FLAME
Fall Final Report

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List of Acronyms

CAD: Computer Aided Design
ConOps: Concept of Operations
DoD: Depth of Discharge
DVR: Digital Video Recorder
ELRS: Express Long Range System
ESC: Electronic Speed Controller
HITL: Human-In-The-Loop
PMW: Pulse Width Modulation

RC: Remote Control
RMS: Root Mean Square
UART: Universal Asynchronous Receiver/Transmitter
FBD: Function Block Diagram
FDM: Fused Deposition Modeling
FMU: Flight Management Unit
FPV: First Person View
GPS: Global Positioning System
IMU: Inertial Measurement Unit
PLA: Polylactic Acid
PVC: Polyvinyl Chloride
NPT: National Pipe Thread
SBUS: Serial Bus
T/W: Thrust-to-Weight
UAS: Unmanned Aerial System

Nomenclature

NOTE: A dot above a variable indicates a time rate of change and a superscript "E" indicates inertial

ω_n: Natural Frequency
ζ: Damping Ratio
τ: Time Constant
Φ: Roll Angle
θ: Pitch Angle
Ψ: Yaw Angle
X: x-Axis Drag Force
Y: y-Axis Drag Force
Z: z-Axis Drag Force
x: x-Axis Position
y: y-Axis Position
z: z-Axis Position
u: Body Frame x Velocity Component
v: Body Frame y Velocity Component
w: Body Frame z Velocity Component
p: Roll Rate
q: Pitch Rate
r: Yaw Rate
L: Roll Moment
M: Pitch Moment
N: Yaw Moment
L_c: Roll Control Moment
M_c: Pitch Control Moment
N_c: Yaw Control Moment
Z_c: Motor Control Forces
I_x: x-Axis Moment of Inertia
I_y: y-Axis Moment of Inertia
I_z: z-Axis Moment of Inertia

Section 1: Project Purpose

This project is a proof of concept for a UAS fire mitigation system. As the urban and suburban developments continue to expand across the state, wildfires will become more destructive, and fixing their damage will become more expensive. The proof of concept is intended to help mitigate the spread of wildfires in the Colorado Valley area, and ultimately the rest of the world. It will show the ability of a hexacopter system to carry and deploy fire retardant at specified locations. It will also show that the hexacopter will safely deploy the fire retardant without impacting the environment around it. The goal of this proof of concept is to show the possible applications for local fire departments and hopefully have the hexacopter be a part of their firefighting team. Overall, the main purpose of this proof of concept is to show all of the possibilities for using drones in different firefighting scenarios in and around the Colorado Valley area.

Fighting wildfires is a very challenging task, with numerous issues involved. For one, it is common for large fires to be located in hazardous terrain. This can pose significant risks to firefighting personnel. Given these risks, officials are sometimes left with no choice but to let these fires burn uncontrollably. As the frequency of destructive fires continues to increase, so too does the need to find more reliable solutions. Given the speed of fires, any proposed solution must have the ability to be deployed quickly and reach the target location before the fire has burned all available fuel. Another problem to be addressed is the ability to navigate to the area of operation and deploy a payload autonomously. This is crucial because it allows for the mitigation of fire behaviour without putting any human lives at risk. One of the last challenges considered in the design process is the continuous operation of the design even in the presence of adverse weather situations. Wildfires, especially those of a larger magnitude, can cause rapid changes in wind patterns. Sometimes these changes are so severe that fixed wing aircraft and large helicopters are restricted to the ground. A smaller, more maneuverable vehicle provides a different solution to accomplish the same goal.

This proof of concept is intended to show the possible benefits of using a hexacopter within a firefighting team. With the use of a drone system, there would be less human risk involved with firefighting. Along with this, the use of a drone would allow firefighters to reach difficult areas with minimal effort. Another benefit of using a hexacopter for firefighting would be overall improved efficiency. By using an autonomous system, a lot of time and effort could be saved in the overall firefight, especially the time to deploy the fire retardant. The UAS fire mitigation system would allow for faster deployment times, better real-time surveillance of the fire, as well as a lower cost to operate. Using the hexacopter for firefighting would allow for enhanced fire suppression, because fine-tuning the accuracy of the hexacopter to a high specification allows for more targeted firefighting, and would allow for small-scale fires to become practically non-issues. This hexacopter allows for responses from the ground station within less than a second as a result of the data collection rate of the hexacopter. With a very fast response time, the hexacopter will provide the firefighters with a fast data collection rate, enabling faster decision-making. Another benefit of this proof of concept is that it applies to all types of fires. The operational flexibility of the hexacopter and its autonomous abilities allow for the drone to be used in many different firefighting scenarios.

This project has several unique aspects. While the use of multi-rotor drones is becoming more common in a variety of different applications, many have different speciality characteristics which are specifically suited for their intended purpose. For firefighting drones, the payload deployment mechanism is usually the driving factor behind the vehicle design itself. This imposes some very novel design choices. Another unconventional aspect of this project was the freedom of design choice. Besides budgetary constraints, the project proposal provided the opportunity to explore a variety of different airframe types, along with several different configurations therein. Many other projects, while perhaps more technically challenging, were much narrower in the scope of their design solutions. The basic breakdown of the project's actions is below, shown in the mission ConOps.

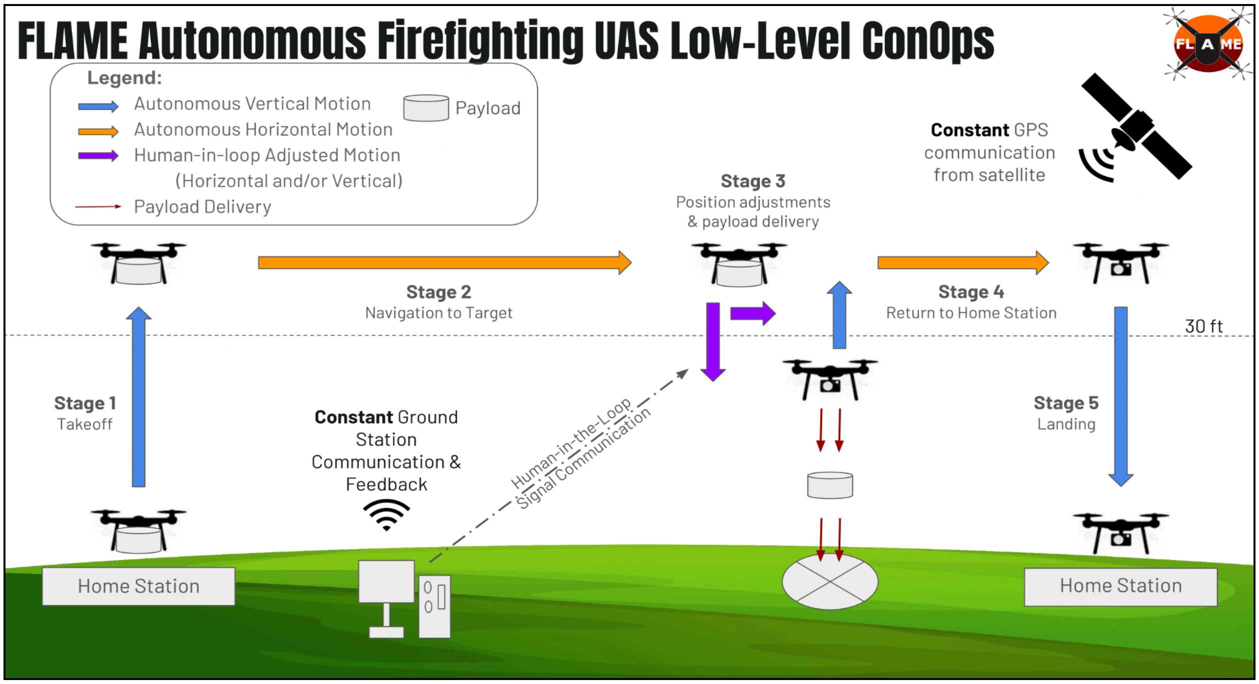


Figure 1-1: FLAME Low-level Concept of Operations

In the interest of showing what actions the system will need to perform and in what order, the team set out to make a ConOps for the mission. Initially, the ConOps had to remain design agnostic, but the given and derived requirements available were sufficient to make the first iteration. The low-level ConOps, as seen in Figure 1-1, is used to break down every signal, action and movement the system performs in one leg of the mission. Stage 1 begins with a fully loaded drone and is the system's autonomous takeoff. Stage 2 is autonomous navigation to the target location. Stage 3 is the human-in-the-loop movement and payload delivery, where the pilots will manually adjust the system's position to be accurately above the target, then deploy the payload onto the target. Continuing, stage 4 is the autonomous navigation to the home station and stage 5 is the autonomous landing. Stages 1 and 5 are vertical motion only, with stages 2 and 4 consisting of horizontal motion. Stage 3 will consist of vertical and horizontal motion, though any movement below the 30-foot hard deck must be vertical. The signals present in the low-level ConOps detail the constant ground station communication and feedback, the constant GPS communication with satellites, and the special human-in-the-loop communication during stage 3.

For the whole mission, the team will be given a mission zone that is 100 meters in diameter and a home station within the mission zone. This mission zone will contain 3 targets given via GPS coordinates. The above low-level ConOps will be repeated for each target location. In between the mission legs, once the drone has landed at home station, the drone will be powered down, and the ground team will reload the drone with a new 5.5 pound payload. During this time, other members of the ground team will be transitioning to the next mission segment within Mission Planner to reduce delay between mission legs. Once this process has been completed 3 times within a 20-minute window, the mission is considered completed and successful.

Section 2: Detailed Design

System Overview

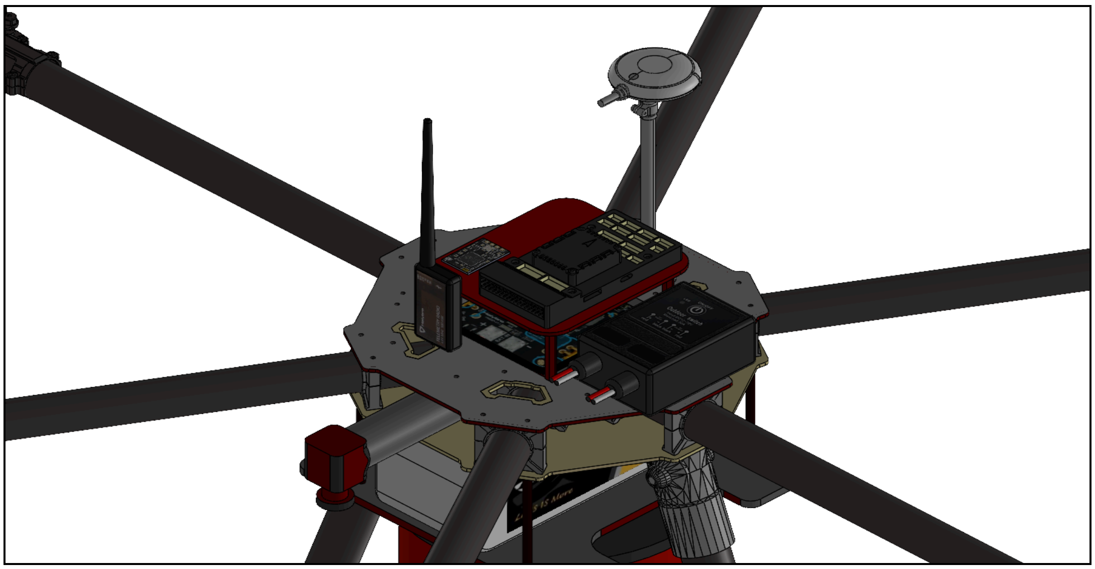


Figure 2-1: Top View of Hexacopter CAD Model

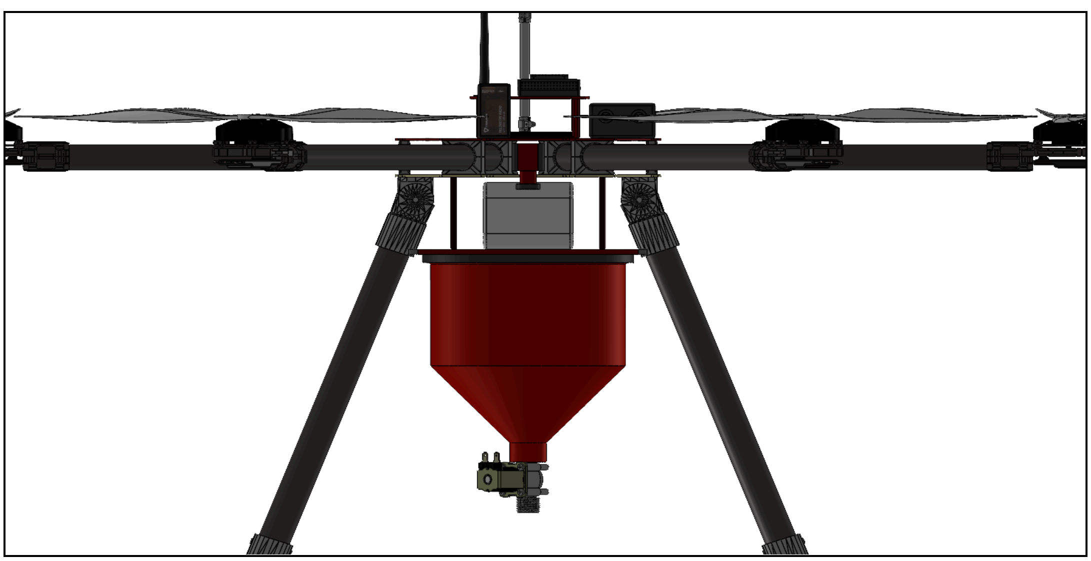


Figure 2-2: Side View of Hexacopter CAD Model

Figures 2-1 and 2-2 show the developed CAD model for the anticipated hexacopter design. While the model does not include mounting fixtures such as screws, bolts, and zip ties or wiring, it contains all major components to be included on the drone except for the tray between the battery and the tank. See Payload Deployment for more information. A dome covering the top of the drone will be designed once it has been assembled in an effort to waterproof the major components on the top of the drone. This will also raise the GPS module and reduce possible interference from the motors of the drone. This section will dive deeper into the details of how the different subsystems will interface.

