Potential maybe changes to outline in red at bottom. Still need tech requirements and more details though.

**Bold Text Are Headers**

* Title page
* Abstract
* Table of Contents

### (Introduction/Background)

#### Chapter 1 Introduction

* + **Project Background and Motivation**
    - USGS Goal
      * Map the earth’s magnetic field

Researchers at the United States Geological Survey (USGS) are collecting data on the earth's magnetic field in order to conduct research on geologic faults and anomalies such as underground rivers. In order to collect this data they use drones with an attached magnetometer that makes 7 consecutive 15 minute flights in order to conduct just one survey.

In order to gain insights into geothermal systems, and predict where resources related to geothermal energy are most likely to occur. Geophysicist Jonathan Glen at The United States Geological Survey (USGS), uses magnetic data from unmanned aerial systems(UAS), to better locate, and map out these geothermal systems.

In 2010 magnetic data was collected at Yellowstone National Park using both aerial and land based collection methods, around geologic anomalies such as Lone Star Geyser. This survey provided significant evidence that “a significant decrease of the substratum total magnetization is observed within altered zones” it finds that these anomalies can be used to map areas of hydrothermal alteration by searching areas characterized by this lower magnetism. This survey was able to provide data on different types of anomalies that would allow researchers to determine characteristics of that anomaly such as whether it is liquid dominated or its depth. Another survey in 2012 by USGS built on this by using UAS to reveal a more than “35km long linear, intra basin magnetic high”. The unprecedented level of detail from this survey allowed for the discovery of several major hot springs that could be used for geothermal research and energy. “These findings could never have been substantiated by ground based data”.

The USGS notes that beyond providing more substantive evidence, surveys conducted by UAS had a multitude of benefits. UAS surveys are highly adaptable, compared to high resolution commercial surveys, that are “relatively inflexible to the need to change survey specifications that may arise as data [is] collected”. UAS surveys have additional safety benefits for surveys that require low-altitude flight paths that would pose risks to pilots of manned aerial vehicles.

Add conclusion \*\*\*

* What drones did they use
* How it could be improved on

[11]

J. M. G. Glen, A. E. Egger, C. Ippolito, and N. D. Athens, “Correlation of Geothermal Springs with Sub-Surface Fault Terminations Revealed by High-Resolution, UAV-acquired Magnetic Data,” p. 8.

Bouligand, Claire. “Distribution of Buried Hydrothermal Alteration Deduced from High-Resolution Magnetic Surveys in Yellowstone National Park.” *Journal Of Geophysical Research-Solid Earth*, vol. 119, no. 4, AMER GEOPHYSICAL UNION, 2014, pp. 2595–630, doi:10.1002/2013JB010802.

Jonathan currently studies geothermal heat, along the northwestern region of the United States, as a resource for renewable energy.

* + - Collecting Data with Drones
      * Pros
        + Advantages of using drones:

Improving safety

One of the most important uses of drones seen today is in improving the safety of dangerous work performed by humans. There are many tasks people have to put their lives at risk for to complete, such as high risk situations like inspecting buildings at high heights or toxic environments, and there are many fatal deaths that come with it every year (INSERT STATISTIC ABOUT WORK RELATED DEATHS HERE). However, with the use of a drone, workers could be miles away looking at the scene through the eyes of a drone, and not have to endanger their life at all. Many jobs have actually already incorporated drones into their everyday work environment, and have already reduced the amount of work-related deaths (INSERT STATISTIC ABOUT LESS WORK RELATED DEATHS HERE). This is just one of the ways drones have been beneficial to society.

