The DORIS Project

Initial Design Report

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Project Sponsor: NAU CEIAS Mechanical Engineering Department

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DISCLAIMER

This report was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this report should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such they are not responsible for the accuracy of results or conclusions.

EXECUTIVE SUMMARY

For our senior mechanical engineering capstone, our team was tasked with designing and creating a drone utilizing commercially available parts. The drone must be able to engage and deploy different payloads while remaining airborne. These payloads will include a camera for potential surveying, a payload that must be equal or greater in weight to 30% of the drone's empty weight, and a 3D-printed cruise missile that must be able hit a target after being deployed. The drone must be able to complete a predesignated course where it will take off, deploy the cruise missile, fly to the first payload, pick it up, fly across the field, drop the payload, fly to the next payload, pick it up, fly across the field, drop the payload, pick up a camera, fly to the team, take a picture, and land safely. We have codenamed this project DORIS – Drone Operated Reconnaissance and Interchange System.

The budget for this project is $3000, sponsored by the Mechanical Engineering Department at Northern Arizona University. On top of the $3000, the team was also required to fundraise 10% of that budget, or $300. For the fundraising, the team decided to use GoFundMe to raise these funds and have already exceeded the $300 needed. The advisor and instructor for our project is Professor David Willy at Northern Arizona University.

The importance of this project is that it satisfies a need for a more affordable and easier to manufacture payload-capable drone. This could allow for an easier and cheaper way to deliver and receive any kind of consumer package, to deliver first aid materials or other emergency supplies, and can be used for many military applications.

Over the course of this project so far, we have benchmarked designs for the drone, compiled a list of literature that will be useful to our project, calculated the thrust due to our selected motors and propellers, calculated the size of the battery that will be needed to power the drone, calculated the shear stress, bending moment, moment of inertia, and the maximum deflection of the drone arms, created a variety of designs for each subsystem, weighed each design against five criteria, selected the best design based on the weighting, and started prototyping.

The design that our team has decided on is a quadcopter with a simplistic carbon fiber frame, octagonal carbon fiber arms, a magnetic payload attachment system that can be turned off using a servo motor, a Pixhawk 6C Flight Controller, iFlight XING X4214 660KV Motors, and HQProp 16X8X3 tri-blade propellers. With this design, we believe that it will be capable of picking up large payloads, have a significant flight time, and being able to resist any damage that may occur. If damage does occur, the design allows for easy repairability.

Moving forward into the project, the team plans to continue prototyping, do material testing on the carbon fiber selected and various types of 3D printing filament, build the drone, test fly it, iterate on any problems that we can find on the drone, and do our final course run.

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1 BACKGROUND

1.1 Project Description

The project involves designing and developing a utility drone capable of carrying variable payloads, sponsored by the Mechanical Engineering Department at Northern Arizona University (NAU). The goal is to create a drone that can engage and deploy different payloads while airborne, such as a camera for surveying and a heavier payload that must be at least 30% of the drone's total weight. Additionally, the project includes a requirement to deploy an MC-01F30 Cruise Missile from AeroJTP [1]. The drone will be required to perform specific tasks, such as payload delivery, retrieval, and returning to its starting point, while meeting Federal Aviation Administration (FAA) regulations. The total budget for this project is $3,000, with an additional $300 successfully raised through a GoFundMe campaign. From the project description, we developed a project name: Drone Operated Reconnaissance and Interchange System, or DORIS for short.

1.2 Deliverables

The major deliverables for this project include a functional drone capable of completing the defined tasks and operating within legal regulations. Key outputs will include an assessment of FAA drone laws, thrust-to-weight ratio calculations, a center of mass analysis, and payload capacity estimations. The project will also involve failure mode analysis, the development of a project website, and the completion of various reports and presentations, culminating in a final report detailing lessons learned and potential real-world applications.

1.3 Success Metrics

The project's success will be assessed based on several key metrics that encompass design, performance, and compliance criteria. Firstly, the drone must demonstrate its ability to perform various mission-critical tasks, including taking off, engaging payloads, and deploying them while airborne without human intervention other than RC signals. The payloads include a camera for aerial surveying and a heavy cargo that must constitute at least 30% of the drone's total weight. Additionally, the drone must deploy an MC-01F30 Cruise Missile accurately onto a designated target, showcasing its ability to execute complex missions.

Flight performance is another critical metric; the drone must sustain a minimum of 10 minutes of continuous flight without battery failure, ensuring it has adequate endurance for practical applications. The drone's thrust-to-weight ratio and center of mass must also meet predefined standards to maintain stability during payload deployment and retrieval. Testing will involve multiple flight trials under different load conditions to confirm these parameters.

Further, the project will be evaluated based on regulatory compliance, requiring the drone to adhere to FAA regulations for registration and operational safety. This includes the use of the B4UFLY app for flight tests, ensuring legal operation in designated airspace. Data from these tests, alongside calculations for payload handling capabilities, center of mass, and failure mode analysis, will be compiled in reports that benchmark the drone's actual performance against design requirements. Overall, the combination of successful task execution, regulatory compliance, and validated engineering calculations will define the project's achievement.

2 REQUIREMENTS

This chapter outlines the key aspects of the drone project by breaking down the requirements and design goals into three main sections: Customer Requirements, Engineering Requirements, and the House of Quality. The Customer Requirements focus on the essential features that the drone must possess according to the client. The team used these requirements to look for quantifiable goals for the project. The Engineering Requirements translate these customer needs into technical specifications, such as achieving a specific thrust-to-weight ratio, keeping the drone's dimensions compact, ensuring it can operate for a minimum of 10 minutes, and maintaining a budget limit. These engineering goals are designed to ensure that the drone can complete its mission effectively while meeting regulatory standards by setting quantifiable guidelines for the final product. In the final section, the House of Quality serves as a framework that links customer expectations with the engineering targets. It ensures that all design decisions reflect the customer's priorities, helping the team make informed trade-offs between performance, cost, and regulatory compliance during the development process.

2.1 Customer Requirements (CRs)

High Mobility – The drone needs to be highly maneuverable. Able to turn sharply and easy to control to be able to pick up and drop the payload at the waypoints.

Small – The drone needs to be fairly small and still fit all essential parts such as battery and receivers as well as the payload pick-up system.

Complete Recon Mission – The drone must be able to fly to and pick-up a payload then fly it to another waypoint to drop it off. The drone must also be capable of flying with a camera and taking at minimum one photo of the team below. Lastly, it must be able to carry and launch a steerable cruise missile.

Payload Capacity – The drone can carry a significantly heavy payload, a third of its own weight.

Battery Capacity – The battery must be efficient/large enough to power the full mission and land back at home point.

Cost Efficiency – There is a limited budget for this project, so the team needs to watch their purchases and look for cheaper options if possible.

Thrust Efficiency – The drone should have a high thrust to weight ratio to be able to move easily and lift heavy payloads.

FAA Registered – The team must meet the regulations set by the Federal Aviation Administration for Unmanned Aircraft Systems (UAS). The most important ones are that the team cannot fly it above 400 ft and the drone must weigh less than 55 lbs. If necessary, the drone should be registered with the FAA.

2.2 Engineering Requirements (ERs)

Thrust to Weight Ratio – The goal ratio is for the thrust to be at least 3 times the weight of the drone. This goal was set so that we can lift the payload and still fly with high mobility.

Compact Design – The drone should be under 3 feet in height, width, and length. If the drone gets too large it will become heavier which gets harder to counter with thrust. Also, maneuverability will be more difficult.

Complete Course in Time Limit – The time limit is 10 minutes. The team must operate the drone to complete all tasks within this time constraint.

Payload Weight – The payload must be at least 30 % of the weight of the drone. To do this the drone needs to have powerful motors with efficient propellors to give it high thrust.

Time of Flight – The minimum requirement for the time in the air is 10 min. This test will be done with a full battery and keeping the drone at a hover.

Total Cost – The budget is $3,000 so all purchases must be tracked to make sure the spending does not exceed the limit.

Meet FAA Requirements - The team must meet the regulations set by the FAA for UAS. The drone cannot fly above 400 ft and it must weigh less than 55 lbs.

