Preliminary Design Review
In fulfillment of the NASA University Student Launch Initiative requirements

University of Illinois at Urbana-Champaign

Illinois Space Society (ISS)

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ACKNOWLEDGEMENT

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Contents

Chapter 1

Preface

This document (`ISS/USLI-PDR`) serves as the Preliminary Design Review (PDR) for the University of Illinois at Urbana-Champaign University Student Launch Initiative team, Illinois Space Society (ISS). The content of this report will chiefly focus on the changes since the original proposal, developments in design and underlying justifications, as well as overall prospects and plans towards the Critical Design Review (CDR). In particular, the launch vehicle design is detailed with reference to the pertinent vehicle requirements, providing an overview of its subsystems, interfaces, and manufacturing methods. Safety considerations are addressed through a multitude of simulations, as well as a qualitative Failure Modes and Effects Analysis (FMEA) and Environmental Impact Assessment (EIA). Following this discussion, the payload requirements and preliminary design of both the airframe and sample retrieval mechanism are presented, culminating in the presentation of a detailed Concept of Operations (CONOPS). The payload–launch vehicle interface as well as the aerial deployment mechanism are discussed, giving rise to a detailed safety analysis. As part of the safety analysis, in addition to a comprehensive FMEA, a Personnel Hazard Analysis (PHA) is presented. Any hazardous activities will be identified as part of this discussion, including any foreseeable contingencies and mitigation procedures. Finally, a project plan is presented, including a project timeline (Gantt chart), bill of materials, list of funding sources and mitigation procedures in case of delays.

This report is composed of six parts, in which each part builds forth upon the previous. These parts are:

I Summary
II Changes
III Launch Vehicle
IV Payload
V Safety
VI Project Plan

Each of these parts describes in due detail the developments and rationale behind the launch vehicle and payload design, as well as the overall implementation.

DISCLAIMER: While the authors have gone through great lengths to ensure the validity of all data presented in this document, all responsibility is assumed for any inconsistencies presented as part of this work.

Part I

Summary

Chapter 2

Executive Summary

Over the period spanning from proposal submission to PDR submission (August–November 2019), the team has made considerable progress in shaping a preliminary vehicle and payload design. Throughout these developments, the project chiefly guided by the the following main goals: safety, feasibility and timeliness. This part will outline the present mission design in relation to these goals, as well as the overall considerations that shaped the leading launch vehicle and payload design.

The launch vehicle is slated to be a single-booster rocket, weighing 10.68 kg (23.55 lbm), with a base-to-tip length of 2.41 m (7 ft 11 in). The vehicle caliber is two-fold, as a transition will be utilized so as to attain a wider fairing diameter; the body diameter is 10.16 cm (4 in), whereas the fairing diameter is 15.24 cm (6 in). In designing the vehicle, a reference altitude of 1.5 km (4921 ft) was aimed at, prompting the appointment of the AeroTech K780R as the motor of choice. This motor has a burn time of 3 s, and produces a total impulse of 2371 N s (L-class). The nose cone was chosen to be of tangent ogive shape, with an aspect ratio of 3:1.

Part II

Changes

Part III

Launch Vehicle

Chapter 3

Flight Dynamics

The primary responsibility of the Flight Dynamics team is to simulate the performance of both the launch vehicle and the payload, to inform other subteams of constraints that must be satisfied to achieve safe flight, and to make design decisions on all structures and control systems that directly influence the flight of the launch vehicle-payload system.

3.1 Simulation Methods

In order to ensure that predictions of flight performance, as well as insights into possible design improvements, are robust and well-informed, the team is using two independent simulation programs to study the flight profile. The team is principally using OpenRocket for simulating the flight of the launch vehicle and predicting critical mission characteristics such as apogee, time to apogee, and total flight time, among many others. However, in addition to OpenRocket, the Flight Dynamics team is developing its own custom-built rocket simulation software, Zenith Estimation through Numerical Integration and Tractable Heuristics (ZENITH). The team considered using other open-source rocket-simulating software, but found that none of them were as sophisticated or accessible as OpenRocket, hence the team decided to develop its own program.

3.1.1 OpenRocket

OpenRocket is a powerful, open-source rocket flight simulation tool. As it is the most robust and informative, cost-free flight simulation tool available, the team is using it as the primary consultant on aerodynamic design considerations and predicting if the launch vehicle satisfies mission requirements. In addition to predicting flight trajectories, from launch to landing, for various possible initial conditions, OpenRocket also provides baseline estimates for the launch vehicles's mechanical and aerodynamic properties, including pre- and post-burnout masses, drag and lift coefficients, CP and CG locations, stability coefficient, and many others.

3.1.2 ZENITH

Due to a lack of satisfactory alternatives to OpenRocket, and in an attempt to gain a valuable learning experience in simulation design and implementation, the team elected to develop its own simulation of the launch vehicle. ZENITH is a Python-based program that simulates the trajectory of a high-power rocket with specified dimensions, mass and moments of inertia, and thrust curve, by numerically integrating a set of differential equations of motion that govern it. Aerodynamic coefficients are obtained from a database called AeroDB, which calculates such coefficients based on the provided dimensions of the rocket (IS THAT RIGHT????).

3.2 Flight Profile

The flight profile for this mission features a relatively simple sequence of events. Nominally at apogee of 4,700ft (and within 2 seconds after apogee), an ejection charge in the tube coupler will separate the upper and lower body tubes and deploy the drogue parachute as displayed in Figure 19. This will be the only explosive separation event of the entire flight. The main parachute will then deploy at 800ft (this is above the minimum parachute deployment altitude of 500ft). Within two seconds of main parachute deployment, the solenoid system in the fairing will trigger after the necessary RSO permission is acquired, priming the drone for deployment. The drone will then deploy passively by pushing the nose cone off and sliding downward from the rocket. The nose cone will not have a parachute. The process for jettisoning the nosecone is described in Sec. 4.2.2.5.The flight profile was simulated in OpenRocket using a model of the rocket with numerous design specifications (e.g. material and motor type) and simulated it with various initial conditions, such as wind speed, launch angle and direction, as well as the launch coordinates. As mentioned in the previous section, current projections show the rocket to satisfy all requirements of flight performance, thus validating the current flight profile. If necessary, the flight profile can be adjusted to better accommodate these requirements; for example, the altitude of main parachute deployment can be lowered to ensure that the drift distance remains within the recovery area.

3.3 Simulation Results

3.3.1 Kinetic Energy Predictions

3.3.2 Drift Predictions

3.3.3 Descent Time Predictions

3.4 Simulation Discrepancies

Chapter 4

Structures

responsibilities of structures and recovery

4.1 Launch Vehicle Overview

4.2 Booster Subsystem

4.3 Payload Bay Subsystem

4.4 Recovery Subsystem

4.5 Mission Performance

4.6 Subscale

Part IV

Payload

Chapter 5

Payload Requirements

During the boost, coast, and the majority of the launch vehicle's flight, the payload will remain idle and securely fixed in the payload bay. This chapter will detail the means of securement and deployment of the payload, as well as a trade-off between the various means that have been consider to arrive at the leading design.