Improved accessibility

Another critical role drones play is having improved accessibility in places not normally or easily reachable by people. There are many places that people cannot physically reach, such as the inside of a volcano, or are extremely inconvenient for them to get to, such as the top of a mountain. Other forms of aircraft, such as a plane or helicopter, could be used to access these areas, but a lot of time and resources have to be allocated in order to use them, and there are potential issues of safety when trying to fly close to where people congregate. With the use of a drone, people can easily access any place in the form of an expendable, small and easily controllable flying aircraft. This is imperative when wanting to investigate something close to the ground. (INSERT SOURCE FOR DRONE GOING INTO DANGEROUS AREA)

Real-time progress monitoring

The last important function drones can be used for is with real-time monitoring. With the easy attachment of a camera onto a drone, a drone can easily capture the scene of an environment and play it back later for further analysis. These drones are even more useful when they provide live footage back to the user, effectively allowing the user to be somewhere far away and yet act as if they were there for themselves in person. This allows a much faster means of seeing things, as some place a human would take days or even months to scale and investigate in person can be completed within hours for a drone capable of flying over the scene and showing the footage live. In turn, this allows for a more efficient workflow. Workplaces have used drones for this reason as well, and have seen substantial improvement in productivity (INSERT STATISTIC ABOUT A JOB IMPROVING EFFICIENCY WITH DRONES).

* + - * Cons
        + Battery issues

Limited battery capacity is the main issue concerning the collection of data using drones. Propulsion systems and the wireless communication systems are two areas which must be efficiently optimized for the longest possible flight time.[[1]](#footnote-0) The first must be as energy efficient as possible to carry the drone over large distances and to get the maximum amount of flight time while doing so. Given a drone’s size and weight, the maximum flight time will decrease as the drone requires more and more power to carry heavier loads, as most of the battery power will be used in the motors. The second must be optimized due to the requirement of the drone to communicate the data it is receiving back to the user. If a drone is farther away, more power must be used to amplify the signal to effectively communicate with the user, also lowering the total possible flight time that the drone may achieve.

* + - * + Magnetometer interference

The drones of our client are designed to carry a magnetometer load, which measures the magnetic field around it. Sufficient measures must be taken to minimize the interference that the drone’s motors may create in the magnetic field. The magnetic field of the motors have a measurable effect on the magnetometer reading if the motors are not far enough away from the magnetometer. This can cause an error in the actual magnetic field being measured. Specifically our client has stated that any interference should be limited to less than 1 nanoTesla. Interference above this value will cause the measured magnetic field to be inaccurate and will cause mismeasurements in mapping the magnetic field around the earth.

* + - * + General drone operations

Other issues that a data-collecting drone may come across involve physical barriers, such as possibly crashing due to drag. Given that the drone must be light to be able to have the largest possible flight time, this also must be balanced with the wind that may push it around if it is too light. The aerodynamics of the drone may also have a dampening effect on the air resistance. Another cause of a collision may be caused by a user error with the controls. If a drone’s rotors are not sufficiently protected, any obstructions or collisions involving the rotors may cause the drone to cease to function and crash. A lighter drone will cause crashes to be more prevalent due to the drag force because of wind causing the drone to deviate from its desired path.[[2]](#footnote-1)

* + **Existing Solutions**
    - DJI Matrice Pro

The USGS currently uses the DJI Matrice 600 Pro for magnetometer data collection. The DJI Matrice is a hexacopter and is a drone designed to carry heavy payloads, up to 6 kg. The drone primarily suffers from a short flight time of 15 minutes, due to the mass of the electronics and frame. To carry the large payload, the drone needs a powerful electrical system and large batteries, massively increasing the size of the drone, and a heavy frame to support the electronics, payload, and propulsion forces.

| Part Name | Use | Number | Power | Mass | Dimensions | Total mass |
| --- | --- | --- | --- | --- | --- | --- |
| DJI 6010 | Propulsion motor | 6 | 5100 g (max thrust) | 230g | 66.7mm Diameter X 29.2mm | 1380g |
| DJI 2170R | Propeller | 6 | N/A | 58g | 21 in Diameter | 348g |
| ESC (Unnamed) | Motor Control | 6 | N/A | 90g (with cables) | 85 mm X 44 mm X 18mm | 540g |
| TB27S | Battery | 6 | 99.9 Wh (Storage) | 595g | Not Listed | 3570g |
| Total mass |  |  |  |  |  | 5838 g |