Functional Block Diagram

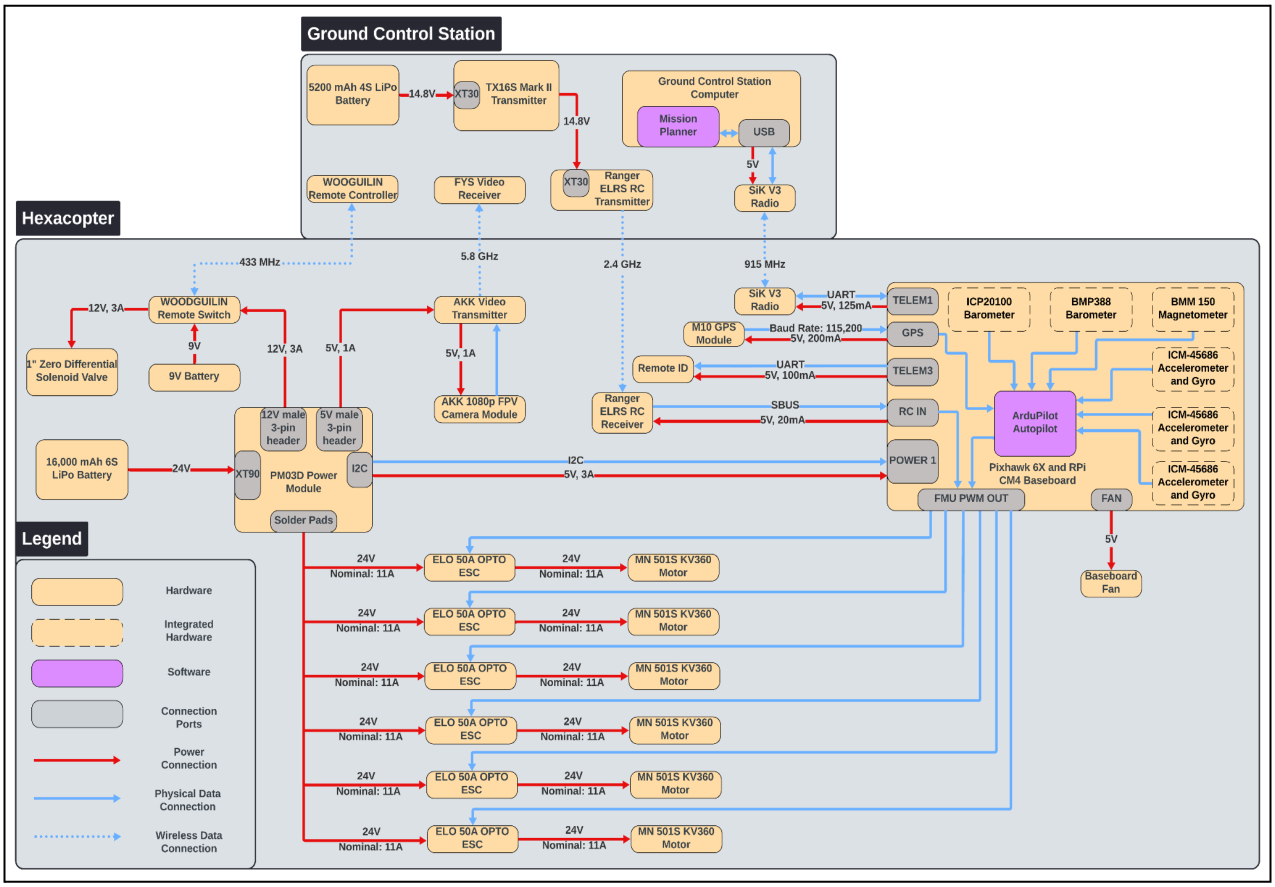


Figure 2-3: FBD

The system, as represented in Figure 2-3, begins at a 6S 16,000mAh battery to power the hexacopter drone. 24V is pushed into the XT90 PM03D Power Module port to be distributed to the rest of the system. Starting at the top left of the power module, 12V with a max of 3A is sent into the Remote Switch for the payload deployment through the 3-pin header. This remote switch is powered by a 9V battery stored internally within the switch. The device then communicates with a handheld switch at 433MHz to allow the 12V to be passed through to the solenoid valve. The solenoid valve opens up when powered with the 12V, allowing the payload to be deployed.

Next, 5V with a max current of 1A is output from the power module through a 3-pin header to the AKK Video Transmitter which is connected directly to AKK 1080p Camera Module. The video transmitter directly relays the video communication at 5.8GHz to the FYS Video Receiver. This allows the user to see directly underneath the drone for the human-in-the-loop corrections in order to meet the 1-meter accuracy requirement.

Moving to the next part, 5V with a max of 3A is output through the I2C port to the Pixhawk 6X flight controller. The I2C is also sent directly to the Pixhawk 6X from the power module as a communication protocol allowing data to be sent between each other.

For the final output of the power module, 24V is sent out to each Eolo 50A Light Version V2 ESC through solder pads that have a nominal amperage of 11A in a hover condition. This output powers the six separate speed controllers that are directly connected to the T-Motor MN501-S at the same voltage and amperage. The power module will only power these components and allow the system to take off at controlled speeds selected by the flight controller.

The next major component is the Pixhawk 6X. Starting with the Power 1 input, the Pixhawk 6X is powered by the power module with a 5V connection at 3A. Moving upward, the RC IN port plugs directly into the Ranger ELRS RC Receiver at 5V and 20mA. This RC receiver is used to talk directly to the controller being operated by a user. The receiver transmits the data at 2.4GHz directly to the Ranger ELRS RC transmitter. Also, the SBUS communication protocol allows for communication between the receiver and flight controller.

The next port up is the TELEM3 that connects directly to the Remote ID at 5V and 100mA. Remote ID is required by the FAA in order to be used to identify the hexacopter. The UART communication protocol allows the device to exchange data serially.

The GPS port is connected directly to the M10 GPS Module which allows the hexacopter to meet its 10 meter GPS accuracy requirement. The GPS Module is powered by 5V and operates at 200mA. The Pixhawk 6X communicates with the GPS Module at a Baud Rate of 115,200. The rate represents 115,200 signal changes per second, allowing for quick communication to meet the requirement.

Moving up, TELEM1 is connected directly to the SiK V3 Radio at 5V and 125mA. The SiK V3 Radio communicates directly to a separate Sik V3 Radio connected directly to the ground station and transmitted at 915MHz. The V3 Radio allows the hexacopter to receive the planned mission and any mission parameters or inputs. This port is important for the system to complete the mission. Most of the communication will be sent through the V3 Radio. This communication is sent between the V3 Radio and the flight controller using the UART communication protocol.

The FMU PWM outputs the signal directly to the six separate speed controllers at the specific throttle percentage directed by the mission. The last port connected to the Pixhawk 6X is the fan output connected directly to the flight controller at 5V to provide airflow to the baseboard. Inside the Pixhawk 6X is an internal barometer, magnetometer, accelerometer, and gyro allowing for smooth flight and control within the hexacopter drone.

The last component is the ground control station which is separate from the hexacopter drone. A 5,200mAh 4S LiPo Battery is used to power the TX16s Mark II controller. 14.8V is sent from the battery to the controller through the XT30 port. Connected internally is the Ranger ELRS RC Transmitter that is used to allow user input directly to the hexacopter drone. Finally the ground station computer will be equipped with the Mission Planner software and connect directly to the SiK V3 Radio through USB communication to allow the mission to be carried out directly to the hexacopter drone.

Subsystem Breakdowns

Power

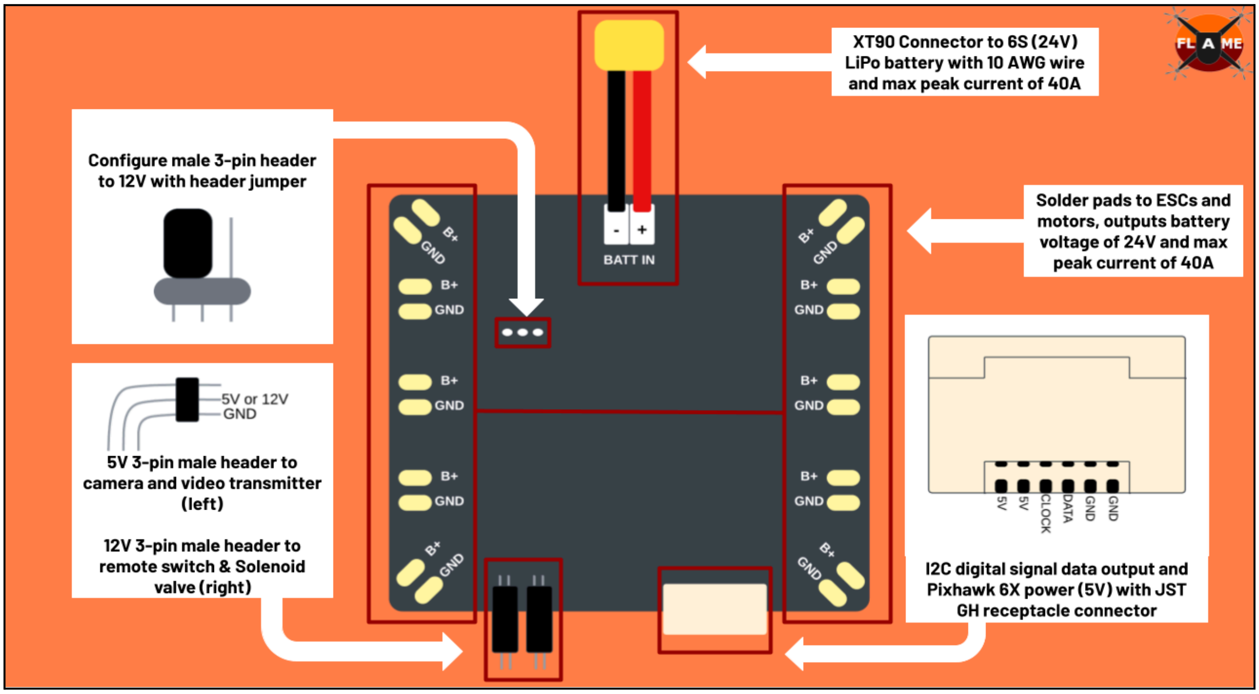


Figure 2-4: PM03D Power Module

The main components of the power subsystem are a PM03D power module, as seen in Figure 2-4, and a Tattu 16,000mAh battery. The selected battery provides power directly to the power module and the ESCs, which power the motors. The PM03D steps down power to the flight controller and will provide power to the remote switch. The stepped-down power to the flight controller allows us to connect and power the communication devices and sensors through the Pixhawk connections.

Communications

The communication subsystem components are as follows: the BetaFPV ELRS receiver, AKK FPV transmitter 5.8GHz, SiK telemetry radio, and the FAA Remote ID. The ELRS receiver gets control signals from the Ranger Micro ELRS transmitter on the ground station at 2.48GHz and sends joystick input control signals to the flight controller. The FPV transmitter sends video signals from the camera at 5.8GHz to the ground station. The SiK Telemetry Radio transmits on-board positional data at 915MHz from the flight controller to a second SiK telemetry radio that is connected to the ground station computer to display real time data. The FAA remote ID is used for FAA identification and sends a 2.4GHz identification signal. Each system has enough range to transmit within the designated mission area, and all onboard subsystem components operate on an input voltage of 5V from the flight controller.

Control

The control subsystem consists of the Pixhawk 6X flight controller, TX16s Mark II controller/transmitter, RadioMaster Ranger Micro 2.4GHz ELRS transmitter module, 4.5” DVR 5.8GHz 40CH FPV monitor, and WOODGUILIN remote switch. The Pixhawk 6X, along with its baseboard, powers and connects components via JST GH receptacle connectors. The Pixhawk 6X serves as the primary control unit for the hexacopter, running ArduPilot autopilot software. ArduPilot communicates with the ground station mission planning software, Mission Planner, to enable autonomous flight operations, including navigation, stabilization, and mission execution. The flight controller processes input from onboard sensors and executes commands to rotate the motors accordingly, ensuring flight stability and mission adherence. The TX16s Mark II controller powers the Ranger ELRS transmitter module, which communicates with the onboard radio receiver. This link allows a human pilot to issue commands to the flight controller for manual control or mission adjustments. The 4.5” FPV monitor receives a live video feed from the AKK FPV transmitter, enabling the pilot to make real-time flight adjustments and precisely position the hexacopter above a target. The WOODGUILIN remote switch allows the pilot to activate the onboard remote switch, triggering the solenoid valve to release the water payload as needed.

Propulsion

The propulsion subsystem includes the T-Motor MN501-S KV 360 motors, Eolo 50A 6S ESCs, and QWinOut 1855 Propellers. The ESCs control the speed of the motors by the command of the flight controller. The propellers are attached to the motor shaft via four 3mm diameter screws, which will provide propulsion to the aircraft. The motors are waterproof and have high cooling performance. Table 2-1 contains the specifications of the motors.