2.3 House of Quality (HoQ)

3 Highest on scale

	Thrust : weight > 3:1	Compact Design under 3'x3'x3'	Complete Course < 10 min	Payload > 30% of weight	Time of flight > 10 min	Total Cost under $3,000	Meets FAA requirements (weight < 55 lbs)
Thrust : weight > 3:1							
Compact Design under 3'x3'x3'							
Complete Course < 10 min	3						
Payload > 30% of weight	1		1				
Time of flight > 10 min	3		1	1			
Total Cost under $3,000		3			1		
Meets FAA requirements (weight < 55 lbs)	3	3		1	3	3	

		Technical Requirements						
Customer Needs	Customer Weights: 1-5	Thrust : weight > 3:1	Compact Design under 3'x3'x3'	Complete Course < 10 min	Payload > 30% of weight	Time of flight > 10 min	Total Cost under $3,000	Meets FAA requirements (weight < 55 lbs)
High mobility	4	5	5	5	1	2	1	
Small	1	4	5	3		5	5	5
Complete Boeing Recon Mission	5	5	3	2	4	2		
Payload Capacity	5	5	1	2	5	1	2	
Battery Capacity for small mission	4	3	2	4	4	5	1	1
Cost Efficiency	3	1	2	3		2	5	4
Thrust Efficiency	4	5	3	5	4	5	2	
FAA Registered	5		3					5
Technical Requirement Units			Feet	minutes	% weight	minutes	USD	pounds
Technical Requirement Targets		3:1	< 3x3x3	< 10	> 30	> 10	>3000	< 55
Absolute Technical Importance		28	24	24	18	22	16	15
Relative Technical Importance		1	3	3	5	4	6	7

3 Research Within Your Design Space

3.1 Benchmarking

3.1.1 Drone System

The three drone designs that the team considered state-of-the-art were: NAU Capstone 2022 Team Hi-Jax's drone, the Aurelia X8 Pro drone, and the Aurelia X6 standard drone. Design 1, the Hi-Jax drone, a 4-rotor drone picture in Figure 3.1, is considered state-of-the-art because it is light weight, compact for its size, it was durable for lower flight altitudes. It is a good jumping off point for the current team's project as it was provided to the team for reference and the flight controller and other electronics were taken from this design to be used on the team's final drone design.

Figure 3.1: Hi-Jax drone [2]

Design 2, the Aurelia X8 Pro, an 8-rotor drone pictured in Figure 3.2, is considered state-of-the-art because it is designed to carry a very large payload of 10 kilograms or approximately 22 pounds [3].

Figure 3.2: Aurelia X8 Pro drone [3]

Design 3, the Aurelia X6 Standard, a 6-rotor drone pictured in Figure 3.3, is considered state-of-the art because, even though it has a small payload capacity of 3 kilograms, it is lighter than the X8, less complicated than it with 2 less rotors (less likely to break), it is also cheaper, and it has an integrated payload release mechanism [4].

Figure 3.3: Aurelia X6 Standard drone [4]

3.1.2 Magnets

The three magnet designs that the team evaluated were: the Mag-switch MAGJIG 60, the MAGMATE ER202, and the MAG-MATE AR1504. The mag-switch MAGJIG 60 is a mechanical magnet, weighing 0.2 pounds, measuring 1.7 inches in height, 1.6” in length, 1.1” in width, with a max hold force of 60 pounds, and a price of 26 dollars [5]. This mechanical magnet would require some type of actuator to engage and disengage its magnetic properties, whereas the following magnets are electro-magnets, which means they only need current to be applied to them to engage/did-engage them. The MAG-MATE ER2-202, is a non-shielded electro-magnet (so the other electronic components on the drone will require shielding) weighing 2 pounds, measuring 2.5 inches in height, 2” in diameter, with a max hold force of 100 pounds, and a total cost of $158 [6]. The MAGMATE AR1504, is a shielded electro-magnet, weighing 1 pound, measuring 1.3 inches in height, 2.5” in diameter, with a max hold force of 35 pounds, and a price of $136 [7]. Ultimately, for its price to max hold force ratio, the team decided on the mag-switch MAGJIG 60 for implementation into the project design.

3.1.3 Propellers

For this assessment, the team assessed three different propeller designs for the three-blade type propeller. The three propeller designs that the team evaluated were: the T-Motor P 17 by 5.8, the Gemfan 16 by 5.5, and the HqProp 16 by 8 by 3. The T-motor P 17x5.8 propeller is made of carbon fiber, weighing 26.5 grams, measuring 17 inches in diameter, with a pitch of 5.8 inches, a thrust limit of 7.5 kilograms, an optimum RPM range of 3500-6000, and a cost of 14.38 dollars per unit [8]. The Gemfan 16x5.5 propeller is made of carbon fiber, weighing 53 grams, measuring 16 inches in diameter, with a pitch of 5.4 inches, a thrust limit of 7 kg, an optimum RPM range of 3000-5000, and a cost of 62.39 dollars for 2 units [9]. The HQProp 16x8x3 propeller is made of black-glass fiber-reinforced nylon, weighing 66.5 grams, measuring 16 inches in diameter, with a pitch of 8 inches, a thrust limit of 7.2 kilograms, an optimum RPM range of 3500-6000, and a cost of 26.28 dollars per unit [10]. Ultimately, the HQProp 16x8x3 was selected because of its low price and comparable thrust limit and optimum RPM range.

3.1.4 Motors

The three motor designs that the team evaluated were: the T-Motor f-1000, the iFlight XING X4214 660KV, and the SunnySky X4120 650KV. The T-Motor f-1000 has a max thrust rating of 6875 grams, it weighs 404 grams, operates with a max current of 125 amps, a max power rating of 4000 watts, and a total cost of 119.90 dollars per unit [11]. The iFlight XING X4214 660KV has a max thrust rating of 7900 grams, it weighs 213 grams, operates with a max current of 98 amps, a max power rating of 2352 watts, and a total cost of 82.99 dollars per unit [12]. The SunnySky X4120 650KV has a max thrust rating of 6592 grams, it weighs 290 grams, operates with a max current of 100 amps, a max power rating of 2750 watts, and a total cost of 136.65 dollars per unit [13]. Ultimately, the iFlight XING was selected due to its lower cost, lower weight, and greater max thrust rating.

3.2 Literature Review

3.2.1 Dylan Boeholt

Websites:

“How to Calculate & Measure Propeller Thrust” [14]

This blog on TYTO Robotics outlines how to calculate and measure propeller thrust. The writer includes necessary equations for our design process. Jeremy and Andre will use this to design the drone rotors.

Journals:

“Design and Analysis of a Topology-Optimized Quadcopter Drone Frame” [15]

This paper is a report on 3 different designs of a drone frame and uses simulations to analyze the stress and strain of the different designs. The frame technicians (Jeremy and Dylan) will use this source.

“A thrust equation treats propellers and rotors as aerodynamic cycles and calculates their thrust without resorting to the blade element method” – ERAU [16]

This source provides equations to calculate the thrust of propellers. A thrust equation treats propellers and rotors as aerodynamic cycles and calculates their thrust without resorting to the blade cycles and calculates their thrust without resorting to the blade. Jeremy and Andre will use this information to analyze the rotors.

“Quadcopter Body Frame Model and Analysis” [17]

This paper discusses the use of computer frame modelling to determine the type of rotor and propeller to assure the necessary flight acceleration. Jeremy and Andre will use this information to pick the right rotors for the drone.

Standard:

Code of Federal Regulations Title 14 Chapter 1 Subchapter F Part 107 [18]

This CFR has all the rules on small, unmanned aircraft. We will use this to understand the rules of recreational drones before flying our drone. The flight engineer (Dylan) will use this.

Books:

Engineering Statics: Chapter 4 Moments and Static Equivalence [19]

This source will be used to understand moments of a structure. This information will be used to analyze the force applied to the arms of the drones. This information will be used by the flight engineer (Dylan) and manufacturer (Jeremy).

Engineering Statics: Chapter 7 Centroids and Centers of Gravity [20]

This source will be used to understand how important the center of gravity is to flight and how it can be changed to improve control. The flight engineer (Dylan) will use this information.

3.2.2 Andre Bonillas

Websites:

"Payloads for Drones in Emergency Response: Guide to what UAVs Carry." - dslrpros.com [21]

This guide provides a comprehensive overview of the types of payloads used by unmanned aerial vehicles (UAVs) in emergency response scenarios. It categorizes payloads into several key areas, including sensors, cameras, communication equipment, and delivery systems. The document emphasizes the flexibility of UAVs in carrying different payload types, depending on the mission's objectives, whether it is surveillance, search and rescue, or the delivery of medical supplies. Additionally, it highlights the technological advancements in sensor accuracy, range, and payload capacity, which have expanded the utility of drones in time-sensitive and critical situations. This resource is particularly useful for engineers and emergency planners looking to integrate UAVs into disaster management systems, as it not only lists common payloads but also provides insight into regulatory considerations and operational constraints. The team will utilize this information when considering the final drone's design importance in within the industry, as well as when evaluating the different type of payloads that the final drone design will carry.

"Heavy Lift Payload Drones." Uavsteminternational.com [22]

This website page details existing drone designs that are intended to carry large payloads (>10kgs). This webpage offers an in-depth technical analysis of heavy drones, focusing on their design, operational capabilities, and applications across various industries. It details the engineering specifications of heavy-lift UAVs, including payload capacities, flight endurance, and propulsion systems. Key use cases are discussed, such as logistics, construction, and emergency response, where heavy drones play a critical role in transporting large or sensitive materials. The guide also addresses the challenges associated with the deployment of these drones, including battery efficiency, regulatory hurdles, and the need for advanced control systems to ensure safe and efficient operations. This reference is highly relevant for engineers involved in drone development, providing a solid technical foundation for understanding the requirements and potential of heavy UAVs. The team will use this source when benchmarking, to gather information on state-of-the-art designs that can be used as benchmarking for the team's final design.