Table 1.1 DJI E2000 Powertrain Specifications. Taken from the DJI Website

Table 1.1 summarizes the specifications of the DJI E2000 powertrain system, the onboard propulsion system for the DJI Matrice Pro. The propulsion system alone weighs almost 6 kg of the drone mass. The total max thrust is 30.6 kg in order to move the drone and payload of up to 6 kg, and this consumes large amounts of power, six 100Wh batteries per flight.

| Specification | Description |
| --- | --- |
| Assembled Drone Dimensions | 1668 mm X 1518 mm X 727 mm |
| Storage Drone Dimensions | 437 mm X 402mm X 553 mm |
| Total Mass | 9.5 kg |
| Wind Resistance | 8 m/s |
| Max Speed (no wind) | 40 mph |
| Max Payload | 6 kg |

Table 1.2 DJI Matrice 600 Pro Specifications. Taken from the DJI Website

Table 1.2 looks at several important system-wide performance specifications for the drone. The overall drone size during flight is fairly large, but the storage size is far smaller, at 26.1%, 26.5%, and 76.1% of the assembled size for length, width and height respectively. The total drone mass is also 9.5 kg, sixty-percent of which is dedicated to the propulsion system.

The drone also has the ability to operate in wind conditions of up to 8 m/s, and has a top speed of 40 mph in no wind conditions. These values are provided by the website for the drone, but these values can change depending on the wind resistance and moments created by the payload mass, position, and drag.

The drone itself is very impressive, boasting a powerful and fast propulsion system that can support large payloads, however, there are several shortcomings. When used by the USGS for collecting magnetometer data, it can only make fifteen minute long flights. This is largely due to the mass and forces of the propulsion system. A large portion of the energy expended during flight is just for counteracting its own flight mass (citation needed or refer to info in general drone stuff in previous section). The drone is also designed to carry payloads of up to 6 kg, but the magnetometer only weighs 2 kg, so the drone isn’t designed to perform most efficiently for the magnetometer mass.

The drone is also very expensive, costing $6,599.00 at dronenerds.com. This is excluding spare batteries listed at $209.00 on the same site, and the drone needs six batteries for flight. The drone can also only make a 15 minute flight (citation from meeting notes needed). The result is the drone must make around 7 flights in a day, requiring plenty of spare batteries, further increasing the cost.

Lastly, the drone has an extremely powerful propulsion system that generates plenty of interference for the magnetometer payload. The estimated interference is (data needed from johnathan), due to the high motor power. This is an error of approximately (data needed) from earth’s standard magnetic field.

The DJI Matrice Pro is a powerful drone, but it has a short flight time due to its weight and power consumption, and also generates magnetometer interference that interferes with the data collection that the USGS needs.

* + - ZeRone

ZeRONE blade-free propulsion drone uses vibrations of piezo elements as propulsion. Propulsion is achieved by microblowers which are piezoelectric elements operating at ultrasonic frequency range and generate less noise than conventional quadcopter drones. The ZeRONE drone uses a 24-inch aluminum-metallized film balloon filled with helium gas making it a neutrally buoyant drone. The total weight without helium uplift of the ZeRONE drone is 106.4g including the balloon, microblower, carbon rods, drive circuit, receiver, battery, joint, screws and etc. The drone can be used as advertisement billboards in indoor crowds or halls. The drone has been tested with carrying a camera for crowd monitoring, human flow analysis and security. However, the microblowers cannot provide enough thrust beyond 1 meter per 7.5 second upwards and downwards. ZeRONE is prone to drift caused by slight winds, either by people walking past it or areas with air conditioning.

Although the drone uses low noise microblowers to provide lift, it cannot counteract external forces such as slight breeze which makes it unideal for precise sensor data collection. ZeRONE cannot add IMU and GPS sensors for autonomous flight control without increasing the balloon diameter and adding more microblowers.

