cost. This parameter has a weight of 4 out of 5, as the team has a limited budget for the year and there are many similar microcontrollers and single-board computers of comparable capabilities with differing prices. Computational functionality represents the ability of the controller to complete its various required tasks. Factors considered included RAM, the processor, and classification as a microcontroller or computer. This is given a weight of 5 because the most important role of the controller is to carry out its programming efficiently and effectively. Comm integration is decided based on whether the board contains a built-in form of communication, how many forms there are, and the ease of working with that form of communication. Since there are many ways to add communication capabilities to a controller, this parameter is given a weight of 2. Hardware interface considers the number of input/output pins available and therefore measures the ability of the controller to receive signals from the rocket, drone, and ground as well as execute its commmands. The ability to manage these responsibilities is key to mission success, but since the programming is of greater importance, hardware interface is assigned a weight of 4. Ease of use measures the relative difficulty of programming and using the controller based on its programming language and built-in comm systems, if applicable. Since this streamlines the development process, a

weight of 3 is assigned. Finally, prior experience is assigned based on team members' familiarity with the device. This also streamlines the development process, leading to a weight of 3.

Controller Type		**Raspberry Pi Zero W**		**Raspberry Pi Zero**		**Arduino Uno**		**Adafruit Radiofruit**		**Adafruit Feather M0 Wi-Fi**	
Parameter	Weight	Score	Viability	Score	Viability	Score	Viability	Score	Viability	Score	Viability
Affordability	4	9	36	9	36	10	40	6	24	5	20
Computational Functionality	5	10	50	10	50	6	30	7	35	8	40
Comm Integration	2	10	20	0	0	0	0	3	6	5	10
Hardware Interface	4	10	40	10	40	6	24	7	35	7	35
Ease of Use	3	5	15	5	15	8	24	6	18	7	21
Prior Experience	3	5	15	5	15	9	27	6	18	7	21
Total Viability		176		156		145		136		147	

Table 6.3: Rocket controller decision matrix.

Controller Type	**Raspberry Pi Zero W**		**Raspberry Pi Zero**		**Arduino Uno**		**Adafruit Radiofruit**		**Adafruit Feather M0 Wi-Fi**	
	% of Budget	Total Viability	% of Budget	Total Viability	% of Budget	Total Viability	% of Budget	Total Viability	% of Budget	Total Viability
	0.23	176	0.12	156	0.01	145	0.59	136	0.83	147
Cost Effectiveness Score	76,521		130,000		1,450,000		23,051		17,711	

Table 6.4: Rocket controller cost-effectiveness matrix.

The abnormally high cost-effectiveness of the Arduino Uno is due to the team already owning two Uno boards, thereby making them free. To avoid infinite cost-effectiveness, the budget percent value of 0.01 was selected.

Raspberry Pi Zero W (Primary):

The Raspberry Pi Zero W has been selected as the primary rocket body communication controller due to its low price, computational abilities, integrated Wi-Fi, and ability to connect to all required peripheral devices. It is assigned an affordability value of 9 due to its low price of $10. Since the Zero W is a single-board computer running a Linux distribution as opposed to a microcontroller, it is assigned a computational functionality value of 10. With built-in Wi-Fi and Bluetooth capabilities, a comm integration score of 10 is assigned. The hardware interface includes a 40-pin header for connecting all the system components together, so a rating of 10 is assigned. Since the code for the Pi must be written in Python, an ease of use score of 5 is assigned, as the team will be learning the language during the development process. Finally, at least one team member has experience working with Raspberry Pis, resulting in a prior experience rating of 5.

Raspberry Pi Zero:

The Raspberry Pi Zero is identical to the Zero W except for not being equipped with Wi-Fi capability. Therefore, all scores are the same except for comm integration, which was 0 for this controller. Adding Wi-Fi to this board would require purchase of a Wi-Fi breakout or plug-in module. This would cost approximately $10, which offsets the $5 saved as compared to the Zero W. Therefore, this controller has not been selected as the primary option.

Arduino Uno:

The Arduino Uno is an entry-level microcontroller. The ARC already owns two Arduino Unos, so the affordability value of 10 was assigned. However, the Uno is an 8-bit microcontroller, which led to a computational functionality score of 4 being assigned. This controller also lacks built-in communication, so a score of 0 was given for comm integration. The hardware interface has 14 digital I/O pins in total, so a score of 6 was given. The Arduino Uno has several tutorials available and a relatively simple coding language, so an ease of use score of 8 is assigned. Several team members have experience working with Arduinos, so a prior experience rating of 9 is assigned. While the Uno is easy to work with, it lacks the computational and hardware capabilities required for the launch vehicle control and communication system. In addition, this system would likely have been used only for the small-scale flight, as the team had planned to upgrade to a Pi-based configuration for the full-scale vehicle.

Adafruit Radiofruit:

The Radiofruit is similar to an Arduino board, but it contains a built-in 915MHz LoRa transmitter/receiver, which is one of the communication options considered by the team. This board has a price of $25, so an affordability rating of 6 is assigned. The Radiofruit's clock speed is 8 MHz slower than the Uno, but it also contains built-in Arduino libraries for its LoRa module, so it is assigned a computational functionality rating of 7. With a single form of communication equipped that requires frequency adjustment to avoid interference with other teams, a comm integration score of 3 is assigned. The hardware interface contains 20 digital I/O pins, so a rating of 7 is assigned. The board runs Arduino, but the LoRa system would steepen the learning curve, so an ease of use rating of 6 is assigned. Finally, the team has experience with Arduinos but not with LoRa, so the prior experience rating is 6. Due to shortcomings in affordability, computational ability, and inexperience with LoRa, this board has not been selected as the primary controller.

Adafruit Feather M0 Wi-Fi:

The Feather is similar to an Arduino board, but it contains built-in Wi-Fi capabilities and an M0 processor, which is significantly more capable than that of the other Arduino-type boards considered. A score of 5 is assigned for affordability because the price of $35 is more than that of other controllers considered. The computational functionality score is 8 due to the M0 processor and higher SRAM as compared to the other Arduino-type boards, but the Feather is still considered a microcontroller. Due to the built in Wi-Fi capabilities, the comm integration score is 5 (as this is the only connectivity method supplied). The hardware interface also contains 20 digital I/O pins, resulting in a rating of 7. The board runs Arduino and would require additional work to learn Wi-Fi configuration, so an ease of use score of 7 is assigned. Finally, while the Feather is an Arduino-type board, the team does not have experience using one that is Wi-Fi capable, so a score of 7 is given. This board is the best option out of the Arduino-type boards considered, but due to its lower computational functionality and higher price, a Raspberry Pi setup was chosen instead.

6.2.2.2 Rocket Body Communication Receiver

Decision Matrix Methodology:
When analyzing the viability of rocket body communication receiver formats, the following parameters are considered: affordability, base range, interference mitigation, ease of use, and prior experience. Affordability measures the financial cost for acquisition of the receiver, with 10 representing no cost. A weight of 4 is assigned to affordability due to the limited team budget and variety of similar solutions available. Base range considers the amount of augmentation (e.g. antennas) required to ensure the system has adequate range; since LoRa is inherently designed for long range communication while Wi-Fi is optimized for short range, LoRa methods score higher in this area. This is given a weight of 5, as greater range means less augmentation that must be integrated. Interference mitigation considers that radio signals must not interfere with other teams; since Wi-Fi does not cause interference with radio

frequencies like LoRa, Wi-Fi methods score higher in this area. This is given a weight of 5, as it is imperative that the team's system does not interfere with other vehicles. Ease of use considers the relative difficulty of setting up the connection, interfacing the hardware, and integrating the connectivity into the controller programming. This is weighted 4 because a system that is easier to use will ensure that the team fully understands the setup and can reliably produce a connection. Finally, prior experience considers team members' familiarity with similar setups. Since this streamlines the development process, a weight of 3 is assigned.

Receiver Type		**Integrated Wi-Fi**		**Add-on Wi-Fi**		**Integrated LoRa**		**Add-on LoRa**	
Parameter	Weight	Score	Viability	Score	Viability	Score	Viability	Score	Viability
Affordability	4	10	40	9	36	10	40	6	24
Base Range	5	5	25	5	25	10	50	10	50
Interference Mitigation	5	10	50	10	50	4	20	4	20
Ease of Use	4	8	32	7	28	7	28	6	24
Prior Experience	3	8	24	7	21	5	15	6	18
Total Viability		171		160		153		136	

Table 6.5: Rocket receiver decision matrix.

Receiver Type	**Integrated Wi-Fi**		**Add-on Wi-Fi**		**Integrated LoRa**		**Add-on Lo Ra**	
	% of Budget	Total Viability	% of Budget	Total Viability	% of Budget	Total Viability	% of Budget	Total Viability
	0.23	171	0.32	160	0.59	153	0.48	136
Cost Effectiveness Score	74,348		50,000		25,932		28,333	

Table 6.6: Rocket receiver cost-effectiveness matrix.

Integrated Wi-Fi (Primary):

A Wi-Fi receiver integrated into the Raspberry Pi has been selected as the primary setup because of its low price (as it comes with the controller), mitigation of interference risk, ease of use, and team experience with similar setups. The Wi-Fi capability comes included with the controller, so no additional cost is required, resulting in an affordability score of 10. Wi-Fi is optimized for short range communications, resulting in a base range of 5. The use of a unique Wi-Fi connection instead of a radio frequency that could overlap with another team leads to an interference mitigation score of 10. The integration of Wi-Fi into the controller and the relative simplicity of establishing Wi-Fi connections result in an ease of use score of 8. Finally, since team members have used similar setups in the past, the prior experience score is 8.

Add-on Wi-Fi:

An add-on Wi-Fi module for a controller lacking connectivity would be wired or plugged into the board to provide a connection for data and command transmission. Since this requires purchase of a separate component (albeit an inexpensive one), an affordability score of 9 is assigned. The inherent short-range optimization of Wi-Fi, which requires additional antennas to overcome, leads to a base range score of 5. Since Wi-Fi overcomes radio interference, the interference mitigation score is 10. The need to ensure a proper physical connection of the module to the controller and set up the software communication between them results in an ease of use score of 7. Finally, while the team has experience working with integrated Wi-Fi systems, the use of a Wi-Fi add-on could result in different system behavior, resulting in a prior experience score of 7. Since the integrated option is cheaper and easier to use, an add-on Wi-Fi module is not the primary receiver form.

Integrated LoRa:

A controller with built-in LoRa connectivity would communicate with a similar setup on the ground. Since the communication functionality is built into the controller, an affordability score of 10 is assigned. LoRa is designed for long-range communications, so a base range score of 10 is given. The limited number of frequency bands available for LoRa in the United States makes interference with other teams very likely, so a score of 4 is assigned for interference mitigation. The LoRa transmitter is built into the board with the necessary libraries, but the team would be learning LoRa during the development process, leading to an ease of use score of 7. Since the team's prior experience with communication systems has been through cellular networks or Wi-Fi, a prior experience score of 5 is assigned. The integrated Wi-Fi setup has the affordability of the integrated LoRa setup while mitigating interference risk and being easier to use, so this setup is not the primary receiver form.

