# DORIS Drone (Boeing V2)

By: Dylan Boeholt, J. Andre Bonillas, Connor Davidson, Jeremy Malmo, and Michael Zielinski

# Project Description

DORIS (Drone Operated Reconnaissance & Interchange System) is a payload-capable drone developed for Boeing. It was designed to lift 30% of its total weight as payload, navigate a defined mission course, and return to the operator. It was built from commercially available parts with a budget of $3,000 from Boeing and an additional $717.70 raised by the team. DORIS supports both camera-based payloads and heavy cargo attachments using a magnetic release system. The project addresses the growing need for modular, reliable UAVs capable of autonomous or semi-autonomous operation while remaining under 55 lbs. to comply with FAA regulations. This drone aims to support missions such as supply delivery, reconnaissance, and payload retrieval in restricted environments.

# Deliverables & Success Metrics

## 1.2 Deliverables:

- Fully functioning drone with modular payload system
- Completion of Boeing Recon Mission test
- Engineering documentation (CAD, BoM, testing data)
- Presentation and demonstration

## 1.3 Success Metrics:

- Lifting ≥ 30% of drone weight as payload
- Flight time of ≥ 10 minutes
- Staying within FAA and budget constraints, under 55 lbs, $3000 total cost
- Reliable payload deployment and return flight

# Requirements

## 2.1 Customer Requirements:

CR1 - High Mobility – highly maneuverable

CR2 – Small dimensions and still fit all essential components

CR3 – Complete Recon Mission

CR4 – Payload Capacity – carry a significantly heavy payload

CR5 – Battery Capacity – efficient/large enough

CR6 – Cost Efficiency – limited budget

CR7 – Thrust Efficiency – high thrust to weight ratio

## 2.2 Engineering Requirements:

ER1 – Thrust to weight Ratio – goal of 3:1

ER2 – Compact design – 5x5x5 ft, under 50 lbs.

ER3 – Payload Weight – 30% of total weight

ER4 – Time of Flight – 10 minutes or more

ER5 – Total Cost – 3300$ budget

ER6 – Meet FAA regulations – under 55lbs, fly under 400 ft

# House of Quality

2.3 Quality Function Deployment (QFD): matrix available in initial testing and mid-project reviews. Key correlations: payload weight strongly correlates with thrust efficiency and motor power. Battery capacity supports flight time. Compact design assists FAA compliance.

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 |
|---|---|---|---|---|---|---|
| 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 |

| 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) |
|---|---|---|---|---|---|---|---|---|
| | | **Technical Requirements** | | | | | | |
| 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 |

Figure 1: QFD For DORIS Drone

# Benchmarking

## Design 1: Boeing drone Version 1 (Hi-Jax); NAU class of 2022 team

Only the drone was developed, light weight and compact, 6.8 lbs. total weight

Pros: Lightweight, compact, durable, and a good jumping off point for our project

Cons: Not stable and no payload capabilities.

Figure 2: Boeing Drone V1

## Design 2: Aurelia X8 Pro; 8 Rotor Drone

Designed to carry a heavy payload, 10 kg

Pros: Heavy payload capabilities

Cons: Expensive and more rotors means more things to break.

Figure 3: Aurelia X8 Pro; 8 rotor drone

## Design 3: Aurelia X6 Standard; 6 Rotor Drone

Carries a lighter load, 1.5-3kg, releasable payload system

Pros: Less likely to break and cheaper than Design 2

Cons: Light payload capabilities and expensive

Figure 4: Aurelia X6 Standard; 6 Rotor Drone

# Literary Review

## 3.2.1 Literature Review (Dylan Boeholt)

- Engineering Statics: Chapter 4 Moments and Static Equivalence
- Engineering Statics: Chapter 7 Centroids and Centers of Gravity
- Design and Analysis of a Topology-Optimized Quadcopter Drone Frame
- Embry-Riddle Aeronautical University Scholarly Paper. This source provides equations to calculate the thrust of propellers
- Quadcopter Body Frame Model and Analysis
- Code of Federal Regulations Title 14 Chapter 1 Subchapter F Part 107
- How to Calculate & Measure Propeller Thrust
- ASM Handbook: Properties and Selection: Nonferrous Alloys and Special-Purpose Materials.
- ASTM F2910-14: Standard Specification for Design and Construction of a Small Unmanned Aircraft System (sUAS).
- ASTM Aerospace Material Standards

# Literary Review

## 3.2.1 Literature Review (J. Andre Bonillas)

- Book & chapters:
  - Make: Getting Started with Drones – chapter 12 - book
    - Describes how to implement a camera into a drone design and how to control it
  - Building Your Own Drones: A Beginner's Guide to Drones, UAVs, and ROVs Chapter 12 - book
    - Describes how to incorporate accessories such as payloads into a drone's overall design
- Papers:
  - "A Practical Perspective on the Drone-with-a-Slung-Load Problem." - Journal
    - Demonstrates drone flight behavior with a payload that is suspended (slung) below the aircraft
  - "Quadcopter Design for Payload Delivery." - Journal
    - provides insight into constructing a drone to carry a payload, such as flight behavior and structural design
  - "Package Retrieval system with funneling mechanism." Patent
    - Demonstrates potential payload retrieval mechanism, using 2 sloped mating surfaces
- Standard:
  - ANSI UAS Standards (Unmanned Aircraft Systems Standardization Collaborative – UASSC)
  - IEEE UAS Standards (IEEE 1937.1 and IEEE 1939.1)
  - FAA small, unmanned aircraft weight requirements for registration (0.55 - 55 lbs) or (0.25 - 25 kg) - FAA.gov
    - Specifies the weight range for the FAA classification of a small unmanned aircraft (drone)

- Other online sources:
  - "Payloads for Drones in Emergency Response: Guide to what UAVs Carry." - dslrpros.com - article
    - Details different type of payloads that drones can carry (active, passive, dispensable)
  - "Heavy Lift Payload Drones." Uavsteminternational.com - website
    - Details existing drone designs that are intended to carry large payloads (>10kgs)
  - "Best Drones using a payload release mechanism – uavsystemsinternational.com - website
    - Details a drone that utilizes a drop mechanism for payload delivery

# Literary Review

## 3.2.3 Literature Review (Connor Davidson)

- Website:
  - “Aircraft Inquiry" Faa.gov
    - This website is where we will register our drone at.
  - “5 Best Heavy Lift Drones [Updated 2020] Large Drones High Lift Capacity,”
    - This website helps us baseline our project by giving us similar drones to our project
- Journal Papers:
  - “The Current Opportunities and Challenges in Drone Technology,”
    - This journal outlines some current opportunities and challenges with drones today
  - “Emerging technologies and the use case: A multi-year study of drone adoption,”
    - This journal evaluates drone technology over a multi-year study
  - "IEEE Approved Draft Standard for Drone Applications Framework,"
    - This journal explains IEEE approved draft standards for drone application
- Standards:
  - "IEEE Approved Draft Standard for Drone Applications Framework“
  - "IEEE Approved Draft Standard for Drone Applications Framework“
  - “Y14.6 - Screw Thread Representation”
- Books:
  - *2024 - 2025 FAA Drone License Exam Guide*. 2024.
    - This book is an exam guide for the FAA drone license.
  - *Remote Pilot - Small Unmanned Aircraft Systems Study Guide (Federal Aviation Administration): FAA-G-8082-22*. 2018.
    - This book is a study guide for FAA regulations for small unmanned aircraft systems

# Literary Review

## 3.2.4 Literature Review (Jeremy Malmo)


Websites

- Devin et al., “How to choose FPV drone motors - considerations and Best Motor Recommendations,” How to Choose FPV Drone Motors – Considerations and Best Motor Recommendations, https://oscarliang.com/motors/ (accessed Sep. 16, 2024).
- J. and Daniel, “The UAV Chronicles,” Step 5: Motor Selection, https://uav.jreyn.net/ (accessed Sep. 17, 2024).