"Best Drones using a payload release mechanism." – uavsystemsinternational.com [23]

This document provides an overview of various drop mechanisms used in UAVs, detailing their design and operational features. It highlights applications such as cargo delivery, emergency supplies, and precision payload deployment. The document is relevant for engineers designing UAVs for delivery and emergency services, offering insights into mechanism reliability and safety. The team will use this resource in the development of the payload interchange system as reference to existing methods of transporting and releasing payloads from a drone.

Journal Papers:

"A Practical Perspective on the Drone-with-a-Slung-Load Problem." [24]

This paper addresses the control and stability challenges involved when drones transport payloads using slung-load systems. The authors propose a control strategy that accounts for unknown or unmeasured variables like the cable deviation angle and the load mass, making it highly applicable to real-world scenarios. The paper's insights are valuable for engineers working on drone logistics, offering solutions for managing dynamic instabilities in cargo transport. The team will use this resource when considering the flight stability of the drone when it is carrying the payload.

"Quadcopter Design for Payload Delivery." [25]

This paper examines the design and control strategies for a quadcopter optimized for payload delivery. The authors focus on mathematical modeling of the quadcopter's flight dynamics, particularly in relation to altitude and attitude adjustments when carrying different payloads. The study also explores motor efficiency and stability, making it valuable for engineers developing UAV systems for logistics and transport. It provides key insights into managing varying payload capacities while maintaining flight control. The team will use this resource when designing the drone to integrate a payload in its operation.

"Package Retrieval system with funneling mechanism." [26]

This patent describes a system designed to retrieve payloads delivered by unmanned aerial vehicles (UAVs) using a funneling mechanism. The system includes sloped surfaces that guide the payload into a secure position, ensuring precision during retrieval. The design improves alignment and stability when handling tethered packages, making it useful for drone-based delivery systems. This innovation enhances efficiency in automated payload handling and retrieval for logistics applications. The team will use this patent for consideration as a state-of-the-art design for a payload retrieval system when designing the final drone payload interchange system.

Standard:

"FAA small, unmanned aircraft weight requirements for registration." [27]

The standard presented by the FAA is as follows: (0.55 - 55 lbs) or (0.25 - 25 kg), which specifies the weight range for the FAA classification of a small, unmanned aircraft (a drone in the case of project DORIS). This FAA regulation/standard will dictate the max weight of the team's final drone design, as the objective is to not exceed this weight standard with the total system weight including a payload. With the project requirement of carrying a heavy payload that weighs a minimum of 30% of the drone's dry weight, means that this FAA regulation will also dictate the maximum weight that the team's final drone will be able to carry. The maximum possible drone dry weight, payload weight, and total system weight are calculated in section 3.3.4.

Books/chapters:

Make: Getting Started with Drones – Chapter 12: Advanced Drone Programming and Control [28]

In this chapter, the author delves into advanced techniques for programming and controlling drones, emphasizing autonomous flight capabilities. The chapter covers essential programming frameworks, particularly Python, and details the integration of various sensors, such as GPS and cameras, to enhance navigational accuracy and environmental awareness. Through a series of practical projects and illustrative code examples, the author guides readers in implementing sophisticated flight algorithms and real-time data processing, highlighting the potential applications in engineering and robotics. This chapter serves as a valuable resource for engineers seeking to expand their understanding of drone technology and its programmable features, promoting innovation in unmanned aerial vehicle (UAV) design and application. The team will use this resource for the design of the drone when integrating the required camera payload.

Building Your Own Drones: A Beginner's Guide to Drones, UAVs, and ROVs - Chapter 12: Advanced Drone Design and Customization [29]

In this chapter, the author explores the intricacies of advanced drone design, focusing on customization for specific applications and performance enhancements. The chapter provides detailed guidance on selecting components, optimizing flight dynamics, and implementing modifications to improve stability, range, and payload capacity. It addresses common challenges encountered during the building process and offers troubleshooting strategies to resolve issues related to hardware and software integration. By emphasizing practical techniques and the importance of iterative design, this chapter serves as a crucial resource for engineers and hobbyists aiming to innovate in drone technology and improve their UAVs' operational effectiveness. The team will use this resource for consideration when designing the payload system and integrating the payload into the design while considering of these will affect the flight dynamics such as stability and range.

3.2.3 Connor Davidson

Websites:

"Aircraft Inquiry" - FAA.gov [30]

The FAA.gov website is useful for our project because it is the place where we can register our drone at. This is important because it is stated in the customer requirements as well as to be able to fly the drone.

"5 Best Heavy Lift Drones [Updated 2020] Large Drones High Lift Capacity" [31]

This website discusses 5 of the best heavy lift capacity drones as of 2020. This website is useful for our project because it gave us good baselines for our drone by giving us similar drones to our project requirements.

Journal Papers:

"The Current Opportunities and Challenges in Drone Technology" [32]

This paper discusses the current opportunities and challenges in drone technology today. It goes into detail on how drones can be used in a variety of different areas like agricultural, medical, and military. The paper also examines some of the risks that drones can have. This paper is useful for our project because it outlines the consequences of making a drone recklessly and helps remind us that we are not building a toy, we are building something that can hurt people if we are reckless.

"Emerging technologies and the use case: A multi-year study of drone adoption" [33]

This journal evaluates drone technology over a 5-year study on economic and strategic factors, operational and supply chain factors, and organizational and behavioral factors. This paper is useful for our project because it evaluates how our drone and payload systems can be adapted to other fields like for supply chains.

"A payload based detail study on design and simulation of hexacopter drone" [34]

This journal is an in-depth analysis of a payload based hexacopter drone. The journal provides calculations like trust per motor, power, performance, torque on the propellers, pitch of the propellers, and total trust. It also shows CAD drawings of the drone, performance graphs, and deformations after loads. This journal will be very useful for our project because it contains the groundwork for a good number of calculations, drawings, and simulations that we will need in our own project.

Standards:

"IEEE Approved Draft Standard for Drone Applications Framework" [35]

This journal explains the IEEE approved draft standards for drone application. This will be very useful for our team because it outlines all the steps we need to fill out to be able to get our drone registered.

Books:

2024 - 2025 FAA Drone License Exam Guide [36]

This book is an exam guide for the FAA drone license exam. It explains every part of the exam and what we will need to know to fly our drone. This will be very useful for our team because we will need a license to be able to fly our drone and this book will help us get that license.

Remote Pilot - Small Unmanned Aircraft Systems Study Guide (Federal Aviation Administration): FAA-G-8082-22 [37]

This book is a guide for FAA regulations for small, unmanned aircraft systems. It explains in depth everything we need to know about getting our drone within FAA regulations. This is useful for our team because we need to register our drone with the FAA, and we cannot register it if we are not within regulations.

3.2.4 Jeremy Malmo

Websites:
https://oscarliang.com/motors/ (accessed Sep. 16, 2024). [38]
This guide provides an in-depth look at FPV drone motor selection, focusing on specifications like KV rating, motor size, and weight. It also offers recommendations for specific motor types based on different drone applications.

https://uav.jreyn.net/ Step 7: Electronics Section (accessed Sep. 17, 2024). [39]
This article outlines the steps involved in selecting proper motors for UAVs, discussing thrust requirements, efficiency, and motor configurations to optimize flight performance for different (heavy) payloads. Specifically it goes in depth into electronic speed controllers (ESCs), power distribution boards (PDBs), and flight controllers.

Journals:
Journal of Advanced Mechanical Design, Systems, and Manufacturing, vol. 12, no. 1. [40]
The journal discusses a 3D-printed device designed to evaluate the aerodynamic performance of rotary wings. The research contributes to understanding how 3D-printed components impact aerodynamic efficiency in drone applications.

D. BBVL, D. Pal Singh, S. Kumar Kuppa, and M. Jayanthi Rao, "Design optimization of drone BLDC motor for delivery service applications." [41]
This article focuses on brushless DC (BLDC) motors for drone applications in delivery services, using advanced materials and design techniques to enhance motor performance, power efficiency, and load capacity. This is a useful source to reference modern benchmarking for payload drones.

Books:
W. H. Yeadon and A. W. Yeadon, Handbook of Small Electric Motors. [42]
This comprehensive book provides technical knowledge about small electric motors, covering their design, operation, and applications in various fields, including drones and UAVs. This has all the basic equations that are needed to design a stable flying drone theoretically.
Source: New York: McGraw-Hill, 2001.

N. Barrera, S. Martin, and M. Stewart, Unmanned Aerial Vehicles. [43]
This book explores the design, engineering, and operational aspects of unmanned aerial vehicles, offering insights into their technological development and practical applications across different industries. This book is relatively new compared to other sources and has new insights into drone optimization.
Source: New York: Nova Science Publishers, Inc, 2021.

Standard:
"The Ultimate Guide to Heavy Lift Drone Motors," JOUAV. [44]
This guide provides information on selecting heavy-lift drone motors, emphasizing the importance of motor power, thrust-to-weight ratio, and efficiency for stable and controlled flight. It is aimed at building drones with higher payload capacities with drone examples and motor capabilities.
Source: https://www.jouav.com/blog/heavy-lift-dronemotors.html (accessed Sep. 17, 2024).