Add-on LoRa:

A separate LoRa transmitter would be connected to the controller to provide a communication link to a ground LoRa transmitter. Since add-on LoRa modules are comparitively expensive (approximately $20), an affordability score of 6 is assigned. LoRa is optimized for long range communication, so a base range score of 10 is given. Due to the likelihood of LoRa frequency overlap with other teams, an interference mitigation score of 4 is given. Since the team would be learning LoRa during development and would have to ensure proper hardware/software connections to the controller, an ease of use score of 6 is assigned. Finally, while the team does not have as much experience with LoRa, there is a former member who has used a separate LoRa transmitter on a model rocket who could provide guidance, so a prior experience score of 6 is given. Since an integrated Wi-Fi setup is more affordable, mitigates interference risk, and is easier to use, this system is not the primary receiver form.

6.2.2.3 Rocket GPS Module

Decision Matrix Methodology:
In the viability analysis of the GPS module configurations, four parameters were considered: affordability, sensitivity, hardware interface, and prior experience. Affordability measures the financial cost of acquisition of the GPS module. This is weighted 5 due to the high cost of several alternatives considered. Sensitivity measures the ability of the GPS to determine its position from a weak signal. Since it is important to acquire an accurate position from inside the rocket body, this is weighted 4. Hardware interface considers the type of connection to the controller as well as the variety of transfer buses available. Since all GPS boards considered are compatible with at least one of the controllers considered, a weight of 2 is assigned. Finally, prior experience measures the team experience with similar systems, which is rated 4 due to the streamlining of the development process.

GPS Module Type		**NEO-M8 Module**		**Adafruit GPS FeatherWing**		**SparkFun GPS Breakout**		**Adafruit GPS Hat**	
Parameter	Weight	Score	Viability	Score	Viability	Score	Viability	Score	Viability
Affordability	5	9	45	6	30	5	25	5	25
Sensitivity	4	10	40	9	36	9	36	9	36
Hardware Interface	2	8	16	6	12	6	12	7	14
Prior Experience	4	8	32	2	8	5	20	4	16
Total Viability		133		86		93		91	

Table 6.7: GPS module decision matrix.

GPS Module Type	NEO-M8 Module		Adafruit GPS FeatherWing		SparkFun GPS Breakout		Adafruit GPS Hat	
	% of Budget	Total Viability	% of Budget	Total Viability	% of Budget	Total Viability	% of Budget	Total Viability
	0.36	133	0.95	86	1.20	93	1.08	91
Cost Effectiveness Score	36,944		9,053		7,750		8,425	

Table 6.8: GPS module cost-effectiveness matrix.

NEO-M8 Module (Primary):

The NEO-M8 GPS module has been selected as the primary GPS module due to its affordability, sensitivity, hardware flexibility, and team prior experience. The NEO-M8 is the least expensive of all module configurations considered, so it receives an affordability score of 9. It also has a sensitivity of -167 dBm, which is the highest of the modules considered, leading to a sensitivity score of 10. The module is not integrated to a circuit board, so wiring and soldering will be necessary; however, this makes it compatible with all controllers considered and gives flexibility to the configuration. In addition, a variety of transfer bus protocols are available, ensuring it will integrate well with the functioning of the controller. For these reason, the hardware interface score is 8. Finally, team members who have used GPS for their projects have used u-Blox NEO modules, so the prior experience score is 8.

Adafruit GPS FeatherWing:

The Adafruit GPS FeatherWing is a GPS module integrated on a circuit board designed to directly integrate with an Adafruit Feather. Due to a price of $40, it receives an affordability score of 6. The sensitivity of the module is -165 dBm, giving it a score of 9. The board only communicates though a serial port and has an interface optimized for one controller, though it could be used with another. Therefore, it receives a hardware interface score of 6. Finally, the team has no experience with the type of GPS chip integrated into the board, so the prior experience score is 2. Since the NEO-M8 is more affordable, offers more hardware flexibility, and is more familiar to the team, the FeatherWing is not the primary GPS module choice.

SparkFun GPS Breakout:

The SparkFun GPS Breakout is a separate GPS module integrated with a circuit board. With a price of $50, the affordability score is 5. The sensitivity is -165 dBm, leading to a score of 9. The SparkFun supports both I^2C and serial transfer bus protocols, but it also requires a specific quick-attach cable setup, so the hardware interface score is 6. Finally, the team does not have experience with the specific GPS chip on the board, but a previous team member has used the SparkFun on a model rocket and could offer guidance if necessary. Therefore, the prior experience score is 5. Since the NEO-8M is more affordable, more sensitive, and has more flexible wiring options, the SparkFun is not the primary GPS option.

Adafruit GPS Hat:

The Adafruit GPS Hat is a separate GPS module integrated with a circuit board designed to conenct to a Raspberry Pi. With a price of $45, the affordability score is 5. The sensitivity is -165 dBm, leading to a score of 9. The hat only communicates through serial, and it is optimized for the Raspberry Pi, which is the primary controller option. Therefore, the hardware interface score is 7. Finally, the team does not have experience with the specific GPS module used on the board, but the team has used GPS on a Raspberry Pi before, so the prior experience score is 4. Since the NEO-M8 is more affordable, more sensitive, has a more versatile hardware interface, and is more familiar to the team, the GPS hat is not the primary GPS module.

Antenna Type	Yagi		Mideatek		Linux Mac	
	0.00	155	0.22	155	0.09	106
Cost Effectiveness Score	1,550		522		1,177	

Table 6.10: Antenna cost-effectiveness matrix.

6.2.2.4 Antenna

Decision Matrix Methodology:

Antenna Type		**Yagi**		**Mideatek**		**W1030**	
Parameter	Weight	Score	Viability	Score	Viability	Score	Viability
Affordability	4	10	40	4	16	9	36
Range	5	8	40	7	35	6	30
Efficiency	5	8	40	8	40	8	40
Power draw	4	7	35	6	24	6	24
Total Viability		155		115		106	

Table 6.9: Antenna decision matrix.

Yagi (Primary): The Yagi antenna that was already on hand would be able to connect to our Raspberry Pi with ease and be sure that everything would be able to communicate smoothly before, during and after flight. A big factor that came into play when deciding which external antenna to use for the Raspberry Pi was affordability and this scored as high as it did because there was already one previously on hand for us to use. The range we would gain from the Yagi antenna was the best out of all the possible options we considered making it so we would easily be able to communicate to the Raspberry Pi post-flight with ease. The efficiency of this antenna was the same as the others we considered and effectively would be able to do what we wanted with ease. Lastly, the power draw, however not the best, was the least out of the other antennas and therefore made it an obvious choice.

Mideatek: The Mideatek antenna would be connected to the Raspberry Pi to extend the range of WiFi to and from the Raspberry Pi. This particular model is made to be adaptable to many different sources which include the specific Raspberry Pi that we have chosen. However fairly affordable, it, unlike the Yagi antenna, we would still have to pay for and that is a large factor when deciding which one we should choose. The range, while good in a smaller scaled environment would not work well and would possibly cut out the farther away from launch it would be. All of the antennas efficiencies seemed to be the same and would depend on what battery is used to make sure it ran smoothly. Finally, the power draw wasn't the best in comparison to the Yagi antenna and we need to make sure that we conserve the most power possible in order for everything to work properly.

Linux Mac: Compared to the other antennas the Linux Mac scored the lowest as it didn't have a lot of the features we were looking for and it was possible that it was not going to work with the Raspberry Pi we had decided on. The affordability, however good, did not beat the Yugi antenna. The range of the Linux Mac antenna had the lowest range out of all the

Battery Type	Lithium Power Pack		LiPo Battery Shield		Raspberry Pi Battery Pack	
	0.41	100	0.57	95	0.60	101
Cost Effectiveness Score	244		167		168	

Table 6.12: Battery cost-effectiveness matrix.

antennas and would have caused problems with communication post launch. Efficiency of the antenna stayed on par with the other two and would have been able to accomplish all we wanted to, but we may not have been able to develop a strong link depending on the distance away from the launch site. Ultimately, the power draw from the battery was about the same as the Mideatek antenna and both drew more power than the Yugi antenna.

6.2.2.5 BATTERY

Battery Type		**Lithium Power Pack**		**LiPo Battery Shield**		**Raspberry Pi Battery Pack**	
Parameter	Weight	Score	Viability	Score	Viability	Score	Viability
Affordability	4	8	32	6	24	6	24
Reliability	4	8	32	8	32	8	32
Weight	3	6	18	6	18	7	21
Size	3	6	18	7	21	8	24
Total Viability		100		95		101	

Table 6.11: Battery decision matrix.

Lithium Power Pack: The Lithium Power Pack was a rather good contender when considering a battery for everything the payload, however it was unclear to if some necessary components were included and would require much more assembly. The affordability was the best out of the three considered, however it was not much less than the other two. Reliability of the Lithium Power Pack was the same as the LiPo Battery Shield and the Raspberry Pi Battery Pack and as long as it stayed charged it would be reliable. The weight was scored low because each battery could be considered heavy with the thought of it being inside the rocket, but would not be a hindrance in the long run. The size of the Lithium Power Pack is the biggest out of each battery considered and may cause problems with other components.

LiPo Battery Shield: The Li Po Battery Shield is around the same price as the Raspberry Pi Battery Pack and a little bit more than the Lithium Power Pack, in regards to affordability. The range however is the same as both of the the other batteries considered. The reliability is the same as the Lithium Power Pack in regards to it being able to do everything that is needed however the charge life is not as good as the Raspberry Pi Battery Pack. For the LiPo Battery Shield weight, it is a bit heavy and would run into the same problems as the Lithium Power Pack were we to make either of them the Primary. Size of the battery, however, would work well within a placement in the body.

Raspberry Pi Battery Pack (Primary): The Raspberry Pi Battery Pack, however a little bit more expensive seems to be more suitable fit for what is needed. Reliability between each battery considered is the same and each should stay charged and give energy to everything that needs it. The weight of the Raspberry Pi Battery Pack is the lightest out of the three options making it easier to accommodate for and the size is also the smallest, therefore it will fit inside the rocket body with ease.

Battery Monitor Type	Adafruit		ACS712		TOL-10617	
	0.24	105	0.14	113	0.26	91
Cost Effectiveness Score	437		787		346	

Table 6.14: Battery Monitor cost-effectiveness matrix.

6.2.2.6 Battery Monitor

Battery Monitor Type		**Adafruit**		**ACS712**		**TOL-10617**	
Parameter	Weight	Score	Viability	Score	Viability	Score	Viability
Affordability	4	7	28	9	36	5	20
Compatibility	5	10	50	10	50	10	50
Reliability	3	9	27	9	27	7	21
Total Viability		105		113		91	

Table 6.13: Battery Monitor decision matrix.

Adafruit: The Adafruit Battery Monitor is a relatively affordable option that makes it able to monitor voltage and current output from the battery. In comparison to the ACS712 and the TOL-10617, the Adafruit is right in between the two on price point. Each of the battery monitors that were considered all are perfectly compatible with the Raspberry Pi that will be used and the Adafruit has the same reliability as the ACS712, meaning it will be able to do everything that is needed in an efficient manor.

ACS712 (Primary): In comparison to the Adafruit and TOL-10617, the ACS712 is a largely affordable option for a battery monitor. The compatibility from the battery monitor to the Raspberry Pi is made so it is easy to plug in and be able to monitor the current and voltage of the battery. The reliability of the ACS712 is the same as the Adafruit, but is more reliable than the TOL-10617.

TOL-10617: The affordability of the TOL-10617 is quite a bit more than the other battery monitors that were considered and that plays a large factor in deciding which one to get. However, the TOL-10617 is very compatible to the Raspberry Pi, just like the other two. The reliability is less than the other options because it is said to work better under a 12V battery and the primary battery choice is only a 5V.