W. Yamada, H, Manabe, and D. Ikeda “ZeRONE: Safety Drone with Blade-Free Propulsion,” thesis, Dept. Research Labs, NTT DOCOMO Yokosuka, Yokosuka, Kanagawa, Japan, 2019.

<http://library.usc.edu.ph/ACM/CHI2019/1proc/paper365.pdf>

* + - H-Aero
  + **The Need for a Better Solution**
    - 4 Lenses
    - Hint at Barone2 design
  + **also include a paragraph that lets the reader know what to expect in this document. 'This document will..." or In the following section, we will present...something like that**

### (Body)

#### Chapter 2: Design Considerations of a Buoyant Drone

* + **Project Goals**
    - Team Goals and System Technical Requirements
  + **Physics of a Buoyant Drone**
    - Why is buoyancy good
      * Reduced Weight
      * Less reliance on motors to lift
        + Less magnetometer interference
        + More battery power = longer flight time
    - Issues it causes
      * Buoyant moment
        + Drone cannot tilt like standard drones
      * Size
        + Increased drag force on body of drone
      * Helium cost
        + Helium must be replenished when lift bag is deflated
      * Makes a more massive frame
        + Motors need to push harder to accelerate
  + **General Design Overview**
    - Using rotating rotors to control drone
    - Ellipsoidal lift bag to decrease drag
    - Motors Mounted far from magnetometer to decrease interference

#### Chapter 3: Lift Bag and Drone Frame Design

* + **Lift Bag Design**
    - Adopted Ellipsoidal shape to Reduce Drag
    - 9’ diameter Lift Bag chosen to hold 4m3 of helium
  + **Gondola Design**
    - Materials chosen for durability
    - Keeps center of mass below center of buoyancy
  + **Ultrasonic Mounting**
    - Design of ultrasonic sensor bracket for best area coverage
    - Placement in front center of drone
  + **Servo Mounting**
    - Placed equidistant around center of envelope

#### Chapter 4: Propulsion Design and Actuator Interface

* + **Physics of a Rotating Rotor Design**
    - Deals with buoyant moment by turning without having to tilt entire drone
  + **Propulsion System Design**
    - Motor, ESC, Propeller, and Servo selections
    - Response times and power output
  + **Interfacing with the Servos**
    - PWM Interface with microcontroller
    - Duty cycle
    - 360 degree angle
  + **Interfacing with the Motors**
    - PWM Interface with microcontroller
    - Duty cycle
    - Update rate

#### Chapter 5: Control Design

* + **Simple Remote Control Response Design**
  + **Plant Definition in State Space Form**
  + **Applying a PID Controller for Path Following and Terrain Tracking**
  + **Integrating State Estimation with Controller Design**
  + **Testing the Discrete Linearized System Against Nonlinear Model**
  + **Auxiliary Functions and State Machine Design**
  + **Remote Control Response with Autonomous Functionality**

#### Chapter 6: Sensor Array, State Estimation, and PCB Interface

* + **Microcontroller PCB Design**
    - Clock rate
    - SPI slave to microprocessor
  + **Interfacing with Ultrasonic Sensors**
    - Terrain tracking
    - Update rate
    - Trigger pins for distance read requests
    - Echo pins for distance read
  + **Interfacing the IMU Sensor**
    - Accelerometer detection
    - Fall detection/ error detection
    - Update rate
    - I2C communication with microcontroller
  + **Interfacing with the Pressure and Temperature Sensor**
    - Altitude tracking
    - Update rate
    - I2C communication with microcontroller
  + **Interfacing with the GPS Sensor**
    - Update rate
    - UART communication with microcontroller
  + **Interfacing with the Lift Bag Pressure Sensor**
    - Detects helium leakage out of the balloon
    - Update rate
    - I2C communication with microcontroller
  + **State Estimation**
    - State Estimation Design
    - Update Rate