Journals

- K. TAKATO and S. SHIRAYAMA, “Development of a 3D-printed device evaluating the aerodynamic performance of rotary wings,” Journal of Advanced Mechanical Design, Systems, and Manufacturing, vol. 12, no. 1, pp. JAMDSM0027–JAMDSM0027, 2018, doi: 10.1299/jamdsm.2018jamdsm0027.
- D. BBVL, D. Pal Singh, S. Kumar Kuppa, and M. Jayanthi Rao, “Design optimization of drone BLDC motor for delivery service applications,” Materials today : proceedings, 2023, doi: 10.1016/j.matpr.2023.07.370.

Books

- W. H. Yeadon and A. W. Yeadon, Handbook of Small Electric Motors. New York: McGraw-Hill, 2001.
- N. Barrera, S. Martin, and M. Stewart, Unmanned Aerial Vehicles. New York: Nova Science Publishers, Inc, 2021.

Standard

- “The Ultimate Guide to Heavy Lift Drone Motors,” JOUAV, https://www.jouav.com/blog/heavy-lift-dronemotors.html#:~:text=Ideally%2C%20for%20standard%20drones%2C%20a,for%20smooth%20and%20controlled%20flight. (accessed Sep. 17, 2024).
- “Xing 4214 2-8s X class FPV Motor,” - iFlight.com
- “IEEE Guide for Test Procedures for Synchronous Machines Including Acceptance and Performance Testing and Parameter Determination for Dynamic Analysis,” -ANSI.org
- “ISO 1940-1 Mechanical vibration — Balance quality requirements for rotors in a constant (rigid) state,” – dcma.mil

# Literary Review

## 3.2.4 Literature Review (Michael Zielinski)

- Books:
  - Building Your Own Drones: A Beginner's Guide to Drones, UAVs, and ROVs (Chapter 14: Software) [22]
  - Make: Getting Started with Drones (Chapter 4: Flight Controllers) [21]
- Papers:
  - A Review on the State of the Art in Copter Drones and Flight Control Systems 2024 [19]
  - Development of Drone based Delivery System using Pixhawk Flight Controller [18]
  - Payload Manipulation for Seed Sowing Unmanned Aerial Vehicle through interface with Pixhawk Flight Controller [17]
- Standard:
  - FCC 22-101A1 Spectrum Rules and Policies for the Operation of Unmanned Aircraft Systems
  - ASTM F3005-22 Standard Specification for Batteries for Use in Small Unmanned Aircraft Systems (sUAS) [20]
- Websites:
  - OscarLiang.com - useful general information about electronic part selection/drone building [14]
  - UAV.ireyn.net - another college capstone that built a quadcopter [15]
  - Ardupilot.org - Ardupilot flight controller and guide for DIY building of drones [16]

# Mathematical Modeling

## Arm Force Calculations:

- Assuming carbon fiber cantilever beam style arms, length = 0.5m, mass = 0.04536kg, thrust force = 100 N,
- $W = 0.04536kg * 9.81m/s^2 = 0.445N$
- $\Sigma F = 0 \Rightarrow 100N - 0.445N - Rf = 0 \Rightarrow$
- $Rf = 100N - .445N = 99.555$ N (shear force)
- (Target weight of drone is approximately 111N)
- $\Sigma M = 0 \Rightarrow 100N * 0.5m - .445N * 0.25m + Rm = 0 \Rightarrow$
- $Rm = -100N * 0.5m + .445N * 0.25m = -49.889$ N*m (bending moment)
- E = 250–350GPa (1), ri = 20mm = 0.02m, ro = 22mm = .022m,
- $I = \pi/4(ro^4-ri^4) = \pi/4[(0.022m)^4 - (0.02m)^4] = 5.832*10^{-8}\ m^4$
- $\Delta max = PL^3/3EI = [100N * (0.5m)^3] / [3 * (300*10^9Pa) * (5.832*10^{-8}m^4) =$
- $\Delta max = 2.381*10^{-4}m = .2381mm \approx 1/100$th of an inch

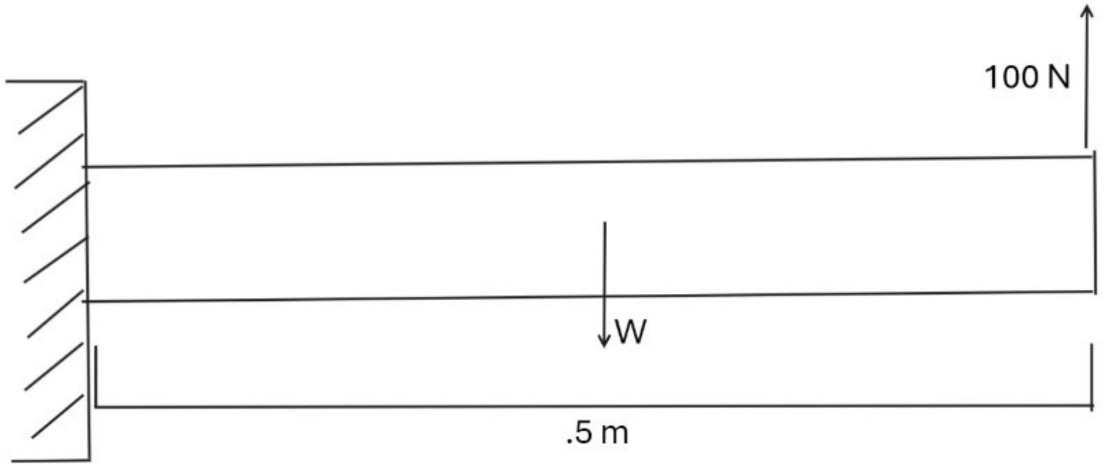


Figure 5: Arm Free Body Diagram

# Mathematical Modeling

## Maximum weight calculations based off FAA regulations:

- Max weight of system <= 25 kg
- $W_D$ = Drone weight
- $W_P$ = payload weight = $0.3W_D$
- $W_D + 0.3W_D = 25$ kg
- $W_D$ MAX = 19.2 kg
- $W_P$ MAX = $0.3W_D$ = 5.8 kg:

## Desired weight calculations based off customer & engineering requirements:

- $W_P$ = 5 lbs
- $W_D = W_P/0.3$ = 16.7 lbs
- Desired weight of system = 21.7 lbs
- Force of payload on connection apparatus:
- $F = mg$: $F = (5kg) * 9.81\ m/s^2 = 49.1\ N$

# Mathematical Modeling

## Motor Selection:

$TWR = \frac{3}{1} = \frac{(9.52kg)*3}{9.52kg} =$ Total thrust 28.56 N

### Quad-Copter:

$\frac{Thrust}{\# \ of \ motors} = \frac{28.56}{4} =$ 7.14 kg required per

### Hex-Copter:

$\frac{Thrust}{\# \ of \ motors} = \frac{28.56}{6} = 4.76 \ kg$ required per

Propeller Thrust: $0.5 * \rho * \pi r^2 * [V_e^2 - V_o^2]$

$\rho = air \ density$ r = propeller radius

$V_e$ = Air Exit Velocity $V_o$ = Air entrance Velocity

# Mathematical Modeling

## Battery capacity formulas:

Power formula (W): P = V x I

Energy consumption over time (Wh): E = V x I x T

Capacity from voltage (Ah): C = E/V

Assumptions: 700W per motor, 15-minute flight time, 4 motors at max draw, 22.2V battery

700W * 0.25hr = 175Wh

175Wh * 4 motors = 700Wh

700Wh / 22.2V = 31.53Ah (31,530mAh) battery required for ONLY MOTORS with NO step down

# Concept Generation (Functional Decomposition)

The team created a functional decomposition of our project to help determine what components were most important to the project and how the flow of the design processes should go.