6.2.2.7 Total Primary System Description

The rocket body will be equipped with a Raspberry Pi Zero W which will communicate with a ground station to enable control of the payload bay servos, initiate startup of the mission vehicle, relay the GPS location of the rocket in real-time, and transmit the voltages of all batteries in the payload bay. The Raspberry Pi will receive a 2.4 GHz Wi-Fi connection from a ground wireless router with a 16 dBi Yagi antenna. In addition, a NEO-M8 will be equipped to enable transmission of the GPS coordinates of the vehicle. Since the operational limits of the GPS module are 4g, the module will not be operable during the boost phase of flight, but it can be used following motor burnout to track vehicle descent. The Raspberry Pi will be powered by a battery that is independent from all other power systems on the vehicle. A signal cord will connect it to the drone until the drone has been released.

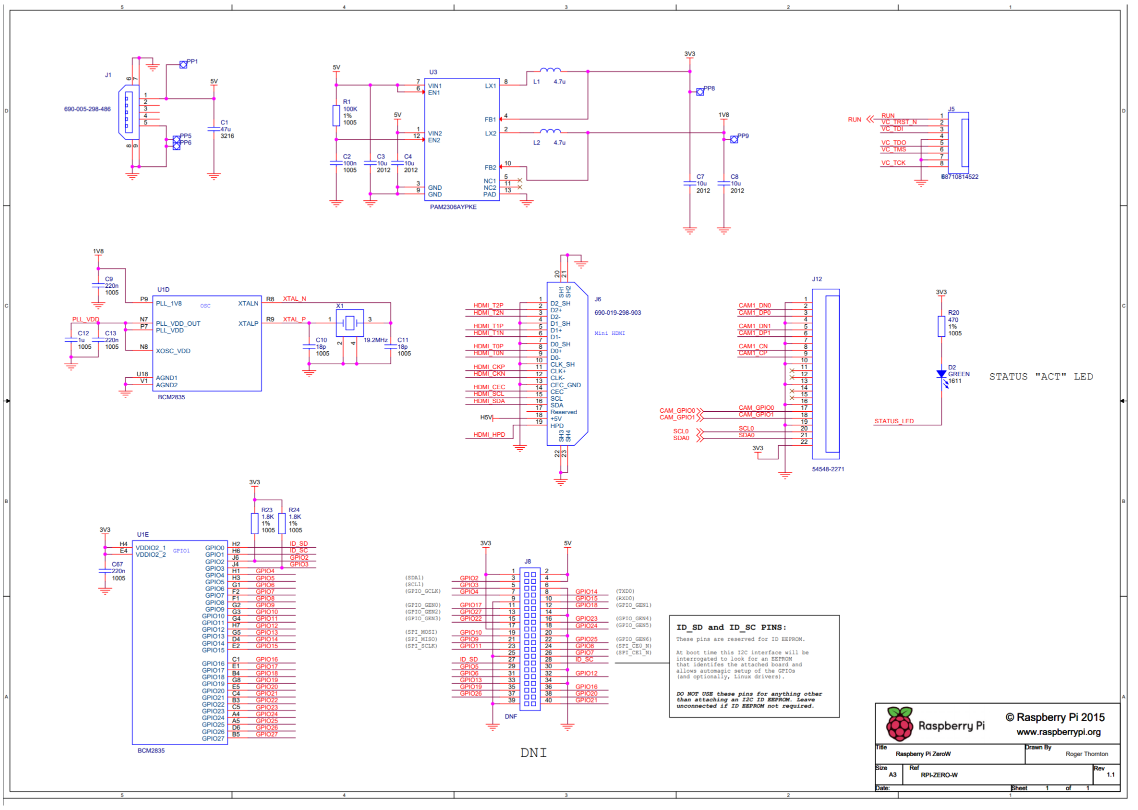


Figure 6.5: Raspberry Pi Wiring Diagram

Component Specifications:

The following figures display the wiring and dimensions of the Raspberry Pi, respectively. Both figures were downloaded from raspberrypi.org.

The mass of the Raspberry Pi Zero W is given as 0.0198 lb (9 g) on the Raspberry Pi website. Similarly, the u-Blox website gives the weight of the NEO-M8 as 0.0035 lb (1.6 g).

Basic Materials List:

Raspberry Pi Zero W, GPS board, solder, electric wiring, mounting mechanism.

6.2.2.8 System Interactions

The launch vehicle communication system will mechanically interact with its attachment mechanism to the rocket body and the drone through a signal cord. Any necessary modifications to ensure the restraint of this system in the rocket body will be made. The drone will initially be dependent on the electrical system of the rocket body, though it will possess a failsafe system in the event of a rocket body power loss. From an electrical standpoint, the communication system will receive battery levels from the drone, awaken the drone from hibernation,

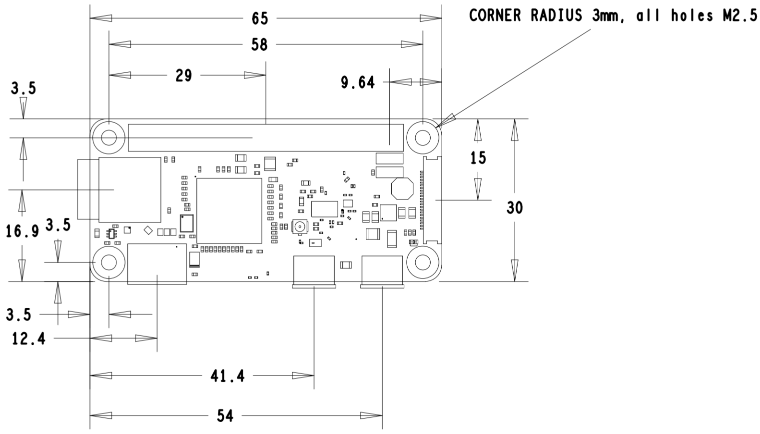


Figure 6.6: Raspberry Pi Dimension Schematic

and initiate the deployment sequence through the signal cord and wiring in the rocket body. Through its Wi-Fi connection, the communication system will also receive commands from the ground to awaken and deploy the drone, and it will transmit the GPS coordinates and battery levels of the rocket body and drone back to the ground station.

6.2.3 Payload Control and Power Monitoring

Power Distribution and Monitoring Objectives:

- Electrically disable payload motion devices (eg: props, mining)
- Provide statistics on current draw from individual motion devices
- Provide statistics on battery voltages and current draw
- Prioritize power input to optimize maximum mission time: Tether -> Idle Pack -> Main Pack

Custom Power Distribution Board
A custom designed circuit and pcb. The circuit is designed around our objectives, allowing us to combine the job of multiple physical boards onto one. This reduces total independent parts on the payload and simplifies payload assembly and reduces connections we would otherwise have to manually solder. In addition, we can also place pads convenient to our application, keeping our electrical neat and tidy. A custom board allows us monitor power usage on any arbitrary device and bake power prioritization into a single part. However, with a brand new design, there is the potential for unforeseen bugs.

Off-the-Shelf Components

There are no single board solutions that will accomplish all of our objectives. This option will require multiple boards and multiple instances of many boards, requiring lots of space and weight. Purchased components, however, are inherently reliable. The UAV hobby is quite large, quality parts and manufactures are known. In addition, replacement and equivalent boards would be relatively easy to obtain and swap out in the event of a failure. Even so, power prioritization and disabling motion devices would still require a custom circuit.

Direct Wiring

The lack of any devices to prevent power flow makes this option the most reliable, however it accomplishes none of our objectives. This leaves us in the dark as far as battery levels and motor performance. While there is nothing to go wrong, this option is unfavorable.

Decision Matrix Methodology

Reliability describes inherent trust in the system. This considers the opportunity for faults to occur, and the ability to detect them early in the testing process. Data Collection represents the particular solutions ability to provide information relating to battery voltage and draw, motor draw, and recovery draw. Without this information our control system is in the dark as to the health of our payload. Physical Size is an important consideration, however it is not a deal breaker. If the solution is the best we can work around it. Ease of Implementation is inversely related to how complex the system is, simpler systems are preferred. Part count is related to physical space and reliability, less independent components are preferred.

Power Distribution and Monitoring		Custom Board		Off-The-Shelf		Direct Wiring	
Parameter	Weight	Score	Viability	Score	Viability	Score	Viability
Reliability	5	7	35	8	40	10	50
Data Collection	5	10	50	8	40	0	0
Physical Size	4	8	32	4	16	10	40
Ease of Implementation	2	5	10	7	14	10	20
Part Count	2	8	16	4	8	10	20
Total Viability		143		118		130	

Table 6.15: Power Distribution and Monitoring Objective Design Decision Matrix

Current Leading Design

A custom circuit on a custom PCB provides the most amount of information to the flight controller, while allowing for the most adaptability to the size and shape of the quad. A preliminary schematic has been laid out

6.2.4 Payload Control

Control System Objectives:

- Allow for autonomous flight
- Allow for pilot initiate, automated functions

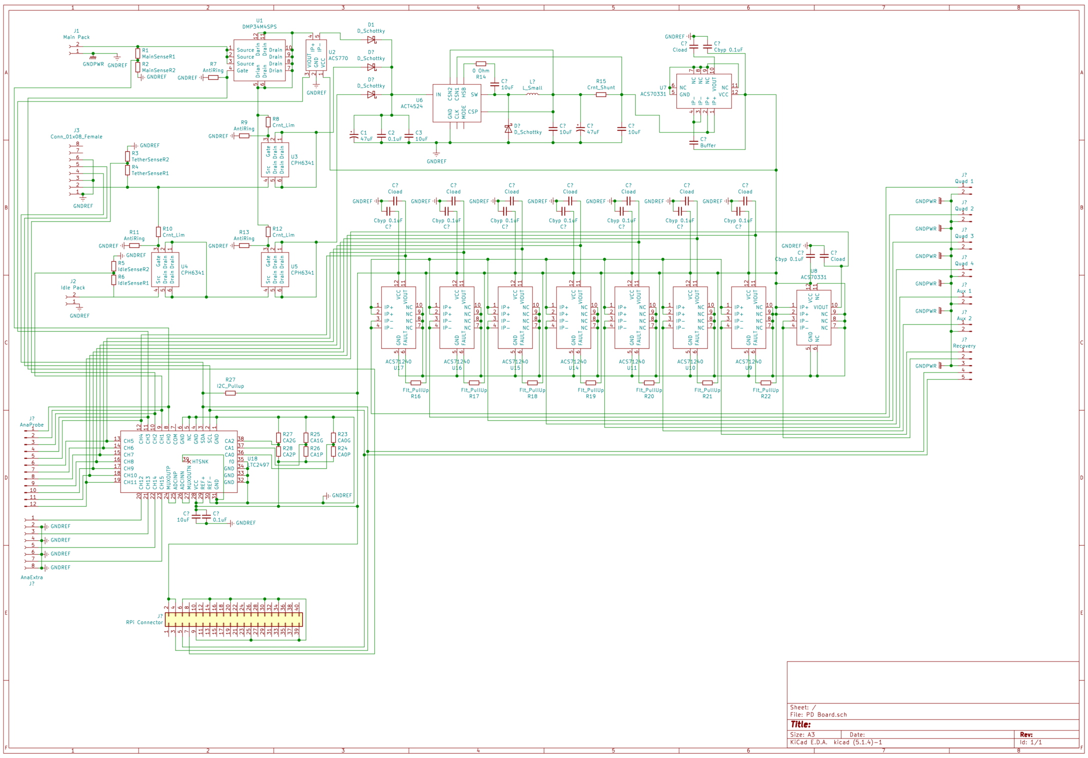


Figure 6.7: Preliminary Schematic

Control System Procedures

- Initial Power Up and Boot
  - Occurs well ahead of loading in rocket
  - IMU calibration is verified
  - Motion devices are tested to verify proper function
    - Deploy system cycled
    - Mining system cycled
    - Props brought to full
  - Current and Voltage sensing checked
- Idle
  - Motion devices de-energized, deploy system locked
  - Payload is secured to the rocket, tether attached
- Active
  - Command to release sent by ground station
  - Payload shuttled out of rocket
  - Motion devices energized
  - Deploy system cycled, Payload takes off

Raspberry Pi and Independent Flight Controller
The control loop of a quadcopter must be incredibly fast. Popular firmwaresâĂŹ control loops run at 8-32KHz depending on individual use case, maximums range in the hundreds of kilohertz. This means any software we write would have to loop in 125us at most, 30us would be ideal. For this reason we are off-loading the real-time control loop to dedicated hardware. This allows us to use slower and easier to program computers as the âĂŸcentral hubâĂŹ. The central hub is responsible for arbitrary tasks: communicating telemetry information, monitoring current and voltage, piloting the flight controller while autonomous, driving any servos not driven by the mining subsystem, and warning the pilot of any errors, warnings, or excessive power usage. The Raspberry Pi supports running arbitrary compiled programs and scripts. This allows us to use languages were more comfortable developing in as well as giving us the ability to use debuggers and have programs running asynchronously.