This chapter will be structured as follows: Sec. **??** details the requirements the payload is to satisfy given the overall mission and top-level requirements, followed by a trade-off study regarding the means of securement in Sec. **??**, as well as the possible deployment modes in Sec. **??**. Finally, the leading design is presented in Sec. **??** in reference to the foregoing trade-off studies.

This section details the various requirements to which the payload deployment scheme must abide. Specifically, two forms of requirements are identified: top-level requirements and team-derived requirements. The first are requirements either imposed by the competition, or legislation that is in effect at the time of launch and operations. The second form of requirements pertain to what the team perceives to be of importance in assuring mission success and robustness.

5.1 Top-level requirements

The top-level requirements for the payload deployment are outlined in Secs. 4.3–4 of [**?**], reading as follows:

4.4. Lunar Ice Sample Recovery Mission Requirements
- 4.3.1. Teams must abide by all Federal Aviation Authority (FAA) and National Association of Rocketry (NAR) rules and regulations.
- 4.3.2. Black Powder and/or similar energetics are only permitted for deployment of in-flight recovery systems. Any ground deployments must utilize mechanical systems.
- 4.3.3. Any part of the payload or vehicle that is designed to be deployed, whether on the ground or in the air, must be fully retained until it is deployed as designed.
  - 4.3.7.1. A mechanical retention system will be designed to prohibit premature deployment.
  - 4.3.7.2. The retention system will be robust enough to successfully endure flight forces experienced during both typical and atypical flights.
  - 4.3.7.3. The designed system will be fail-safe.
  - 4.3.7.4. Exclusive use of shear pins will not meet this requirement.

4.6. Special Requirements for UAVs and Jettisoned Payloads

4.4.1. Any experiment element that is jettisoned during the recovery phase will receive real-time Range Safety Officer (RSO) permission prior to initiating the jettison event.

4.4.2. Unmanned Aerial Vehicle (UAV) payloads, if designed to be deployed during descent, will be tethered to the vehicle with a remotely controlled release mechanism until the RSO has given permission to release the UAV.

4.4.3. Teams flying UAVs will abide by all applicable FAA regulations, including the FAA's Special Rule for Model Aircraft (Public Law 112-95 Section 336; see `https://www.faa.gov/uas/faqs`).

4.4.4. Any UAV weighing more than .55 lbs. will be registered with the FAA and the registration number marked on the vehicle.

In addition, by FAA regulations [?], the UAV may only be operated below 400 ft in Line of Sight (LOS)[1]. From the FAA Reauthorization Act of 2018, the following pertinent regulations may be found. The UAV must have a gross weight under 4.4 lbm, and must be operated:

(i) within or beyond visual LOS of the operator;
(ii) less than 400 ft above ground;
(iii) during daylight conditions;
(iv) within Class G airspace; and
(v) outside of 5 statute miles from any airport, heliport, seaplane base, spaceport, or other location with aviation activities.

As a supplement to these regulations, an aeronautical chart of the surroundings of the launch site (Bragg Farms, Hazel Green, AL) is given in Fig. 5.1.

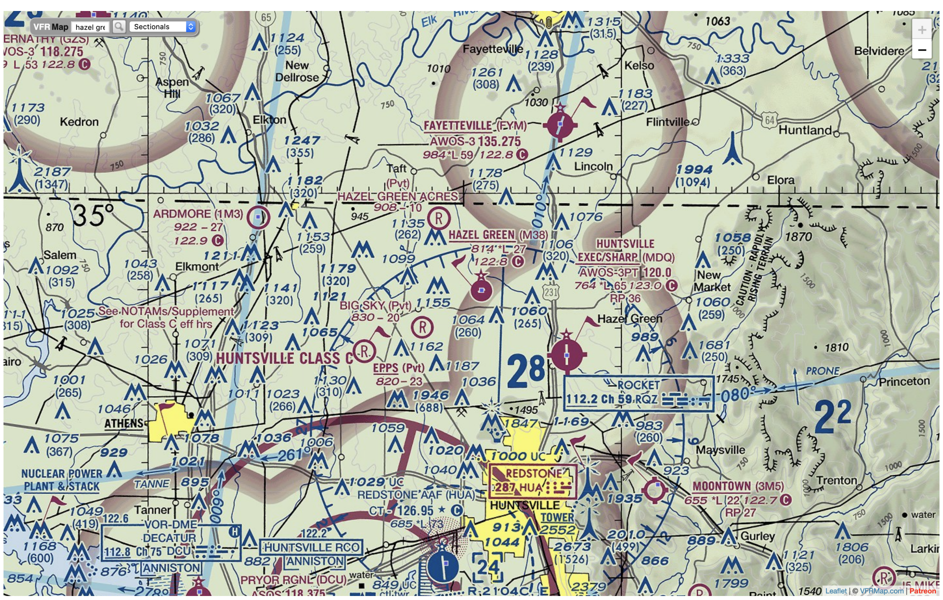

Figure 5.1: Visual Flight Rules (VFR) aeronautical chart of the Hazel Green, AL area. Adapted from VFRMap.com

[1]FAA Reauthorization Act of 2018 §346(b.2.C), 49 U.S.C. §44806

In this chart, the Class E airspace is bounded by a vignette magenta border, and spans down to 700 ft; anything below that is Class G airspace, and thus open for UAV operations. Incidentally, the area of payload operations lies beyond a 5 mile radius of the closest airfield.

5.2 Team-derived requirements

In addition to the above, a number of additional requirements have been compiled by the team. In particular, the robustness of the securement system, as well as the reliability of the deployment system are at the center of the discussion.

1. Deployment
   - 1.1. UAV Transport
     - 1.1.1. The UAV must be securely transported from launch until deployment. There must be no physical damage to the UAV, and its functionality must be maintained.
     - 1.1.2. The security mechanism of the UAV and the UAV itself must be built to be able to withstand FILLER Gs.
     - 1.1.3. This security mechanism must be released when the rocket reaches 120m as regulated by the FAA.
   - 1.2. Nose Cone Release
     - 1.2.1. The nose cone must be safely jettisoned to allow for proper UAV deployment. A safe jettison requires the nose cone's kinetic energy to be less than 100J as it impacts the ground.
     - 1.2.2. A parachute with an area of FILLER must deploy from its stored location in the tip of the nose cone in order to satisfy the kinetic energy requirement as shown in equation FILLER.
   - 1.3. UAV Release
     - 1.3.1. The UAV must be safely lowered from the payload bay so that it can begin its independent flight.
     - 1.3.2. The lowering mechanism must be able to withstand a force greater than the weight of the UAV.
     - 1.3.3. The lowering mechanism must be able to deploy the UAV within ten seconds of the jettison of the nose cone.
   - 1.4. Critical Systems Check
     - 1.4.1. A critical systems check must be performed quickly to ensure the UAV's ability to fly independently.
     - 1.4.2. The arms of the UAV must be properly deployed.
     - 1.4.3. The power system of the UAV must functional.
     - 1.4.4. The motors with propellers must be actively running.
     - 1.4.5. The orientation of the UAV must be upright as confirmed by accurate readings from the appropriate sensors.
   - 1.5. Separation Protocol
     - 1.5.1. There must be a mechanism to detach the UAV from the upper body tube so that it can achieve independent flight.
     - 1.5.2. An automatic maneuver must be executed by the UAV to move itself away from the falling body tube.
2. Hover
   - 2.1. Take longer Kenneth