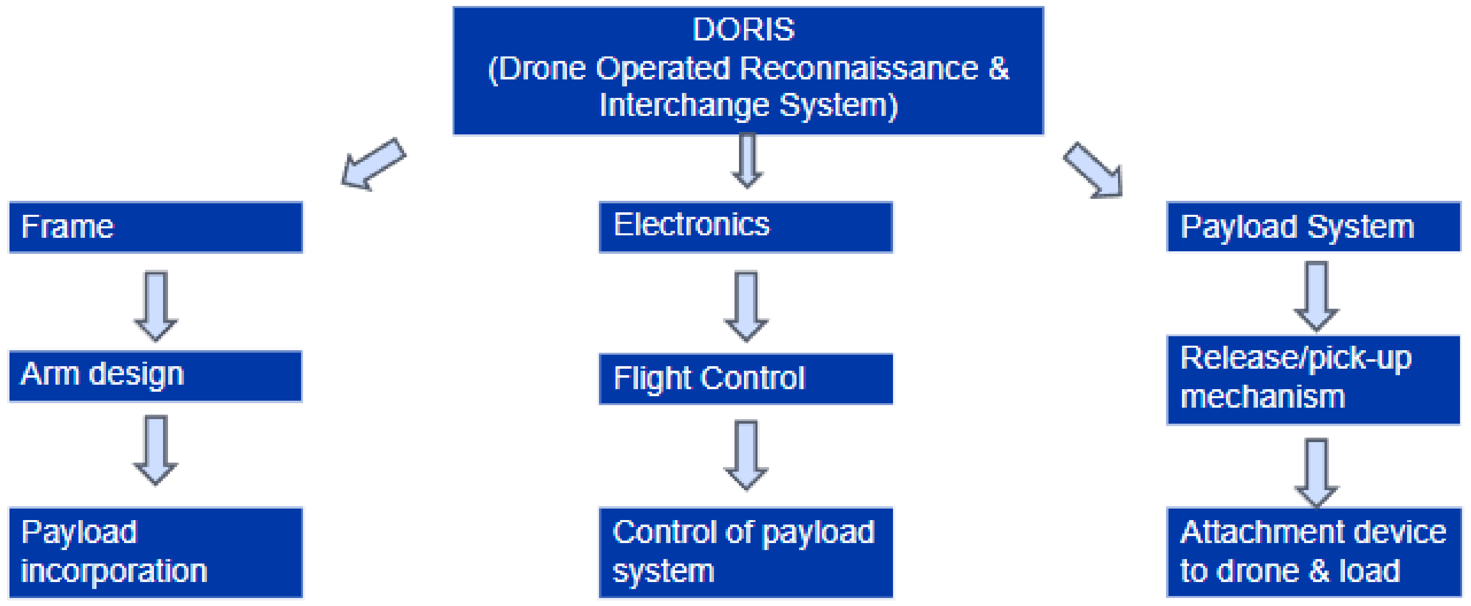


Figure 6: Functional Decomposition For DORIS Drone

# Concept Generation (Best)

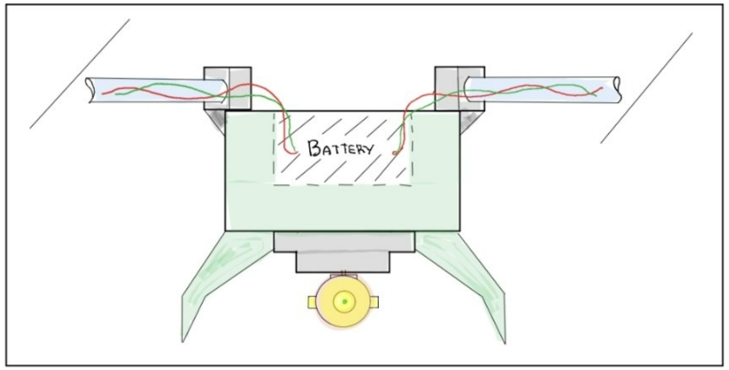


Figure 7: Concept 3 For Frame Design

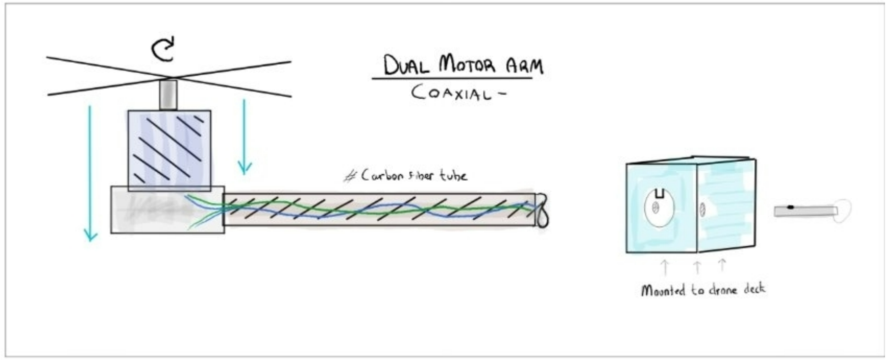


Figure 9: Concept 3 For Arm Design

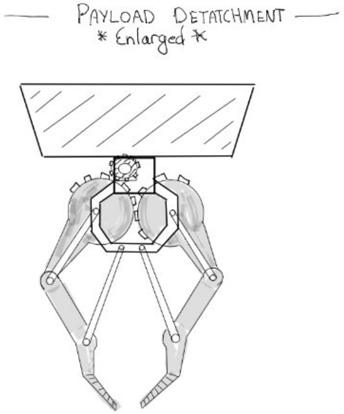


Figure 11: Design 3 For Payload System Design

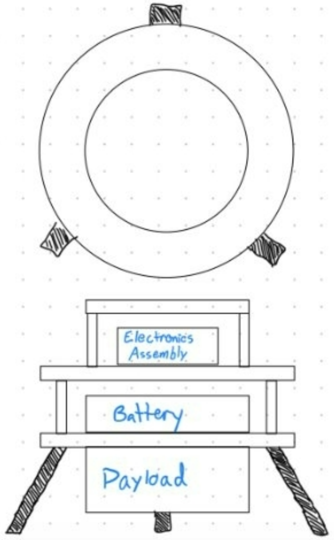


Figure 8: Concept 5 For Frame Design

Figure 10: Concept 1 For Arm Design

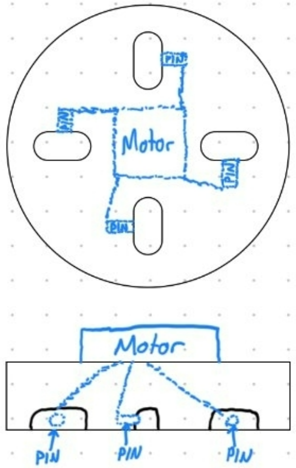


Figure 12: Design 5 For Payload System Design

# Selection Criteria & Concept Evaluation (Designed Parts)

Each team member created five designs for each subsystems and picked one their best one to be evaluated by the team. The five designs (one from each team member) were evaluated based on weight, cost, simplicity, aesthetics, durability, and repairability. The weight of each category changed biased on the subsystem.

| | 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 |

Figure 13: Evaluation For Frame 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 |

Figure 14: Evaluation For Arm Design

| | 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 |

Figure 15: Evaluation For Payload System Design

# Selection Criteria & Concept Evaluation (Purchased Parts)

## Motors:

T-Motor f-1000
Weight: 404 (g)
Max Thrust: 6875 (g)
Max Current: 125 A
Max Power: 4000 W
Price: $119.90

iFlight XING X4214 660KV
Weight: 213 (g)
Max Thrust: 7900 (g)
Max Current: 98 A
Max Power:2352 W
Price: $82.99

SunySky X4120 650KV
Weight: 290 (g)
Max Thrust: 6592 (g)
Max Current:100A
Max Power: 2750 W
Price: $136.65

## Propellers:

T-Motor P17x5.8
Diameter: 17 inches
Pitch: 5.8 inches
Material: Carbon fiber
Weight: 26.5 g
Thrust Limit: 7.5 kg
Optimum RPM : 3500-6000
Price (2): $71.90

Gemfan 16x5.4
Diameter: 16 inches
Pitch: 5.4 inches
Material: Carbon fiber
Weight: 53 g
Thrust Limit: 7 kg
Optimum RPM: 3000-5000
Price (2): $62.39

HQProp 16X8X3 (3 prop)
Diameter: 16 inches
Pitch: 8 inches
Material: black-glass fiber-reinforced nylon
Weight: 66.5 g
Thrust Limit: ~7.2 kg
Optimum RPM : 3500-6000
Price (1): $26.28