3.2.5 Michael Zielinski

Websites:

“ArduPilot Copter” – Ardupilot.org [45]

ArduPilot is an open-source flight control software with a large community of users that provides a simple and easy setup and maintenance of the drone flight control system. For our project, the team will either use ArduPilot or another open-source software called PX4, but it was determined that ArduPilot has better community support so the team will likely be using this software. This page on the ArduPilot site provides the portal to all the documentation on the setup and tuning of the version of ArduPilot that is tailored for multi-rotor applications.

uav.jeryn.net – Step 6: Battery Selection [46]

This website has no specific title or name for their drone project but is curated by two engineering graduates who set out to design a consumer budget-friendly DIY drone. The Battery Selection step includes educational information on the types of LiPo batteries and a detailed, data-driven comparison of a variety of cell counts and capacities to show how there are diminishing returns as you go higher in capacity, which also increases weight significantly. This will be helpful to the team by helping us in our own battery selection process.

Oscar Liang – oscarliang.com [47]

Oscar Liang is a DIY FPV (First Person View) drone enthusiast that has published his website to provide a comprehensive record on how to buy, build, and fly FPV drones. Although FPV is not the current focus of the DORIS project, the information pertaining to electronics is still relevant. As there are many pages within his blog related to electronics, I have only cited the home page of the website. The team will use the information from this website to assist in the assembly of the electronics system.

Journal Papers

“A Review on the State of the Art in Copter Drones and Flight Control Systems 2024” [48]

This paper reviews a wide selection of current drone designs from fixed wing to octocopter. It also provides detail on the variety of uses of drone technology from aerial surveillance to precision planting in agricultural settings. The team found this very useful in determining real-world applications of the DORIS project and how our system could be adapted to different mission settings.

“Development of Drone based Delivery System using Pixhawk Flight Controller” [49]

This paper presents the application of a delivery drone utilizing a flight controller of the same brand that DORIS currently uses. It provides a simple outline of the capabilities of the Pixhawk series of flight controllers and the viability of their use in delivery applications. The team found this useful to confirm that the Pixhawk controller is a viable option for use in what is essentially payload delivery – the same mission set we are designing for.

“Payload Manipulation for Seed Sowing Unmanned Aerial Vehicle through interface with Pixhawk Flight Controller” [50]

This article provides the same confirmation as the previous reference that the Pixhawk flight controller is a viable option for payload delivery missions. In addition to this general confirmation, the article provides key information regarding the integration of a peripheral system (in the article's case, a seed sower) into the flight control system and operating environment. The drone used in the study was operated semi-autonomously, but the team would not like to rule out autonomous flight from our own design and will keep the lessons learned in the article in mind after the initial project goals have been achieved. Autonomous flight would be an addition to the project and is not a concern during the initial design phases.

Books

"Building Your Own Drones: A Beginner's Guide to Drones, UAVs, and ROVs" – Chapter 8: Building a Quadcopter III: Flight Control [51]

This book, although a little older (published in 2015), provides a detailed description of ESCs, receivers, and (now dated) flight controllers. The information useful to this project is the description of how programmable ESCs are programmed and what they can be programmed to do. The DORIS drone will have four ESCs in its current design, all of which will likely need to be programmed to store settings such as throttle range on the receiver and others.

"Make: Getting Started with Drones: Build and Customize Your Own Quadcopter" – Chapter 4: Flight Controller [52]

As textbook literature on drone construction is somewhat sparse, this book is also published in 2015. Despite its age, it provides information specific to the ArduPilot program and its Mission Planner software. It is also a good source of information regarding what each pinout on the flight controller is and what it is used for (i.e. I2C, CANBUS, JP1, etc.). The team will use this, in addition to the documentation specific to our flight controller, to assist in wiring up our flight controller correctly.

Standard

ASTM F3005-22 Standard Specification for Batteries for Use in Small Unmanned Aircraft Systems (sUAS) [53]

This American Society for Testing and Materials standard tells the team the requirements set for the construction and maintenance of batteries used in drones. It also helps the team understand the common terminology found in the world of LiPo batteries (i.e. 6S for 6 cells), which is very beneficial in our battery selection. Throughout the project, the team will strive to meet this standard in regard to the charging and general maintenance of our LiPo batteries.

3.3 Mathematical Modeling

3.3.1 Motor, Propeller, and Frame Arms sub-assembly – Jeremy Malmo

To manage motor selection, battery capacity, and drone flight time a MATLAB code was created called UAVtoolboxtest that utilizes selected parameters to simulate a drone at hover. (Appen. 6.1)

Overview of Code Functionality: Motor Selection and Battery Compatibility.
The code performs calculations to verify whether a quadcopter design meets its thrust-to-weight ratio

requirement, ensuring the system can hover and perform well. It uses parameters like the drone's weight, motor thrust, and the desired thrust-to-weight ratio (3:1). Additionally, it checks the required throttle for hovering and whether the total available thrust is sufficient for stable flight. It also estimates the flight time at different throttle percentages (50%, 75%, 100%) and the required throttle to sustain flight.

1. Physical Constants:
   - The code defines gravitational acceleration as 9.81 m/s^2, which is needed to convert between weight in kilograms and force in Newtons.
2. Quadcopter Parameters:
   - Thrust per Motor: $\text{motor}_{\text{thrust}_{\text{per}_{\text{motor}}}} = 7.9\text{kg} * 1000$ (grams), which is the maximum thrust a single motor can provide (iFlight XING X4214 660KV).
   - Number of Motors: $\text{num\_motors} = 4$, for a standard quadcopter configuration.
3. Weight Estimation:
   - Payload Weight: `payload_weight = 4.5kg * 1000` (grams), converting the payload weight from kilograms to grams.
   - Drone Frame Weight: $\text{drone\_frame\_weight} = 6\text{kg} * 1000$ (grams), converting the estimated frame weight from kilograms to grams.
   - Total Weight: The total system weight is calculated as the sum of the payload and frame: This is then converted to kilograms.
4. Thrust-to-Weight Ratio:
   - Available Thrust: The total available thrust from all four motors is calculated by multiplying the thrust per motor by the number of motors:
   - Thrust-to-Weight Ratio: The thrust-to-weight ratio is then calculated as the amount of total thrust divided by the total system weight. The code checks if this ratio meets the design requirement of 3:1.
5. Hover Check:
   - Thrust Needed for Hovering: To hover, the total thrust must equal the total weight of the system:
   - Hover Throttle: The throttle percentage required to maintain a hover is calculated.

   The code prints out whether the available thrust is sufficient for hovering and displays the hover throttle in percentage.

7. Battery Selection and Flight Time Calculations:

- Battery Capacity: The code uses a predefined battery capacity (in mAh) and a voltage rating (6S, 22.2V). The total energy stored in the battery is calculated based on this capacity and voltage, typically expressed in watt-hours (Wh).

- Power Consumption: The power consumption of the motors is based on the current draw at different throttle percentages (e.g., 50%, 75%, and 100% throttle). Power is calculated using the formula:

$$P = V * I \tag{1}$$

where P is power, V is voltage, and I is current. The code estimates the current required for different throttle levels and calculates the total power consumption of the motors.

-Flight Time Estimation: Using the battery's total energy and the motor's power consumption, the flight time is estimated for different throttle percentages. This is done using the formula:

$$Flight_{Time} = \frac{battery\_capacity\ (Wh)}{Power_{consumption}(W)} \tag{2}$$

The code prints the estimated flight times at 50%, 75%, and 100% throttle. These estimates help determine how long the drone can stay airborne under different flying conditions, balancing efficiency and performance.

```
>> UAVtoolboxtest
Total available thrust (31600.00 g) is enough for hovering.
Throttle required to hover: 33.23%
Total Weight: 103.01 N (10.50 kg)
Available Thrust: 31600.00 g (31.60 kg)
Thrust-to-Weight Ratio: 3.01
Design meets the thrust-to-weight requirement.
Estimated flight time at 100% throttle: 2.65 minutes
Estimated flight time at 75% throttle: 4.41 minutes
Estimated flight time at 50% throttle: 9.56 minutes
Adjusted estimated flight time at hover: 14.39 minutes
```

Figure 2.4: Output of the motor selection code.

3.3.2 Flight Controller, Power, & Sensor sub-assembly – Michael Zielinski

One of the first things the team needed to figure out was how much battery capacity is needed to both complete the flying course and the minimum endurance time limit for flight. Equation 1 is the power formula for determining the number of watts P based on the voltage V and current (in amps) I output of a battery. From that equation, you can then use Equation 3 to find the energy consumption over time in watt-hours Wh by multiplying P by the time T in hours. The battery capacity in amp-hours (Ah) C can then be found from Equation 4.

$$P = V \cdot I \qquad [1]$$

$$E = P \cdot T \qquad [3]$$

$$C = \frac{E}{V} \qquad [4]$$

We assumed a 700-watt max draw per motor for 15 minutes of flight from a 22.2-volt battery to match the motors we selected, which led to the apparent need of at least 31.53 Ah of battery capacity. The team purchased a 22 Ah battery to begin with, and further practical testing may lead to the decision to purchase another and run them in parallel. These calculations also assumed that there is no step down in voltage using Battery Eliminator Circuits since our selected motors take 22.2 volts directly.