Off-the-shelf (eg: PixHawk)
The PixHawk is very rigid, it wants to be an autopilot, and solely and autopilot. Configuring a PixHawk to perform arbitrary tasks would be difficult at best. Ardupilot/Librepilot are open source autopilot projects that have been used by others to achieve similar objectives. Ultimately, these use either MavLink or MultiWii Serial Protocols to allow a flight controller and a computer to communicate. There are advantages to a commercial product, technical support and forums exist.

Decision Matrix Methodology
Adaptability refers to how easy it is to configure the particular solution to perform arbitrary tasks. This is similar to ease of use, however, it is important to note that just because a partic-

ular solution is more approachable (eg: Graphical front-end for modifying parameters) this does not make it easier to configure to, say, cycle the recovery system. Autonomous Flight is fully computer controlled, and as close to hands off as safely possible. A fully autonomous mission would be ideal. Automated Flight is similar to autonomous flight, this is the ability to configure the control system to perform autonomous tasks initiated by a human pilot, for instance: press and hold a switch to autonomously land, cycle recovery, and take off.

Control System		Raspberry Pi and Off-The-Shelf Flight Controller		PixHawk	
Parameter	Weight	Score	Viability	Score	Viability
Adaptability	5	9	45	4	20
Autonomous Flight	4	6	24	9	36
Ease of Implementation	2	5	10	7	14
Part Count	2	8	16	4	8
Total Viability		93		68	

Table 6.16: Control System Objective Design Decision Matrix

Current Leading Design

Raspberry Pi and Flight Controller communicating over MultiWii Serial Protocol (MSP) fulfils our objectives best. MSP is the de-facto standard for serial communication with a flight controller, most common firmwares use MSP to allow a Graphical UI to set and modify parameters. In addition, the Raspberry Pi allows us to perform tasks simultaneously with relative ease.

6.2.5 Payload Communication

Payload Communication Objectives

- Two Independant communication systems, one or the other can fail or loose connection and not compromise the mission
- Have at least one connection not reliant on a tracking antenna for range
- Stream camera feeds back to the ground station with minimal latency, to be used for piloting payload

2.4 GHz WiFi via Tracking Antenna

The Raspberry Pi already has a 2.4GHz WiFi modem installed. Since we are already using a directional antenna to maintain communication with the rocket body, Implementing a similar system to track the Raspberry Pi on the payload should be relatively straight forward. Wifi will have enough bandwidth to support a camera stream, this makes communicating telemetry and streaming convenient. However, a tracking directional antenna is a must, standard omnidirectional antennas do not have anywhere close to the desired range.

5 GHz WiFi via Tracking Antenna

5Ghz is very similar to 2.4. 5Ghz has the advantage of increased bandwidth, however it is not already present in the Raspberry PiâĂŹs WiFi modem. 5Ghz shares the same limitations as 2.4; a directional tracking antenna would be mandatory for the range.

915MHz LoRa
LoRa has an inherent advantage, standard ranges for even the lowest powered modems are in excess of 2 kilometers, full power ranges often exceed 10 kilometers, line of sight. However, LoRa radios are not comparable to WiFi, in terms of uplink/downlink speeds.

5W 2.5-5 GHz Amplifier
This would certainly boost the effective range of both WiFi standards, However this is not preferable. This will stomp all over other teams attempting to use 2.4 and 5 GHz protocols.

AMPRNet
AMPRNet is a packet-based network protocol designed to be used with amateur radio. Range would not be a concern, any amplification is likely to not interfere with other teams as the 1.25-m band is well outside the range of common telemetry and wifi modems. However, AMPRNet is fundamentally limited by this frequency. Standard speed is 1200 baud, 9600 baud is considered high speed. This would force us to be selective with telemetry, and will not support a camera stream. Also, since AMPRNet uses ham radios, this would require us to be licensed in order to communicate.

Primary Telemetry Decision Matrix Methodology
Primary telemetry will support a camera stream, therefore network speed is of utmost importance. Efficiency is inversely related to power consumption and related network speed. Range is not as important, the ground station can support a directional tracking antenna, for this reason the 5W amplifier is not considered. Ease of implementation is effectively the inverse of how complex the system is. Working around a complicated system is worth it if it gives us speed or range.

Primary Telemetry		2.4GHz WiFi via tracking antenna		5GHz WiFi via tracking antenna		915MHz LoRa		AMRPNet	
Parameter	Weight	Score	Viability	Score	Viability	Score	Viability	Score	Viability
Bandwidth	5	6	30	8	40	4	20	0	0
Efficiency	4.5	8	36	7	31.5	6	27	2	9
Range	4	5	25	5	25	8	40	9	45
Ease of Implementation	3	8	24	6	24	6	18	2	6
Total Viability		115		111.5		105		60	

Table 6.17: Primary Telemetry Objective Design Decision Matrix

Secondary Telemetry Decision Matrix Methodology
Secondary Telemetry exists as a failover if the tracking antenna loses its lock. Communication via an omnidirectional antenna is required, it is impossible to predict where and in what position the payload might lose its primary link. Efficiency gauges how much power it takes to run the radio, compared to how fast the link is. This isn't as important as primary, since secondary serves mainly as a fail-safe. Susceptibility to interference describes the radioâĂŹs ability to interfere, and its vulnerability to interference. At the range where Primary telemetry lose is likely, interference with other teams is unlikely. Ease of implementation is not nearly as important. Complexity doesn't matter much, so long as communication is guaranteed.

Secondary Telemetry		AMRPNet		5W Amplifier		915MHz LoRa	
Parameter	Weight	Score	Viability	Score	Viability	Score	Viability
Range	5	9	45	6	30	8	40
Efficiency	3	2	6	4	12	8	24
Susceptibility to Interference	3.5	8	28	2	7	6	21
Ease of Implementation	2	2	4	8	16	7	14
Total Viability		73		65		99	

Table 6.18: Secondary Telemetry Objective Design Decision Matrix

6.2.6 Payload Objective System

Decision Matrix Methodology:
Durability for the payload objective is the ability to withstand forces and wear so the system functions properly when needed. This is very important since the mission cannot be accomplished without the system functioning. Since the durability is important to mission success it is given a high weight of 5. The reliability factor measures the consistency of the system to constantly perform to the standards necessary for mission success. This is also important since the system must be trustworthy to perform the tasks, thus reliability is given a weight of 5. The weight of the system is weighted based off that fact that the objective system will be placed on a drone where every gram counts. Weight factors to be decently important with a weight of 4. Power is less important than weight since after the sample has been gathered, the mission is nearly done. For this reason power is given a weight of 3. Sample size is whether the correct volume of sample is collected and also takes in account the reliability of measuring the amount of ice sampled. This is a definite mission parameter so the weight of sample size is set to 5. Piloting ability is determined on how important the pilots actions are toward mission success criteria for the objective system. The more important the pilot is the lower the score or the less important the pilots actions are the higher the score. Piloting ability is set to a weight of 2. Sample disruption is how measured by how much the objective system will impact the sample area and whether it could potentially make it more difficult for the system itself to collect the ice. This seems unlikely so the weight of sample disruption is set at 2.

Design		**Brush Roller**		**Auger**		**Bay Door**		**Scoop**	
Parameter	Weight	Score	Viability	Score	Viability	Score	Viability	Score	Viability
Durability	5	8	40	6	30	6	30	6	30
reliability	5	7	35	6	30	7	35	7	35
Weight	4	7	28	7	28	6	24	6	24
Power	3	6	18	6	18	6	18	7	21
Sample Size	5	7	35	6	35	5	25	3	15
Piloting Ability	2	6	12	4	12	4	8	2	4
Sample Disruption	2	6	12	6	12	6	12	4	8
Total Viability		180		156		152		137	

Table 6.19: Payload Objective Design Decision Matrix

Current Leading System Design

Brush Roller:
A brush roller, similar to that of the front of a vacuum cleaner, will be secured on the drone. The brush roller will spin from a servo to brush the ice pellets into the drone, where a storage system will be awaiting the ice. The when the spinning brush impacts the ice sample, it will be swept into the collection bin.

The brush roller will be very simple with only a servo that will cause the brush to spin, this simplistic design will function when necessary thus creating a high reliability. With the small amount of parts the system will be very durable increasing the durability score. With only one servo the power draw will be very low so the power score is high. Since the brush and collection bin will be made of plastic the overall design will be very light effecting the weight score. The brush will consistently sweep ice into the storage bin which has enough volume for mission success so the design has a high sample size score. Very little piloting needs to be done other than landing on the ice sample so the sample disruption score and the piloting score are high.

Specifications:
The brush needs to fit within the confines of the width of the drone. It will also need to spin fast enough to properly launch the ice into the collection box.

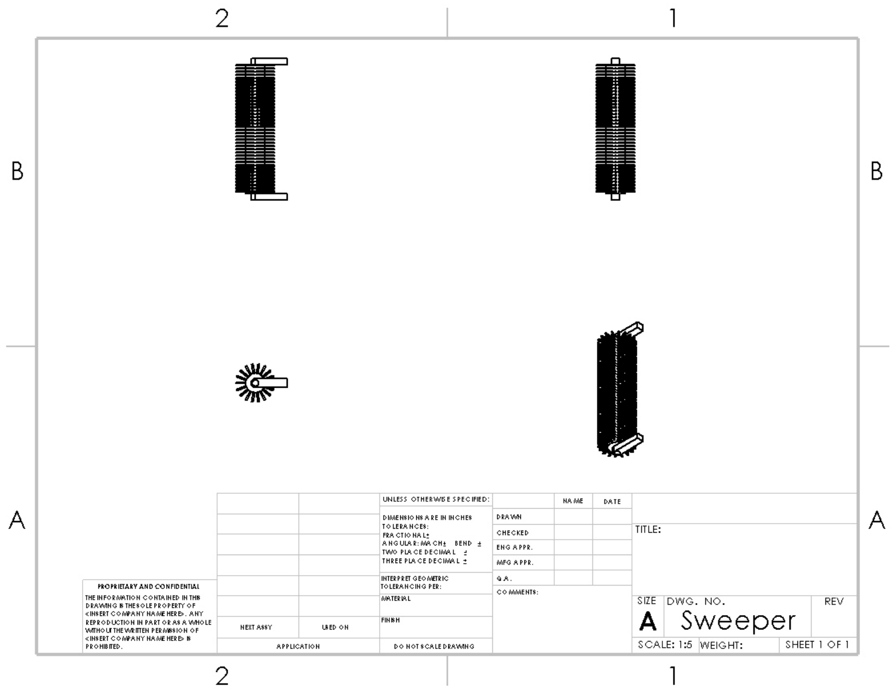


Figure 6.8: Brush Roller Design

Basic material list:
Servo
Collection Box (Plastic)
Spinning brush (Plastic)

Auger:
A spiral auger surrounded by a tube will be actuated by a servo. The spinning motion of the auger will move the ice up the augers walls and once the ice reaches the top there will be a storage bin to accumulate the ice. The auger system will be placed within the drone and actuated once the drone is maneuvered so the auger is in contact with the ice.