Table 2-1: Motor Specifications

Parameter	Specification
Idle Current (15V)	1.4A
Peak Current (180s)	40A
Internal Resistance	45mΩ
Motor Weight (Including cable)	175g
Rated Voltage (LiPo)	24V (6S)
Propeller Recommendation	17-18”

Notice that the max current draw for the motors is 40A at 100% throttle, and the chosen ESC can handle up to 50A, giving the system a 25% buffer. The chosen battery mentioned in the power subsection is also able to provide the necessary voltage levels that the motor needs to operate. The chosen propellers are also within the recommended size range from the motor datasheet.

Payload Deployment

Table 2-2: Payload Container CAD Model

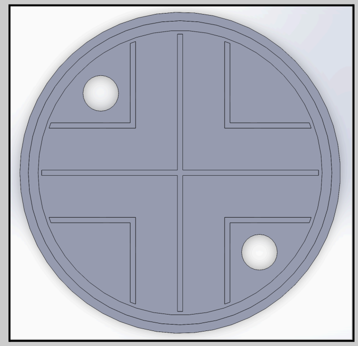
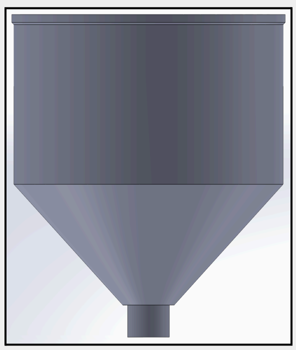
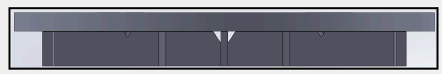
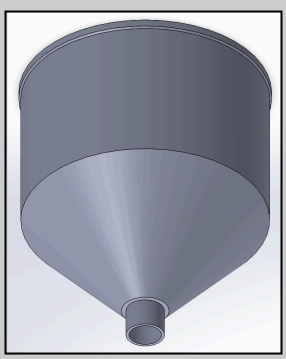
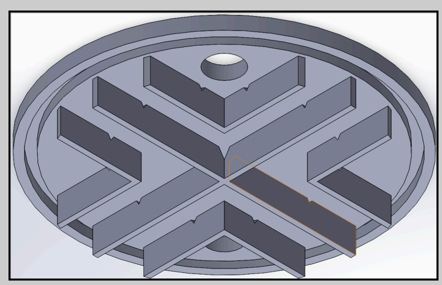
View:	Tank Body:	Cap:
Top		
Side		
Isometric		

Table 2-3: Payload Container Measurements

Cylinder Height	Total Height	Slant Angle	Inner Radius	Top Radius
9.94 cm	16 cm	48°	8 cm	1.27 cm

Contained Volume	Printed Volume	PLA Density	PLA Mass	Total Mass (with payload)
2,479 cm^3	255 cm^3	1.24 g/cm^3	316 g	2,735 g

The container will be printed in two halves that will be glued together before the tank is attached to the drone as seen in Table 2-2, with dimensions contained within Table 2-3. This allows for the installation of mounting hardware on the inside of the lid, reducing space, mass, and complexity compared to mounting hardware on the outside of the tank. Preliminary concepts for mounting hardware include installing captive bolts extending to the top of the tank, attached to nuts on the other side of the battery tray. Mounting hardware design has not been completed because the team has been unable to obtain exact dimensions or CAD models of the battery tray. The mounting hardware will be designed upon delivery on the airframe, when the team is able to take detailed measurements and validate the strength of the battery tray.

Various features of the tank are designed for the purpose of fluid control and stability. The tank is intended to be filled to maximum capacity, but if for any reason it is not, the ortholinear baffles in the cap are intended to mitigate the free surface effect. Movement of water in the tank has the potential to severely degrade the stability characteristics of the UAS, and it was deemed that the increased stability and safety provided justified the negligible mass and fluid volume penalties incurred. Additionally, the 48 degree conical slope at the bottom of the tank promotes fluid flow towards the outlet, and also satisfies overhang constraints inherent to the 3D printing process. Small holes in the baffles are intended to allow air to flow at a rate sufficient to prevent trapped air in the tank when filling while mitigating the free surface effect. Testing and validation of this behavior will occur in the spring. The 48 degree conical slope at the bottom of the tank also promotes flow towards the drain under variable attitude conditions while satisfying constraints with the FDM 3D Printing manufacturing process.

The two holes in the cap will accommodate the installation of two flexible plastic tubes with an outer diameter of 20mm. The other ends of these tubes will be connected to the primary airframe assembly such that their height is greater than the top plate shown in Figure 2-1. This prevents spillage from the top of the tank under normal flight attitudes, and allows the team to easily refill the tank by placing a funnel atop one tube and pouring in water from a separate container. Two tubes are used to ensure sufficient ventilation and prevent adverse air pressure gradients during filling and draining procedures.

3D printing was chosen as the preferred manufacturing method, as it provides high precision, is low in material cost and labor, and allows for rapid design iteration. PLA was chosen as the material due to low cost, high strength compared to weight, and ease of fabrication. One potential issue with PLA is water-tightness and the potential for leaks in the tank. Preliminary testing has shown this to not be an issue, but if future testing proves otherwise, the interior surfaces of the tank will be coated in waterproof resin.

The tank will drain using a solenoid attached to the bottom of the tank, which will be commanded to open by radio signal from human operators. The solenoid valve will be attached to the tank via a PVC adapter, which converts between the 1” NPT fitting on the solenoid valve and a Schedule 40 1” slip coupling, which will be glued to the bottom of the tank. This is done due to the infeasibility of 3D printing 1” NPT threads, and to ensure that the valve can be removed from the tank non-destructively. One potential issue with this system is in adhering the PVC coupling to the tank. The chemical resistance of PVC requires specialized adhesives. Experts in the 3D printing shop believe standard PVC cement will be chemically compatible with PLA, but preliminary research has identified external sources that claim otherwise. Overall chemical compatibility is inconclusive, and this will be tested by the team in the spring. In the event that an adhesive compatible with PLA and PVC cannot be found, an adapter of a different material will be purchased or, if necessary, fabricated.

One last area of uncertainty in the payload deployment system is the time required to fill and drain. Preliminary testing demonstrated that the tank drains completely in approximately 5.5 seconds. However, flow restrictions imposed by the valve and adapter, as well as filling times, are unknown. Based on preliminary testing and inference based on tank geometry, the likelihood of issues requiring significant redesign is believed to be negligible.

Airframe/Structure

The airframe subsystem is what all components excluding the ground station will be mounted to. The airframe that was selected is the Tarot X6, which is capable of handling the weight capacity and has space for all components to mount. This airframe package also includes landing gear.

Sensing

The sensing subsystem consists of 3 ICM-45686 Accelerometer and Gyro, a BMP 388 Barometer, an ICP-20100 Barometer, a BMM 150 Magnetometer, an FPV camera, and a HolyBro M10 GPS. A large portion of the sensing subsystem is included in and handled by the flight controller. The flight controller includes the three accelerometers, two barometers, and the magnetometer to sense its orientation, altitude, and heading. The ICM-45686 is a 3-gyro and 3-accelerator system system. The flight controller has three total ICMs for IMU redundancy. The BMP 388 barometer is a pressure altimeter within the flight controller with an accuracy within one meter of altitude. The ICP-20100 barometer is also within the flight controller, and takes temperature and pressure readings with high accuracy. The BMM 150 Magnetometer is the last sensing component installed within the flight controller, and provides magnetic heading information with a resolution of 0.3 microTeslas. The FPV camera is directly mounted to the drone and connected to the FPV transmitter. The camera captures a resolution of 1080p. Finally, the HolyBro M10 GPS antenna will give the flight controller GPS positional data within an accuracy of 2 meters.

Section 3: Engineering Models and Prototyping

Table 3-1: Completed Engineering Models

Model	Model Description	Design Requirements
Energy Consumption Analysis	Breaks mission into different mission legs, intakes motor data sheet values for thrust and current draw; vehicle mass; T/W ratio; segment time, and outputs mission leg energy consumption	FR 1.4, FR 2.1, DR 2.1.1, DR 3.1.1, DR 3.2.1
Flight Dynamics	This model simulates the system's flight and performance during a single mission leg. It is built on the foundation of the Quadrotor Dynamics lab but formatted with new control gains, physical parameters such as moment of inertia, and even new control laws for vertical motion.	FR 1.2, FR 1.3, FR 1.5, DR 5.1.1, DR 5.3.1

Payload Deployment Time	This model predicts the time it takes for 5.5 pounds of water to flow out of the payload container.	DR 6.1.2, DR 6.2.2
Payload Container Size	Divides the payload container into a few distinct geometries. Intakes drone frame size and shape specifications, container volume requirements, and 3D printing specifications, and outputs shape dimensions to minimize container surface area while meeting volume requirements.	DR 1.1.3, DR 6.2.2, DR 7.2.3

Table 3-1 contains a list of all engineering models completed for the design synthesis portion of senior projects. This section will conduct a deep dive into the energy consumption model and the flight dynamics model.

Energy Consumption Model

The energy consumption model was created with the intent to determine the total mission energy consumption so that an appropriate battery size could be selected. It also allowed the testing of different motors as long as the datasheet for the motor had throttle percentages, thrust values, and current draw. It was also initially used as a trade study parameter for the number of rotors that the vehicle should have. The model takes inputs of motor datasheet values for thrust, throttle percent, current draw; T/W ratio; segment time (which comes from the flight dynamics model); and vehicle mass, then calculates the energy consumption for each mission leg. This process is repeated for nine separate mission legs, as seen in Table 3-2.

Table 3-2: Model Mission Segments

Segment Number	Mission Segment
1	Takeoff
2	Cruise With Payload
3	Hover Transition
4	HITL Horizontal Adjustments
5	HITL Vertical Adjustments
6	Payload Deployment/Hover
7	Ascent
8	Cruise Without Payload
9	Landing

The motor datasheet values for thrust and current draw occur at discrete throttle percentages, so least squares fitting was used to interpolate the data between throttle percentages so more accurate values for thrust and current draw could be determined, as seen in Figures 3-1 and 3-2.

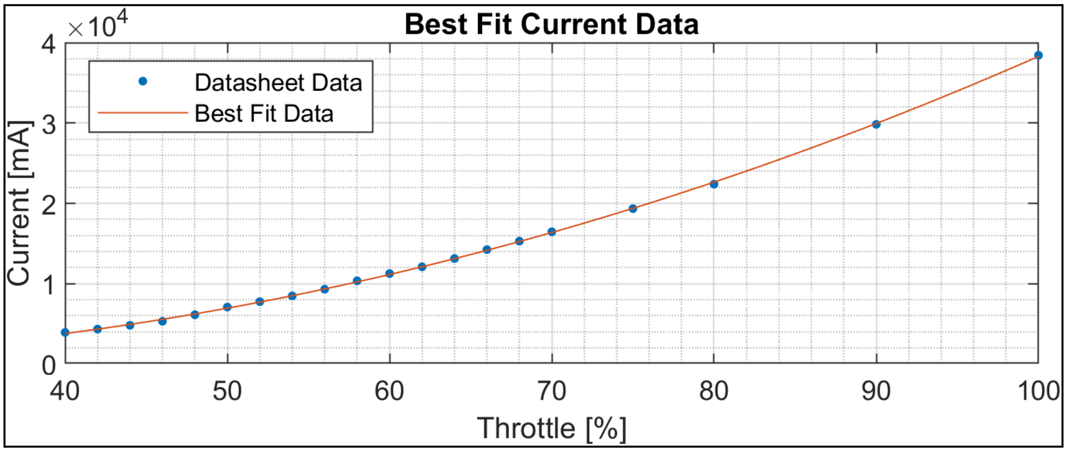


Figure 3-1: Motor Datasheet Current Best Fit

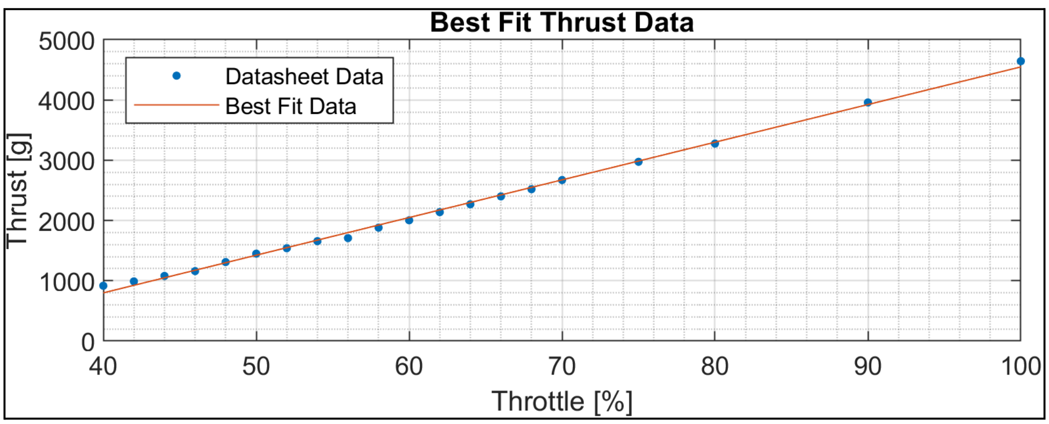


Figure 3-2: Motor Datasheet Thrust Best Fit

Because the model intakes the T/W ratio, it is assumed within the model that the velocity and tilt angle of the vehicle are constant. This is deemed to be a reasonable assumption because the velocity can be averaged over the course of the mission leg in order to represent a constant velocity.