Additionally, the team needed to investigate more into the flight controller that we received from the previous capstone drone team: a Pixhawk 6C. Figure 2.5 shows the graphic from the HolyBro website (where Pixhawk 6C's are sold) demonstrating the overall capability in the number of connections from the flight controller. Appendix C contains a bulleted list of the technical specifications of the flight controller from the HolyBro website.

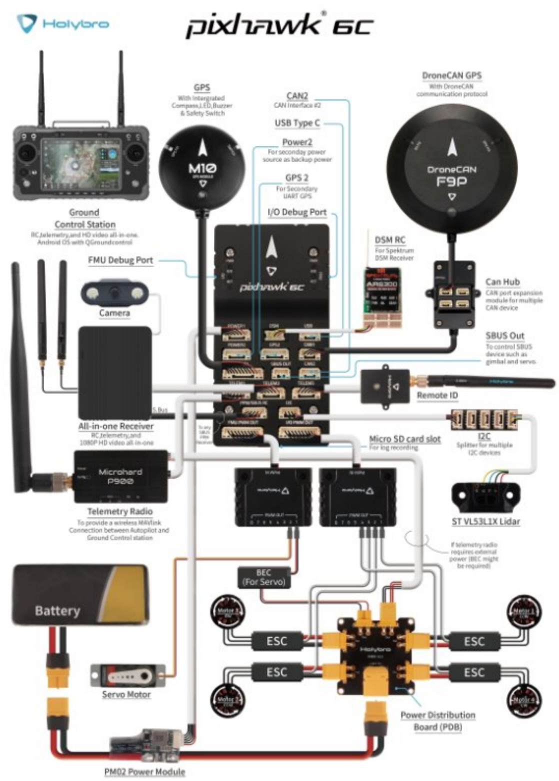


Figure 3.5: HolyBro Pixhawk 6C ecosystem chart [54].

Based on the sensors included (accelerometer, gyroscope, inertial measurement units, magnetometer, and barometer) as well as the number of interfaces (16 Pulse Width Modulated [PWM] outputs, 3 serial ports, 3 telemetry ports, 2 GPS ports, and S.BUS output), the team determined that we can continue to use the Pixhawk 6C as our primary flight controller and avoid having to purchase a new one.

3.3.3 Frame Body sub-assembly – Connor Davidson

Assuming cylindrical carbon fiber cantilever beam style arms with length = 0.5m, mass = 0.04536kg, and thrust force = 100N.

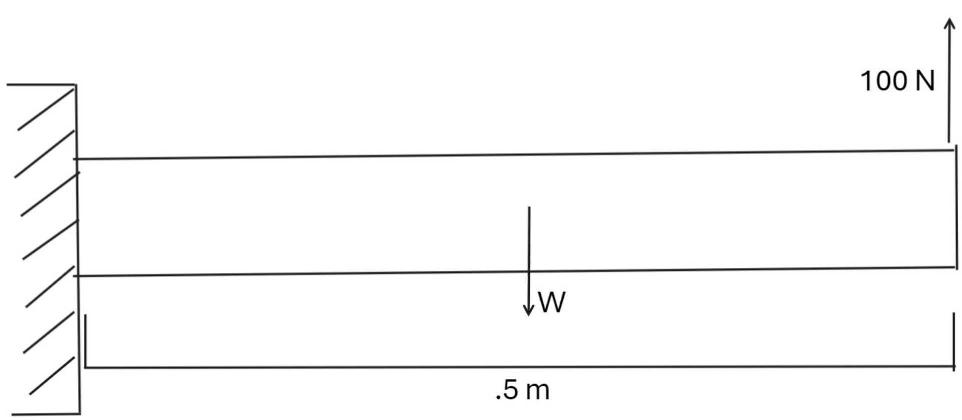


Figure 3.6. Cantilever beam diagram of the drone arm.

Force of the arm due to gravity:

$$W = 0.04536\text{kg} \cdot 9.81\frac{\text{m}}{\text{s}^2} = 0.445\text{N} \quad [5]$$

Shear Force Calculation:

$$\sum F = 0 \rightarrow 100\text{N} - 0.445\text{N} - R_f = 0 \therefore R_f = 100\text{N} - 0.445\text{N} = 99.555\text{N} \quad [6]$$

The target weight of the drone is approximately 111N, so the bending moment is calculated as follows:

$$\sum M = 0{:}100N \cdot 0.5m - 0.445N \cdot 0.25m + R_m = 0 \therefore \quad [7]$$

$$R_m = -\,100\text{N} \cdot 0.5\text{m} + 0.445\text{N} \cdot 0.25\text{m} = -49.889\text{Nm}$$

The equations above help us determine how much shear stress and how much of a bending moment that our drone arms will be taking when our motors are maxed. This is important to know when selecting the material the arms will be made of.

Assuming the inner radius of the carbon fiber tube (d_i) is 0.02m and the outer radius (d_o) is 0.022m:

$$E = 250\text{GPa} - 350\text{GPa} \quad [8]$$

From the engineering toolbox we can solve for the moment of inertia for a hollow rod.

$$I = \frac{\pi}{4}\left(d_o^4 - d_i^4\right) = \frac{\pi}{4}\left[(0.022m)^4 - (0.02m)^4\right] = 5.832 \cdot 10^{-8}\, m^4 \quad [9]$$

Using this, we can solve for the maximum defection.

$$\Delta_{max} = \frac{PL^3}{3EI} = \frac{100\text{N} \cdot (0.5\text{m})^3}{3 \cdot (300 \cdot 10^9\text{Pa}) \cdot (5.832 \cdot 10^{-8}\text{m}^4)} = 0.2381\text{mm} \approx 0.01\text{in} \quad [10]$$

The equations above calculate the maximum defection that the arms will deflect when the motors are maxed using the moment of inertia equation for a circular hollow pipe. This is important to know because if the arms bend too much, it could cause devastating problems for the drone.

3.3.4 Payload Attachment & Carrier Design sub-assembly – Dylan Boeholt & Andre Bonillas

The team needs to understand the limits on the payload weight, the dry drone weight, and the total weight of the drone system. Then from the predicted weight of the drone, the theoretical thrust to weight ratio can be calculated.

For Maximum weight calculations based off of FAA regulations:

$$W_D + W_P = W_s => W_D + 0.3W_D = 25kg => W_D = 19.2\ kg\ and\ W_P = 5.8\ kg \qquad [11]$$

Where W_D is the dry weight of the drone, W_P is the weight of the payload, and W_S is the total weight of the drone system, the 0.3 in the equation denotes that the payload will be 30 percent of the drone's dry weight without the payload attached. 25 kilograms denotes that maximum weight measurement for a small, unmanned aircraft from the FAA regulations.

For desired weight calculations based on customer requirements:

$$W_P = 5\ lbs; W_D = \frac{W_P}{0.3} = 16.7\ lbs;\ 16.7lbs + 5lbs = 21.7\ lbs = W_S \qquad [12]$$

The desired weight of the drone unloaded will be 16.7 pounds, which means the total loaded weight will be 21.7 pounds.

For the force of the payload acting on the connection apparatus:

$$F = m * g,\ 5lbs = 2.268\ kg = m; g = 9.81\frac{m}{s^2}; F = 22.25\ N \qquad [13]$$

For thrust calculation:

$$Thrust\ to\ Weight\ ratio = 3{:}1; T = W_S * ratio = 21.7lbf * 3 = 65.1\ lbf \qquad [14]$$

Where W_S is the total system weight derived earlier in pound-force, 21.7 lbf, ratio equals the desired thrust to weight ratio, 3:1, and the variable, T, is the theoretical thrust force requirement for the drone based off the desired ratio and desired drone weight, which was found to be 65.1 lbf.

3.3.5 Cruise Missile Payload sub-assembly – Michael Zielinski & Jeremy Malmo

The cruise missile payload is not something designed by the team. The original designer of the MC-01F30 Micro-Cruise missile is AeroJTP which sells their design via their website [1]. AeroJTP provides all the STL/3MF files to 3D print the major fuselage, wing, control surface, and aircraft attachment parts as well as a bill of materials for the electronic components. Figure 2.7 shows the design of the missile direct from AeroJTP. The team is currently calibrating a team member's Ender 3 V3 KE printer to print the required Lightweight PLA for the fuselage. This involves adjusting settings such as print speed, retraction distance and speed, and print temperature. No real equations are involved in this calibration, it is more of a step-by-step process. Settings are adjusted by small increments until the desired print quality is achieved.