The auger system would be very simplistic with few parts so the reliability score would be higher. The storage bin would have enough volume to hold the required sample size for mission success and with testing it could be determined with a certain level of precision how much ice sample would be collected. This increases the sample size score. The system would run off of one servo so the power score will also me higher than average. The durability of the system would be around average because the servo would have to be actuating constantly to achieve movement of the auger bit. The weight score would be very high since the system will be made mostly of plastic and most of the weight would be the single servo. The single servo would draw that much power either causing a high score for the power. The piloting score is slightly below average since the drone would have to be maneuvered so the auger was place adequately on the ice sample. However, the auger could be stationary on the ice sample increasing the sample disruption score.

Bay door:
The belly of the done would split down the middle and open up like bomb bay doors. These doors would be actuated by servos. The drone would then be maneuvered over top of the ice pile. Either the engines would cut or the drone would have a controlled decent on top of the ice. At which point, the bay doors will close, capturing the ice within the bay.

Since the system is still simple but slightly more complex than the simplest system the bay door gets an above average score for reliability. The system would be durable enough to be dropped onto the ice sample so the durability score would also be higher than normal. The power draw of the system will be very low since it will only need one or two servos depending on the gearing used to actuate the bay doors. The bay doors would have more than enough volume to hold the necessary sample size, but there is a factor of randomization to how much ice actually makes it into the doors making the sample size score average. The weight of the system will be relatively low since most of the construction will be made of plastic. The piloting ability score will be slightly less than average since the pilot either needs to drop the drone or have a controlled decent on the ice sample right where the bay doors are located. That being said the sample disruption score would be above average since the rotors don't need to be spinning for the system.

Vacuum:
A vacuum pump will be located within the drone body and the suction tube would be placed on the belly of the drone. The suction tube would also be connected to a storage bin with a filter so the ice wouldn't pass through the vacuum. The vacuum would actuate when the drone was maneuvered on top of the ice pile creating a pressure difference to allow the ice to travel up the tube into the storage bin.

Since the drone could be stationary on the ice sample site while the vacuum actuates the sample disruption score is higher than average along with an increased pilot ability score. However, the vacuum would have a complex system that has multiple failure modes. This decreases the score on the reliability score. Since there are multiple different parts and connections needed both electronically and mechanically the durability of the systems score will be lower. A vacuum pump is also heavy and high power draw so the weight and power scores are low. The storage bin would have the volume needed for the mission, but it is unknown whether a vacuum could move the ice into the storage bin so the sample size score is mid tier.

Scoop:
A box would be paired with the drone design that would have a rotating front face. The hinge for the front face would be connected to the bottom of the box so when the front face rotates it would go parallel to the bottom face, thus creating an open box with a scoop. The front face would be controlled by a servo that would open the box once near the ice pile. The drone would then scrape the scoop face across the ice pile and the servo would close the box, effectively capturing the ice within the box

This scoop system with its high simplicity and robust design should be able to hold up with multiple uses and perform its task each use. This gives the scoop a high scoring in durability and reliability. Although the system would be able to function properly, the sample sizes would be inconsistent since the pilot would have to maneuver the drone to properly scoop the ice. This inconsistency leads the scoop to have a lower score for sample size. Since the pilot of the drone has such a high impact on the system the pilot ability score is very low.The scores in weight and power are both higher since the construction would just be a plastic box and one servo. Another downside to this design is that the rotors on the drone would have to be spinning to achieve the horizontal speed needed for the scoop to function. This could disrupt the ice sample site and have it difficult for the scoop to acquire the sample needed thus making the scoop have a low sample disruption score.

6.2.7 Payload Withdrawal System

Decision Matrix Methodology:
The Durability parameter of a system pertains to the ability to withstand harsh forces, such as those present at takeoff, and maintain optimal operation. If a system does not maintain optimal operation, the deployment of the payload could fail and result in mission failure. For this reason, the durability parameter is given a weight of 4. The weight of the system affects the total weight of the rocket which then requires additional calculations to reach our desired altitude. If the system is heavy, all that is needed is a recalculation. For this reason, the low weight parameter is given a weight of 1. The ease of manufacturing parameter determines how easily it is to make parts for the system. Since we have access to a student machine shop manufacturing, parts are not a large problem. For this reason, the ease of manufacturing parameter is given a weight of 2. The safety of payload parameter pertains to the usability of other systems after activation. If for some reason our drone or vital systems are inoperable after activation, the result would be mission failure. For this reason the safety of payload parameter is given a weight of 5. The repeatably parameter is the quality of a system to be reset and reactivated for any reason. Only if deployment fails due to other circumstances would

the deployment system need to reset and repeat. For this reason, the repeatably parameter is given a weight of 3. The reliability parameter is the quality of the system to operate according to its design. If a system does not operate according to its design, problems can occur with system interfaces and the withdrawal of the drone itself. For this reason, the reliability parameter is given a weight of 4.

Design		Constant Force Spring		Body Side Breach		Solenoid		Pneumatic Piston		Linear Servo		Belt Winch		Electromagnet	
Parameter	Weight	Score	Viability	Score	Viability	Score	Viability	Score	Viability	Score	Viability	Score	Viability	Score	Viability
Durability	4	8	32	5	20	6	24	4	16	6	24	4	16	7	28
Low Weight	1	7	7	10	10	8	8	8	8	6	6	5	5	8	8
Ease of Manufacturing	2	9	18	7	14	10	20	8	16	9	18	7	14	9	18
Safety of Payload	5	9	45	4	20	2	10	5	25	8	40	7	35	1	5
Repeatability	3	3	9	6	18	7	21	4	12	8	24	9	27	8	24
Reliability	4	10	40	6	24	6	24	5	20	7	28	6	24	8	32
Total Viability			151		106		107		97		140		121		115

Table 6.20: Payload Withdrawal System Decision Matrix

Design	Constant Force Spring		Linear Servo		Belt Winch	
	% of budget	Viability	% of budget	Viability	% of budget	Viability
	7.7	151	7	140	6.5	121
Cost Effectiveness Score	1961		2000		1861	

Table 6.21: Payload Withdrawal System Cost Effectiveness Matrix

Current Leading System Design

Constant Force Spring Ejection:
A constant force spring is paired with a rotary damper and is attached to the rear end of the drone carriage to pull the drone carriage out the mouth of the rocket body with sufficient force and a constrained speed. The drone carriage will be restricted with a servo arm pin, located at the rear of the carriage, to oppose the force of the spring. The carriage will be constrained by the placement of the constant force spring such that the drone carriage is exposed from the mouth of the rocket body once the spring reaches its original displacement.

The primary deciding factors that resulted in the selection of this design for the withdrawal system were the high scores in durability, safety of payload, and reliability. This system is given an 8 for durability and a 9 for safety of payload because of the mechanical nature of the system. The primary component of this system is the constant force spring, which is very reliable for several thousand cycles. This system is given a 10 in reliability because of the reliability of constant force springs. This system has the drawback that it is not resetable, because of this, the system is given a 3 for repeatability.

Even though the cost effectiveness score of this system was lower than that of the linear servo, the reliability and safety of payload factors are worth the extra cost. For these reasons the constant force spring ejection system was chosen from tables 6.20 and 6.21.

Component Specifications:
Let the mass of the drone and drone carriage be denoted, respectively, as

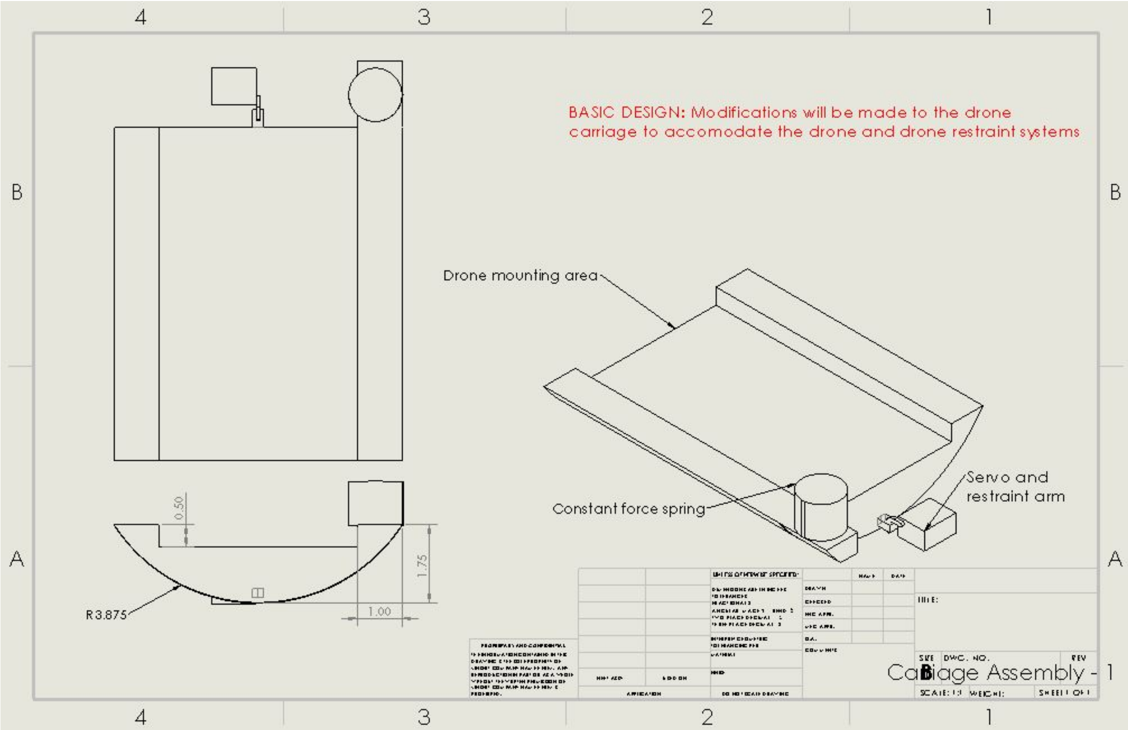


Figure 6.9: Drone Carriage Assembly

$$M_d = 5.5lb, M_c = 2.0lb$$

Assuming the coefficient of friction between the wood drone carriage and the cardboard rocket body is $\mu_B = .5$ and with a maximum angle of 45 degrees

$$\Sigma F = 0 : (M_d + M_c)sin(45) + \mu_B(M_d + M_c)cos(45) - F_s = 0$$
$$\Sigma F = 0 : (5.5 + 2.0)lb * sin(45) + .5 * (5.5 + 2.0)lb * cos(45) - F_s = 0$$
$$F_s = 7.95lb$$

Where F_s is the force applied by the spring to overcome static friction. Assuming a coefficient of friction $\mu_p = .6$ for the metal restraint pin and wooden carriage and a maximum servo arm of .3in, the required torque to overcome static friction and pull the pin that restrains the drone carriage is

$$T = r(\mu_p)(M_d + M_c)(16oz/lb)$$
$$T = (.3in)(.6)(7.95lb)(16oz/lb) = 22.9oz * in$$

Basic material list:
A wood block to cut and shape into the drone carriage. A constant force spring that would then be attached to a rotary damper to act as the deployment force and speed constraint component for this system. A mid torque radial servo connected with an aluminum or wooden pin to operate as the withdrawal restraint component of this system.