The energy consumption model has two main uncertainties: motor test conditions for datasheet values, and HITL time segments. In order to compensate for the thrust values, the model multiplies the datasheet values by the ratio of air densities between sea-level and Boulder, as this would be the largest discrepancy. This turns out to be a 15% reduction in thrust. For the HITL time segments, the model allows for 60 seconds in total for hover transition, horizontal and vertical adjustments, and payload deployment. This is a reasonable time length as the pilots will take control of the drone as soon as Mission Planner has indicated the drone has reached its target destination, the horizontal adjustments only need to go from 10 meters RMS to 1 meter RMS, the vertical adjustment will be straight down after the horizontal adjustments, and because the payload deployment is expected to take less than 10 seconds. The ground team will be uploading the return mission segment while the pilot is in control, reducing the delay between pilot and autonomous control.

In order to determine energy consumption for a mission leg, the current draw was multiplied by the nominal voltage level at which the motor operated using the equation 3-1. These current values are found by determining the thrust necessary for each motor during a segment using the information of T/W ratio and vehicle mass. Once the thrust for each motor is known, so too is the throttle percentage. The correlating current draw for that throttle percent is the current value used in the calculation of power draw for a given mission segment. The power consumption is then multiplied by the time length of each mission leg using equation 3-2. From here, the DoD of the battery needs to be accounted for so as to not damage the health of the battery. This is a primary concern as large size batteries are fairly expensive. For Lithium-Polymer batteries, the typical depth of discharge is around 85%. With this in mind, the minimum energy capacity of the battery can be determined using equation 3-3. In order to add a buffer for the mission, an additional mission leg is accounted for when determining the minimum energy battery capacity.

$$P = IV$$

Equation 3-1: Power

$$E = Pt$$

Equation 3-2: Energy

$$E_{batt} = \frac{E_{mission}}{DoD}$$

Equation 3-3: Battery Energy

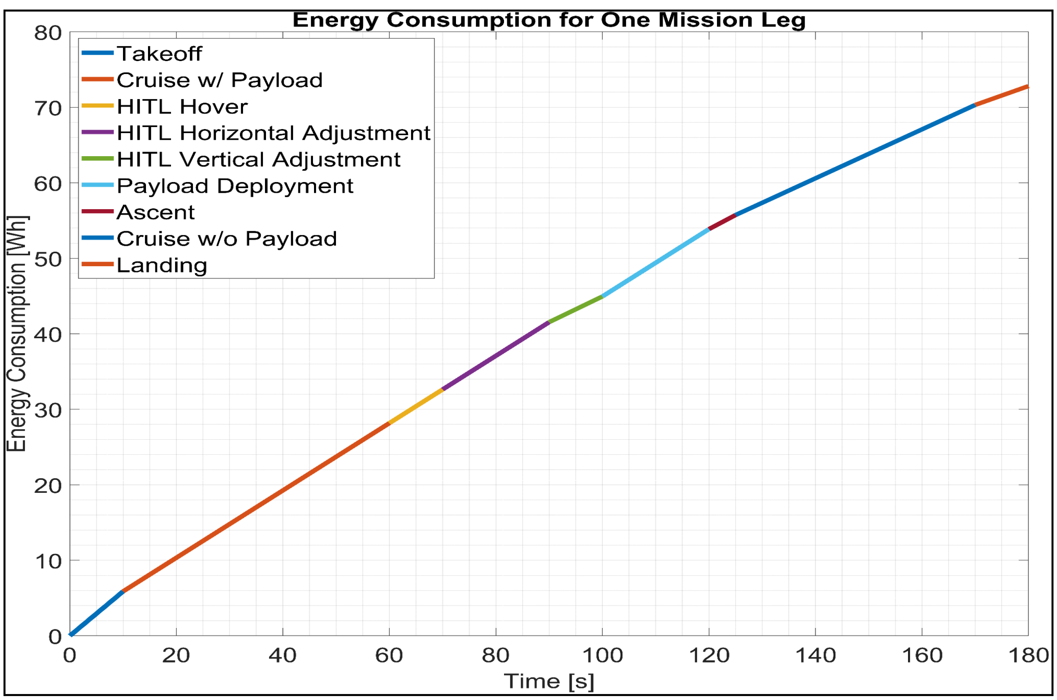


Figure 3-3: 100 Meter Mission Leg Energy Consumption

Figure 3-3 shows the energy consumption for a single mission leg, which is calculated to be 72.8 Wh of energy. This gives an entire mission energy consumption of 342.6 Wh (for four legs) when considering the DoD of the battery. It also shows an estimated mission leg completion time of three minutes, leading to a mission time of twelve minutes. This allows for eight minutes of reloading, which is expected to be plenty of time as the reloading procedure, which was outlined earlier in the report, will be very simple.

Flight Dynamics Model

This model was created to simulate and predict the drone's flight to better understand the performance as well as the feasibility of the mission. It is intended to find the bounds of nominal operation and understand the limitations of the system in terms of flight time and time taken to deploy the payload. Since the entire mission is limited to 20 minutes, it is important to give leeway in case the system performs below standard, so the simulation was capped at 4 minutes per leg resulting in a maximum of 12 minutes for total flight. This gives the drone extra time to fly to the destinations, deploy the payload, and reload the payload between flights. It also allows for an extra leg to be flown in case something were to go drastically wrong and the team needs time to fix an issue with the drone.

This model was created using the fundamental dynamics of a multirotor system. The equations used to express the 12 state variable can be seen in Eqs. 3-4 to 3-7 below.

Governing Dynamics Equations:

$$\begin{bmatrix} \dot{x}_E \\ \dot{y}_E \\ \dot{z}_E \end{bmatrix} = \begin{bmatrix} c_\theta c_\varphi & s_\phi s_\theta c_\varphi - c_\phi s_\varphi & c_\phi s_\theta c_\varphi + s_\phi s_\varphi \\ c_\theta s_\varphi & s_\phi s_\theta s_\varphi + c_\varphi c_\varphi & c_\phi s_\theta s_\varphi + s_\phi c_\varphi \\ -s_\theta & s_\phi c_\theta & c_\phi c_\theta \end{bmatrix} \begin{bmatrix} u^E \\ v^E \\ w^E \end{bmatrix}$$

Equations 3-4: Inertial Velocity Matrix
***c = cosine, s = sine**

$$\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\varphi} \end{bmatrix} = \begin{bmatrix} 1 & \sin\phi\tan\theta & \cos\phi\tan\theta \\ 0 & \cos\phi & -\sin\phi \\ 0 & \sin\phi sec\theta & \cos\phi sec\theta \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix}$$

Equations 3-5: Euler Angle Rate Matrix

$$\begin{bmatrix} \dot{u}^E \\ \dot{v}^E \\ \dot{w}^E \end{bmatrix} = \begin{bmatrix} rv^E - qw^E \\ pw^E - ru^E \\ qu^E - pv^E \end{bmatrix} + g \begin{bmatrix} -\sin\theta \\ \cos\theta\sin\phi \\ \cos\theta\cos\phi \end{bmatrix} + \frac{1}{m} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \frac{1}{m} \begin{bmatrix} 0 \\ 0 \\ Z_c \end{bmatrix}$$

Equations 3-6: Inertial Acceleration Matrix

$$\begin{bmatrix} \dot{p} \\ \dot{q} \\ \dot{r} \end{bmatrix} = \begin{bmatrix} \frac{I_y - I_z}{I_x} qr \\ \frac{I_z - I_x}{I_y} pr \\ \frac{I_x - I_y}{I_z} pq \end{bmatrix} + \begin{bmatrix} \frac{1}{I_x} L \\ \frac{1}{I_y} M \\ \frac{1}{I_z} N \end{bmatrix} + \begin{bmatrix} \frac{1}{I_x} L_c \\ \frac{1}{I_y} M_c \\ \frac{1}{I_z} N_c \end{bmatrix}$$

Equations 3-7: Angular Acceleration Matrix

Beyond the 12 state variables, several other important equations were used to help develop the simulation. The most important of these were the natural frequency and damping ratio equations of a second-order differential equation as seen in 3-8 and 3-9 below. These equations allow for the design of the eigenvectors for the dynamical state-space matrix in order to maintain control throughout the simulation. To ensure stability, the value of the natural frequency and damping ratio were maintained from the ASEN 3801 Lab 4, which were 6.3246 radians per second and 1.7393, respectively. These values were computed using the given time constants of $\tau_1 = 0.5$ and $\tau_2 = 0.05$. These values are also applicable to this system due to the need for a quick response time. This ultimately allowed for the computation of control gains k_1 and k_2. Using the previously calculated control gains, k_3 was computed through the tuning of the eigenvalues of the state-space matrix. k_4 was calculated as seen in equation 3-10 below.

$$\omega_n = \sqrt{\frac{k_2}{I_x}}$$

Equation 3-8: Natural Frequency

$$\zeta = \frac{k_1}{2\sqrt{k_2 I_x}}$$

Equation 3-9: Damping Ratio

$$k_4 = \frac{1}{\tau_2}$$

Equation 3-10: Control Gain 4 Calculation

Once the 4 control gains are calculated, they can be used to calculate the control forces for the system. These control forces are used within equations 3-4 -3-9 (as seen above) in order to modify the state vector based on the needs of the system. The equations for these control forces are determined based on the three modes of the system: ascension, descension, and horizontal translation. The modes for horizontal translation can be seen in equations 3-11 - 3-14 below:

$$Z_C = -mg$$

Equation 3-11: Control Z Force

$$L_C = -k_1 \cdot p - k_2 \cdot \phi$$

Equation 3-12: Control Roll Moment

$$M_C = -k_1 \cdot q - k_2 \cdot \theta + k_3 \left(u_{ref} - u \right)$$

Equation 3-13: Control Pitch Moment

$$N_C = -k_1 \cdot r$$

Equation 3-14: Control Yaw Moment

The model makes a few assumptions about the motion and condition of the multirotor. It is assumed that the vehicle is symmetric and has symmetric thrust, that there is no center of gravity shift during flight (including the payload deployment segment), the vehicle is a rigid body, the vehicle maintains constant drag and moment coefficients, and that the vehicle is stable at all points of the mission. The most glaring of these assumptions is that there is no center of gravity shift during flight, most notably during the payload deployment portion, and that the vehicle is stable at all points. Although this is a very large assumption, it is vital to assume that stability holds in order to facilitate properly looking at the time of flight of the system. The model does update the mass and moments of inertia in accordance with the 3D model once the payload is fully deployed, but again, these are constant while the payload is deploying. One final set of assumptions made involved the payload deployment. Using a few mathematical principles of flow rates, it was calculated that the water would expel from the payload container in roughly 6 seconds. This value is very susceptible to change, as the team can now test the physical payload container itself and get an accurate time to deploy. The team also assumed that during these 6 seconds, the water linearly expels from the payload container. This assumption allowed for linear modeling of the change in mass. The assumptions listed above allowed the team to create the dynamics model of the UAS. The results of this model can be seen in figures 3-4 to 3-7 below:

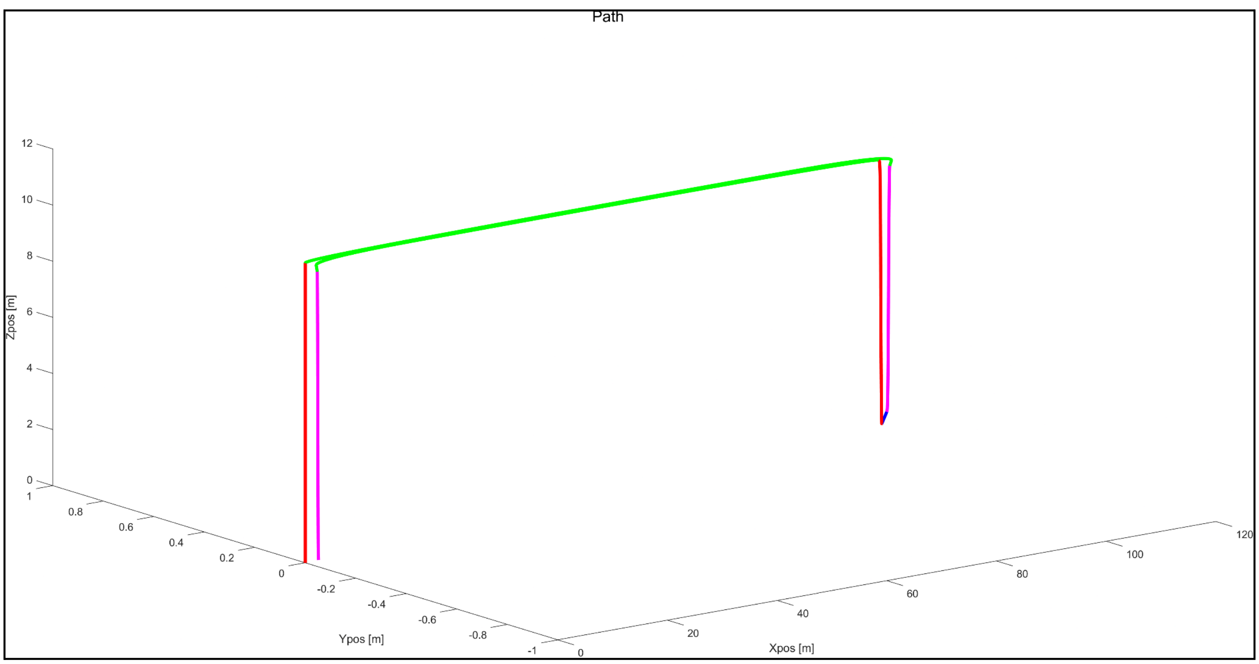


Figure 3-4: Dynamics Model - 3D Position Graph

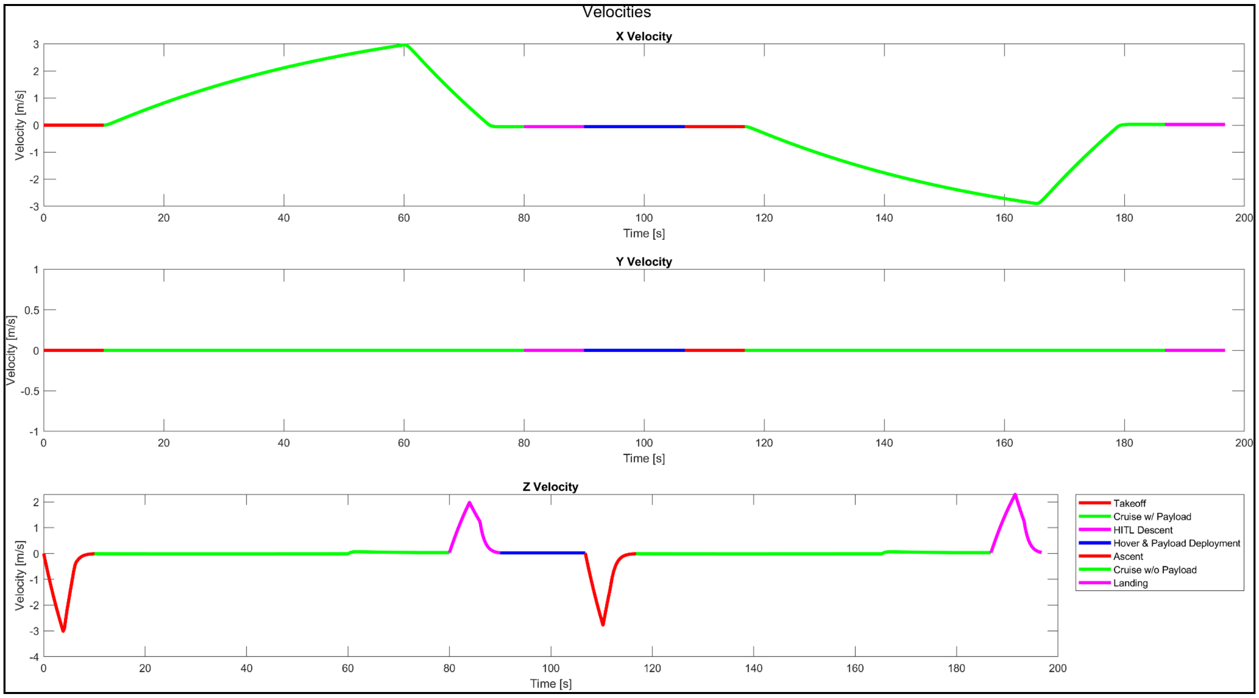


Figure 3-5: Dynamics Model - Velocity

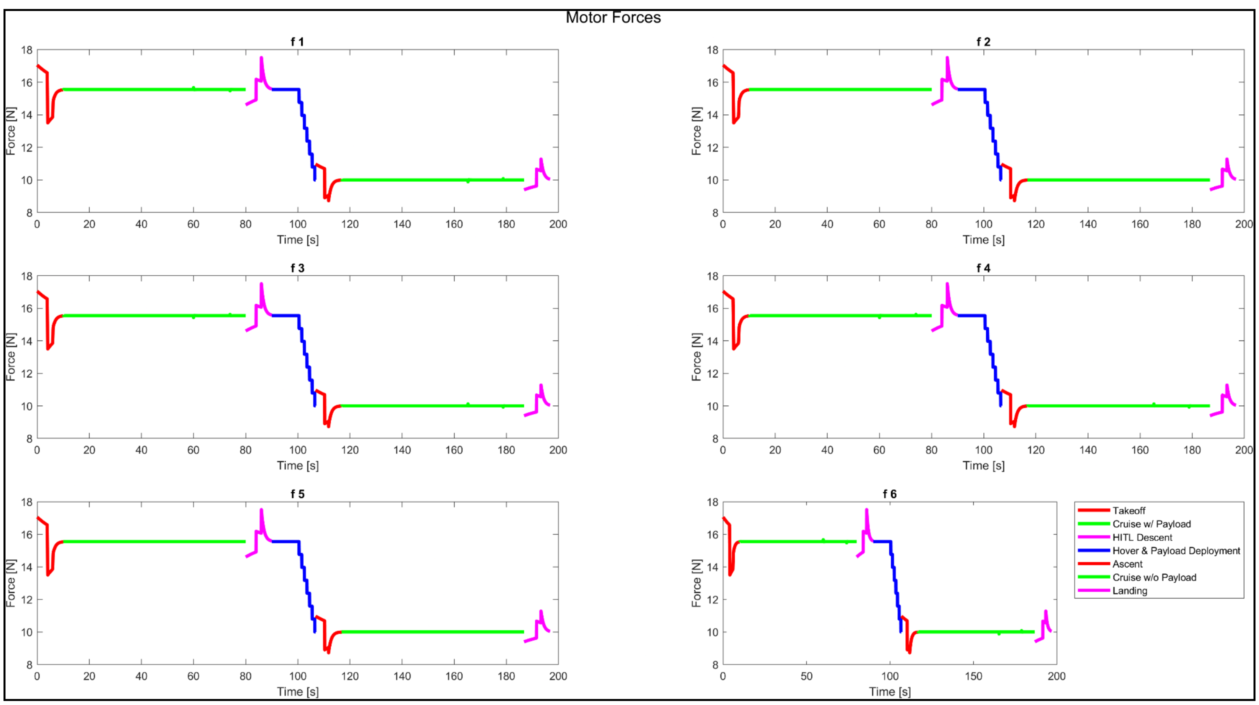


Figure 3-6: Dynamics Model - Motor Forces

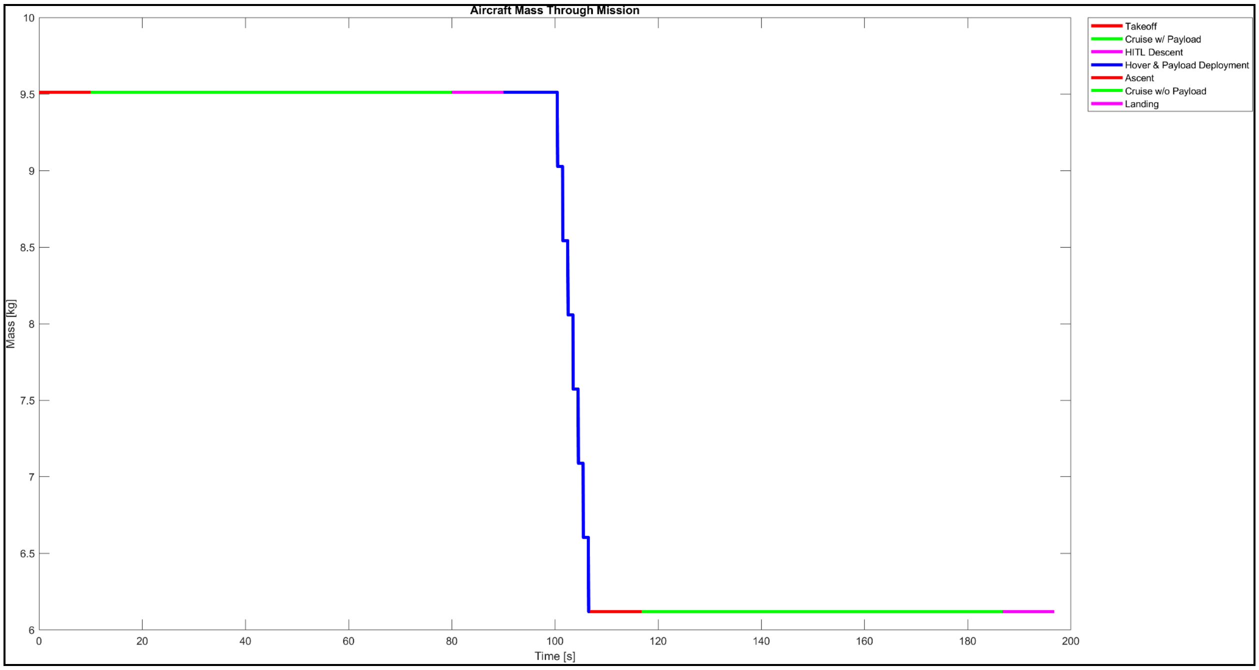


Figure 3-7: Dynamics Model - Mass Through Flight

The figures above are just the most vital sample of the all variables modeled. The position of the drone, velocity of each section, and thrust produced by the motors are the most important to discuss. It is important to note that the colors correspond to the specific mission section described by the legend in each figure. The main points of discussion of this model involve the time of travel, meeting the correct position solution, and the feasibility of the speed of travel, as well as the motor forces. The time of travel of the overall mission is slightly over 3 minutes including time to deploy the payload. The goal was to have the drone travel each leg within a maximum of four minutes which means the model performed within expectations. To travel in this time, the team designed reasonable velocities of the drone during the movement segments of travel. The maximum velocity at which the drone moves is roughly 3 m/s, or about 7 mph. These velocities are believed to be quite moderate and achievable even when experiencing adverse winds of 10 mph. The corresponding maximum thrust to produce a maximum velocity of 7 mph is approximately 17N. This value is slightly above the range of expected values, as the power model requires a maximum thrust of 14N. This slight discrepancy can be attributed to the power model, assuming the drone instantaneously begins moving at a constant velocity. The dynamics model varies slightly because it models for the acceleration of the drone which requires a slightly higher thrust during those brief acceleration segments. Overall, the drone reaches the target within a reasonable amount of time, and the velocity and thrust required to make that happen are relatively within expectations.

The results above validate the expectations for the mission, although there are few uncertainties that must be considered. The first being that the global parameters such as moment of inertia, drag coefficient, and mass, are estimates. These values were estimated through methods such as CAD software, mathematical principles, and data sheets. The parameters in the simulation are considered accurate, but not exact. When dealing with complicated dynamics, slight changes to a value matter. Future testing will allow the team to hone in these values and tune the model so they are able to better understand the system. Another bit of uncertainty lies within the payload deployment. The team assumed that the payload linearly expels from the container over the course of 6 seconds. The assumption is not a notable impact, but it is a piece of the model that is known to be inaccurate. The team will tune these values with future testing to gain a better understanding of how the payload flows from the container. The final and most impactful bit of uncertainty lies within the stability of the system throughout the model. Understanding the shift in the center of gravity and the overall stability of the vehicle is vital for minimizing uncertainties for the mission. Modelling the stability would require understanding the control laws that the controller will use, which are currently unknown. The current model is based in MATLAB for feasibility purposes, but it should be noted that for future model validation, there are softwares that can integrate with Ardupilot to simulate the mission. The team will look into this possibility in order to shrink the large uncertainties present in this section.

Section 4: Spring Tests, Schedule, Budget

Spring Tests

Table 4-1: Spring Tests

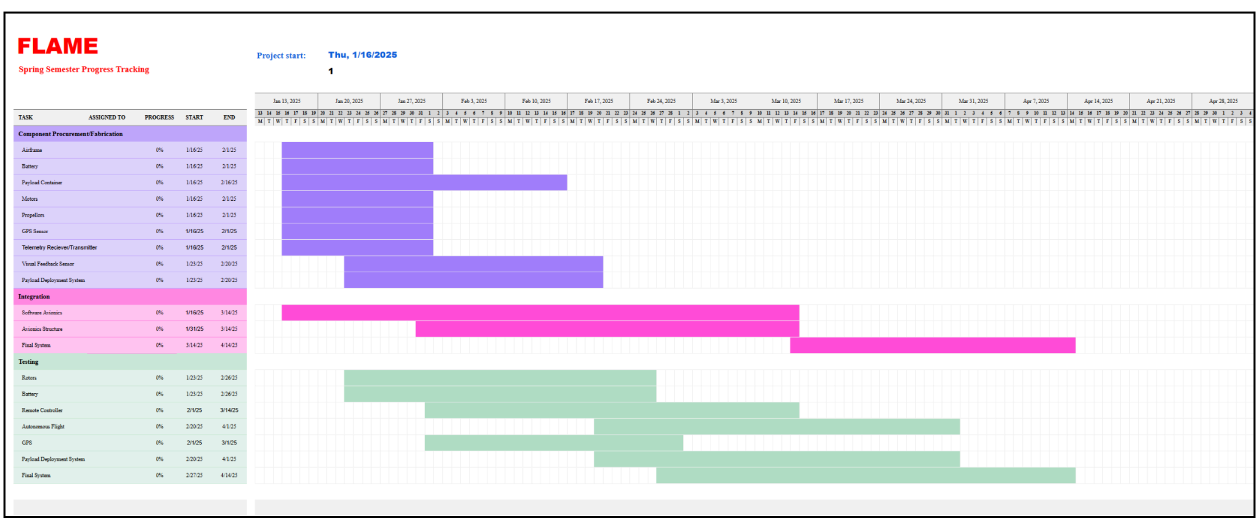
Tests Remaining	Required Equipment	Required Facilities	Requirements Verified
Rotor Thrust Evaluation	Thrust test stand, calibration tools, RCBenchmark GUI	Aero Building	FR 1.1, 1.4, 2.2 DR 3.2.1
Payload Deployment	Target(s) and measurement equipment	Flight Site	FR 1.4, 2.1, 3.5 DR 2.1, 5.1.1, 6.1.1
GPS Accuracy	Ground Station	CU South	FR 3.5 DR 1.2, 1.1.1
Battery Capacity/Flight Time	Battery, UAS, RC/Autonomous Control	Flight Site	FR 1.1, 1.4 DR 2.2, 2.1.3
RC Control	RC Controller, UAS	Flight Site	FR 1.6, 1.7, 3.1, 3.5 DR 1.1, 1.5, 2.4, 4.2.1, 5.1.6
Autonomous Flight	Autonomous Flight Controller, UAS	Flight Site	FR 1.2, 1.3, 1.6 DR 1.2, 1.6, 1.7, 4.1.2, 4.1.3, 4.2.1, 4.3.1, 5.1.2, 5.1.6

Propulsion subsystem verification will be encompassed through the rotor thrust evaluation. The propulsion subsystem, consisting of the UAS propellers, motors, and ESCs, will be verified through the use of the thrust test stand right here in the Aero Building. Individual propellers and motors will be paired and fastened to the thrust test stand, at which point the motor will run, spinning the propeller, and then the test stand will collect the corresponding thrust data. This data will be used to validate the power and dynamics models. As well as this, this information can be used for more exact inputs to give to the autopilot software. The accuracy of the data collected will also have to be assessed after conducting each test to reduce the risk of faulty information due to issues with the test stand, load cells, etc. It is of high importance to verify the propulsion subsystem as it directly relates to multiple functional requirements as well as the success of the mission as a whole. These requirements mainly concern the flight time and distance demands that the UAS must fulfill, specifically the 20-minute time limit and the 100-meter mission zone. The current models show the ability of the system to complete these requirements, and this test will verify the accuracy of those models.