#### Chapter 7: Power Distribution

* + **Power Budget**
    - Microcontroller and Microprocessor
    - Sensors
    - Motors, Servos, and Transmitter/Receiver
  + **Power Simulation Analysis**
  + **Power Rails**
  + **Heat Dissipation**
  + **Battery Selection and Drone Flight Time**

#### Chapter 8: Full System Simulation Verification of Drone Design

* + **Force implementation in Design Using GUI**
    - Buoyant Forces
    - Throttle/Thrust Forces
    - Drag Forces
    - Individual Gravity Forces
  + **RC Control**
  + **Sensors Array**
  + **Autonomous Controls**

#### Chapter 9: Legal Requirements

* + **FAA Registration**
  + **Drone Insurance**
  + **Flight Requests**
  + **Covid**

#### Chapter 10: Testing in a Controlled Environment

* + **Designing tests to test drone capabilities**
  + **Analysis of test flight data**
    - Flight Time
    - Crashes
    - Helium Loss
    - Control Systems
    - Autonomous/Remote Control

#### Chapter 11: Test Flights

* + **Designing Tests to Test Drone Capabilities**
  + **Analysis of Test Flight Data**

### (Lessons Learned)

#### Chapter 12: Success and Failures

#### Chapter 13: Next Steps

### (References)

#### Chapter 14: Appendix

https://pubs.er.usgs.gov/publication/ofr20151032

Cress, Jill, Hutt, Michael, Sloan, Jeff, Bauer, Mark, Feller, Mark, and Goplen, Susan, 2015, U.S. Geological Survey Unmanned Aircraft Systems (UAS) Roadmap 2014: U.S. Geological Survey Open-File Report 2015–1032, 60 p., <http://dx.doi.org/10.3133/ofr20151032>.

**Key: Chapters are numbered. Bold Text Are Headers. Other text is content information**

Cover Pages

* Title page
* Abstract
* Table of Contents

### (Introduction/Background)

#### Chapter 1: Introduction

* + **Project Background and Motivation**
    - USGS Goal
      * Map the earth’s magnetic field
      * Researchers at the United States Geological Institute (USGS) are collecting data on the earth's magnetic field in order to conduct research on geologic faults and anomalies such as underground rivers(citation needed). In order to collect this data they use drones with an attached magnetometer that makes 7 consecutive 15 minute flights in order to conduct just one survey.
    - **Collecting Data with Drones**
      * Pros
        + Mobility
        + Safety
        + Control
        + Autonomous design
      * Cons
        + Battery issues
        + Magnetometer interference
        + General drone operations
  + **Existing Solutions**
    - DJI Matrice Pro
    - H-Aero
  + **The Need for a Better Solution**
    - 4 Lenses
    - Hint at Barone2 design
  + **Project Description**

### (Body)

#### Chapter 2: Design Considerations of a Buoyant Drone

* + Introduction to the Chapter. Brief summary of chapter contents and what to expect, 1~2 paragraphs, directly under chapter title, no section header.
    - In this chapter, we first introduce the flight conditions and payload requirements. Next, we address the necessary physics to consider with a buoyant drone design, as well the problem with drone controllability. Finally, with the high level system understanding developed in this chapter, we introduce the general design of the drone.
  + **Project Goals and Requirements**
    - Team Goals and System Technical Requirements
    - Minimum flight requirements
      * (List Tech Requirements here for flight conditions)
  + **Physics of a Buoyant Drone**
    - Benefits of Buoyancy
      * Reduced Weight
      * Less reliance on motors to lift
        + Less magnetometer interference
        + More battery power = longer flight time
      * Self correcting buoyant moment
    - Issues buoyancy causes
      * Buoyant moment
        + Drone cannot tilt like standard drones
        + Lose controllability with normal quadcopter flight controllers
      * Limited Flight conditions
        + The drones larger size increased drag force on the body of the drone limiting the conditions it can fly in, to lower wind speeds.
      * Makes a more massive frame
        + Motors need more energy to accelerate
  + **General Design Overview**
    - Using rotating rotors to control drone
      * We can rotate our propulsion force axes using servos to change direction of forces so we can fly.
        + Propeller can point up, down, forward, backwards, and anywhere in between
    - Ellipsoidal lift bag to decrease drag
      * Increases controllability and reduces energy needed to fly.
      * Provide wind tech req
    - Motors Mounted far from magnetometer to decrease interference
      * Magnetometer interf req
    - Using Ultrasonic Sensors for terrain tracking
      * Approx 1 m off ground
      * Terrain tracking req