Alternative System Designs

Rocket Body Side Breach:
The side of the rocket body is able to open along a hinge powered by a radial servo. The breach door is locked with a servo operated pin. The side breach is large enough for the drone to deploy its flight booms and take off unhindered directly from the rocket body.

The lowest scores for this system are a 4 in safety of payload and a 5 in durability. These scores are given because of the possibility of structural instability due to the require size of the breach door. However, this system scored well with a 10 in low weight and a 7 in ease of manufacturing. These high scores are from the fact that the drone would not need a carriage to withdrawal and only a few servos to operate the breach door and safety pin.

Solenoid:
A solenoid is wrapped along the inside diameter of the rocket body. A secondary lining is placed between the drone bay and the solenoid to prevent an unintentional short circuits. Once active, the solenoid provides magnetic force on an opposing magnet attached to the drone carriage propelling the carriage to the mouth of the rocket body.

The lowest score for this system is a 2 in payload safety. This score was given because of the possibility to interfere with and ruin the electronics within our drone and rocket. If this were to happen there is a large risk for mission failure. However, this system scored well with a 10 in ease of manufacturing and an 8 in low weight. These scores are due to the simplicity of constructing and operating a solenoid.

Pneumatic Piston:
A pneumatic piston is actuated by the release of an on board pressure canister. The pressure canister is operated with a release system controlled by the flight controller.

The lowest scores for this system are a 4 in both durability and repeatability. These scores are given because of the unfamiliarity with the flexible tubing that connects the pressure canister to the piston and the single use nature of the pressure canister. The highest scores are an 8 in both low weight and ease of manufacturing. These scores are given because of the low weight of each component and the simplicity of the system.

Linear Servo:
A linear servo is mounted at the rear end of the drone carriage. The servo actuates with a long enough arm and sufficient force to push the drone carriage out the mouth of the rocket body.

The lowest scores for this system are a 6 in both durability and low weight. These scores were given because the linear servos found were either bulky with a sufficient length or light weight and do not meet the force specifications. The highest scores given to the system were a 9 in ease of manufacturing and an 8 in safety of payload. These scores are given because the actuator component is already made and all that is necessary to design is a connection to the drone carriage. Additionally, the speed at which linear servos typically operate incurs very little risk to the safety of the payload.

Belt Winch:
A motor operated belt with a small clamp attached to the belt is connected to the drone carriage. The belt is positioned along the length of the rocket body and exerts force on the drone carriage as it is rotated by the motor, pushing the drone carriage out the mouth of the rocket body.

The lowest score given to this system is a 4 in durability. This score is given because the belt and clamp are friction held to prevent structural damage to the belt. This aspect of the design limits how much force can be applied to system. The highest score is a 9 given to repeatability. This score is given because of the cyclical nature of a belt driven machine.

Electromagnet:
An electromagnet is attached to the rear end of the drone carriage and a magnet attached to the opposing wall within the drone bay. Once the electromagnet is activated, the opposing magnetic fields provide enough force to push the drone carriage out the mouth of the rocket body.

The lowest score given to this system is a 1 in safety of payload. This score is given because the strength of the electromagnet needed to deploy the carriage would be large enough to completely ruin onboard electronics, which would result in mission failure. The highest score is a 9 given to ease of manufacturing. This score is given because the system only has one operable component.

System Interactions

The payload withdrawal system will only interact in a mechanical nature with the payload restraint system and the payload itself to transport these systems outside the rocket body. The payload retention system will be mounted on the drone carriage and all necessary modifications will be made to accommodate the restraint mechanism and the payload.

6.2.8 Payload Retention System

Decision Matrix Methodology:
There are four main parameters that are taken into consideration when choosing a payload retention system: reliability, overall weight, durability, and the safety of the payload. Reliability measures how much trust can be put into the system to perform its task perfectly. This system must be executed perfectly, else the mission stops before the drone can leave the launch vehicle; this justifies the high weight. The overall weight should also be studied, although its effects are minimal compared to the other categories. The durability of the system determines how the system can handle the forces applied at takeoff. If the system breaks, then the mission is at risk, and thus deserves a higher weight. Finally, the safety of the payload considers how the system interacts with the drone. Damage to the drone should be mitigated for better results. This category also scored higher.

Design		Over-Leg Latches		Pins		Springs		Electromagnet	
Parameter	Weight	Score	Viability	Score	Viability	Score	Viability	Score	Viability
Reliability	5	10	50	8	30	6	20	4	40
Overall Weight	2	8	16	10	20	6	12	4	8
Durability	4	8	32	4	16	10	40	6	24
Safety of Payload	4	10	40	8	32	6	24	4	16
Total Viability		138		98		96		88	

Table 6.22: Latch design decision matrix.

There are three main parameters that are taken into consideration when choosing a latch material: cost, weight, and material strength. The cost is important when factored into the budget and the weight is important when factored into the rocket as a whole, but the material strength is critical. This parameter controls how likely the latches will fail under the forces applied during takeoff. If the latches fail, then the drone is unrestricted and could cause damage to the drone; this warrants a high weight.

Material		Wood		Plastic		Aluminum		Steel	
Parameter	Weight	Score	Viability	Score	Viability	Score	Viability	Score	Viability
Cost	3	10	30	4	12	8	24	6	18
Weight	3	10	30	8	24	6	18	4	12
Material Strength	5	8	40	4	20	6	30	10	50
Total Viability		100		56		72		80	

Table 6.23: Latch material decision matrix.

Design	Over-Leg Latches		Pins	
	% of Budget	Viability	% of Budget	Viability
	1.06%	138	.55%	98
Cost-Effectiveness Score	12962.96		17883.21	

Table 6.24: Payload Retention System Cost-Effectiveness decision matrix.

Current Leading System Design

Over-Leg Latches:
4 over-leg latches are mounted onto the drone carriage and attached to radial servos that are embedded into the carriage and connected to the electronics bay. The drone legs will be pushed into grooves with a foam-like material on the carriage. While being pushed downward, the latches will be rotated above the legs, causing the legs to be pressed between the latches and the foam-like material attempting to return to its initial state by filling with air. When the launch vehicle completes its landing, the radial servos will rotate the latches so that the drone is no longer restricted.

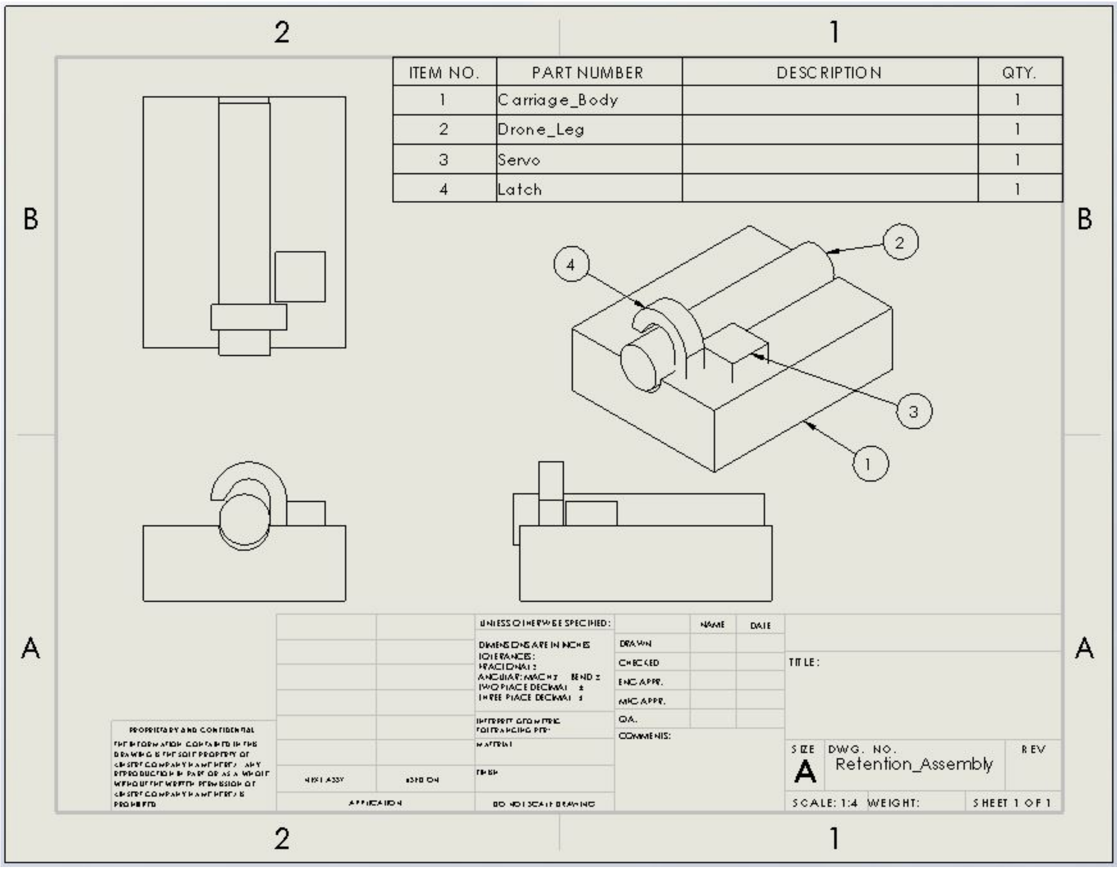


Figure 6.10: Payload Retention Technical Drawing

The leading design is low in overall weight, as we can control the material for the latches to account and was given a higher score in the design matrix because of this fact. Next, the ability to place multiple latches will allow for a better durability and distribution of takeoff forces, which will make them less likely to break. Again, a higher score was given. The drone is restricted through mechanical needs, which is the most reliable way of restriction. This was subsequently given the highest score. The design is the least likely to cause damage to the drone and was given the highest score in the safety category. Finally, the design has multiple moving parts involved, as there are multiple latches and servos. This would result in a greater chance of component failure.

$$M_d = 5.5lbm$$

As the force applied to the drone is removed, the foam agent will return to its initial state by filling with air. Let the force resulting from this inflation be denoted as F_f, with a density of 1 lb expanding with an acceleration of $3ft/s^2$. To counteract this inflation force, the over-leg latches will restrict this movement by producing a force in the opposite direction, denoted as F_l. Accounting for the acceleration during takeoff, which will be roughly sixteen times the acceleration due to gravity, the maximum force that the over-leg latches must overcome is roughly

$$\Sigma F_y = M_d * a : 4F_l - F_f = (5.5lb) * (32.2ft/s^2)$$
$$F_l = ((5.5lb) * (32.2ft/s^2) + 3lbft/s^2)/4 = 45.025lbf$$

Basic Material List:
Mid torque radial servos, over-leg latches, foaming agent

Alternative System Design

Pins:
With small holes in the main body of the drone and or carriage, multiple pins can be fitted into the small holes and keep the drone in place. The pins would then be pulled, using servos connected to the electronics bay, out of the body when desired.