## Magnets:

MAG-MATE AR1504
Class – shielded electro-magnet
Weight: 1 lb
Dimensions: 1.3" H, 2.5" D
Max hold force: 35 lbs
Price: 215$

MAG-MATE ER2-202
Class – non-shielded electro-magnet
Weight: 2 lbs
Dimensions: 2-½" H, 2" D
Max hold force: 100 lbs
Price: 140$

Magswitch MAGJIG 60
Class – mechanical magnet (will require actuator to engage/dis-engage)
Weight: 0.2 lbs
Dimensions: 1.7" H, 1.6" L, 1.1" W
Max hold force: 60 lbs
Price: 26$

# Concept Selection

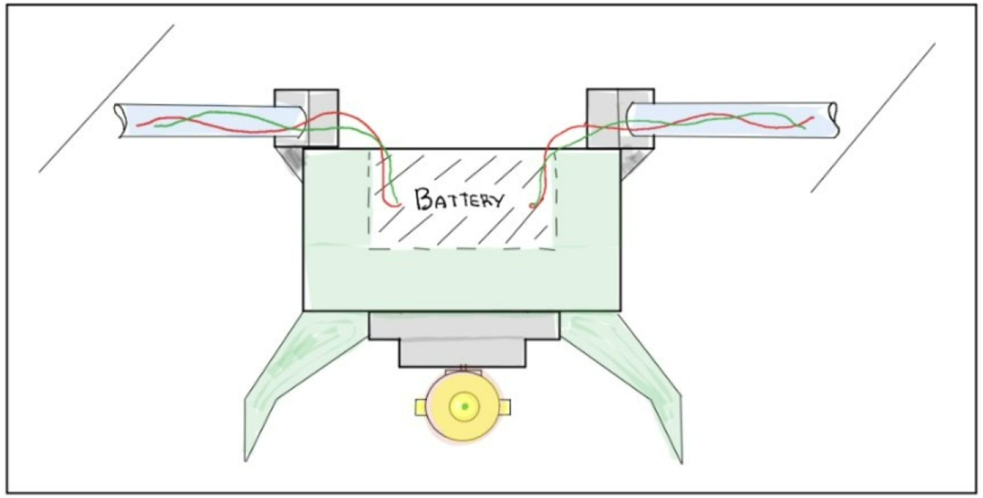


Figure 7: Concept 3 For Frame Design

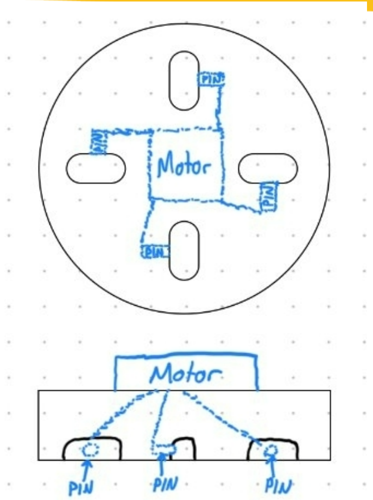


Figure 12: Design 5 For Payload System Design

Figure 14: iFlight XING X4214 660KV

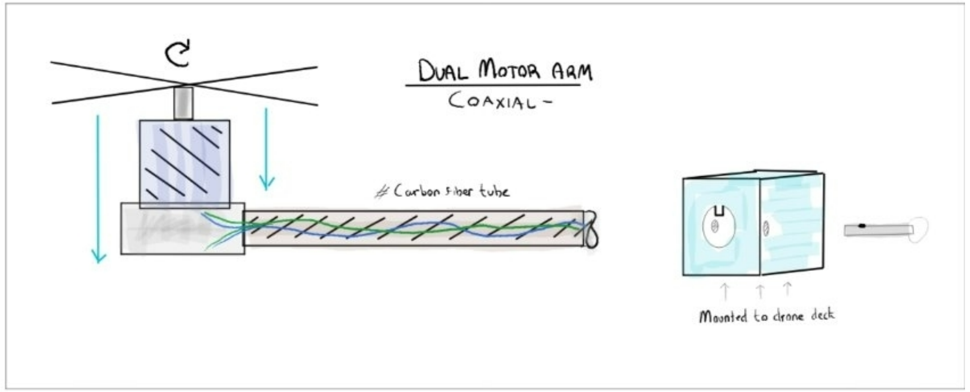


Figure 9: Concept 3 For Arm Design

Figure 13: Magswitch MAGJIG 60

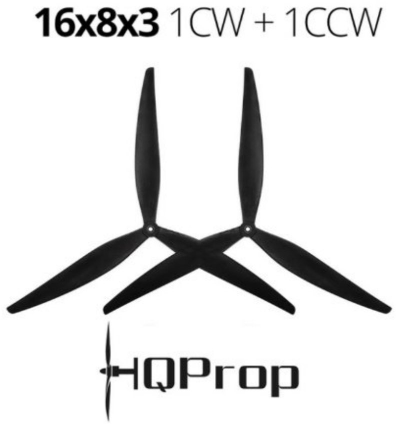


Figure 15: HQProp 16X8X3 (3 prop)

# Gantt Chart

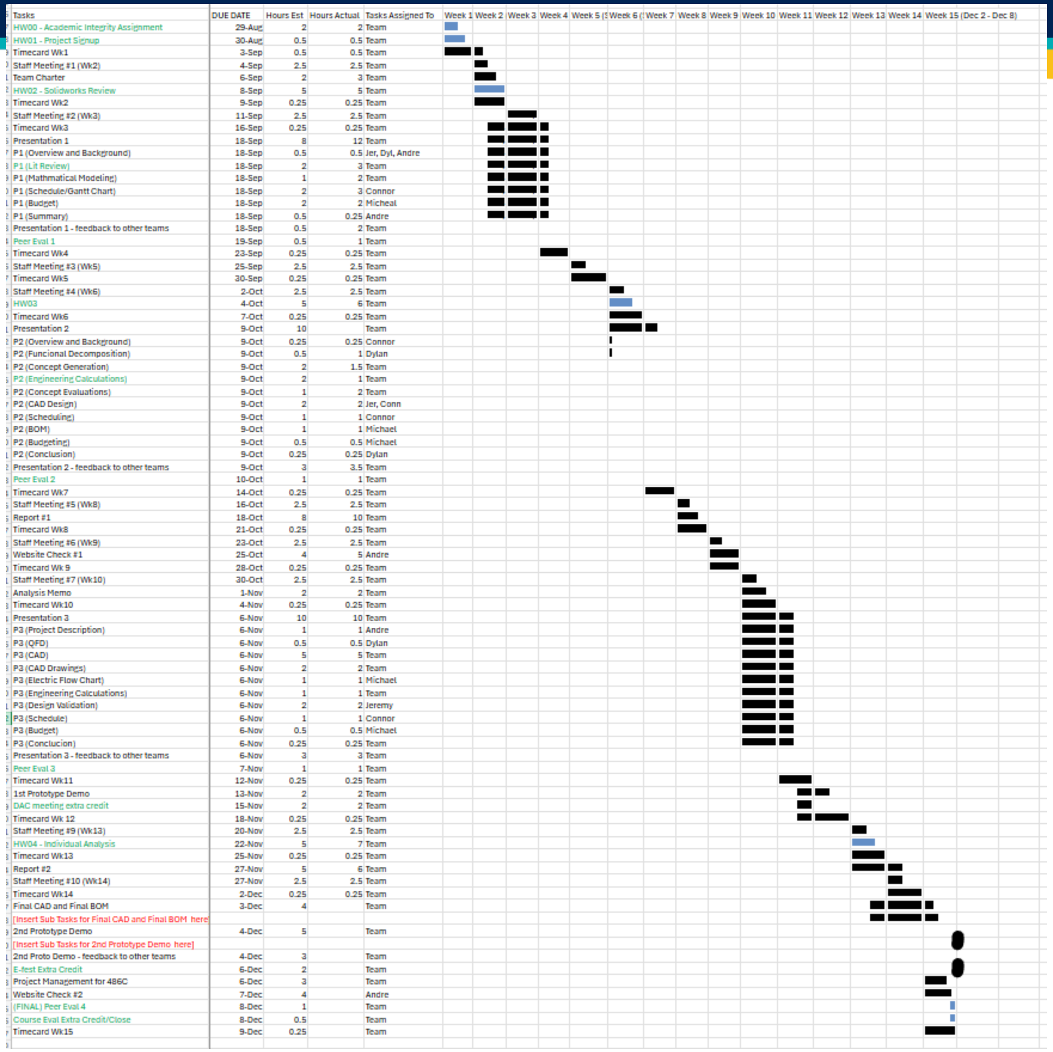

Figure 16: DORIS Gantt Chart (Semester 1)