Payload deployment subsystem verification will be done through extensive payload deployment tests. The payload subsystem, which consists of the payload container, solenoid valve, and remote switch, will be verified first by holding the container and opening the valve to ensure the mechanism works as expected and within the deployment time threshold. Next, the UAS will be tested by flying at the flight location and releasing the payload into the proposed targets and measurement system from test height in differing weather conditions. These tests will verify the accuracy and payload volume requirements. Specifically, the need for 5 pounds of payload to be deployed within 1 meter diameter accuracy. These are functional requirements that, when fulfilled, will ensure the success of the payload deployment subsystem.

The GPS accuracy test will be conducted by comparing the GPS location of the aircraft to known GPS locations through Google Earth coordinates. This is essential to the mission because the aircraft must be able to reach within 10 meters RMS autonomously, so the GPS must be at least that accurate. The battery capacity and flight time test will be conducted by launching the vehicle in a hover and monitoring the capacity of the battery throughout the hover time. At 85% DoD, the drone will land, having measured the total hover flight time. Another variation of this test is running the mission with takeoff, translation, human control, return to launch, and landing. This will test how long the mission takes and measure the DoD at the end. RC control is an important test for the pilot of the drone. The pilots will practice hovering, ascending, descending and translation through joystick inputs. This will ensure that the RC controls work as expected, and familiarize the pilot with the response of the vehicle. Autonomous flight will be conducted through flying a mission path at different GPS input locations and monitoring the flight of the vehicle as it translates.

Schedule



TASK	ASSIGNED TO	PROGRESS	START	END
Component Procurement/Fabrication				
Airframe		0%	1/16/25	2/1/25
Battery		0%	1/16/25	2/1/25
Payload Container		0%	1/16/25	2/16/25
Motors		0%	1/16/25	2/1/25
Propellors		0%	1/16/25	2/1/25
GPS Sensor		0%	1/16/25	2/1/25
Telemetry Reciever/Transmitter		0%	1/16/25	2/1/25
Visual Feedback Sensor		0%	1/23/25	2/20/25
Payload Deployment System		0%	1/23/25	2/20/25

Integration				
Software Avionics		0%	1/16/25	3/14/25
Avionics Structure		0%	1/31/25	3/14/25
Final System		0%	3/14/25	4/14/25
Testing				
Rotors		0%	1/23/25	2/26/25
Battery		0%	1/23/25	2/26/25
Remote Controller		0%	2/1/25	3/14/25
Autonomous Flight		0%	2/20/25	4/1/25
GPS		0%	2/1/25	3/1/25
Payload Deployment System		0%	2/20/25	4/1/25
Final System		0%	2/27/25	4/14/25

Figure 4-1: Spring GANTT

The critical path in the spring semester GANTT chart, shown in Figure 4-1, follows the logical path of testing an aerial system. The most important tests were therefore given the most time to be completed, given the need for multiple tests and retests as the engineering decisions are perfected. Therefore, the critical path will begin with RC flight control testing, to prove the stability, flight performance, and human-in-the-loop control accuracy of the drone. Concurrently, autonomous flight control tests will begin as the subsystems begin to integrate. The next step in the critical path will be to verify the readiness of the payload deployment system through the tests described above. Once all of these tests have been proven viable, final system testing and integration will be done to comply with the April 14th due date.

For any testing plans to begin, the necessary components must be procured. Specifically, the semester purchase path begins with procuring the components necessary to build and fly the drone that have not already been acquired. With these components, along with the already acquired components, simple flight and control tests of the drone are able to begin. The flight controller and RC controller have already been checked-out from the electronics shop in the AERO building. The only other component already beginning procurement at the start of the semester is the payload container, for the simple reason that the fabrication process began in order to verify the container can hold the necessary payload amount. This will be, as of the current plans, the only component completely fabricated in-house, with portions of the airframe being manufactured as needed, as seen in Table 4-2 below. A two-week lead time was allocated for the procurement of each purchased component as shipping times in the US are usually between 3-10 days, with a buffer for any unexpected delays. The visual feedback sensor and the rest of the components for the payload deployment system will be purchased shortly after to continue with tests, as preliminary testing for the drone system is completed. These tests will verify essential functional system requirements, most of which require a functioning drone system to be completed. These tests include the GPS accuracy, autonomous and RC flight control, and payload deployment.

While the procurement plans are underway, work will continue to integrate the subsystems together to allow for final testing and system integration. Work on the software subsystem is already underway, but more in-depth engineering will be completed as it is possible to model the flight using the Mission Planner software. Then, the work done on Mission Planner will be integrated with the autopilot software, ArduPilot, and formatted into the flight controller. This will begin as soon as the necessary components to do so are acquired, and it will continue long into the semester as the mission profile is refined. Once the software has been integrated with the avionics, and the avionics integrated with the drone structure, final testing will prove the total integration of all three subsystems.

As testing plans begin, safety and risk mitigation will be a top priority throughout the semester. The main risk to human safety will be during testing that requires the flight of the drone. To prevent any accidents, the system will go through internal safety reviews with the AERO department before any flight tests. Additionally, both preflight and during flight, all members present will follow CU flight operations procedures and checklists. Specifically, all policies mentioned in Section 2.5 of the CU Flight Operations Manual regarding operational policies and safety precautions.

Table 4-2: Component Overview

Component	Purchased	Manufactured
Airframe	✓	✓
Battery	✓	
Payload Container		✓
Rotors	✓	
Propellers	✓	
GPS Sensor	✓	
Telemetry Receiver/Transmitter	✓	
Visual Feedback Sensor	✓	
Payload Deployment System	✓	✓

Budget

The overall budget for the design of this system can be seen in Tables 4-3 - 4-9 below. For all of these items, lead times vary. It is possible to pay more for quicker shipping, so that will be taken into consideration. Some of the more uncertain lead times include the 4.3" DVR 5.8GHz 40CH FPV Monitor, the RadioMaster Ranger Micro 2.4GHz ELRS Module, the BETAFPV SuperD ELRS 2.4GHz Diversity Receiver, and the Tattu 16,000mAh 22.2V 6S 30C LiPo Battery Pack w/ XT90-S Plug. All of these items have a large range of lead time falling within 3-10 days. Critical purchases have also been identified, and some have already been made. The three products in Table 4-2 were determined to be extremely important for rotors, battery, and remote controller testing, and will instantly be utilized to support this testing in January. Another critical purchase will be the Tarot X6 Drone Kit. This will be crucial for the fabrication of the airframe and is also one of the most expensive purchases of the project. Ordering this will be a priority come January.

The budget margins for this project were chosen with the intent of budget flexibility. The manufacturing phase will be the most cost-intensive portion of the project, so $3,000.00 was allocated to this section. $3,000.00 was chosen based on research and experience with manufacturing drones. The second most expensive portion of this project will most likely be the testing phase. $500.00 was allocated to this phase with a list of potential tests in mind, starting with the rotors, battery, and remote controller tests. This $500.00 allows for flexibility to either improve testing or add additional testing if deemed necessary in the Spring. The last $500.00 of the budget is allocated to a miscellaneous section. Once again, this was done with budget flexibility in mind, along with the presence of unestablished costs. Some unestablished costs include the phase 3 exposition and the target. The prices of these are currently unknown, but have been considered as potential implications to the budget. Therefore, the $500.00 from the miscellaneous section can be used for those purchases. Additionally, portions of the miscellaneous section can be allocated to support either the testing or manufacturing sections of the budget. This miscellaneous section, as well as the current positive budget margins, give plenty of flexibility for components, testing, and manufacturing failure.

Table 4-3: Phase 1 - Testing

Product	Quantity	Unit Price	Total Price	Status
T-Motor MN501-S	1	$94.46	$94.46	Purchased and Delivered
Eolo 50A Light Version V2 ESC 4-6S	1	$40.96	$40.96	Purchased and Delivered
Polymaker PLA PRO Filament 1.75mm Color Black	2	$24.99	$40.98	1 Unit Purchased and Delivered 1 Unit to be Ordered

Table 4-4: Phase 2 - Manufacturing

Product	Quantity	Unit Price	Total Price	Status
4.3" DVR 5.8GHz 40CH FPV Monitor	1	$59.99	$59.99	To be ordered
RadioMaster Ranger Micro 2.4Ghz ELRS Module	1	$39.99	$39.99	To be ordered
BETAFPV SuperD ELRS 2.4GHz Diversity Receiver	1	$19.99	$19.99	To be ordered
AKK KC04 5.8G 600mW FPV Transmitter 700TVL 2.8mm 120 Degree FPV Camera for Racing Quadcopter	1	$32.99	$32.99	To be ordered
SiK Telemetry Radio V3	1	$58.99	$58.99	To be ordered

Tarot X6 Drone Kit	1	$499.99	$499.99	To be ordered
PM03D Power Module	1	$45.99	$45.99	To be ordered
Eolo 50A Light Version V2 ESC 4-6S	5	$35.99	$184.92	To be ordered
T-Motor MN501-S	5	$89.91	$454.10	To be ordered
WOODGUILIN Remote Switch	1	$36.99	$36.99	To be ordered
Pixhawk 6X	1	$144.00	$144.00	To be ordered
TX16s Mark II	1	$210.00	$210.00	To be ordered
M10 GPS	1	$43.99	$43.99	To be ordered
Remote ID	1	$29.59	$29.59	To be ordered
Tattu 16000mAh 22.2V 6S 30C LiPo Battery Pack w/ XT90-S Plug	2	$335.99	$671.98	To be ordered
1" Plastic Zero Differential Solenoid Valve	1	$62.95	$72.60	To be ordered
1" PVC Pipe Fitting Adapter	1	$13.99	$20.98	To be ordered
QWinOut 1855 propellers	1	$56.68	$56.68	To be ordered
Flex Tape	1	$20.00	$20.00	To be ordered
Pipe Cement	1	$4.00	$4.00	To be ordered
XT90 to XT60 plugs	1	$9.96	$9.96	To be ordered
Yeah Racing RC XT60 1-6S Smoke Stopper	1	$6.99	$6.99	To be ordered
Pixhawk 6X Cable Set	1	$22.59	$22.59	To be ordered
Zeee Fireproof Explosionproof Large Capacity Battery Storage Guard Pouch for LiPo Charge & Storage	1	$11.99	$11.99	To be ordered
ESKONKE Blue Thread Locker 243	1	$9.99	$9.99	To be ordered

Table 4-5: Phase 1 (Testing) Overview

Phase 1 Current Expected Cost	Phase 1 Allocated Budget	Phase 1 Margin
$185.40	$500.00	62.9% Under Budget

Table 4-6: Phase 2 (Manufacturing) Overview

Phase 2 Current Expected Cost	Phase 2 Allocated Budget	Phase 2 Margin
$2,769.28	$3,000.00	7.7% Under Budget

Table 4-7: Phase 3 (Exposition) Overview

Phase 3 Current Expected Cost	Phase 3 Allocated Budget	Phase 3 Margin
TBD	TBD	TBD

Table 4-8: Miscellaneous Budget Overview

Miscellaneous Expected Costs	Miscellaneous Allocated Budget	Miscellaneous Margin
$0.00	$500	100% Under Budget

Table 4-9: Overall Project Overview

Expected Cost	Allocated Budget	Margin
$2,954.68	$4,000.00	26.1% Under Budget

Section 5: Individual Report Contributions

Christian Bowman

During the CDR phase, I concerned myself almost exclusively with the payload deployment system, and in particular the design and fabrication of the payload tank. Once Alex provided dimensions of the tank according to the structural analysis he completed, I discussed with 3D printing experts, designed the tank in SolidWorks, and was responsible for fabricating two iterations of the design. Alex also found the solenoid valve that we used, but aside from that I assumed responsibility for other design aspects and fabrication of the tank. I also completed the sections of the CDR presentation and FRR pertaining to the payload deployment system. I would also like to attest that Alex was extremely helpful in completing the structural analysis of the tank. I concur with Alex's statement below that, despite his work arguably receiving little recognition in this report, he contributed more than his fair share to the project overall.

Maximillian Brown

I added the section explaining the ConOps in Section 1. This went through each signal sent and action or maneuver performed by the system in the mission. This section also explained the timing of each action, maneuver and signal through the use of different mission stages. I also added the dynamical plots present in section 3, as well as adding explanations of these plots in a few different areas, mostly just explaining what the plots mean for the system and the model as well as introducing them. This semester I worked on the dynamics model code, adding the mass breakdown code and the hover section code, as well as research and design into GPS RTK which was eventually phased out for better GPS system options. Furthermore I was the main contributor for building the structure / design of the ConOps. I also contributed to both the CR and CDR slides.