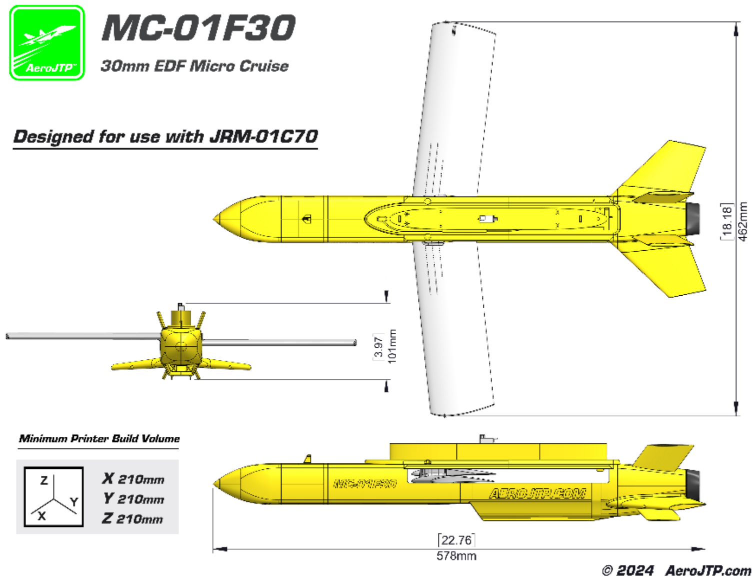


Figure 3.7: Engineering views of the AeroJTP MC-01F30 Micro-Cruise.

4 Design Concepts

4.1 Functional Decomposition

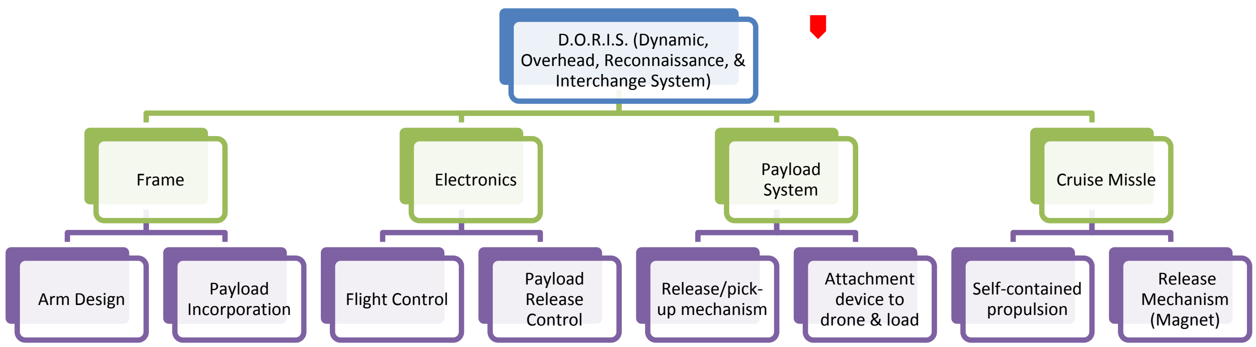


Figure 3.1:DORIS Functional Decomposition Chart

Above, Figure 3.1, shows D.O.R.I.S. (Dynamic, Overhead, Reconnaissance, & Interchange System) functional decomposition chart, outlining the functions required for the project's success. The chart divides the system into four primary areas: Frame, Electronics, Payload System, and Cruise Missile. The Frame section focuses on structural design, addressing components like Arm Design and Payload Incorporation, both essential for maintaining the drone’s stability and integrating the payload system. The Electronics section covers control and operational functions, such as Flight Control and Payload Release Control, ensuring the systems can operate and be effective at payload delivery. In the Payload System section, the emphasis is on mechanisms like the Release/Pick-up Mechanism and the Attachment Device, which play a key role in secure payload handling. Lastly, the Cruise Missile section involves propulsion and release mechanisms, ensuring that the drone can perform missions involving self-propelled payloads.

4.2 Concept Generation

<u>Frame (Main Body)</u>

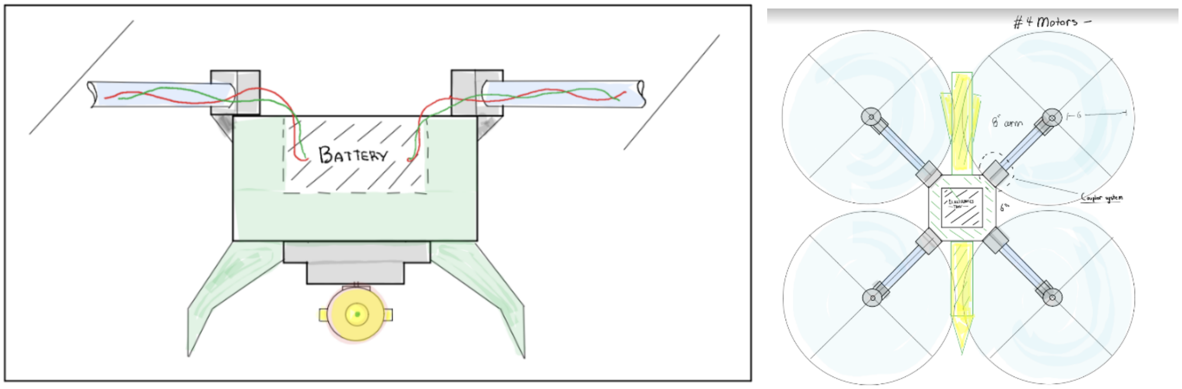


Figure 4.2: Design 3.

Design 3 This design encompasses a square body design that has attachment points for arms protruding at 45 degrees from the frame creating a symmetric pattern. Legs will be positioned so the drone can land and take off with payload 1 (MC-01F30). The frame itself will be an 8 inch by 8 inch plate to start and will be optimized for weight reduction depending on the positioning of the 22000 mAh battery. The next iteration to be tested will involve a "sandwich" style frame to create the least amount of wasted space.

Payload Attach/Detach System

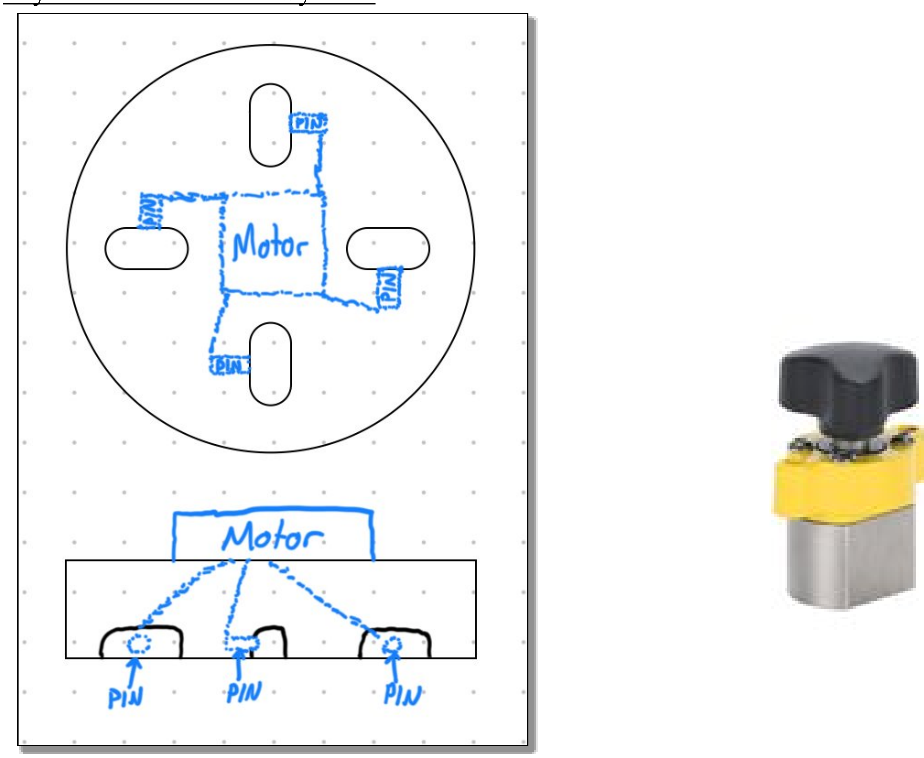


Figure 4.3: Design 5 and a Magswitch MAGJIG 60.

Design 5: This design uses magnets that are aligned with using servo motors to activate and deactivate the release. The payload for this design is required to have a metal plate for the magnet to attach too. This design was chosen for its simplicity and assured release with minimal contact. The magnet chosen can support up to 60 lb which will be enough to support a 20 lb payload with a safety factor of 3. (Thrust Ratio 3:1 → 20lb x 3 = 60lb). For prototyping one magnet will be used for proof of concept and initial cost reduction. Pictured above is the Magswitch MAGJIG 60.