2.22.1.1. For real

3. Landing Protocol
    3.1. Computer Vision Check
        3.1.1. The computer vision program must be working as designed as the UAV approaches GPS waypoint for the landing site of the sample material. The pilot will have to manually confirm that the system is functioning properly.
    3.2. IRMA System Check
        3.2.1. The IRMA system must confirm its functionality post-deployment.
        3.2.2. The flight computer must confirm that the members of the IRMA can close to scoop the material.
    3.3. UAV Descent on Target
        3.3.1. The UAV must begin to descend towards the ground as it processes its final systems check.
        3.3.2. The descent velocity must be kept under FILLER m/s to ensure that any impact with a landing surface does not harm the UAV.
        3.3.3. The computer vision software must guide the UAV towards the sample collection site.
        3.3.4. The UAV must land upright atop the sample site with a final velocity of 0 m/s.
4. Sample Retrieval Protocol
    4.1. Engage IRMA
        4.1.1. The IRMA must close its members around a collection of the sample.
        4.1.2. The UAV pilot must confirm that a sufficient that the IRMA has retrieved a sufficient amount of the sample.
    4.2. Return to Hover
        4.2.1. The UAV must return to the altitude of the initial hover.
        4.2.2. The IRMA must maintain a sufficient amount of sample.
    4.3. Flee Sample Site
        4.3.1. The UAV must move 5m in any cardinal direction from its location above the sample site.

Chapter 6

Payload Sizing

One of the core tenets of the payload design, lies in proper sizing of the UAV so as to ensure that the mission requirements are satisfied with due confidence. As such, an informed sizing methodology is required, few of which may be found in the literature pertaining to Micro Air Vehicles (MAVs), the collective term for small UAVs. This chapter outlines the various algorithms considered, as well as the limitations and results obtained from the algorithm of choice. In this treatment, a brief overview of the state of the art is presented, followed by a number of implementational considerations pertaining to the algorithm of choice. Finally, sizing results are presented, which will be referred back to over the course of the remainder of this document.

6.1 Sizing Algorithms

In recent literature, the topic of Micro Air Vehicle (MAV) sizing has been treated at a number of occasions, but not to the extent of aircraft sizing. **?**] have developed the Electric Multirotor Sizing Tool (EMST), an online MAV sizing algorithm. While this methodology seems very promising in its ability to accurately size MAVs, its implementation is not detailed in the aforementioned paper, and the online implementation has since been terminated.

A more recent approach has been presented by **?**], which shows excellent correlation with a set of reference MAVs. This approach rests on a series of parametric exponential equations that relate key inputs to component weight estimates as outputs. The approach presented in [**?**], as is the case in the sizing approach proposed by **?**], draws heavily on results from Blade Element Momentum Theory (BEMT). This requires a degree of Computational Fluid Dynamics (CFD) to be implemented in the design loop, which was not regarded as a desirable property for the team's purposes. It was therefore sought to find tractable alternative that were less cumbersome in implementation, yet of higher fidelity. In particular, BEMT necessitates a two-dimensional CFD code to be ran so as to obtain planar aerodynamic coefficients. Subsequently, these coefficients are integrated over the complete blade lengths in an element-wise fashion (hence the name *blade element* momentum theory). A discussion regarding this decision follows below.

Aerodynamic data. A number of considerations have lead to the decision to employ manufacturer-provided experimental data, as opposed to either theoretical predictions or wind tunnel experiments. With reference to CFD-based approaches, given the abundance of standardized low-speed propeller geometries, as well as associated wind tunnel measurements, it is natural to opt for physical results, as they bear more fidelity. If CFD were to have been pursued, a number of simulation software packages would have substantially aided in design, where XFLR5[1] and Q-Blade[2] would have been the prime contenders. These codes, having been produced for low speed aerodynamics and wind turbine blades, respectively, do not perform well for rotors with small cord length and high angular velocity. In the presence of high Reynolds numbers and localized supersonicity, both of which are observed in the rotors under consideration, the underlying aerodynamic models (in this case, the ISES model) fail, as they do not account for compressibility or trans-/supersonic effects [**?**].

Having discussed the drawbacks of computational methods, the two main experimental data sources can now be compared: wind tunnel data and motor-specific data. As for the first, there is a great wealth of low speed aerodynamic wind tunnel data that has been acquired as part of the work of Prof. Selig's group at the University of Illinois [**?**]. This database provides high-fidelity aerodynamic coefficients for a wide variety of standardized propeller geometries, at different flow conditions and orientations. For these reasons, it would appear to be an excellent source of data for the purpose of sizing the UAV. However, to properly determine the required power system sizing and engines of choice, it is necessary to include existing motor–propeller combinations in the sizing algorithm. This mainly stems from the fact that different torques and levels of power consumption are experienced depending on both the motor and rotor choice, thereby necessitating either an implicit assumption regarding motor efficiency, or the use of existing empirical data supplied by manufacturers. In the interest of attaining a high-fidelity code, it was deemed more appropriate to utilize test data provided by manufacturers, and augment this as needed by means of the data from [**?**]. Having made this decision, it is now of importance to compile a list of reference motors for use in the subsequent trade-off study and optimization effort.

Reference motor selection. As mentioned before, a number of motors is to be selected for use in the sizing algorithm based on the methodology of **?**]. In an attempt to maintain homogeneity of the test setup and data format across the various types of motors, it was quickly realized that selecting a single vendor would insure data integrity and equivalence to a greater degree, as opposed to mixing data. As such, SunnySky USA[3] was chosen as the prime vendor, given the quality of their test data and general data sheets, as well as past experience with the company. The following engines and propeller considerations have been implemented as part of the framework adapted from **?**]:

[1] http://www.xflr5.tech/xflr5.htm

[2] http://q-blade.org/

[3] https://sunnyskyusa.com/

Motor	Speed constant (K_v)	Propeller	Voltage
SunnySky X2302 V3	1500/1650	GWS8043, GWS8060, GWS9050	7.4/8.4
SunnySky X2304 V3	1400	GWS8043, GWS8060, GWS9050, GWS1047	7.4/8.4
	1480	GWS8043, GWS8060, GWS9047, GWS9050	7.4/8.4
	1800	GWS8043, GWS8060, GWS9047, GWS9050	7.4/8.4
SunnySky X2212 V3	980	APC9045, APC9047, APC1038, APC1047	11.1
		APC8038, APC9045, APC9047, APC1047	14.8
	1250	APC8060, APC9045, APC9047, APC9060	11.1
		APC8060	14.8
	1400	APC7060, APC8038, APC8060, APC9045, APC9047	11.1
		APC7060	14.8
SunnySky X2216 V3	880	APC9045, APC1047, APC1147	11.1
		APC8038, APC9045, APC9060, APC1047	14.8
	950	APC9045, APC1047, APC1147	11.1
		APC9045, APC9060, APC1047	14.8
	1100	APC9045, APC9047, APC9060, APC1047, APC1147	11.1
		APC8060, APC9045, APC9047, APC9060	14.8
	1250	APC9045, APC9047, APC9060, APC1047, APC1147	11.1
		APC8060	14.8
	1400	APC8060, APC9045, APC9047, APC9060	11.1
		APC7060, APC8060	14.8

Chapter 7

Payload Design Tradeoffs

7.1 Means of Securement

7.1.1 Locking Mechanism

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7.1.2 UAV Arm Configuration

Parallel Unfolding Arms

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Vertically Unfolding Arms

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7.2 Means of Deployment

The challenge posed to the team regarding the release of the payload is to deploy the UAV in the proper orientation for flight. The UAV requires a fast, consistent, and reliable release mechanism to deploy it from the rocket. During descent, the UAV will be deployed out of the top of the rocket as described below.

7.2.1 Launch Rails

The drone is secured within the rocket with guide rails. The retracted arms are connected to guide rails that hold the drone securely and will guide the drone out of the head of the rocket. The arms fold vertically as shown in the CAD models. Upon release, the drone will slide down the guide rails, out of the head, and the arms will flip open. This process must be controlled to ensure the drone comes out and deploys fully and in the correct orientation. A mechanism will be used to control the drones descent out of the rocket and ensure that the drone is ready before releasing it from the rocket.

7.2.2 Lowering Mechanism

To control the speed of the drone exiting the rocket, a lowering mechanism will be used to limit the speed. The mechanism can be either passively controlled through friction or actively controlled through a servo motor. The passive system relies on friction in the winch.

One option is for a servo motor to tactically lower the UAV by an exact amount at an exact speed. The UAV can be accelerated and decelerated at the beginning and ending of its descent to ensure it doesn't experience extreme jerk. This will ensure the further safety of the UAV. Since only the descent of the UAV needs to be controlled, the motor does not need to be powerful. The motor can be geared to the speed necessary to deploy the UAV. However, the motor can fail. It requires electronic input and has more points of failure than a passive friction system.

The passive system will eliminate the points of failure that arise from the use of a servo. The winch can be built with a specific resistance to restrict the acceleration of the drone as gravity pulls it out of the rocket. One benefit of this solution is that it will also keep costs down. However, this solution poses a larger threat to the safety of the drone. The drone will accelerate out of the rocket and may be traveling at a high velocity when the limit of the winch is reached. In this case, the drone could experience a large jerk, which could cause damage.The descent will also have less control, resulting in a less consistent deployment.

7.2.3 Lowering Mechanism Release System

Once the UAV has been deployed outside of the rocket, the line attached to the winch must be disconnected. The team came up with three potential ways to accomplish this. The first option utilizes a sharp cutter attached to the UAV to sever the string. The second option uses a quick-release mechanism attached to the UAV to disconnect the line. Lastly, a nylon string could be attached to a winch and an electric connection could be used to burn through the nylon string.

The cutter mechanism would require mechanical components and a motor to execute the operation. The design is simple, but will require care to ensure that the cutter will completely sever the string in all conditions, such as in both the presence and the absence of tension.

The quick-release mechanism is similar to the cutter mechanism. It will require a motor or similar mechanical source to pull a pin. The advantage of this system is that it does not depend on the line being cut. This also allows the line to be made of almost any material, including options more durable than nylon that do not cut easily. However, the quick-release would need to be designed carefully to ensure that it is not accidentally triggered before intended. The risk of premature triggering of the release is significant, and factors heavily into the team's consideration of the viability of this option.

The electric system is a viable option for burning through nylon string. This system has no moving parts, which corresponds to less points of failure. It is the most reliable option. However, it will could longer to burn through the string than it might take to execute the other options. Additionally, this system limits the material for the string to nylon.

7.2.4 Nose Cone Jettison

Without Parachute

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With Parachute

This is a filler paragraph

7.3 Payload Structures

7.3.1 Landing Leg Design

Retractable Landing Mechanism

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Static Landing Mechanism

This is a filler paragraph

7.3.2 Ice Retrieval and Mobility Agent

Pin Joint Mechanism

The goal of the payload is to retrieve ten milliliters of ice and move the ice from one bucket to another. To achieve this, the team decided to construct a claw-like mechanism to scoop the ice from underneath the drone, close the claw, and drop the ice in the bucket at the destination. The design has a servo rotate a bolt with a nut without moving the bolt vertically. The nut then moves with respect to the bolt, thus opening the claw as the nut moves down. To close the claw, the nut moves up and the lever arm becomes horizontal, thus pushing the top of claw arm outward. The bottom of the claw will have a slanted shape to easier scoop ice pieces and lower the risk of pushing the ice pieces outwards.

INSERT IMAGE HERE

Sliding Pin Mechanism

Another design the team is considering for the Ice Retrieval and Mobility Agent is a sliding pin mechanism. The sliding pin mechanism relies on the same movement of a nut sliding down a bolt to open and close the claws, but instead of a pin, it has slots that force the scooping mechanism to move out and in. To secure the scooping mechanism to the drone, two rods with pins at each end will be secured to the drone. The pin will connect the scooping mechanism to the rods and thus the drone. The figure shows the sliding pin mechanism closed (left) and open when the pin is near the top of the slot (right).

INSERT IMAGE HERE

Wormgear Mechanism

The third consideration was a design that operated using a worm gear to control the claw motion. A fixed position, vertically-oriented worm gear would be rotated using a servo. On either side of the worm gear are conventional round gears that naturally contra-rotate with respect to each other due to the radial symmetry of the worm gear action. The solid claw arms directly mount to their respective round gears, so that as the gears rotate, the arms swing open or closed about the same rotation axis as seen in INSERT FIGURE HERE. The rotation axes are provided by pin joints located on vertical support bars connected to the underside of the drone(not shown).

It is easy to obtain the critical components of the design since worm gear packages are readily available in a wide range of sizes. Also, the design is very simplistic and easy to build. A major factor against the worm gear design is the cost of materials. Worm gears are harder to manufacture than round gears, and thus cost more. We decided against spending a large sum of money for a single mechanism. A critical aspect in the structural soundness of the design was identified in the region where the claw arms attached to the gears.

The forces acting on the gears would have to be accounted for, and reinforcement of the region may offset the simplicity advantage of the overall design.

INSERT IMAGE HERE.