The drone is restricted through mechanical means, which is the most reliable way of restriction. This was given a high score in the design matrix to reflect this quality. Also, the components would have a collective low weight and was given the highest score. Lastly, the simplicity of the design would be safer for the drone, reflected in a higher score. The design involves multiple moving part; with the addition of each moving part, the probability of system failure increases. Holes in drone could also add structural instability and thus its durability to the drone body. Since there would be have to be modifications made to the drone body, this qualified the design for the lowest score for durability in the design matrix.

Springs:
Springs would be mounted to the body of the drone and the carriage and connected to the rocket walls using pins controlled by servos connected to the electronics bay.

The drone is restricted through mechanical means, which is the most reliable method of restriction. It scored a moderate score when compared to other designs. Also, the nature and typical material of springs make them very durable, and was given the highest score because of this. Since springs produce forces to return to its initial state, the springs will be in near constant movement, resulting in a drone body that would be moving with these springs. This was given a lower score in the design matrix.

Electromagnets:
Electromagnets powered by the electronics bay would hold the drone axially, while a few foam stoppers would hold the drone against the body of the rocket to fully prevent movement of the drone. Foam stoppers would be small enough to be ejected from top when flight booms are deployed.

There is one operable part, making the design simplistic. The electromagnet is durable, giving it a moderate score in the category. The magnetic nature could interfere with and destroy other electronics,rendering them useless. This puts the drone at risk, giving the design a low score in the design matrix. The electromagnet would require constant power to maintain; this constant powering of the electromagnet would drain our battery, which could cause other systems to remain without power, making the system unreliable and given a low score. Finally, the electromagnet would be somewhat heavy, contributing to a higher overall weight and a lower score.

7 Safety

7.1 Preface

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 the attached appendices. The manual in standalone form can be found at the link in the same appendix.

7.2 Personnel Hazard Analysis

The following tables assess the personnel risks due to hazardous materials, the build process, and flight operations.

The likelihood and severity of each event are measured using the scales shown in the following figures:

Value	Likelihood	Probability
A	Very Unlikely	< 5%
B	Unlikely	5% - 25%
C	Possible	26% - 50%
D	Likely	51% - 89%
E	Very Likely	> 90%

Figure 7.1: Scale for measuring likelihood of event.

Value	Severity	Result
1	Marginal	Negligible injuries
2	Moderate	Minor injuries
3	Critical	Severe injuries
4	Catastrophic	Life-threatening injuries/death

Figure 7.2: Scale for measuring severity of event.

The personnel hazard analysis was conducted using the standard risk assessment matrix in the following figures.

Following review of the Material Safety Data Sheets (hereinafter referred to as MSDS) for the hazardous materials to be used in construction, the associated personnel risks are displayed in Figure 7.4. Similarly, based on required regulations, team launch protocols, and the failure modes of the vehicle, personnel risks for flight operations are displayed in Figure 7.5.

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

Figure 7.3: Risk assessment matrix.

Material	Hazard	Cause	Risk	Mitigation
Acetone	Fire, severe eye irritation, dizziness/drowsiness	Exposing to heat source, improper handling, fume inhalation	3C	Wear PPE, keep away from heat sources, 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 PPE, keep away from heat sources, limit exposure time, restrict handling to lvl 2 cert
Body Filler	Fire, severe eye irritation, permanent organ damage, possible carcinogen, impacts on fertility	Exposing to heat source, improper handling, prolonged exposure	4B	Wear 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 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 PPE
Epoxy Accelerator	Fire, headaches, dizziness, drowsiness	Exposing to heat source, prolonged fume exposure	2C	Wear PPE, keep away from heat sources
Ferrosoferric Oxide	Mild skin/eye irritation	Improper handling	1C	Wear PPE
Fiberglass	Fiberglass splinters, mild skin irritation, respiratory hazards	Handling prior to sanding, heavy sanding	2C	Wear 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 PPE, keep away from heat sources, restrict handling to lvl 2 cert
Lead Solder	Possible carcinogen, acutely toxic, may impact fertility, organ damage	Ingestion, inhaling, prolonged exposure	4A	Wear 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 PPE, do not ingest, keep away from eyes
Thread Locker	Skin/eye irritation, respiratory tract irritation	Improper handling, fume inhalation	2B	Wear PPE, do not inhale fumes

Figure 7.4: Personnel risk assessment of material hazards.

Failure Mode	Possible Hazards	Cause	Risk	Mitigation
Safe misfire	Fire, risk of sudden ignition, risk to ground personnel	Ignition system failure, improper arming, operator error	2C	Follow launch protocols, restrict personnel in exclusion zone, restrict ignition to lvl 2 cert, wear PPEs while motor is armed
Catastrophic misfire	Fire, explosion, airborne debris, release of flammable substances, risk to ground personnel	Ignition system failure, improper arming, operator error	4A	Follow launch protocols, restrict personnel in exclusion zone, restrict ignition to lvl 2 cert, wear PPEs while motor is armed
Insufficient thrust to clear pad	Fire, erratic flight path, risk to spectators and ground personnel	Incomplete ignition, insufficient TWR	3B	Follow launch protocols, communicate changes in weight, have TWR of at least 3:1, wear PPEs
Vehicle loses control while intact	Erratic flight path, risk to spectators and ground personnel	Insufficient stability margin, build errors, aero surface shears off	4A	Have static stability of at least 2.0, have team leads examine build work, wear PPEs
Motor casing fails (CATO)	Propellant expelled irregularly, erratic flight path, fire, explosion, danger to spectators and ground personnel	Improper motor handling, motor failure	4C	Follow launch protocols, restrict motor handling to level 2 cert, wear PPEs
Motor explodes	Explosion, falling debris, danger to spectators and ground personnel	Improper motor handling, motor failure	4A	Follow launch protocols, restrict motor handling to level 2 cert, wear PPEs
Staging incomplete/does not occur	Vehicle descent uncontrolled, danger to ground personnel and spectators	Improper build/installation of staging hardware	3B	Follow launch protocols, have team leads examine build work, wear PPEs
Parachute does not deploy/breaks off	Vehicle descent uncontrolled, danger to ground personnel and spectators	Insufficient strength of parachute lines, improper installation	3C	Ensure parachute supports vehicle weight, have team leads examine build work, wear PPEs
Parachute partially deploys/tangles	Rapid vehicle descent, danger to ground personnel and spectators	Improper parachute installation, unfavorable winds	2C	Follow launch protocols,have team leads examine build work, only launch in conditions within parachute tolerances, wear PPEs
Anomalous pyrotechnic detonation	Explosion, falling debris, danger to spectators and ground personnel	Improper installation or arming of parachute cord/altimeters	4A	Follow launch protocols, have team leads examine build work, wear PPEs
Structural failure in flight	Falling debris, motor continues flying, danger to ground personnel and spectators	Vehicle designed with insufficient safety margins	4A	Ensure vehicle is designed to withstand flight loads, wear PPEs
Premature spring release while loading drone	Injury from spring force or drone ejection	Improper installation of drone or release system	2B	Have team leads examine build work, wear PPEs
Drone restraint failure during launch	Loss of stability in flight, erratic flight path, risk to spectators and ground personnel	Improper installation of drone or restraint system, insufficient restraining system	4A	Have team leads examine build work, wear PPEs
Drone control loss after deployment	Inability to control drone, risk to spectators and ground personnel	Power loss, improper setup of control system	3B	Ensure batteries charged, validate control system, wear PPEs
Drone motor failure	Flying debris, loss of control, risk to spectators and ground personnel	Unusual wear and tear, flawed motor, improper handling/installation	3A	Inspect motors regularly, have team leads examine build work, wear PPEs
Major electrical fault	Electric shock, fire, explosion, loss of control, risk to spectators and ground personnel	Improper wiring, component fatigue	4B	Inspect electrical components regularly, have team leads examine build work, wear PPEs

Figure 7.5: Personnel risk assessment of vehicle failure modes.

7.3 Environmental Effects Analysis

The environmental effects analysis was conducted using the same risk assessment matrix as in the personnel hazard analysis; however, the matrix accounts for severity of environmental damage or damage caused by the environment instead of personnel injuries.

Hazard	Cause	Effect	Risk	Mitigation
Brush fire	Uncontained launch exhaust, vehicle loss of control/explosion, failure to clear pad, electrical fault	Possible fire damage to ecosystem and facilities, risk to wildlife, spread of fire beyond ignition point	3C	Have fire suppression equipment nearby during flights, clear launch area, carefully review build work, restrict motor handling to lvl 2 cert
Flying debris	Vehicle explosion, structural failure, failed staging or parachute deploy	Possible impact damage to ecosystem and facilities, risk to wildlife	4C	Carefully review build work and staging systems, restrict motor handling to lvl 2 cert
Release of toxic or flammable materials	Vehicle explosion, structural failure	Exposes ecosystem to toxins	4A	Carefully review build work, restrict motor handling to lvl 2 cert
High-speed impact	Failed staging or parachute deploy, motor failure	Possible wildlife injuries/deaths, impact damage to facilities	3B	Carefully review build work, restrict motor handling to lvl 2 cert
Landing attitude impairs drone deploy	Rough terrain at landing site, improper orientation prior to touchdown	Partial or total mission failure, depending on specific vehicle orientation	2D	Carefully review staging systems, equip vehicle with countermeasure to ensure proper deployment orientation
Departure of rocket from flight area	High winds during recovery, loss of control during launch, motor failure	Rocket travels to area not expecting such an intrusion, risk to wildlife, risk to facilities outside launch area	2C	Do not launch in adverse conditions, carefully review build work, have GPS tracking on vehicle
Wind shear	Weather conditions	Loss of control, structural failure, departure of vehicle from flight area	4B	Do not launch in adverse conditions
Precipitation	Weather conditions	Components operating when wet, possible vehicle damage from high-speed impact with precipitation	3C	Do not launch in adverse conditions

Figure 7.6: Risk assessment of environmental interactions.