#### Chapter 3: Lift Bag and Drone Frame Design

* + Introduction to the Chapter. Brief summary of chapter contents and what to expect, 1~2 paragraphs, directly under chapter title, no section header.
    - Chapter 3 covers the mechanical design of the drone, addressing drag and secure physical system mounting.
  + **Lift Bag Design**
    - Technical Requirements that need to be met. 5mph in 15mph wind. Minimize energy expenditure by reducing forces during flight
    - Adopted Ellipsoidal shape to Reduce Drag
    - Drag Analysis
    - 9’ diameter Lift Bag chosen to hold 4m3 of helium
  + **Gondola Design**
    - Technical Requirements
    - Requirements for Gondola
      * What it needs to carry, how its mounted
    - Materials chosen for durability
      * Pugh Chart
    - Keeps center of mass below center of buoyancy
  + **Ultrasonic Mounting**
    - Technical Requirements
    - Design of ultrasonic sensor bracket for best area coverage for terrain tracking
    - Placement in front center of drone
  + **Servo Mounting**
    - Technical Requirements
    - Placed equidistant around center of envelope
    - Discussion of placement to reduce interference. (interference analysis may be done here or maybe in power?)

#### Chapter 4: Propulsion Design and Actuator Interface

* + Introduction to the Chapter. Brief summary of chapter contents and what to expect, 1~2 paragraphs, directly under chapter title, no section header.
    - Propulsion design explores in detail the physics of our approach to achieving system controllability. From there, motor, ESC, servo, and propeller selection are analyzed to develop an effective rotating rotor system. Finally, we go over how we interface with the propulsion system.
  + **Physics of a Rotating Rotor Design**
    - Deals with buoyant moment by turning without having to tilt entire drone
    - Describe physics nonlinear model and effects on controllability.
  + **Propulsion System Design**
    - Minimum flight requirements listed. Wind, mass etc
    - Motor, ESC, Propeller, and Servo selections
    - Response times and power output
  + **Interfacing with the Servos**
    - Technical Requirements
    - PWM Interface with microcontroller
    - Duty cycle
    - 360 degree angle
    - Control Software for position
    - PCB
  + **Interfacing with the Motors**
    - Technical Requirements
    - PWM Interface with microcontroller
    - Duty cycle
    - Update rate
    - PCB

#### Chapter 5: Sensor Array, State Estimation, and PCB Interface

* + Introduction to the Chapter. Brief summary of chapter contents and what to expect, 1~2 paragraphs, directly under chapter title, no section header.
    - Chapter five goes over the sensor array needed to determine the current state of the drone, error handling, and PCB interface. The process of how the state is estimated, through integration and complementary filters, is analyzed at the end
  + **Microcontroller PCB Design**
    - Technical Requirements
    - Clock rate
    - SPI slave to microprocessor
  + **Interfacing with Ultrasonic Sensors**
    - Technical Requirements
      * Terrain tracking
    - Update rate
    - Name of Sensor.
      * Sensor Specs
    - Trigger pins for distance read requests
    - Echo pins for distance read
  + **Interfacing the IMU Sensor**
    - Technical Requirements
    - Accelerometer detection
    - Fall detection/error detection
    - Name of Sensor.
      * Sensor Specs
    - Update rate
    - I2C communication with microcontroller
  + **Interfacing with the Pressure and Temperature Sensor**
    - Technical Requirements
    - Altitude tracking
    - Name of Sensor.
      * Sensor Specs
    - Update rate
    - I2C communication with microcontroller
  + **Interfacing with the GPS Sensor**
    - Technical Requirements
    - Name of Sensor
      * Sensor Specs
    - Update rate
    - UART communication with microcontroller
  + **Interfacing with the Lift Bag Pressure Sensor**
    - Technical Requirements
    - Detects helium leakage out of the balloon
    - Name of Sensor.
      * Sensor Specs
    - Update rate
    - I2C communication with microcontroller
  + **State Estimation**
    - Technical Requirements
    - State Estimation Design
      * Integration
      * Complementary filters
    - Update Rate