Ethan Davis

During the design phase, I worked on determining products for the communications and sensing subsystems, particularly GPS, as well as assisting the payload deployment team find valves and developing the deployment container. My communications and sensing work is important for the project due to the importance of GPS within an autonomous system. I contributed to the FFR by working on the subsystem section with communications and sensing and acting as co-editor.

Donovan Gavito

This semester, I focused on research and development using MissionPlanner and ArduPilot, simulating our mission with a binded transmitter for input. I familiarized myself with ArduPilot flight parameters. Additionally, I selected many key components for the drone, covering communication, control, and sensing. For the FFR, I contributed to the detailed design section by breaking down subsystems like power, propulsion, and sensing and explaining component interactions. I also played a significant role in the budget since I picked a lot of the components.

Joshua Geeting

As Power Lead, I provided a detailed explanation of the Functional Block Diagram in Section 2: Detailed Design, thoroughly outlining the function of each port and component along with their required electrical values. Additionally, I developed a high-level CAD model of the hexacopter drone, offering a clear vision of the layout and providing an initial concept of its design.

Drew Kane

My main contribution to the FFR was within the 4th section, mainly relating to our schedule, spring tests, and safety risk reduction. I developed a critical plan for the coming spring semester and subsequently created a GANTT chart to visualize that critical path. While planning this path, I determined each remaining test that must be completed for mission success. To do this, I worked closely with other members of the team to verify the accuracy and feasibility of each of those tests. My main focus though, leading up to and through the FFR, was making sure that all team members were focused and working on directly applicable engineering analyses for our project needs. I delegated tasks to those looking for more work to do, and filled in on tasks myself that needed extra hands. I tried my best to fit each member's interest with what needed to be done for each milestone, and set due dates to allow for feedback and revision.

Ian McCarty

I put the majority of my effort towards the first section of the FFR, going through the scope of the project and mentioning what makes it unique. I worked closely with Jack to ensure this section was acceptable. Additionally, I also helped do some general proofreading of the entire document to make it flow better, from a grammatical point of view. Lastly, I also spent a large portion of the semester investigating various hardware components so I helped verify everything mentioned about our system components in section 2.

Braden Nelson

I worked primarily on the dynamics portion of the modeling section. I wrote almost all of this section including the overall description of the project, the models assumptions, the uncertainties of the model, and the model results. I specifically worked on this portion of the report because I was the main developer of this model. I reformatted the entire lab model to work for our specific project, including calculating new gains for a controller, creating the separate model legs and ode calls, designing the overall logic and flow of the model, and creating necessary sub functions and scripts that were necessary for our implementation.

Jack Pearse

For the FFR, my main contribution was within the first section, the project scope. Specifically, the goal of the project and the overall possible applications of the hexacopter. I also helped with anything that the systems engineer could help with during the semester as well as the FFR. This included helping a lot with section 2 of the FFR for the system and subsystem breakdown. During the semester, I was worried about our subsystem and system designs. I also made all of the functional, system, and subsystem requirements for our project. During the trade study process, I was very involved in

Alex Putnam

The majority of contribution to the FFR was in the background. Most of my time this semester was spent designing the payload container and its deployment. Unfortunately, the model used in designing the payload subsystem was not chosen to be one of the two main models focused on in section 3. My payload subsystem partner spearheaded writing the section about the construction of the payload container and its features, but I was unable to go into detail about the engineering modeling I did to determine the optimal shape for the container to maximize the ratio of volume to mass, while keeping the moment of inertia manageable, and staying within the size limits. As a result of this, my main job while writing the FFR was correcting grammatical errors, syntax, and improving readability in other peoples' sections. I did contribute my fair share to the project, but not in a way which is obvious in this report.

Brady Sivey

This semester, I was selected as CFO for our project. For this, I was responsible for everything regarding our budget and procurement. I have already made 3 purchases using the Pcard and have designed a budget plan to ensure success of our project. I wrote the entirety of the budgeting section for this report and presented the cost plan section of the CDR. After SRR, I developed our modeling plans.

This included my creation of our preliminary dynamics model. This model was used to determine flight times, drag parameters, and other dynamical properties of our system. Ultimately, myself and the software team built on this model to develop the dynamics model that we have today. For this report, I contributed to writing out the details and equations used in the development of the dynamics model. Additionally, I supported grammar and formatting on the FRR.

Jared Steffen

In terms of the FRR, I spent a lot of time figuring out subsystem interfacing that is broken down in the subsystem section. I also developed the energy consumption model that is talked about in the modelling section. For the actual report, I wrote the energy consumption model section, assisted in writing the subsystem section for propulsion and airframe, and helped develop the outline of the report for ease of use. I also went through the whole FRR and conducted editing for grammar, punctuation, and consistency.

Appendix 1: Requirements Flow Down

Verification Methods:
T: Test, **D:** Demonstration, **A:** Analysis, **I:** Inspection

Level 0: Functional				
Requirement Number		Parent Requirement	Child Requirement	Verification Method
FR 1.1	The system shall have a minimum range of 100 meters		DR 1.3,DR 2.2	T/D
FR 1.2	The system shall be able to take off autonomously		DR 1.4	D
FR 1.3	The system shall be able to land autonomously		DR 1.4	D
FR 1.4	The system shall be capable of making 3 drops in a 20-minute span		DR 1.7	T
FR 1.5	The system shall reach target location above the 30 foot hard deck		DR 1.8	D
FR 1.6	The system shall only vertically translate below the 30 foot hard deck, at the location of interest and take-off/landing position		DR 1.6	T/A
FR 1.7	The system shall be operable in mild weather conditions		DR 1.9, DR 2.4	T/D/A
FR 1.8	The system shall return to a known safe waypoint altitude if loss of communication and control		DR 1.12	D
FR 2.1	The system shall carry and deploy 5 pounds of fire retardant per target location		DR 2.5, DR 3.1	T/D
FR 2.2	The system shall be able to take off, fly, and land with a minimum fire retardant weight of 5 pounds		DR 1.4, DR 2.1	T/D
FR 2.3	The payload shall consist of dyed water solution to mimic the viscosity and density of a PHOS-CHEK mixture		DR 1.10	I
FR 2.4	The system components shall be less than 55 pounds with payload		DR 2.3, DR 2.6,	I
FR 3.1	The system shall utilize human-in-the-loop to navigate from 10 meters RMS accuracy to 1 meter from location of interest		DR 1.2, DR 1.5	D
FR 3.2	The system shall be able to fly in US airspace		DR 1.11,DR 2.7	I
FR 3.3	The system components shall maintain visual line of sight from pilot		DR 3.3	D
FR 3.4	The system components meet the certification requirements set by CU flight operations		DR 1.13	I
FR 3.5	The system shall deploy the payload and		DR 1.1	

	have it land within a +/- 1 meter accuracy of target location			T
Level 1: System Requirements				
Requirement Number	Requirement	Parent Requirement	Child Requirement	Verification Method
DR 1.1	The avionics system shall control the deployment mechanism for the fire retardant with a precision of +/- 1 meter from the intended drop zone	FR 3.5	DR 4.1.1, DR 6.1.1	T/A
DR 1.2	The avionics system shall ensure autonomous navigation within 10 meters RMS accuracy	FR 3.1	DR 1.1.1	T/D
DR 1.3	The avionics system shall be capable of maintaining operational control and communication within a 100 meter diameter	FR 1.1	DR 2.1.1, DR 5.1.1	A/D
DR 1.4	The avionics system shall support autonomous takeoff and landing with a specified payload of 5 pounds	FR 2.2	DR 3.1.1, DR 3.1.2, DR 3.1.3, DR 5.1.4, DR 5.1.5	D
DR 1.5	The avionics system shall allow human-in-the-loop input for precision navigation within 1 meter of the target using visual markers and payload deployment	FR 3.1	DR 5.1.3, DR 6.1.3	D
DR 1.6	The avionics system shall only allow vertical translation below the 30 foot hard deck only at the locations of interest.	FR 1.6	DR 3.1.4	T/D
DR 1.7	The avionics system shall enable at least 3, 5 pound fire retardant drops in 20 minutes	FR 1.4	DR 5.1.6	T
DR 1.8	The avionics system shall maintain an altitude greater than 30 feet during approach to the target location	FR 1.5	DR 3.1.4, DR 5.1.2	D
DR 1.9	The avionics system shall ensure stable operation under mild weather conditions	FR 1.7	DR 1.2.1, DR 2.1.2, DR 4.1.2, DR 5.1.7	D
DR 1.10	The avionics system shall be capable of deploying a dyed water solution that mimics the viscosity and density of a PHOS-CHEK mixture	FR 2.3	DR 6.1.2	D
DR 1.11	The avionics system shall comply with FAA regulations for unmanned aircraft systems operating in US airspace	FR 3.2	DR 1.1.3 DR 4.1.4, DR 5.1.9, DR 6.1.4, DR 7.1.2	I
DR 1.12	The avionics system shall autonomously return the aircraft to a predefined safe waypoint altitude upon loss of communication	FR 1.8	DR 1.1.2, DR 2.1.3, DR 3.1.5, DR 4.1.3,	D

			DR 5.1.8 DR 7.1.1	
DR 1.13	The avionics system shall meet the specific certification requirements set by CU flight operations	FR 3.4	DR 1.1.3, DR 4.1.4, DR 5.1.9, DR 6.1.4, DR 7.1.2	I
DR 2.1	The structure system shall support a payload capacity of at least 5 pounds for carrying fire retardant materials	FR 2.2	DR 6.2.2, DR 7.2.3	T/D
DR 2.2	The structure system shall support flight over a minimum operational range of 100 meters	FR 1.1	DR 3.2.1, DR 4.2.1, DR 7.2.6	T/D
DR 2.3	The structure system shall handle a maximum takeoff weight not exceeding 55 pounds	FR 2.4	DR 7.2.5	A/D
DR 2.4	The structure system shall withstand mild weather conditions	FR 1.7	DR 1.2.1, DR 7.2.2	T/D/I
DR 2.5	The structure system shall accommodate a payload designed to hold the dyed water solution without leakage	FR 2.1	DR 6.2.1, DR 7.2.4	D
DR 2.6	The structure system shall ensure that the total weight, including all components and payload, does not exceed 55 pounds	FR 2.4	DR 7.2.1	I
DR 2.7	The structure system shall be FAA compliant	FR 3.2	DR 1.1.3, DR 4.1.4, DR 5.1.9, DR 6.1.4, DR 7.1.2	I
DR 3.1	The ground system shall allow for pre-programming of target locations for fire retardant deployment	FR 2.1	DR 4.3.1, DR 5.3.1	I/D
DR 3.2	The ground system shall provide telemetry data to the operator during flight	FR 1.2, FR 1.3	DR 1.3.1, DR 4.3.2, DR 4.3.3	D
DR 3.3	The ground control system shall allow the operator to maintain line of sight with the UAS	FR 3.3	DR 4.2.1	D

Level 2: Sub System Requirements				
Requirement Number	Requirement	Parent Requirement	Child Requirement	Verification Method
Sensing				
DR 1.1.1	The sensing subsystem shall be capable of providing real-time location data with an accuracy of +/- 10 meters	DR 1.2		T/D
DR 1.3.1	The sensing subsystem shall be capable of determining orientation and motion direction	DR 3.2		I/D
DR 1.3.2	The sensing subsystem shall be capable of	DR 3.2		

	tracking the aircraft's position in [x,y,z] coordinates			D
DR 1.1.2	The sensing subsystem shall continuously monitor communication signals to detect loss of connectivity with ground control	DR 1.12		D
DR 1.1.3	The sensing subsystem shall comply with FAA and CU Flight Op guidelines	DR 1.11, DR 1.13, DR 2.7		I
Power				
DR 2.1.1	The power subsystem shall provide power to support operation of all systems for the mission duration	DR 1.3		D
DR 2.1.2	The power subsystem shall be able to operate in mild weather conditions	DR 1.9, DR 2.4		D
DR 2.1.3	The power subsystem shall provide power to support operation of essential systems under fail-safe conditions	DR 1.12		T/D
Propulsion				
DR 3.1.1	The propulsion subsystem shall provide thrust sufficient to lift the aircraft and its payload during take off and landing	DR 1.4		D
DR 3.1.2	The propulsion subsystem shall support autonomous takeoff capabilities	DR 1.4		D
DR 3.1.3	The propulsion subsystem shall support autonomous landing capabilities	DR 1.4		D
DR 3.1.4	The propulsion subsystem shall provide sufficient thrust to reach the 30 foot hard deck	DR 1.6, DR 1.8		D
DR 3.1.5	The propulsion subsystem shall be able to maneuver under fail-safe conditions	DR 1.12		D
DR 3.2.1	The propulsion subsystem shall deliver thrust within an operational range of a 100 meter diameter	DR 2.2		T/D
Communications				
DR 4.2.1	The communication subsystem shall be capable of data transmission between the avionics and ground systems during the mission with a range of a 100 meter diameter	DR 2.2, DR 3.3		T/D
DR 4.3.1	The communication subsystem shall be capable of receiving and transmitting GPS data	DR 3.1		T/D/I
DR 4.3.2	The communication subsystem shall update the ground system with telemetry data	DR 3.2		I/D
DR 4.3.3	The communication subsystem shall update the avionics system with telemetry data	DR 3.2		D/I
DR 4.1.2	The communication subsystem shall be capable of transmitting environmental data	DR 1.9		T/D/I