Arm Design

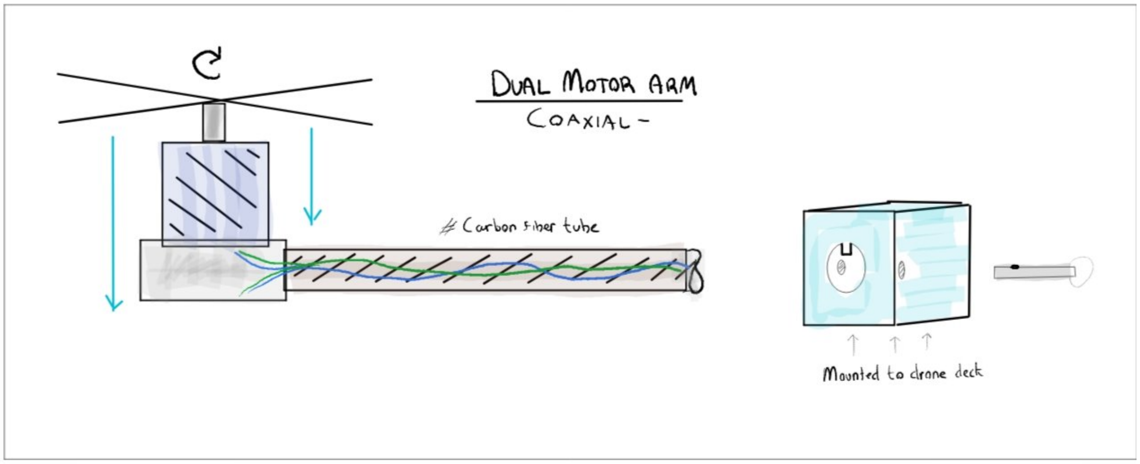


Figure 4.4: Arm Design 3

Design 3: The arm design selected uses carbon fiber tubes (20mm in diameter and 500mm in length with a 6mm wall thickness) and is attached to the main (middle) frame using 3D printed connections. The purpose of this design is to allow the carbon fiber tubes to be replaced easily if they receive damages that compromise their strength. This also allows all electronics to be ran inside the tubes to protect them from the elements. Displayed is a "pin" style attachment system to ensure the motors face perpendicular to the drone frame.

4.3 Selection Criteria

Motor Selection

The motors required for the quadcopter will need to have a thrust to weight ratio of 3:1 to meet the projects requirements. The projected total system weight is 23.15 lb or 10.5 kg, with 4.5kg being the payload and 6 kg being the drone weight (43% of system). For these specifications the drone motors must have individual max thrust capacities of 7.9 kg or a combine's system of 31.6 kg. Three motors where selected to compare, the T-Motor f-1000, iFlight XING X4214 660KV, and SunnySky X4120 650KV.

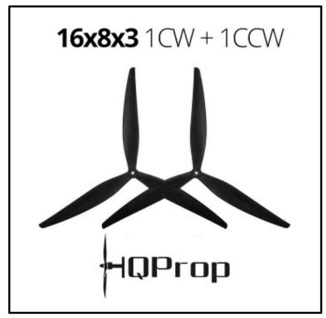
We ultimately selected the iFlight XING X4214 660KV motor because it offered the highest thrust of 7900 grams (7kg) while maintaining a lower current draw (98 A) and power consumption (2352 W) compared to its competitors. Additionally, the iFlight motor was significantly lighter (213 grams) and more cost-effective at $82.99, providing the best balance between performance and affordability for our quadcopter design.

Battery Selection

The battery choice for the quadcopter is critical in determining the flight time and ensuring the motors receive adequate power. The battery must provide enough voltage and capacity to sustain the current draw from the motors while balancing the overall weight of the system. Given the power requirements of the selected motors (T-Motor F1000, iFlight XING X4214 660KV, and SunnySky X4120 650KV), the battery should be able to provide a continuous discharge rate that matches or exceeds the combined current draw of the motors under load. Additionally, flight time will depend on the battery's capacity (measured in mAh) and the drone's total power consumption. Lithium polymer (LiPo) batteries will be used due to their high energy density and power output. A 6S (22.2V) LiPo battery with a capacity of around 10,000 to 15,000 mAh is recommended to meet the energy demands and 22,000 mAh for longer flight time.

Propeller Selection

Propeller selection is another crucial factor in optimizing the performance of the drone. To achieve the required 7.9 kg of thrust per motor while maintaining efficiency, the propeller must be well-matched to the motor's KV rating and power output. For the selected motors (T-Motor F1000, iFlight XING X4214 660KV, and SunnySky X4120 650KV), the propeller size will likely need to be between 15 and 18 inches in diameter, depending on the specific motor characteristics and thrust curves. For the Iflight selected motor, the recommended propeller for 7.9kg is 16 inches diameter.



For the propeller selection, we compared three options: the T-Motor P17x5.8, Gemfan 16x5.4, and HQProp 16x8x3. The HQProp 16x8x3 was chosen due to its ideal diameter and pitch configuration for maximizing thrust (7.2 -8.1 kg) at the target RPM range (3000-5000), crucial for our payload capacity. Additionally, it was made from a durable glass fiber-reinforced nylon, which balances strength and weight, at 66.5 grams per prop. Though the T-Motor prop offered slightly higher thrust, the HQProp's cost-effectiveness and compatibility with our motor choice made it the preferred option.

Arm Material Selection

The material used for the drone arms is critical for maintaining structural integrity while minimizing weight. The selected material Carbon fiber has high strength-to-weight ratio and stiffness, which is the ideal choice for this project. The arms will be constructed from carbon fiber tubing with a 20 mm radius and 500 mm length shaped in an octagonal pattern. This configuration provides the necessary rigidity to support the motor mounts while withstanding the stresses from motor vibrations, propeller torque, and potential impacts during flight.

ESC Selection

The electronic speed controllers (ESCs) selected for the drone must be capable of handling the power requirements of the motors, which for the iFlight 4214 is 98 A. For this project, each ESC will need a capacity of 120 amps to handle the current draw from the high-powered motors safely. These ESCs will ensure smooth power delivery and control, with features like active braking and motor timing adjustments to optimize performance. The ESCs must also be compatible with the 6S battery configuration and ensure efficient heat dissipation to prevent overheating during heavy use, especially when lifting payloads and maintaining stable flight under load.

4.4 Concept Selection

Evaluation Matrices

Frame (Main Body)

Table 1: Decomposition Matrix for Center Frame Construction

	Weight	Cost	Simplicity	Aesthetics	Durability	Repairability	Total
Weights	0.2	0.3	0.1	0.05	0.15	0.2	1
Design 1	2	2	3	4	3	4	2.75
Design 2	4	3	2	4	2	2	2.8
Design 3	5	4	4	3	4	4	4.15
Design 4	4	4	3	2	3	3	3.45
Design 5	3	4	4	3	3	4	3.6

Table 1 shows the decomposition matrix for the center frame design of the drone. The evaluation criteria include weight, cost, simplicity, aesthetics, durability, and repairability. Design 3, which balances cost and simplicity with durability, was selected for further prototyping.

Payload Attach/Detach System

Table 2: Decomposition Matrix for Payload Attach/Detach System

	Weight	Cost	Simplicity	Aesthetics	Durability	Repairability	Total
Weights	0.05	0.15	0.2	0.1	0.2	0.3	1
Design 1	4	3	2	4	2	1	2.15
Design 2	4	2	1	5	3	3	2.6
Design 3	3	2	2	4	2	3	2.55
Design 4	2	2	1	3	2	2	1.9
Design 5	3	2	4	3	4	4	3.35

Table 2 presents the evaluation matrix for the payload attach/detach system. The criteria assessed include weight, cost, simplicity, aesthetics, durability, and repairability. Design 5 scored the highest, making it the preferred option for further development.

Arm Design

Table 3: Decomposition Matrix for Arm Design

	Weight	Cost	Simplicity	Aesthetics	Durability	Repairability	Total
Weights	0.05	0.25	0.15	0.05	0.3	0.3	1
Design 1	4	2	3	4	4	2	3.15
Design 2	4	3	3	4	2	4	3.4
Design 3	5	3	4	3	4	4	4.15

Design 4	4	3	2	3	2	2	2.6
Design 5	4	1	3	5	4	2	2.9

Table 3 evaluates different designs for the drone's arms based on weight, cost, simplicity, aesthetics, durability, and repairability. Design 3 is the chosen concept due to its high scores in durability and simplicity.

Propellers

Table 4: Decomposition Matrix for Propeller Design

	Weight	Cost	Simplicity	Aesthetics	Durability	Performance	Total
Weights	0.1	0.2	0.05	0.05	0.3	0.3	1
Tri-blade	3	4	3	3	3	3	3.2
toroidal	3	2	2	5	3	4	3.15
Var-pitch	2	2	2	4	2	4	2.7
2-blade	4	4	5	3	4	2	3.1

Table 4 compares propeller design concepts, assessing factors such as weight, cost, simplicity, aesthetics, durability, and performance. The tri-blade propeller design ranked highest, offering a balance between performance and durability.

Our initial CAD design for the D.O.R.I.S. quadcopter represents a rough, yet foundational, layout of the project's structural and functional components. While still in the early stages of development, the design prioritizes essential elements such as frame durability, stability, and payload integration, utilizing lightweight materials like carbon fiber to balance strength with efficiency. This design serves as a visual blueprint to guide future iterations and refinements as we finalize the motor, propeller, and electronic component selections. It provides a flexible starting point for improvements and iterations, ensuring that all parts will eventually work together to meet the quadcopter's final goals.