7.4 Payload Avionics

7.4.1 Computer Vision

Algorithmic Approach

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Deep Learning Approach

The deep learning approach to using computer vision on the drone is to utilize neural networks. Neural networks can be used to detect and classify objects; they are used in various emerging technologies, such as self-driving cars and automatic facial recognition. Neural networks function by consecutively modeling small pieces of information and then combining them to form templates, and then finally weighing inputs with the templates to create a final prediction.

During a training process, neural networks utilize algorithms that automatically find patterns in objects by evaluating external features of the object, such as color and structure, to divide objects into different classes. The process then updates weights, which correlate to the strength of association from an input image to the prediction, for the model and improves the performance every iteration. By doing so, it results in minimal error when evaluating the input images.

For the competition, the process would require the team to feed the neural network images similar to that of the excavation area to “train” it to recognize what the excavation area would look like.These images would have labels and tags on them that identify each object. The neural network would analyze features such as the color of the boundary of the excavation area, and then update weights for the excavation area class. The same thing can be done with images of the “ice” sample that needs to be retrieved. Images with different amounts of ice can be input into the neural network to teach it the difference between areas with a high or low amount of ice concentration. Doing so would aid the drone in deciding the specific area it should retrieve the ice from.

Neural networks have specific benefits and setbacks that need to be considered before choosing an approach to employ for computer vision. One useful benefit is that if the neural network is trained correctly, it can be extremely fast, and would be able to detect different objects accurately and reliably. On the other hand, a major setback to using a deep learning approach is the immense training time needed. The number of images needed to train the neural network to an adequate level is unknown, but could range from 1,000 to 100,000 comparison images, based on previous implementations.

7.4.2 Flight Controller

From the multitude of different flight controllers available that would suit the mission parameters, the team was able to narrow the list down to 3 choices. These flight controllers, the ArduPilot APM, the Pixhawk 4 and the Navio2, are all widely used by the UAV community. The team identified the factors that were most pertinent to the mission and weighted them by their importance. Ultimately, the flight controller in tandem with its companion computer would require the adequate processing power for the computer vision system and a high degree of reliability, which often varies depending upon software or physical design.

ArduPilot

The ArduPilot APM, although revolutionary on its initial release, has several downfalls. The most severe of which is its lackluster 8-bit processor. It consists of two components, the main processor board and the IMU shield that can be attached on top. The APM's framework is based on that of the Arduino Mega and is capable of tasks such as autopilot, autonomous stabilization and way-point based navigation.

Pixhawk

The Pixhawk is also a renowned flight controller. It contains a much more powerful 32-bit processor and a built-in IMU + Barometer. One of the benefits of the Pixhawk is its ability to interface with a companion computer, such as a Raspberry Pi. A setup like this would be ideal for the high computing power a computer vision navigation system would require.

Navio2

The Navio2 is slightly different from the Pixhawk and ArduPilot APM; it requires a Raspberry Pi to function. The Navio2 itself is just a shield containing high resolution sensors, a UART interface and a GNSS receiver that fits onto a Raspberry Pi. This combined system coalesces to become the flight controller. A set up like this removes the need to carry an extra companion computer in addition to the flight controller because the flight controller system itself has a high power, 64-bit, 1.5 GHz processor on the Raspberry Pi which can handle the processing needs for the computer vision system.

Table 7.1: Flight Controller Fact Sheet

Factor	ArduPilot	Pixhawk + RaspberryPi	Navio2
Size (mm)	70.5 x 45 x 10	44 x 84 x 12	55 x 65
Mass (g)	31.0	15.8	23.0
Ease of Integration	8-bit processor requires aid of companion computer and several peripheral sensors	Requires configuration of linux files to set up UART bridge	Very easy due to extensively tested integration procedures
Power consumption (W)	0.5	3.6	2.79
Reliability	No fall back option	Failures can occur in UART connection	Reliable integration due to 3rd-party product design

Chapter 8

Leading Design of the Payload

8.1 Deployment

The challenge posed to the team regarding the release of the payload is to deploy the UAV in the proper orientation for flight. The UAV requires a fast, consistent, and reliable release mechanism to deploy it from the rocket. During descent, the UAV will be deployed out of the top of the rocket as described below.

8.1.1 Guide Rails

The UAV will be secured to the rocket by a system of guide rails. These rails will be connected to both the base of the fairing section and the retracted arms of the UAV. As the UAV is lowered out of the rocket, the arms will be released into the open position and ready for operation, pending approval from the RSO. The lowering of the UAV will be described by the winch system below.

8.1.2 Lowering Mechanism

To lower the UAV out of the rocket body, the team has chosen to use a servo motor to power the winch. The team found this option suitable because it will allow the drone to be lowered at a constant speed within the safety margin. The team weighed the success of the mission over the complexities involved with integrating the servo powered winch system. In the case of electrical failure relating to the winch's servo, the UAV will be lowered by gravity assisted by mechanical resistance from the dead servo. Leveraging the mechanical resistance, the servo-winch system will be within the safety margin and able to operate in the case of servo failure.

8.1.3 Lowering Mechanism Release System

To sever the winch line from the UAV, the team selected the method of burning a nylon string using an electric system. The other options were eliminated due to the complexity of the mechanical execution of the concepts; that is to say, the team feared that too many moving parts would lead to an overly complex release mechanism. The simplicity of severing a nylon string via heat appealed to the team because of its small risk of failure. The team plans on performing several rounds of tests to ensure that the electric system will be able to sever the nylon cord under any circumstances.

8.2 Drone Structures

8.2.1 Arm Configuration

This is a filler paragraph

8.2.2 Landing Legs

This is a filler paragraph

8.2.3 Ice Recovery and Mobility Agent

The pin joint design was chosen because the design has the best sturdiness, manufacturability, and because of its absence of a sliding motion. The bolt in the pin joint mechanism makes the retrieval mechanism sturdy in the direction going into and out of the page, perpendicular to the scooping motion, when looking at Figure INSERT FIGURE OF CAD OF PIN JOINT. The rod connecting the drone to the scoop mechanism keeps a point on the scoop fixed to the drone at all times so the scoop is not flimsy. The connecting rod creates sturdiness in the direction parallel to the scooping motion because the rod is a fixed length. This allows control over how much the scoop can open or close based on how high the bottom of the connecting rod is on the bolt. Every part on the pin joint mechanism is thick with few potential points for failure.

The pin joint mechanism was also chosen due to its ability to convert rotational motion into translational motion. Instead of moving a mechanism up and down, which would not be feasible given the space inside the rocket, the team decided that a rotating motion to actuate the scoop would be ideal. This way there can just be a servo at the top instead of creating a new mechanism to slide up and down a railing. The team decided that having a nut on the bolt would be easiest to manufacture and simplest because it requires the least amount of moving parts, and the tolerances are easiest to fit into the bolt. The pin joint idea also allows for the easiest movement without friction because the moving part is the bolt which allows the mechanism to stay but move easily on command.