#### Chapter 6: Control Design

* + Introduction to the Chapter. Brief summary of chapter contents and what to expect, 1~2 paragraphs, directly under chapter title, no section header.
    - Control design analyzes the drone physics, and develops a control system for the drone. There is open loop control implemented in our Simple Remote Control Design, that allows for basic RC functionality. Next, is autonomous flight control that is necessary for terrain tracking and path following. Next, we confirm functionality through simulation. The state machine and auxiliary autonomous functions, such as auto take off and landing, are developed and tested. Finally, an RC system was developed that uses some autonomous functionality to assist the user.
  + **Simple Remote Control Response Design**
    - System Tech Req
    - Open loop controls
    - Used for early testing
    - No autonomous functions
    - New layout of drone controller
      * Since we don’t fly like normal quadcopters for hexacopters, we have different inputs so we lay them out for the user
  + **Plant Definition in State Space Form**
    - Applying force equations defined in chapter 2 and 4 and solving for the accelerations for the drone
    - Define all states and inputs
    - We applied small angle approximation to the rotation matrix since we don’t change the pitch and roll angles
    - Description of the linearization of the system
      * Describe limits of plant definition. For example, if the pitch angle is 45 degrees, a small angle won't apply.
  + **Applying a PID Controller for Path Following and Terrain Tracking**
    - System Tech Req
    - Applying root locus to pole placement
    - Adding in integral control for robustness
    - System step responses to different inputs
    - Testing model for path following and terrain tracking
  + **Integrating State Estimation with Controller Design**
    - How state estimation is integrated with controller
    - Noise rejection
    - Noisy sensor response to step inputs and autopilot
  + **Testing the Discrete Linearized System Against Nonlinear Model**
    - Discretizing the control system for application on our drone
    - Development of a nonlinear model for system responses
    - Testing the linearized discrete time system with the nonlinear response model
    - Stability analysis
  + **Auxiliary Functions and State Machine Design**
    - System Tech Req
    - State machine design
      * Landing, take off, error handling, switching between control systems (if applicable)
    - Take off and landing procedures
    - Error response
      * Tech req
      * Dead motor
      * Sensor malfunction
      * Crash detection
  + **Remote Control Response with Autonomous Functionality**
    - New input and output definition
    - Applying root locus to pole placement
    - Adding in integral control for robustness
    - System step responses to different inputs
    - Testing system response in simulation

#### Chapter 7: Power Analysis and Flight Time

* + Introduction to the Chapter. Brief summary of chapter contents and what to expect, 1~2 paragraphs, directly under chapter title, no section header.
    - This chapter analyzes the power consumption of the drone during flight, how power is distributed throughout the system, selecting an appropriate battery to meet the minimum flight requirement with minimum wind speed requirement, and dissipating heat on the drone, and the estimated flight time for the drone.
  + **Power Usage During Flight**
    - Technical Requirements
    - Microcontroller and Microprocessor
    - Sensors
    - Motors, Servos
  + **Power Simulation Analysis**
    - Added power consumption estimations into flight simulation tests to confirm power usage estimations
  + **Distributing Onboard Power**
    - Technical Requirements
    - Power Rails
    - Stepping Down Voltage
  + **Heat Dissipation**
    - Technical Requirements
    - List everything analyzed
    - Gondola plate
  + **Battery Selection and Drone Flight Time**
    - Technical Requirements
    - Battery selection
    - Pugh chart of different battery options
    - Estimation of final flight time