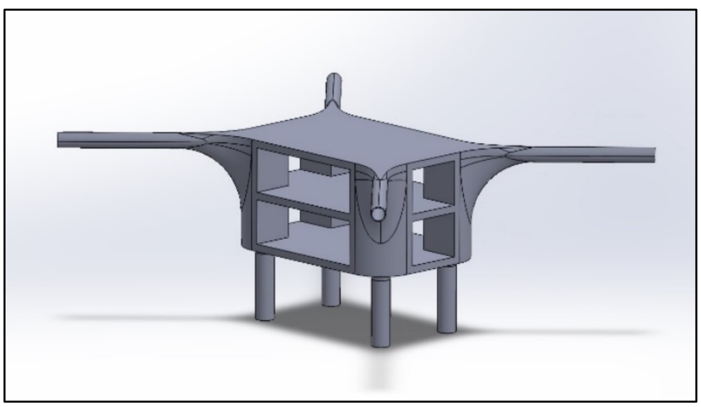


Figure 4.5: Initial CAD design for DORIS drone.

5 CONCLUSIONS

In conclusion, with a $3000 budget sponsored by the Mechanical Engineering Department at Northern Arizona University, our team was tasked with designing and creating a drone utilizing commercially available parts. The drone must be able to engage and deploy different payloads while remaining airborne. These payloads will include a camera for potential surveying, a payload that must be equal or greater in weight to 30% of the drone's empty weight, and a MC-01F30 Cruise Missile that must be able hit a target after being deployed. The drone must be able to complete a predesigned course where it will pick up the various payloads and drop them off at a separate location. The design that our team has decided on is a quadcopter with a simplistic carbon fiber frame, octagonal carbon fiber arms, a magnetic payload attachment system that can be turned off using a servo motor, a Pixhawk 6C Flight Controller, iFlight XING X4214 660KV Motors, and HQProp 16X8X3 (3 prop) propellers. With this design, we believe that it will be capable of picking up large payloads, have a long enough run time, and being able to resist any damage that may occur. If damage does occur, the design allows for easy repairability.

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7 APPENDICES

7.1 Appendix A: MatLab code: UAVtoolboxtest

```
%% Parameters`
% Physical constants
g = 9.81; % Gravitational acceleration (m/s^2)

% Quadcopter parameters
motor_thrust_per_motor = 7.9 * 1000; % Thrust per motor (grams)
num_motors = 4; % Number of motors

% Weight estimation
payload_weight =  4.5*1000; % Payload weight (grams)
drone_frame_weight = 6 * 1000; % Frame weight (grams)
total_weight_g = payload_weight + drone_frame_weight; % Total weight (grams)
total_weight_kg = total_weight_g / 1000; % Total weight (kilograms)
total_weight_n = total_weight_kg * g; % Total weight in Newtons

% Desired thrust-to-weight ratio
desired_ratio = 3; % Design requirement (3:1 thrust-to-weight)
available_thrust_g = motor_thrust_per_motor * num_motors; % Total available thrust in grams
thrust_to_weight_ratio = available_thrust_g / total_weight_g; % Thrust-to-weight ratio

%% Hover Check
% Total thrust needed to hover (equal to total weight in grams)
required_thrust_hover_g = total_weight_g; % Total thrust needed in grams
hover_throttle = required_thrust_hover_g / available_thrust_g; % Throttle required to hover

% Check if available thrust is enough for hover
if available_thrust_g >= required_thrust_hover_g
    fprintf('Total available thrust (%.2f g) is enough for hovering.\n', available_thrust_g);
else
    fprintf('WARNING: Total available thrust (%.2f g) is NOT enough for hovering.\n', available_thrust_g);
end

fprintf('Throttle required to hover: %.2f%%\n', hover_throttle * 100);

%% Debug Information for Thrust and Weight
fprintf('Total Weight: %.2f N (%.2f kg)\n', total_weight_n, total_weight_kg);
fprintf('Available Thrust: %.2f g (%.2f kg)\n', available_thrust_g, available_thrust_g / 1000);
fprintf('Thrust-to-Weight Ratio: %.2f\n', thrust_to_weight_ratio);

% Check if the design meets the thrust-to-weight ratio
if thrust_to_weight_ratio >= desired_ratio
    disp('Design meets the thrust-to-weight requirement.');
else
    disp('Design does NOT meet the thrust-to-weight requirement.');
end

%% Motor Efficiency and Flight Time Estimation
efficiencies = [3.359, 4.2, 6.066]; % Efficiency in g/W at 100%, 75%, 50% throttle
throttle_levels = [1.0, 0.75, 0.5]; % Throttle levels

% Battery parameters
battery_capacity_mah = 22000; % Battery capacity (mAh)
battery_voltage = 22.2; % Battery voltage (V)
usable_capacity_factor = 0.85; % Usable battery capacity percentage
```

```
battery_capacity_wh = (battery_capacity_mah / 1000) * battery_voltage * usable_capacity_factor; % Capacity in Wh
battery_capacity_joules = battery_capacity_wh * 3600; % Convert to Joules

%% Estimate Flight Time at Various Throttle Levels
flight_times = zeros(1, length(throttle_levels));

for i = 1:length(throttle_levels)
    throttle = throttle_levels(i);
    efficiency = efficiencies(i);

    % Adjust the required thrust based on throttle level
    thrust_at_throttle = throttle * available_thrust_g;

    % Power consumption per motor (using thrust at throttle)
    total_power_per_motor = thrust_at_throttle / num_motors / efficiency; % Power per motor (W)
    total_power_consumed = total_power_per_motor * num_motors; % Total power consumed (W)

    % Calculate flight time in hours
    flight_time_hours = battery_capacity_wh / total_power_consumed; % Flight time in hours
    flight_time_minutes = flight_time_hours * 60; % Convert to minutes
    flight_times(i) = flight_time_minutes; % Store flight time
end

% Display flight times at various throttle levels
for i = 1:length(throttle_levels)
    fprintf('Estimated flight time at %.0f%% throttle: %.2f minutes\n', throttle_levels(i) * 100, flight_times(i));
end

%% Adjusted Estimate Flight Time at Hover
% Adjust the required thrust based on hover throttle level
thrust_at_hover = hover_throttle * available_thrust_g;

% Use efficiency at 50% throttle (since hover is closer to 50% throttle)
efficiency_hover = efficiencies(3); % Efficiency at 50% throttle

% Power consumption per motor (using thrust at hover)
total_power_per_motor_hover = thrust_at_hover / num_motors / efficiency_hover; % Power per motor (W) at hover
total_power_consumed_hover = total_power_per_motor_hover * num_motors; % Total power consumed (W) at hover

% Calculate flight time in hours at hover
flight_time_hours_hover = battery_capacity_wh / total_power_consumed_hover; % Flight time in hours
flight_time_minutes_hover = flight_time_hours_hover * 60; % Convert to minutes

% Display estimated flight time at hover
fprintf('Adjusted estimated flight time at hover: %.2f minutes\n', flight_time_minutes_hover);
```

7.2 Appendix B: Thrust Efficiencies of iFlight XING X4214 660KV

Prop (inch)	Voltages (V)	Throttle (%)	Load Currency (A)	Pull(g)	Power(W)	Efficiency (g/W)	Temperature(in full throttle load 1 min)
16×6	24	50%	22.2	3232	532.8	6.066	90C°
		60%	33.8	4233	811.2	5.218	
		70%	48.1	5297	1154.4	4.589	
		80%	64.2	6246	1540.8	4.054	
		90%	83.1	7116	1994.4	3.568	
		100%	98	7900	2352.0	3.359	
15X6	24	50%	18.7	2745	448.8	6.116	85C°
		60%	29.2	3738	700.8	5.334	
		70%	40.6	4636	974.4	4.758	
		80%	55.7	5651	1336.8	4.227	
		90%	72.2	6575	1732.8	3.794	
		100%	83.5	7120	2004.0	3.553	
14X6	24	50%	14.7	2191	352.8	6.210	70C°
		60%	22.4	3008	537.6	5.595	
		70%	32.5	3880	780.0	4.974	
		80%	44	4754	1056.0	4.502	
		90%	58.8	5692	1411.2	4.033	
		100%	67.1	6179	1610.4	3.837	
15×6	12	50%	6.6	692	79.2	8.737	50C°
		60%	9.8	1001	117.6	8.512	
		70%	14.6	1384	175.2	7.900	
		80%	20.6	1785	247.2	7.221	
		90%	26.7	2162	320.4	6.748	
		100%	30.3	2383	363.6	6.554	
■Airplane			□Helicopter			■Vtol	

Figure B.1: Thrust efficiency chart of XING X4214 motors [12]

7.3 Appendix C: HolyBro Pixhawk 6C Specifications

Processors & Sensors

- FMU Processor: STM32H743
    - 32 Bit Arm® Cortex®-M7, 480MHz, 2MB memory, 1MB SRAM
- IO Processor: STM32F103
    - 32 Bit Arm® Cortex®-M3, 72MHz, 64KB SRAM
- On-board sensors
    - Accel/Gyro: ICM-42688-P
    - Accel/Gyro: BMI055
    - Mag: IST8310
    - Barometer: MS5611

Electrical data

- Voltage Ratings:
    - Max input voltage: 6V
    - USB Power Input: 4.75~5.25V
    - Servo Rail Input: 0~36V
- Current Ratings:
    - Telem1 Max output current limiter: 1.5A
    - All other port combined output current limiter: 1.5A

Mechanical data

- Dimensions: 84.8 * 44 * 12.4 mm
- Weight (Aluminum Case) : 59.3g
- Weight (Plastic Case) : 34.6g