7.4 DFAI's for Preliminary Designs

7.4.1 Launch Vehicle

Launch Vehicle DFMEA						
Subsystem	Failure Mode	Cause	Effect	Risk	Mitigation	Recommended Actions
Airframe	Material buckling	Hard landing due to recovery failure	LV lost, unlaunchable again	4A	Redundant recovery system to prevent single point of recovery failure	Subscale recovery system test
	Burning/melting of material	Propulsion system failure or ejection system failure	Structural integrity compromised	3A	Dog barf and fire blanket provides redundant fire mitigation in LV	Grounded ejection test
	Delamination of material	Instability of boost causes LV to go ballistic	Total LV loss	4B	Manually test LV stability prior to launch to ensure vehicle is safe to boost	Subscale launch test
	Unplanned ejection	Poor tethering/tether failure	Loss of Upper body telemetry	1B	Test flight loads of shock chord attachment point	Grounded shock load test
	Unoptimized geometry	Manufacturer inconsistency	LV ascent instability	3A	Confirm geometry of nose cone after delivery	Geometry analysis
Fins	Shearing at launch	Damage prior to launch	Instability of boost and ballistic action of LV	3C	Prelaunch structural integrity inspection	N/A
		Manufacturer inconsistency	Instability of boost and ballistic action of LV	3A	Inspection upon reception of component	N/A
	Misalignment	Inconsistent construction	Instability of boost and possible ballistic action of LV	4C	Rigorous alignment analysis following construction	Unloaded full scale launch
		Damage prior to launch	Damage in lab/transporting/or preparing LV	4A	Alignment inspection prior to launch	Unloaded full scale launch
	Inconsistent Geometry	Manufacturer inconsistency	LV ascent instability	2A	Geometry inspection upon reception of component	Unloaded full scale launch
Coupling	Buckling of material	Excessive flight loads	Loss of ejection system and telemetry	4A	Reinforcement of coupling section	Unloaded full scale launch
	Shear pin early shear	Excessive flight loads	Early separation/Lower body loss	4C	Extra shear pins to increase safety margin at drogue deployment	Subscale launch test and unloaded full scale launch
	Shear pin fail to shear	Insufficient ejection pressure	Main deployment failure/Loss of LV	4C	Increase ejection force relative to drogue deployment force (increase safety margin)	Subscale launch test and unloaded full scale launch

Figure 7.7: DFMEA for LV

7.4.2 Mission Vehicle

Mission Vehicle DFMEA						
Subsystem	**Failure Mode**	**Cause**	**Effect**	**Risk**	**Mitigation**	**Recommended Actions**
Mission Objective System	Sample Size Too Small	Brush Roller Too Slow	Mission Failure	4A		Sample Collection Testing
	Seized Rotor	Simulated Material Too Dense	Mission Failure	4A		Sample Estimation Analysis
	No Power	Dead / Wrong / No Batteries	Mission Failure	4A	Add to Pre-Flight Check	
FPV	No Signal Out	No Antenna Connection	Difficulty Remote Piloting	1A		Test Signal Range
	No Power	Dead / Wrong / No Batteries	Difficulty Remote Piloting	2A	Add to Pre-Flight Check	
	Low Visibility	Camera Movement In Flight	Difficulty Remote Piloting	1A		Test Mount's Resistance to Turbulence
Payload Communication and Control	No GS connection	No Antenna Connection	Mission Delay	2A		Test Signal Range
	No Telemetry	Telemetry Interference	Difficulty Remote Piloting	2A		Test for Required Shielding
	Flight Computer Failure	Saturated FLight Controller	Mission Failure	4B		Run in Full Scale Flight Test
	No Power	Dead / Wrong / No Batteries	Mission Failure	3A	Add to Pre-Flight Check	
ESC's and Rotors	Blocked Props	MV Damage During Launch	Mission Failure	3A	Design Robust Rotor Booms	
	No Power	Dead / Wrong / No Batteries	Mission Failure	3A	Add to Pre-Flight Check	

Figure 7.8: DFMEA for MV

7.4.3 Payload Bay

Payload Bay System DFMEA						
Subsystem	**Failure Mode**	**Cause**	**Effect**	**Risk**	**Mitigation**	**Recommended Actions**
Payload Retention System	Latch Failure Due	Induced forces from LV Flight	Damage to MV	3B	Design Robust Latches	Full Size System Test
	Accidental Decoupling	Programming Error	Damage to MV	3A	Programming Reviews	Iterated Code Tests
	Failure to De-couple	In Flight Payload Shifts	MV Failure	4A	Design Robust Latches	Small Scale Test
	No Power	Dead / Wrong / No Batteries	MV Failure	4A	Add to Pre Flight Check	
Payload Withdraw System	Spring Restraint Mechanism Fail	Induced forces from LV Flight	MV Failure	3B		Full Size System Test
	Incomplete Deployment	Landing Conditions	Damage to MV	1D	Implement Landing Legs	Small Scale Test
	Accidental Deployment	Induced forces from LV Flight	Damage to MV	2C		Full Size System Test
	No Deployment	Communication Errors	MV Failure	3A	Programming Reviews	Iterated Code Tests
		Landing Conditions	Damage to MV	2C	Implement Landing Legs	
	Power	Dead / Wrong / No Batteries	MV Failure	4A	Add to Pre Flight Check	
Payload Bay Communication and Control	No GS Connection	Communication Errors	MV Failure	3A		
		Programming Errors	MV Failure	3A	Programming Reviews	Iterated Code Tests
		Antenna Disconnected	MV Failure	3B	Add to Pre Flight Check	
		Antenna Improperly Shielded	MV Failure	3A		Range / Interference Testing
	No Location Data	Poor Uplink Connection	MV Failure	2B		Range / Interference Testing
		GPS Disconnected	MV Failure	2A	Add to Pre Flight Check	
		Programming Errors	MV Failure	2B	Programming Reviews	Iterated Code Tests
	No MV Connection	Induced forces from LV Flight	MV Failure	4B		Small Scale Tests
		Programming Errors	MV Failure	4A	Programming Reviews	Iterated Code Tests
	Power	Dead / Wrong / No Batteries	MV Failure	4A	Add to Pre Flight Check	
	Computer Failure	Induced forces from LV Flight	MV Failure	4B		Small Scale Tests

Figure 7.9: DFMEA for PB

7.4.4 Ground Station

Ground Station DFMEA					
Subsystem	**Failure Mode**	**Cause**	**Effect**	**Risk**	**Mitigation**
Router	No Connection LV	Antenna Range	Loss of LV Control	3B	Design Antenna Is Long Range
		Antenna Orientation	Loss of LV Control	1B	
	No Connection MV	Antenna Range	Loss of MV Control	2A	Design Antenna Is Long Range
		Antenna Orientation	Loss of MV Control	1C	
	Power	Power System Failure	Complete Loss of Contact	3B	Bring Two Power Systems
Laptop	No Connection	Ethernet Cable Failure	Complete Loss of Contact	1A	Bring Multiple Cords
	Power	Power System Failure	Limited Contact Time	2B	Fully Charge Laptop Battery
	Updating Issues	System Programming Error	Deley of Mission	1B	Bring Alternate Laptop
	Program Failure	Component Programming Error	Deley of Mission	2A	Bring Alternate Laptop
Power System	Fully Discharged	Dead Power System	Limited Contact Time	3B	Add to Pre- Launch Checklist
	Poor Connections	Poor Connection	Limited Contact Time	2A	Inspect all Wired COmponents

Figure 7.10: DFMEA for GS

8 Project Plan

To ensure the development of the project is on track as well as being conducted in an effective manner there must be some method verify progress. The completion of USLI requirements is obviously pivotal to project success, and such completion needs to verified. In addition, prerequisite goals must be met on the journey to the completion of USLI requirements. The goals are specific to ARC and as a result must be explicitly defined. Following these definitions, a plan must be established to reach these goals.

8.1 Requirement Verification

The USLI requirements span design, construction, and team planning. Different verification methods lend themselves more effective to different types of requirements. The specific verification methods are tests (T), analysis (A), demonstration (D), and inspection (I). The following tables delineate USLI requirements, ARC's planned method of verification.

8.2 Budgeting & Timeline

8.2.1 Budget

The primary source of ARCâĂŹs 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 AIAAâĂŹs 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 fundraisers. 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 ARCâĂŹs 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 âĂIJHands on NASA âĂŞ oriented experiences for studentsâĂİ. 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.

8.2.2 Timeline

Just as presented in the proposal for entry, ARC's project schedule has deviated little to none. The following figures represent the project plan as broken down by subteam.

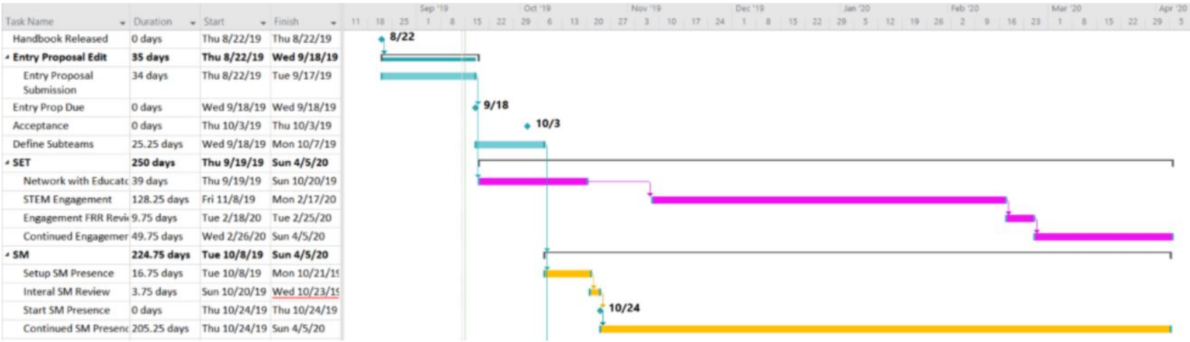


Figure 8.1: SET and SM Team Schedule

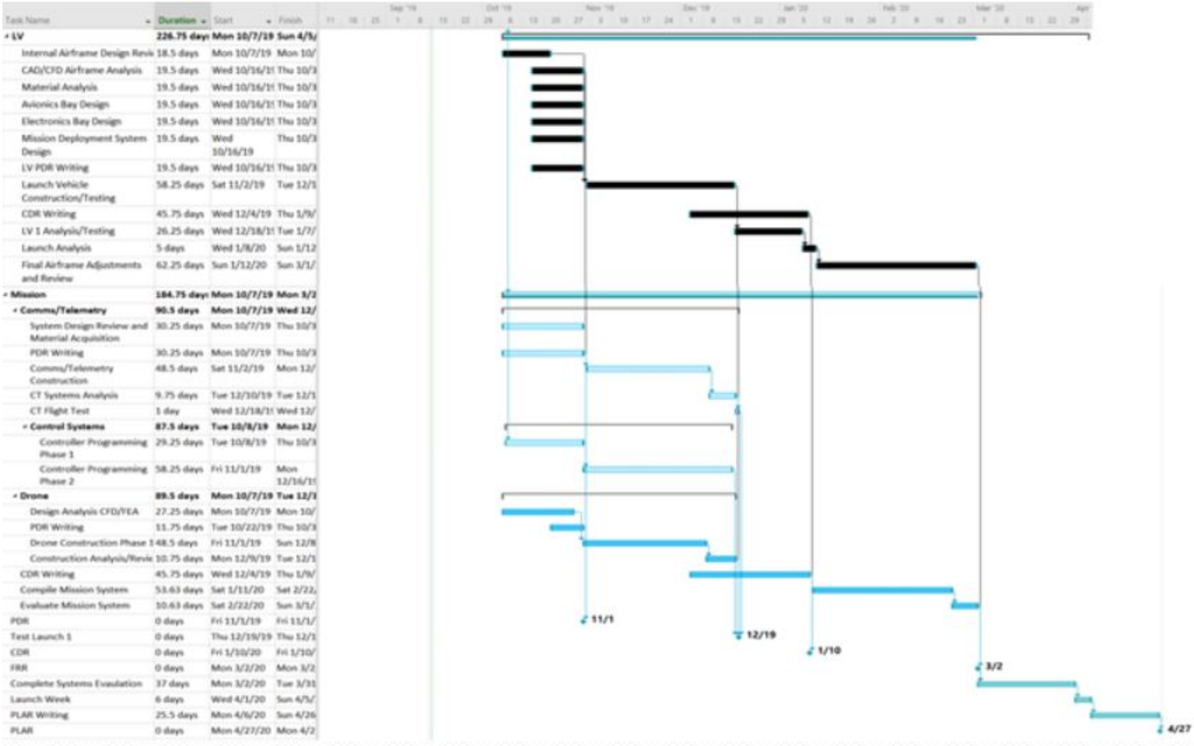


Figure 8.2: LV and Mission Team Schedule

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

Figure 8.3: Mission Team Budget

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

Figure 8.4: Launch Vehicle Team Budget

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

Figure 8.5: Team Travel 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

Figure 8.6: Student Engagement Team Budget