#### Chapter 8: Full System Simulation and Validation of Drone Design

* + Introduction to the Chapter. Brief summary of chapter contents and what to expect, 1~2 paragraphs, directly under chapter title, no section header.
    - Chapter 8 analyses the detailed simulation for drone flight that is developed in a V-Rep environment. The simulation covers physical response to inputs, tests of the state machine, noisy sensor inputs, and control system response to identify flight response before test runs and inform of any necessary design changes.
  + **Force implementation in Design Using GUI**
    - Technical Requirements
    - Buoyant Forces
    - Throttle/Thrust Forces
    - Drag Forces
    - Individual Gravity Forces
  + **RC Control**
    - Technical Requirements
    - Input Layout in GUI
    - Tests run
    - Analysis of data
  + **Sensors Array**
    - Technical Requirements
    - Noisy sensors and the accuracy of state estimation onboard the drone.
  + **Autonomous Controls**
    - Technical Requirements

#### Chapter 9: Testing in a Controlled Environment

* + Introduction to the Chapter. Brief summary of chapter contents and what to expect, 1~2 paragraphs, directly under chapter title, no section header.
    - Chapter 9 is where we test the drone in a lab setting in order to ensure safety during test flights. We also test certain functions only in this setting, such as crash detection, since it is not feasible or safe to test these functions in an actual flight for our team.
  + **Designing tests to test drone capabilities**
    - Description of each test and setup
  + **Analysis of Test Data**
    - Flight Time
    - Crashes
    - Helium Loss
    - Control Systems
    - Autonomous/Remote Control

#### Chapter 10: Testing in a Variable Environment

* + Introduction to the Chapter. Brief summary of chapter contents and what to expect, 1~2 paragraphs, directly under chapter title, no section header.
    - Chapter 10 goes over test flights outside on campus
  + **Designing Tests to Test Drone Capabilities**
    - Description of tests and setup
  + **Analysis of Test Flight Data**
    - Flight Time
    - Helium Loss
    - Control Systems
    - Autonomous/Remote Control

#### Chapter 11: Legal and Safety Requirements

* + Introduction to the Chapter. Brief summary of chapter contents and what to expect, 1~2 paragraphs, directly under chapter title, no section header.
    - Flying drones requires XYZ and we go over the processes we went through in order to meet minimum FAA and campus requirements.
  + **FAA Registration**
  + **Drone Insurance**
    - “Insurance for school projects is provided through the school when you submit your documentation. “
  + **Flight Requests**

### uas safety to processes paperwork

* + **Covid Restrictions**
    - Limits on people in lab

### (Lessons Learned)

#### Chapter 12: Successes and Failures

* + Introduction to the Chapter. Brief summary of chapter contents and what to expect, 1~2 paragraphs, directly under chapter title, no section header.
    - Chapter 12 analysis the ability of the drone to meet the system technical requirements and determines that the project is (successful/unsuccessful)
  + **Meeting Technical Requirements**
    - List all requirements and whether they were met or not
  + **Client Response**

#### Chapter 13: Next Steps

* + Introduction to the Chapter. Brief summary of chapter contents and what to expect, 1~2 paragraphs, directly under chapter title, no section header.
  + Areas that need improvement, or changes to consider in future iterations
    - Improvements to client response
  + What to watch out for in further iterations
  + Research these other areas
  + Future/developing technology

### (References)

#### Chapter 14: Appendix

* + **Github**
  + **Other links**
  + **CAD Drawings**
  + **Bibliography**

1. https://par.nsf.gov/servlets/purl/10112909 [↑](#footnote-ref-0)
2. https://tsue.scienceweb.uz/index.php/archive/article/download/2066/1411 [↑](#footnote-ref-1)