DR 4.1.3	The communication subsystem shall be capable of detecting communication loss	DR 1.12		T/D
DR 4.1.4	The communication subsystem shall comply with FAA and CU Flight Op guidelines	DR 1.11, DR 1.13, DR 2.7		I
Control				
DR 5.1.1	The control subsystem shall ensure stability and responsiveness of the aircraft during operation	DR 1.3		T
DR 5.1.2	The control subsystem shall maintain flight above the 30 foot hard deck during horizontal translation	DR 1.8		T/D
DR 5.3.1	The control subsystem shall enable autonomous movement between locations of interest	DR 3.1		D
DR 5.1.3	The control subsystem shall allow for human-in-the-loop control	DR 1.5		D
DR 5.1.4	The control subsystem shall support autonomous take-off	DR 1.4		D
DR 5.1.5	The control subsystem shall support autonomous landing	DR 1.4		D
DR 5.1.6	The control subsystem shall maintain stable operation in mild weather conditions	DR 1.9		D
DR 5.1.7	The control subsystem shall allow for an automatic return to a predefined safe waypoint upon loss of communication	DR 1.12		D
DR 5.1.8	The control subsystem shall comply with FAA and CU Flight Op guidelines on autonomous flight	DR 1.11, DR 1.13, DR 2.7		I
Payload Deployment				
DR 6.1.1	The payload deployment subsystem shall include a payload deployment mechanism that allows for release of fire retardant with a precision of +/- 1 meter	DR 1.1		T
DR 6.2.1	The payload deployment subsystem shall hold the payload of a dyed water solution while preventing leakage during flight	DR 2.5		I/D
DR 6.1.2	The payload deployment subsystem shall be capable of deploying the dyed water solution at the locations of interest	DR 1.10		D
DR 6.2.2	The payload deployment subsystem shall be capable of deploying a 5 pound payload per target location	DR 2.1		A/I
DR 6.1.3	The payload deployment subsystem shall support human-in-the-loop deployment capabilities	DR 1.5		D
DR 6.1.4	The payload deployment subsystem shall	DR 1.11, DR		I

	comply with FAA and CU Flight Op guidelines	1.13, DR 2.7		
Airframe				
DR 7.2.1	The airframe subsystem shall be able to support the total weight of the UAS	DR 2.6		D
DR 7.2.2	The airframe subsystem shall be constructed using materials that can resist mild weather conditions	DR 2.4		I
DR 7.2.3	The airframe subsystem shall include payload mounting and storage capabilities of an at least 5 pound payload	DR 2.1		I/D
DR 7.2.4	The airframe subsystem shall include appropriate storage of the payload to prevent spillage	DR 2.5		I/D
DR 7.2.5	The airframe subsystem shall be constructed to withstand the forces associated with controlled takeoffs, descents and landings at locations of interest	DR 2.3		D
DR 7.1.1	The airframe subsystem shall be designed to withstand flight during fail-safe conditions	DR 1.12		D
DR 7.2.6	The airframe subsystem shall be designed to support operational ranges within a 100 meter diameter	DR 2.2		D
DR 7.1.2	The airframe shall be designed to comply with FAA and CU Flight Op guidelines	DR 1.11, DR 1.13, DR 2.7		I

Appendix 2: Individual Goals: Fall Reflection

Team Name: FLAME		
Student Name	**Team Role(s)**	**Original Goals and Self Assessment**
Christian Bowman	Hardware Team Member	**Original Goals:** I plan to assist in designing the hardware of the UAS; performing structural and aerodynamic analysis, working with the electronics team to determine propulsion, battery and sensor requirements, and working with the software team in designing stability/control software. I would also like to contribute to the manufacturing/assembly of the system. In addition, I want to utilize my existing skills and expertise as a private pilot to take responsibility for the system’s flight operations; by taking the necessary courses/flight to be certified by the Flight Operations department, and working with others to ensure all subsystems are designed in a safe manner.

		Self Assessment: The role I ended up performing this semester ended up being rather different from the role I had envisioned, in how I worked on the payload deployment system instead of the dynamics modelling. I attribute this largely to my relative expertise in 3D printing and CAD modelling being well-suited to developing the tank. To a slight degree I wish I could have contributed more, both generally and in the ways I had originally envisioned. However, I also experienced many difficulties in my personal life this semester that complicated my ability to work, including my mother undergoing life-saving emergency surgery and being hospitalized for a week. Given that context, and the fact that I feel I was able to contribute my fair share in a way that constructively utilized my areas of expertise, I am overall satisfied with the way things turned out.
Maximillian Brown	Software Team Member	**Original Goals:** My goal is to drastically improve my coding skills. Specifically, developing a deep knowledge of controls, uncertainty analysis, feedback loops, & modeling flight through function based coding in different coding languages. I have a goal to not only simulate autonomous flight with uncertainty through coding, but be able to functionally code the autonomous controls and guidance of the drone to be able to meet the team's goals. I have goals to improve my toolset to both model and practically enable the drone's flight to a high degree of accuracy given the mission & resources. I will collaborate with the software team.
		Self Assessment: I believe I am on track to meet my goals as outlined at the start of the semester. Through working with the other software team members, I have been able to improve my knowledge of uncertainty analysis, modeling the flight through function based coding (I coded several functions to aid understanding and models throughout the semester), and some improvement in controls. I will be able to gain much more knowledge about coding the autonomous controls and guidance for the drone, but due to the complex nature and time available, I do not think the team will create a custom flight controller for the mission (our industry lead told us not to, too much in too little time).

Ethan Davis	Power/Electrical Team Member	**Original Goals:** My goal is to apply my GPS and avionics background to improve accuracy of the GPS system and assist in ensuring a working electronics suite to drive our autonomous system. I will do this by working together with the electronics and software team and mentors within the department to program, build, and troubleshoot problems to ensure we succeed in our mission.
		Self Assessment: I contributed to parts of the electronics suite and focused heavily on our communications and sensing subsystems, including GPS. However, as we have been working on the project we learned just how costly high precision GPS systems cost, so it was more of learning experience on newer systems I was unfamiliar with and how to balance all of it within our platform. I didn't get to program this semester and I hope I will have the chance next semester, and I am ready to help both teams when spring construction begins so we can prevent electronics problems before they appear and ensure safe practices and build up our electronics system.
Donovan Gavito	Hardware Team Lead	**Original Goals:** My goal is to use my quadcopter and RC knowledge to integrate a flight controller and autonomous system that allows our UAV to navigate autonomously. Another goal is to use and integrate hardware that can withstand Boulder weather conditions and complete our mission during those conditions. I also want to use and modify hardware that is capable of meeting the weight lifting needs of our vehicle and mission.
		Self Assessment: So far I am meeting my goal. My goal lies more in the spring semester when it comes to assembling all of our components and programming the hardware to communicate effectively. But so far I have selected components that will allow this to be accomplished. I have done work in ensuring that our components are compatible with our selected software and will meet mission requirements.
Joshua Geeting	Power/Electrical Team Lead	**Original Goals:** My goal this year, especially in my senior projects, is to ensure the highest standard of connectivity for all wiring and hardware through optimal electrical connections. I am also committed to maintaining electrical safety protocols throughout the entire development process. My goals can be verified through testing with electrical equipment. I will be working closely with the hardware team, electrical team, project

		manager, and systems engineer to accomplish these goals
		Self Assessment: This semester, there was minimal hands-on wiring required. However, as the power lead, I collaborated extensively with Jared Steffen to verify the functional block diagram and ensure all electrical outputs met the system's requirements for proper functionality. Fortunately, many of our electronics included detailed diagrams and pre-selected connections to enhance safety. Additionally, I carefully selected several electrical components, such as the battery, to guarantee suitability for our hexacopter drone. Overall, despite the reduced need for electrical connections, I maintained strict adherence to safety protocols throughout the design process and worked closely with each team to develop the hexacopter drone design.
Drew Kane	Project Manager	**Original Goals:** My overall goal this year is to ensure the success of the team, and more importantly the success of each team member, through communication, leadership, and hard work. I plan to follow up on the team's goals by working closely with the systems engineer to guarantee deliverables are completed timely and with our best quality of work. I will also make certain each individual team member's goals are completed by maintaining a constant open line of communication with each person, and providing assistance and guidance wherever necessary.
		Self Assessment: I believe in broad terms our team was successful when it comes to the required assignments, but I do feel there was plenty of room for improvement on my end. Thanks to the helpful notes and advice from team members, I made adjustments in my managing and leadership style, but I believe there is still much I can do as I learn more about what my team needs from their PM. This can be done by continuing my constant efforts to keep open lines of communication between myself and my teammates.
Ian McCarty	Hardware Team Member	**Original Goals:** My overall goal is to be responsible for the interface between several of the different hardware components of the UAS, specifically the airframe, propulsion and power components. I would also like to be involved in the integration between the propulsion and control systems. By working with the software and hardware teams, this goal will result in the successful autonomous horizontal and vertical translation of the UAS. Lastly, I also want to familiarize myself with the full engineering life cycle, and understand the big picture ideas of how the design process works in the aerospace industry.

		Self Assessment: I believe I made progress towards my goals, but have much more to accomplish. Much of my goals are orientated to the drone itself, and it was difficult to guage my progress given we are unable to start progress on much of the design until the Spring Semester. I am pleased with my contributions to airframe decisions so far, but I'd like to do much more work on the propulsion hardware as we start to physically assemble our drone. To do so, I will likely need to increase my involvement with the software team to better understand what governs the autonomous flight portion of our design.
Braden Nelson	Software Team Member	**Original Goals:** My primary goal is to create an autonomous controller for our drone. I want to work on interacting with the 'human in the loop' control and create a working system that will flow smoothly between the manual human input and the autonomous flight mode. In order to check this, we can run our flight tests and visually check the drone's behavior in flight. Ideally, the drone is not moving spontaneously in any certain direction, especially after the payload is dropped.
		Self Assessment: Looking back at my original goals, I did accomplish one of them. This semester, I was able to work on an autonomous controller for the drone. This controller was primarily built from the ASEN 3801 lab course, but formatted to include 6 motors, and a vertical portion of control. Although this controller will not be used in the actual flight of the drone. Our team decided to use Ardupilot, which means we will not be able to really develop our own control laws. As for the human in the loop portion of my goals, I was unable to work on this section for this semester. Although I did not have the opportunity, I believe that this will be a vital part of our development next semester and I will eventually be able to see this goal through. In the listed goals above, I mentioned a bit about how we will visually test the drone's behavior. This semester did not involve much testing since the drone has yet to be built, but this idea will soon come to life as we will be working to build and test the drone next semester.
Jack Pearse	Systems Engineer	**Original Goals:** My goals include tracking the project's technical requirements, verifying subsystem compatibility, and conducting risk assessments. I will support the team by identifying design conflicts early and ensuring all deliverables meet system-level requirements. Success will be measured by the timely identification and resolution of technical issues. These goals can

		be measured by the successful mission completion at the end of the course. I will work closely with the project manager and team leads to ensure all milestones are met.
		Self Assessment: Overall I believe I did a good job of keeping track of our technical requirements. I also made sure that our different subsystems would work with each other and interface correctly. I could have done a better job of conducting risk assessments, as I really only was doing that come time for our presentations. I believe that we have done a very good job, especially recently, of completing all of our assigned deadlines. I have been working with the PM throughout the year and helped when needed with PM duties.
Alex Putnam	Power/Electric Team Member Hardware Team Member	**Original Goals:** My goal is to design/construct the circuit which connects the comms to the payload deployment system, and possibly to the propeller controls. Specifically, I'd like to design the mechanism which releases the payload. This can be validated through testing. I will be working closely with the software and electrical teams**.**
		Self Assessment: I did not really achieve my original goals, as they didn't align well with our final design. The "circuit" connecting the comms to the payload deployment ended up being just a single remote switch, and required minimal construction and zero designing. Similarly, the payload deployment mechanism was just a prebuilt off-the-shelf solenoid valve which opens and closes on command. I had come up with multiple designs for potential payload deployment systems ahead of time, but all of them were objectively outclassed by pre-existing options. I did still end up working on the payload subsystem, just not in the way that I had hoped. I will still seemingly work with the electrical team, but not until the parts arrive in Spring and we begin the assembly.
Brady Sivey	Chief Financial Officer Software Team Member	**Original Goals:** My goal is to enhance my software skills while contributing to the controls portion of this project. I plan to be a key contributor to the control design, which will require refining my skills in potential coding software such as Matlab Simulink, C/C++, and Python. I aim to write the control diagrams and algorithms for our system, testing them against our requirements. Success will be measured by the system's ability to fly autonomously to a target and back. I will collaborate closely with the software team, including Jared (Team Lead), Braden, and Max, and later integrate with the entire team. However, we will have to

		integrate with the rest of the team later on with the project.
		Self Assessment: My goals of developing the flight software were unrealistic. After talking with our project sponsor, it became clear that we would not be the ones writing the controls for our project. I did, however, end up being a big part of creating our dynamical model. I was able to apply my MATLAB skills during that task. I also feel that I have a good understanding on how the controls for the system work even though I wasn't the one writing them. I did end up spending a lot of my time collaborating with the software team this semester.
Jared Steffen	Software Team Lead Hardware Team Member	**Original Goals:** My primary goal for this senior project is to gain familiarity with developing flight software, specifically focusing on autonomous flight controls. I will set up a development environment for Raspberry Pi or Arduino and enhance my coding skills in C/C++ or Python. Additionally, I'll assist in developing and testing flight control algorithms, data processing, and signal processing/communications, validating their performance through simulation and testing. The software team, Drew (PM), and Jack (Systems Engineer) will be my main collaborators throughout this process.
		Self Assessment: After delving into how autonomous drones operate and speaking to others more experienced in the field, I learned that the goal of developing flight software was quite unrealistic, especially when there are COTS solutions that work and have a large history of successful heritage use. I did, however, spend much time diving into our software selections of Mission Planner and ArduPilot, so I could grasp how they conduct autonomous flight. I ended up collaborating with Drew, Jack, and Donovan to accomplish this understanding.