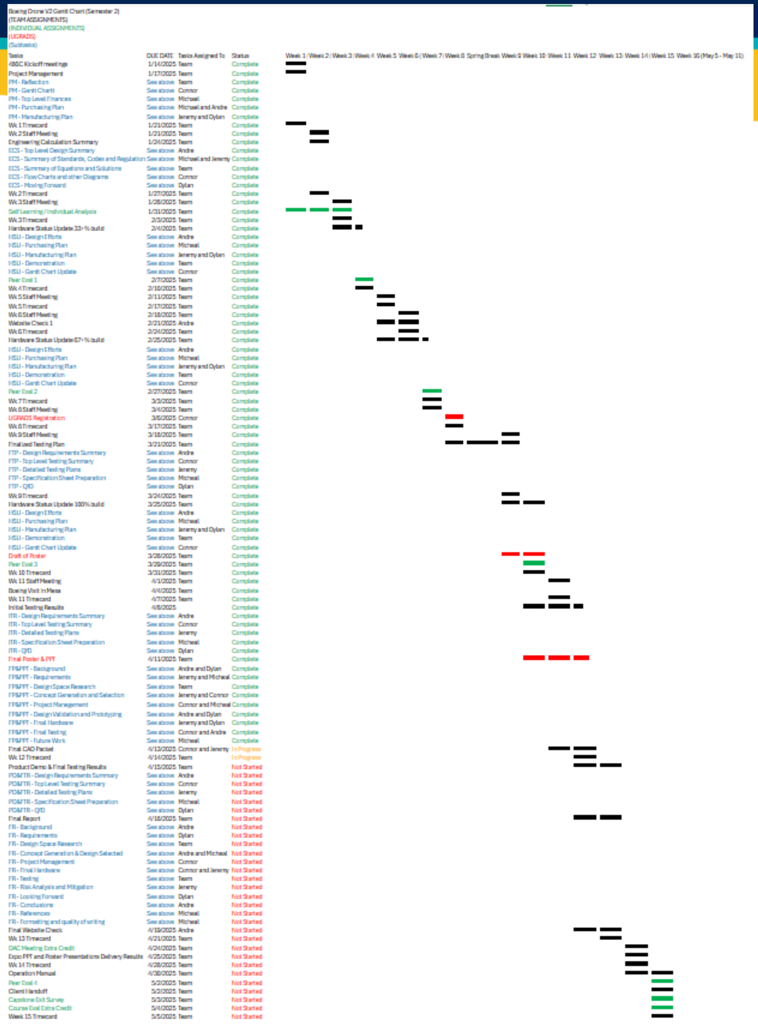

Figure 17: DORIS Gantt Chart (Semester 2)

(See Gantt Chart Excel for more in depth look)

# Budget

| | | | | | |
|---|---|---|---|---|---|
| Team: | DORIS | Total Budget: | $ 3,717.70 | Total Donations: | $ 717.70 |
| Team Number: | F24toSp25_13 | Total Expense: | $ 3,434.61 | Left in SCE: | $ 190.21 |
| Speedchart: | 2920381F25 | Total Remaining: | $ 283.09 | Left in donations: | $ 92.88 |
| Sub-Debt: | CP19 | | | | |

| | |
|---|---|
| Drone Expense: | $1,786.69 |
| Camera Payload Expense: | $ 16.46 |
| Heavy Payload Expense: | $ - |
| Missile Payload Expense: | $ 257.52 |
| Motor Test Stand Expense: | $ 79.65 |
| Total Expense: | $2,140.32 |

| | |
|---|---|
| Expected Expenses Total: | $ 815.20 |
| Predicted Total Budget Remaining: | $ (532.11) |

Figure 18: DORIS Budget Summary

# Bill of Materials (BoM)

| Purchased Item | Primary Vendor | Manufacturer | Lead Time (incl. shipping) | Qty | Cost Per Unit | Total Cost | Part Status | Weight (g) | |
|---|---|---|---|---|---|---|---|---|---|
| **DRONE ONLY** | | | | | **Total Cost:** | **$2,107.50** | | **4677** | |
| 22Ah 6S LiPo Battery | Aliexpress | Tattu | 2 weeks | 2 | $ 240.00 | $ 480.00 | Partial Install | 2460 | |
| Flight Controller (Pixhawk 6C) | HolyBro | HolyBro | 7-10 business days | 1 | $ 231.46 | $ 231.46 | Installed | 34.6 | |
| GPS/Compass (M10, included w/ FC) | HolyBro | HolyBro | 7-10 business days | 1 | $ - | $ - | Installed | | |
| Pixhawk Wiring Kit | HolyBro | HolyBro | 7-10 business days | 1 | $ 35.00 | $ 35.00 | Installed | | |
| 6-pin Molex PicoBlade to 6-pin JST-GH wire | 3DR | 3DR | 7-10 business days | 1 | $ 8.76 | $ 8.76 | Installed | | |
| XING 4214 660KV Motor | iFlight | iFlight | 2 weeks | 4 | $ 62.75 | $ 251.00 | Installed | 1080.4 | 270.1 |
| 6-channel RC receiver | Any | Any | 7-10 business days | 1 | $ 35.00 | $ 35.00 | Installed | | |
| Power Distribution Module (Sky-Drones SmartAP PDB) | Sky-Drones | Sky-Drones | 7-10 business days | 1 | $ 90.00 | $ 90.00 | Installed | 40 | |
| Electronic Speed Controller (150A) | Amazon | Flycolor | 7-10 business days | 4 | $ 119.00 | $ 476.00 | Ordered | 572 | 143 |
| RC Controller | Any | Any | 7-10 business days | 1 | $ 50.00 | $ 50.00 | Installed | | |
| Wiring kit (12AWG, 60ft) | Amazon | NAOEVO | 3 business days | 1 | $ 25.00 | $ 25.00 | In use | 50 | |
| LiPo Battery Charging Kit | Amazon | SmartCharger | 3 business days | 1 | $ 52.00 | $ 52.00 | In use | | |
| Octagonal Carbon Fiber Tubing (500mm, 4pk) | Amazon | ZSJ | 2 weeks | 2 | $ 25.00 | $ 50.00 | Installed | 40 | |
| 3D Printing Filament (ABS) | Amazon | Any | 3 business days | 2 | $ 20.00 | $ 40.00 | In use | | |
| 3D Printing Filament (PLA) | Amazon | Any | 3 business days | 1 | $ 24.00 | $ 24.00 | In use | | |
| 3D Printing Filament (TPU 95A) | Amazon | Any | 3 business days | 1 | $ 26.19 | $ 26.19 | In use | 400 | |
| XT90 Connectors (10pk) | Amazon | Amass | 3 business days | 1 | $ 14.17 | $ 14.17 | Installed | | |
| Propellers (16", tri-blade) | HQProp | HQProp | 7-10 business days | 4 | $ 35.68 | $ 142.72 | Installed | | |
| Extreme Fasteners | Home Depot | Scotch | 0 days | 2 | $ 13.03 | $ 26.06 | Installed | | |
| M6 100mm lag bolts | Home Depot | Any | 0 days | 8 | $ 2.63 | $ 21.04 | Installed | | |
| M6 locking nut | Home Depot | Any | 0 days | 8 | $ 0.68 | $ 5.44 | Installed | | |
| 4mm x 15mm socket cap bolt | HomCo | Any | 0 days | 4 | $ 1.21 | $ 4.84 | Installed | | |
| 4mm nut | HomCo | Any | 0 days | 4 | $ 0.68 | $ 2.72 | Installed | | |
| MDF Board (1/4" x 2' x 4') | Home Depot | Any | 0 days | 2 | $ 8.05 | $ 16.10 | Installed | | 100 |
| **REGULAR PAYLOADS** | | | | | **Total Cost:** | **$ 316.99** | | | |
| GoPro/similar camera | GoPro | GoPro | 7-10 business days | 1 | $ 220.00 | $ 220.00 | Delivered | | |
| MG995 Servo Motor 4pk | Amazon | Any | 7-10 business days | 1 | $ 16.99 | $ 16.99 | Ordered | | |
| Magswitch MagJig Magnet | Amazon | Magswitch | 3 business days | 2 | $ 30.00 | $ 60.00 | Delivered | | |
| 3D Printing Filament (ABS) | Amazon | Any | 3 business days | 1 | $ 20.00 | $ 20.00 | In use | | |
| **TOTAL OVERALL COST:** | | | | | | **$2,424.49** | | | |
| Percent Purchased: | 100.00% | | | | | | | | |