The biggest risk to the current design is that the pin joint mechanism relies on an electrical servo which creates another method of failure if the avionics fail to perform as intended. Another problem is that the pin doesn't entirely eliminate friction. The pin joint mechanism could theoretically get stuck if the servo force is not as strong as the frictional force on the pin. Another disadvantage is that there is little material on the other side of the pin from the scoop connecting the rod to the scoop. To compensate for this, strong material will be used like metal, and there will be testing performed to ensure that there is enough material with a safety factor.

8.3 Avionics

8.3.1 Flight Controller

This is a filler paragraph

8.3.2 Computer Vision

This is a filler paragraph

Chapter 9

Testing Campaign

9.1 Structual Testing

9.1.1 Deployment Tests

This is a filler paragraph

9.1.2 Ice Retrieval and Mobility Agent Tests

Longevity Test

The Ice Retrieval and Mobility Agent will be tested by letting open and close repeatedly for an extended period of time. This ensures that the mechanism can loop through many times without any part getting unaligned. The test will also be performed and running over a long period of time so the team can observe the mechanical wear on the mechanism. The test of cycling the open and close motion also confirms that the mechanism performs the way as designed when turned on.

Mechanism in Action Tests

The team will test the mechanism on an ice sample to ensure that the retrieval mechanism can acquire and hold an ice sample in the area where the scoops intersect. The first part is to ensure the ice retrieval and mobility agent can scoop the ice inside the mechanism instead of just pushing or sliding the ice to a different location. The amount of sample the claw can scoop in one trial will also be observed during this test. Additionally, the team will have the UAV transport the ice to a different location to test for sample leakages and design deficiencies.

Rigidity Test

One of the reasons the leading design was chosen was because of its structural integrity. To confirm this, the structural integrity of the mechanism will be tested by observing what happens when vibrations and forces in all directions are applied to the mechanism. The conditions the mechanism experiences in the testing phase will be far harsher than those it should experience in flight. A few tests may look like rigorously shaking the mechanism, pushing hard against the scoop simulating resistance from the ice, and pulling and pushing on the pins to confirm their strength.

Optimization Tests

The final action will be to optimize the mechanism after seeing the mechanism work in practice. If any part of the mechanism does not work according to plan, the dimensions will be changed to maximize the amount of ice acquired in one scoop. The mechanism will also be optimized to minimize leakage and space the mechanism takes inside of the rocket.

9.2 Avionics Testings

9.2.1 Flight Controller Tests

This is a filler paragraph

9.2.2 Computer Vision Tests

This is a filler paragraph

Chapter 10

Operational Protocols

Throughout the mission, the UAV will encounter a number of varied tasks that must be completed sequentially so as to satisfy the mission objectives. As such, it is natural to define a number of regimes in which the vehicle must operate, as these dictate the operational protocols that are to be effectuated. This chapter details these operational regimes, including the pertinent operational protocols. Specifically, the following regimes are identified and discussed in due detail:

I. Transit & Deployment
II. Descent
III. Loiter
IV. Landing
V. Retrieval

10.1 Transit & Deployment

Throughout stand-by, launch and passive descent, referred to as 'transit', the UAV will assume a low-power mode, periodically sending status updates and seeking connection with a ground station. This passive mode stems from multiple considerations. First, given the limited power supply, as much power as possible is to be saved will still maintaining a connection with the UAV. Second, by FAA regulations, the UAV may only be operated below 400 ft in LOS[1] [**?**]. To ensure that no active operation takes place above this ceiling, the vehicle will restrict its operations by considering its current altimeter reading as a locking mechanism. This 'altitude lock' constitutes the transit phase.

From the FAA Reauthorization Act of 2018, the following pertinent regulations may be found. The UAV must have a gross weight under 4.4 lbm, and must be operated:

(i) within or beyond visual LOS of the operator;
(ii) less than 400 ft above ground;
(iii) during daylight conditions;
(iv) within Class G airspace; and
(v) outside of 5 statute miles from any airport, heliport, seaplane base, spaceport, or other location with aviation activities.

[1]FAA Reauthorization Act of 2018 §346(b.2.C), 49 U.S.C. §44806

Regarding points (iv) and (v), it is found that the closest airport is the Hazel Green airport. However, the launch site, Bragg Farms, is located outside of the Class E airspace, thus respecting the Class G airspace requirement

Given the fact that the payload will only be deployed upon being granted permission from the RSO, it is of importance to achieve a timely response in the event of late notification. In addition, proper coordination with the avionics systems is of importance, as solenoid disengagement and winch lowering must be followed by UAV arm deployment in close succession.

HE

Expand on deployment requirements (robustness, rapidity) and ground proximity considerations

10.2 Descent

Given the limited time of flight the UAV is capable of achieving, it is of importance to conclude the descent phase in as small of a time frame as possible.

HE

Expand on descent phase, including trade-offs between guidance algorithms ((N)MPC, GPC) and waypoint tracking vs. visual guidance at close proximity (CV).

10.3 Loiter

HE

Expand on loiter phase, highlighting energy efficiency and data acquisition (feature detection and path planning) during idle phase. Also detail what safety features must be incorporated into this phase (geofencing, no-fly zones have to default back to loiter).

10.4 Landing

HE

Expand on final approach and landing phase, including close-quarters operations and the role of computer vision in detecting the landing site, as well as the accuracy and terminal touch down conditions (velocity, attitude). Explain touch-and-go maneuvers in case of failed landing attempt.

10.5 Retrieval

HE

Expand on retrieval protocol, including claw operations and validation of claw contents. Explain the details on distancing and

Part V

Safety

Chapter 11

Safety Plan Overview

The safety of all team members is of the absolute highest priority for the Illinois Space Society Student Launch team. Should a situation arise in which a project-critical choice needs to be made, safety is considered before the success of the project. The safety officer this year is Zana Essmyer, who is overseeing a small team to conduct a thorough analysis of any hazards the team may encounter this year throughout the design, construction, assembly, and launches of the rocket and payload. Zana and the safety team are also implementing plans and procedures to minimize the risk of associated hazards.

This year, using a combination of in-person briefings, online classes and thorough documentation, the team is actively encouraging participation in the adherence to safety procedures. Safety training is required for any member that wishes to participate in construction sessions or attend a launch. By keeping lists of safety-trained members and having experienced members actively involved at every build session, the team can ensure that everyone working in lab spaces understands safety protocol for both day-to-day work and potential emergency situations. Forthcoming checklists will also be developed to ensure total safety during the off-pad, on-pad and post flight procedures.

11.1 Emergency Preparedness

Though the Illinois Space Society strives to maintain a safe working environment during all phases of the competition, the team also recognizes that accidents remain a possibility even with the strictest safety precautions in place. With this in mind, emergency preparedness forms another pillar of the team's safety plan. First aid kits are easily accessible in all of the team's main workspaces, and the safety officer has familiarized herself with their contents. The kits themselves are up-to-date and include wound dressings, antibiotic ointments, painkillers, and antihistamines. For any injuries requiring more than basic first aid, medical facilities are available both on and off the University of Illinois campus.