| Manufactured Item | Vendor | Manufacturing Method | Lead Time | Qty | Cost Per Unit | Total Cost | Part Status | Deadline | Printer | Member Responsible | Manufacturing Location |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **DRONE ONLY** | | | | | **Total Cost:** | **$ -** | | | | | |
| Outer Arm Mount (TPU) | In-House | 3D FDM Printing | 4 hours | 8 | $ - | $ - | Installed | - | - | - | - |
| Motor Mount (TPU & ABS) | In-House | 3D FDM Printing | 2 hours | 4 | $ - | $ - | Installed | - | - | - | - |
| Drone Legs (TPU) | In-House | 3D FDM Printing | 4 hours | 4 | $ - | $ - | Installed | 2/4/2025 | Qudi Tech | Jeremy | Personal Residence |
| Body Plates (Fiberglass on birch) | In-House | Jigsaw cutting, layups | 10 hours | 2 | $ - | $ - | Partial Make | - | - | Jeremy/Andre | Personal Residence |
| **REGULAR PAYLOADS** | | | | | **Total Cost:** | **$ -** | | | | | |
| Magswitch Turning knob (PLA) | In-House | 3D FDM Printing | 1 hour | 2 | $ - | $ - | Partial Print | 2/25/2025 | Bambu Lab A1 | Michael | Personal Residence |
| Magswitch Attachment Plate (ABS) | In-House | 3D FDM Printing | 2 hours | 1 | $ - | $ - | Printed | 2/4/2025 | - | Jeremy | Personal Residence |
| **TOTAL OVERALL COST:** | | | | | | **$ -** | | | | | |

Figure 19: DORIS Bill of Materials

# Failure Modes & Effect Analysis (FMEA)

| Part | Potential Failure Mode | Potential Failure Effects | Mechanisms of Failure | Likelihood of Occurrence | Recommended Action |
|---|---|---|---|---|---|
| Flight Controller | Software Failure | Loss of control | Incorrect programming, firm ware bug | Low | Ensure programming accurate before flight |
| Regular Payload Release | Servo Failure | Unreleasable/ Early released payload | Servo not strong enough, not receiving enough power | Moderate | Test all servos before flight, use factor of safety during selection |
| RC Communication (Missile and Drone) | Loss of signal | Loss of manual control | Loose connections, malfunctioning part | Low | Ensure all connections secure before flight, test on ground |
| Battery | Reduced Voltage | Reduced power | Aging, improper charging | Moderate | Ensure storage charge when not in use |

Figure 20: Electrical FMEA

# Failure Modes & Effect Analysis (FMEA)

| Part | Potential Failure Mode | Potential Failure Effects | Mechanisms of Failure | Likelihood of Occurrence | Recommended Action |
|---|---|---|---|---|---|
| Mounting bracket | Cracking/ breaking | Loss of stability and alignment | Stress concentration, fatigue cracks, impact | medium | Use strong material, ensure sufficient load capacity |
| Actuator wheel | Misalignment | Poor fitment & vibration | Uneven torque, part wear | medium | Ensure secure install, frequently check alignment |
| Stand-offs | Material fatigue & loosening | Loss of control of magnet, potential payload drop | Vibration, material fatigue | medium | Use strong material, verify secure install |
| Switched magnet (x2) | Misalignment & loss of force | Vibration loosening & exposure to high heat | Demagnetization & mechanical shock | low | Ensure magnet is fully engages, protect from heat & impact |
| Servo motors (x2) | Over heating, electrical failure | Reduced performance, loss of control | Excessive current draw, high load, over-voltage, short-circuit | medium | Ensure proper wiring, monitor cooling |

Figure 21: Payload FMEA

# Failure Modes & Effect Analysis (FMEA)

| Part | Potential Failure Mode | Potential Failure Effects | Mechanisms of Failure | Likelihood of Occurrence | Recommended Action |
|---|---|---|---|---|---|
| Frame Arm Mount | Twisting/Deformation of TPU mount | Unstable Flight | Part (TPU) infill density to low. | Not likely, TPU density is at 35% | Increase infill density. |
| Octagonal Carbon Fiber Arm | Carbon fiber critical failure. | Highly unstable flight/ inoperable drone | Cracked carbon fiber arm | Likely after testing. | Purchase extra carbon fiber tubes |
| Motor Mount | Twisting/Deformation of TPU mount | Misaligned motors causing unstable flight | Part (TPU) infill density to low. | Unlikely, infill density will be rigid enough to counteract | Increase infill density |

Figure 22: Arm Bracket to Motor Mount FMEA

# Prototyping

## 6.2 Initial Prototyping: Prototype #1

**Question:** How will the drone parts and electronics practically fit together? How big will it be?

**Methods:** MDF cutting, FDM 3D printing with TPU

**Answer:** The drone will be approximately 44 inches across in current configuration, and approximately 15 lbs in total weight. The layout can be seen in the figure on the next slide.

**Moving forward:**

- More standardized bolts need to be purchased for arm brackets

- Arms can be analyzed for stability to determine if they need to be shorter

- Motor mounts will be further refined for manufacturability and needed parameters

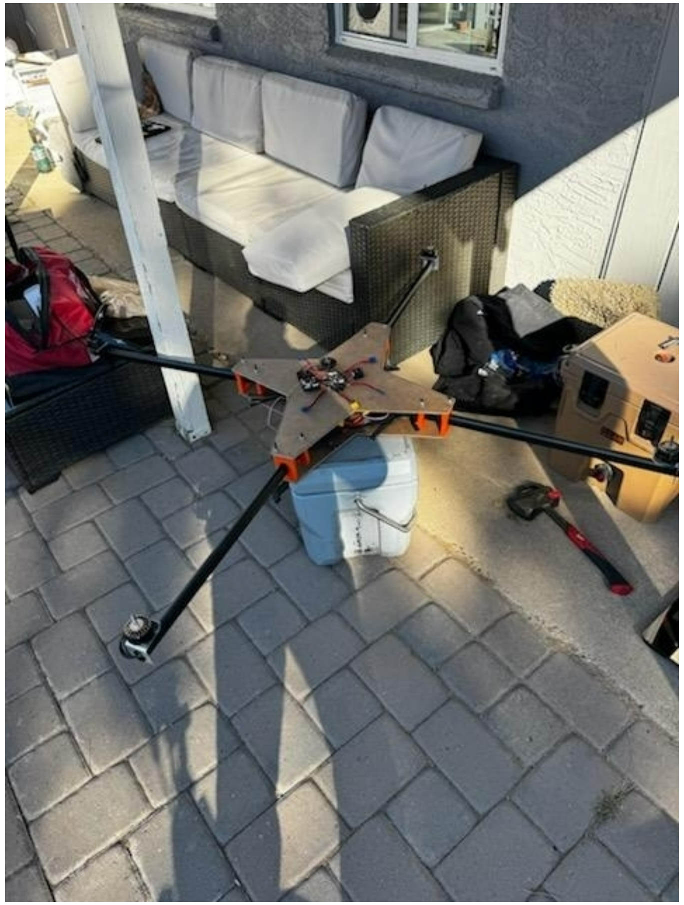

Figure 23: Drone prototype #1 (no legs)

# Prototyping

## 6.2 Initial Prototyping: Prototype #2

**Question:** How can we raise the drone off the ground statically and give it something to land with? How will the motors securely mount to the drone?