11.2 Incident Reporting

In the rare event that an accident requiring first aid occurs, the primary goal is always to care for and assist the injured team member. That said, once the incident has passed, the safety team's next priority is to actively prevent accident reoccurrence. Any incident is to be reported immediately to the safety officer, and from there it will be her responsibility to speak to those involved and determine the exact cause of the accident. Review of an incident will be considered complete once the safety officer has surveyed the scenario to her satisfaction and offered recommendations to the team leadership on how to prevent similar incidents in the future.

If an incident happens to occur, a series of actions will enact. The non-injured team member will assess the situation for any immediate dangers before contacting the Safety Officer, Technical Manager, and, if needed, emergency personnel. The Safety Officer will document the incident. The safety team will then take action to prevent further incidents.

11.3 Equipment Training

In order to provide team members with the experience necessary to operate a wide array of equipment and tooling, the safety team provides tutorial sessions on all machinery and tooling that may be used during the course of construction that is provided in the Nuclear Engineering Laboratory. To that end, the safety team has duplicated or adapted manufacturer-provided operating procedures for these tools and uploaded them to the team's shared drive for easy access. A collection of all training documents can be found in APPENDIX D: ISS Common Materials and Equipment Training with information included for the following devices:

- Full Spectrum Laser Professional Series CO2 48"×36" Cutter
- Ultimaker 2 Extended 3D Printer
- Milwaukee Sawzall Reciprocating Saw
- DeWalt 18V Wireless Power Drill
- Dremel 8200-1/28 12-Volt Max Cordless Rotary Tool
- G5000 RocketPoxy
- Grizzly Model G7297 12" Disc Sander
- Water-Cooled Diamond Table Saw
- Grizzly H2936 Vacuum Sanding Table
- GMC 16" Scroll Saw
- JET 15" Bench Drill Press
- Soldering Station
- Miscellaneous Hand Tools (Screwdrivers, Hammer, Clamps, etc.)

In order to operate this machinery, a team member must attend tutorial sessions or receive training separately from a member of the safety team or team management. In providing and requiring these sessions, the team not only reduces the risk of mishaps due to misuse of equipment, but also ensures redundancy in knowledge of construction techniques. The Safety Officer will host tutorial sessions for ESPL machinery at the beginning of the semester for all members before access will be granted.

11.4 NAR/Tripoli Rocketry Association (TRA) Procedures

The team will comply with the "High Power Rocket Safety Code" provided on the NAR website that has been effective since August 2012. The 13-step code and Minimum Distance Table on the website will be reviewed by the safety officer. All members on the team will be required to read the safety code online as it is a relatively short list of codes. The rules set forth by the NAR High Power Rocketry Code will always be respected and followed as they are set to ensure the safety of people and the environment. The safety officer, team manager, and sub-team managers will always make sure to comply with the safety code and ensure the rest of the team is properly complying. A copy of the NAR High Power Rocketry Code is included in this report as App. A. Additionally, sections and elaborate on the hazardous operations and mitigation of risks. Hazardous materials and proper protocol is detailed under section.

HE

Add sec. on hazardous operations

HE

Add sec. on risk mitigation

HE

NAR Mentor. Mark Joseph will be the NAR mentor for the ISS Student Launch team for this year's competition. In addition to his longtime involvement in the high-power rocketry community, Mark has worked with the ISS team for several years now in the NASA Space Grant, Intercollegiate Rocket Engineering, and Student Launch Competitions.

Chapter 12

Risk Assessment Overview

To better prepare for issues that inevitably arise during any project of large scale and to prioritize the team's time, the safety team has conducted a thorough risk analysis based on incident severity. The safety team analyzed risks to the project, the environment, and above all, the health of team members during the construction process. The team used Risk Assessment Codes (RACs) to evaluate the various hazards to both personnel and the project. Table 12.1 introduces the risk matrix and the risk assessment codes that will be used to classify risks throughout the rest of the safety section. Risks are color-coded based on their severity, and discusses the team's response to these various levels. defines the levels of severity as it relates to personnel, project, and environmental health. Table 9 defines individual instance probability and probability of occurrence throughout the entire project timeline.

Table 12.1: Level of risk and member requirements

Probability	**Severity**			
	1—Catastrophic	2—Critical	3—Marginal	4—Negligible
A—Frequent	1A	2A	3A	4A
B—Probable	1B	2B	3B	4B
C—Occasional	1C	2C	3C	4C
D—Remote	1D	2D	3D	4D
E—Improbable	1E	2E	3E	4E

Part VI

Project Plan

Chapter 13

Budget

13.1 Structures and Recovery

ID	Item	Purpose	Number	Unit Cost	Total Cost	Owned?
SR.1	Epoxy and resin	Structural joints	N.A.	70 USD	70 USD	✗
SR.2	60”×4” (L×W) Blue Tube	Upper and lower air-frame	1	90 USD	90 USD	✓
SR.3	12”×4” (L×D) Blue Tube coupler	Main rocket coupler bay	1	45 USD	45 USD	✗
SR.4	9”×6” (L×D) Fiber-glass tube	Fairing tube	1	60 USD	60 USD	✗

Appendices

Appendix A

NAR High-Power Rocketry Safety Code

High Power Rocket Safety Code

Effective August 2012

1. Certification. I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.

2. Materials. I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.

3. Motors. I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25-ft. of these motors.

4. Ignition System. I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the "off" position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.

5. Misfires. If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.

6. Launch Safety. I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of NFPA 1127.

7. Launcher. I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the

wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 and clear that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.

8. Size. My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.

9. Flight Safety. I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.

10. Launch Site. I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500-ft., whichever is greater, or 1000-ft. for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams, and a maximum expected altitude of less than 610 meters (2000-ft.).

11. Launcher Location. My launcher will be 1500-ft. from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.

12. Recovery System. I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.

13. Recovery Safety. I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.

Appendix B

Federal Aviation Regulations 14 CFR, Part 107, Small Unmanned Aircraft Regulations

The Federal Aviation Authority (FAA) rules for small unmanned aircraft (referred to as 'Unmanned Aerial Systems (UASs)') operations other than model aircraft—Part 107 of FAA regulations–cover a broad spectrum of commercial and government uses for UAVs weighing less than 55 pounds. This chapter lists the highlights of the rule.

Operating Requirements. When you are manipulating the controls of a drone, always avoid manned aircraft and never operate in a careless or reckless manner. You must keep your drone within sight. Alternatively, if you use First Person View (FPV) or similar technology, you must have a visual observer always keep your aircraft within unaided sight (for example, no binoculars). Neither you nor a visual observer can be responsible for more than one unmanned aircraft operation at a time.

You can fly during daylight (30 minutes before official sunrise to 30 minutes after official sunset, local time) or in twilight with appropriate anti-collision lighting. Minimum weather visibility is three miles from your control station. The maximum allowable altitude is 400 feet above the ground, higher if your drone remains within 400 feet of a structure. Maximum speed is 100 mph (87 knots).

You currently cannot fly a small Unmanned Aerial System (UAS) over anyone not directly participating in the operation, not under a covered structure, or not inside a covered stationary vehicle. No operations from a moving vehicle are allowed unless you are flying over a sparsely populated area.

You can carry an external load if it is securely attached and does not adversely affect the flight characteristics or controllability of the aircraft. You also may transport property for compensation or hire within state boundaries provided the drone, including its attached systems, payload and cargo, weighs less than 55 pounds total and you obey the other flight rules. (Some exceptions apply to Hawaii and the District of Columbia.)

You can request a waiver of most restrictions if you can show your operation will provide a level of safety at least equivalent to the restriction from which you want the waiver.

Registration. Anyone flying under Part 107 has to register each drone they intend to operate. If your drone weighs less than 55 lbm, you can use the automated registration system.

Pilot Certification. To operate the controls of a small UAS under Part 107, you need a remote pilot certificate with a small UAS rating, or be under the direct supervision of a person who holds such a certificate

You must be at least 16 years old to qualify for a remote pilot certificate, and you can obtain it in one of two ways.

You may pass an initial aeronautical knowledge test at an FAA-approved knowledge testing center.

If you already have a Part 61 pilot certificate, you must have completed a flight review in the previous 24 months and you must take a small UAS online training course provided by the FAA.

If you have a Part 61 certificate, you will immediately receive a temporary remote pilot certificate when you apply for a permanent certificate. Other applicants will obtain a temporary remote pilot certificate upon successful completion of Transportation Security Administration (TSA) security vetting. We anticipate we will be able to issue temporary certificates within 10 business days after receiving a completed application.

UAS Certification. You are responsible for ensuring a drone is safe before flying, but the FAA does not require small UAS to comply with current agency airworthiness standards or obtain aircraft certification. For example, you will have to perform a preflight inspection that includes checking the communications link between the control station and the UAS.

Other Requirements. If you are acting as pilot in command, you have to comply with several other provisions of the rule:

- You must make your drone available to the FAA for inspection or testing on request, and you must provide any associated records required to be kept under the rule.
- You must report any operation that results in serious injury, loss of consciousness, or property damage of at least $500 to the FAA within 10 days

Waivers and Airspace Authorizations. The FAA can issue waivers to certain requirements of Part 107 if an operator demonstrates they can fly safely under the waiver without endangering other aircraft or people and property on the ground or in the air. Operations in Class G airspace are allowed without air traffic control permission. Operations in Class B, C, D and E airspace need Air Traffic Control (ATC) approval.

In November 2017, the FAA deployed the Low Altitude Authorization and Notification Capability (LAANC – pronounced “LANCE”) for drone operators at several air traffic facilities in an evaluation to see how well the prototype system functions and to address any issues that arise during testing. A beta test expansion of the system began on April 30, 2018 to deploy LAANC incrementally at nearly 300 air traffic facilities covering approximately 500 airports. The final deployment will begin on September 13.

The FAA expects LAANC will ultimately provide near real-time processing of airspace authorization requests for drone operators nationwide. The system is designed to automatically approve most requests to operate in specific areas of airspace below designated altitudes.

Appendix C

Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C – Amateur Rockets

§ 101.21 Applicability.

(a) This subpart applies to operating unmanned rockets. However, a person operating an unmanned rocket within a restricted area must comply with § 101.25(b)(7)(ii) and with any additional limitations imposed by the using or controlling agency.

(b) A person operating an unmanned rocket other than an amateur rocket as defined in § 1.1 of this chapter must comply with 14 CFR Chapter III.

§ 101.22 Definitions.

The following definitions apply to this subpart:

(a) ***Class 1 - Model Rocket*** means an amateur rocket that:

> **(1)** Uses no more than 125 grams (4.4 ounces) of propellant;
>
> **(2)** Uses a slow-burning propellant;
>
> **(3)** Is made of paper, wood, or breakable plastic;
>
> **(4)** Contains no substantial metal parts; and
>
> **(5)** Weighs no more than 1,500 grams (53 ounces), including the propellant.

(b) ***Class 2 - High-Power Rocket*** means an amateur rocket other than a model rocket that is propelled by a motor or motors having a combined total impulse of 40,960 Newton-seconds (9,208 pound-seconds) or less.

(c) ***Class 3 - Advanced High-Power Rocket*** means an amateur rocket other than a model rocket or high-power rocket.

§ 101.23 General operating limitations.

(a) You must operate an amateur rocket in such a manner that it:

> **(1)** Is launched on a suborbital trajectory;

(2) When launched, must not cross into the territory of a foreign country unless an agreement is in place between the United States and the country of concern;

(3) Is unmanned; and

(4) Does not create a hazard to persons, property, or other aircraft.

(b) The FAA may specify additional operating limitations necessary to ensure that air traffic is not adversely affected, and public safety is not jeopardized.

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

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

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

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

(c) Into any cloud;

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

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

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

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

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

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

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

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

§ 101.27 ATC notification for all launches.

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

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

(b) Date and time the activity will begin;

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

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

(e) Highest affected altitude;

(f) Duration of the activity;

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

§ 101.29 Information requirements.

(a) ***Class 2 - High-Power Rockets.*** When a *Class 2 - High-Power Rocket* requires a certificate of waiver or authorization, the person planning the operation must provide the information below on each type of rocket to the FAA at least 45 days before the proposed operation. The FAA may request additional information if necessary to ensure the proposed operations can be safely conducted. The information shall include for each type of Class 2 rocket expected to be flown:

(1) Estimated number of rockets,

(2) Type of propulsion (liquid or solid), fuel(s) and oxidizer(s),

(3) Description of the launcher(s) planned to be used, including any airborne platform(s),

(4) Description of recovery system,

(5) Highest altitude, above ground level, expected to be reached,

(6) Launch site latitude, longitude, and elevation, and

(7) Any additional safety procedures that will be followed.

(b) ***Class 3 - Advanced High-Power Rockets.*** When a *Class 3 - Advanced High-Power Rocket* requires a certificate of waiver or authorization the person planning the operation must provide the information below for each type of rocket to the FAA at least 45 days before the proposed operation. The FAA may request additional information if necessary to ensure the proposed operations can be safely conducted. The information shall include for each type of Class 3 rocket expected to be flown:

(1) The information requirements of paragraph (a) of this section,

(2) Maximum possible range,

(3) The dynamic stability characteristics for the entire flight profile

(4) A description of all major rocket systems, including structural, pneumatic, propellant, propulsion, ignition, electrical, avionics, recovery, wind-weighting, flight control, and tracking,

(5) A description of other support equipment necessary for a safe operation,

(6) The planned flight profile and sequence of events,

(7) All nominal impact areas, including those for any spent motors and other discarded hardware, within three standard deviations of the mean impact point,

(8) Launch commit criteria,

(9) Countdown procedures, and

(10) Mishap procedures.