**Methods:** FDM 3D printing with PLA, ABS, & TPU

**Answer:** Legs were created, but initial were too flimsy and could support the weight but were not statically stable

**Moving forward:**

- Larger, thicker, leg design

- use triangle and truss method for the inner structure of each leg

- Look for stronger 3D-printable material

Figure 24: Drone Prototype #2 (thin legs)

# Prototyping

## 6.2 Initial Prototyping: Prototype #3

**Question:** How does the drone fly and does it fly for long enough? Is the frame strong enough and can we make it lighter? Can we make the legs stronger?

**Methods:** FDM 3D printing with PLA, ABS, & TPU, composite manufacturing with wood & fiberglass

**Answer:** Drone still does not fly and will not fly for as long as we need it to. Frame does need to be stronger and more lightweight. Lack of flight. was due to a bad ESC. Weight was reduced by making frame out of fiberglass and lighter wood. Legs were made stronger with better member analysis.

**Moving forward:**

- Add an additional battery

- Make a stronger light-weight out of birch wood and fiberglass reinforcement

-Replace ESC with better ones

Figure 25: Drone Prototype #3 (improved legs)

# Design Validation

## 6.3 Other Engineering Calculations

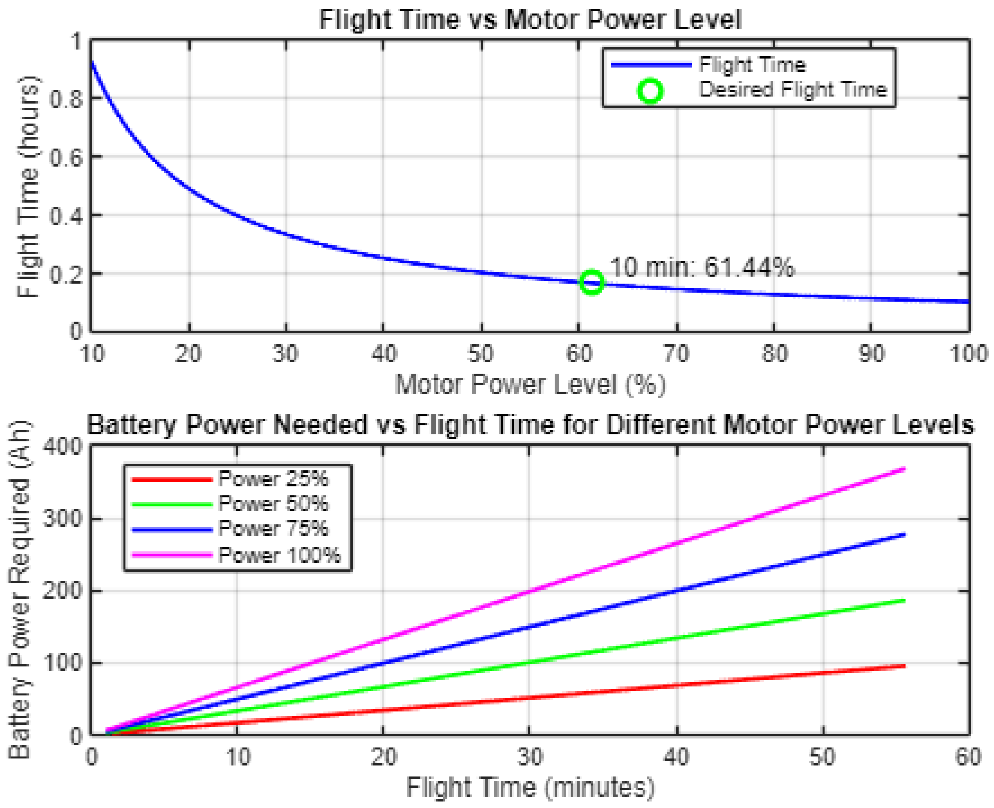


Figure 26: Battery Validation Graphs

```
=== Calculation Results ===
Components and Current Requirements (100% Power):
Motor 1        : 98.00 A
Motor 2        : 98.00 A
Motor 3        : 98.00 A
Motor 4        : 98.00 A
Pixhawk        : 3.00 A
Servo 1        : 1.00 A
Servo 2        : 1.00 A
Total Battery Capacity: 44.00 Ah
Usable Battery Capacity (after 3Ah reserve): 41.00 Ah
Power Setting for Desired Flight Time (10.00 minutes): 61.44%
Battery Needed for Desired Flight Time (10.00 minutes) at Different Power Levels:
  25% Power: 17.17 Ah
  50% Power: 33.50 Ah
  75% Power: 49.83 Ah
  100% Power: 66.17 Ah
```

# Design Validation

## 6.3 Other Engineering Calculations

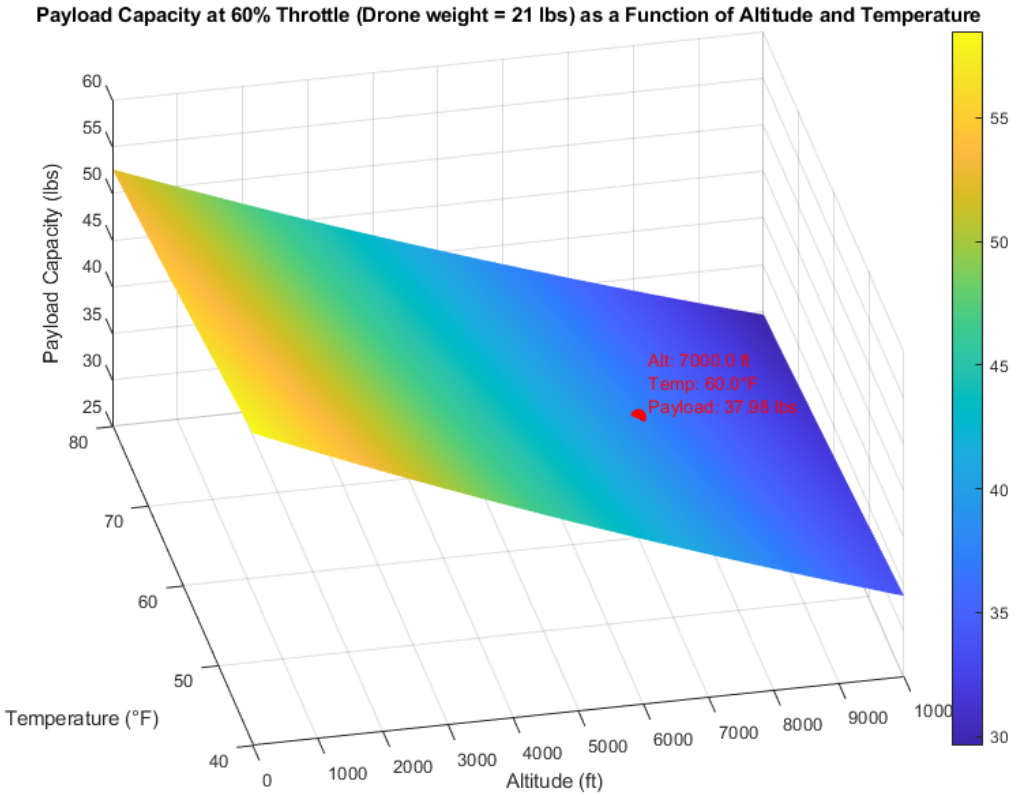


Figure 27: Surface plot of Payload Capacity (varying altitude & temp.)

**Flagstaff:**

```
=== Payload Capacity Calculation ===
Drone Weight: 21.0 lbs
Throttle Percentage: 60.0%
User-Specified Altitude: 7000.0 ft
User-Specified Temperature: 60.0 °F
Interpolated Thrust (Total): 59.78 lbs
Air Density at Reference Conditions (6900 ft, 55°F): 0.9562 kg/m³
Air Density at User-Specified Conditions: 0.9434 kg/m³
Payload Capacity at Given Conditions: 37.98 lbs
```

**Mesa:**

```
=== Payload Capacity Calculation ===
Drone Weight: 21.0 lbs
Throttle Percentage: 60.0%
User-Specified Altitude: 1400.0 ft
User-Specified Temperature: 70.0 °F
Interpolated Thrust (Total): 59.78 lbs
Air Density at Reference Conditions (6900 ft, 55°F): 0.9562 kg/m³
Air Density at User-Specified Conditions: 1.1401 kg/m³
Payload Capacity at Given Conditions: 50.28 lbs
```

# Final Hardware

## 7.1 Top Level Design – Full Assembly

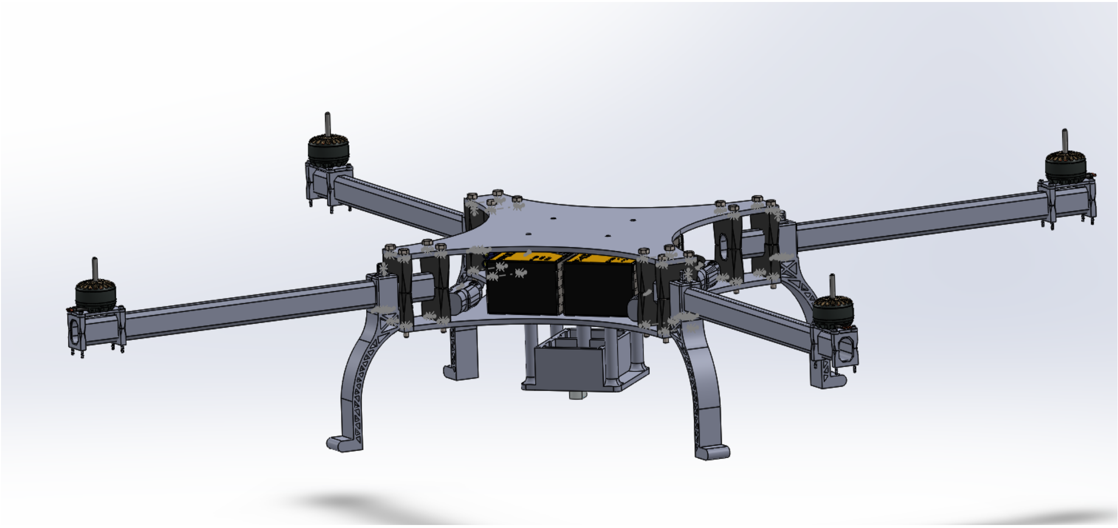

Figure 28: CAD Model – Full Drone Assembly

Figure 29: DORIS Drone Fully Assembled & painted

# Final Hardware

## 7.1 Top Level Design – Payload Sub Assembly

Figure 30: payload assembly (magnet mounting)

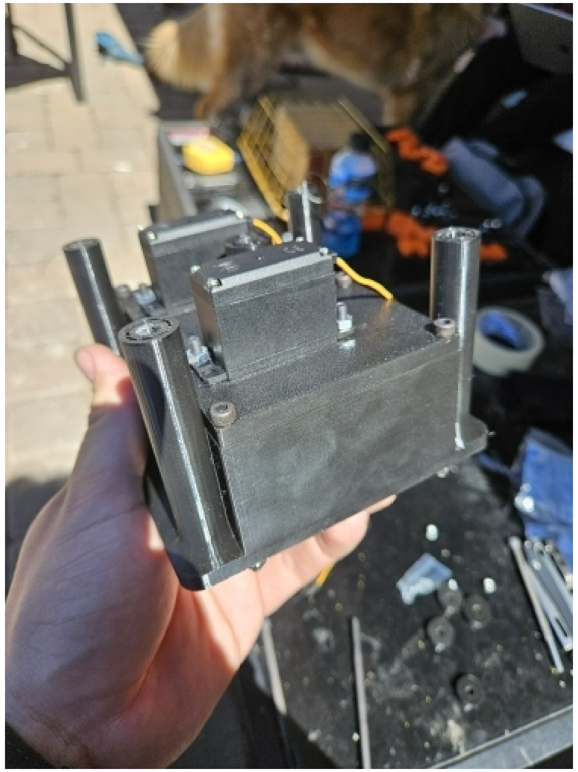

Figure 31: payload assembly (servo mounting)

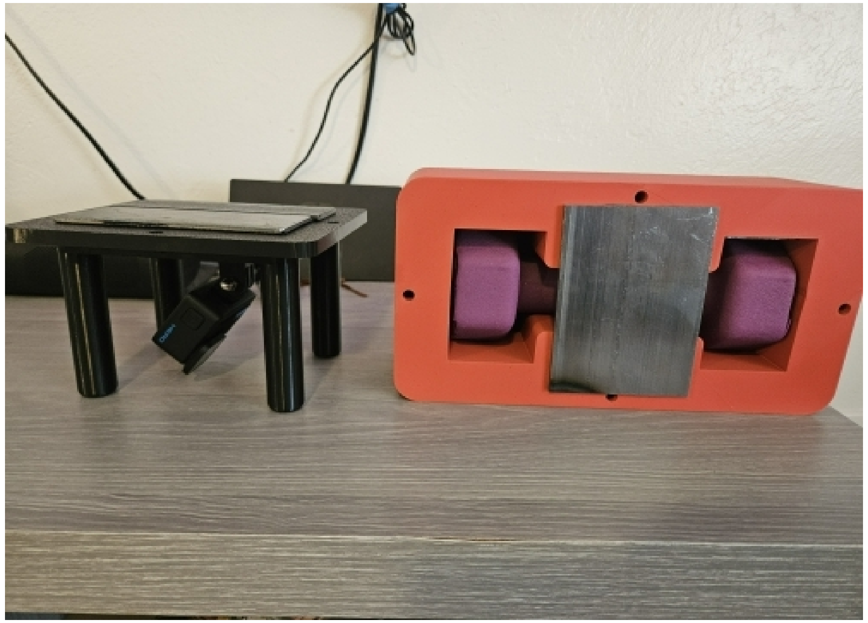

Figure 32: Deployable payloads (camera & weight)

# Final Testing

## 8.1 Top Level Testing

| Experiment/Test | Relevant DRs | Testing Equipment Required | Other Resources |
|---|---|---|---|
| Exp 1: Take-off Test | ER – 4<br>ER – 6<br>CR – 3<br>CR – 5 | -Drone System<br>-FlySky Remote<br>-Recording Device (iPhone)<br>-stopwatch | -Good weather or large indoor location<br>-certified drone pilot<br>-Level Ground |
| Exp 2: Landing | ER – 4<br>ER – 6<br>CR – 3<br>CR – 5 | -Drone System<br>-FlySky Remote<br>-Recording Device (iPhone)<br>-stopwatch | -Good weather or large indoor location<br>-certified drone pilot<br>-level ground |
| Exp 3: Thrust Dyno Testing | ER – 1<br>CR – 7 | -Strain gauge test stand/dynamometer<br>-Motor + propeller<br>-Digital multimeter | -excel spreadsheet<br>-Ear Protection<br>-Eye Protection<br>-Video Camera |
| Exp 4: Side-to-side mobility test | ER – 2<br>CR – 1<br>CR – 2 | -Drone System<br>-FlySky Remote<br>-Recording Device (iPhone) | -Good weather or large indoor location<br>-certified drone pilot |
| Exp 5: Payload pickup and deployment | ER – 3<br>CR – 4 | -Drone System<br>-FlySky Remote | -weighted payload (hand weight)<br>-camera payload |

Figure 33: Top Level Testing Table

# Final Testing

## 8.2 Detailed Testing Plan

**Flight & Thrust Tests**

- **Main Objective:**
  - Determine if the drone can lift off with its intended payload
  - "Will it go up?" – baseline flight readiness
- **Testing Focus:**
  - Static thrust testing using custom thrust test stand
  - Payload lift reliability and consistency
- **Test Stand Setup:**
  - Motor mounted on linear rail
  - 10 kg load cell for thrust measurement
  - Arduino + ESC for throttle control
  - Powered by LiPo battery
  - Data collected: thrust (g), current draw(A)
- **Pass Criteria:**
  - Thrust output ≥ total weight (drone + payload)
  - Reliable, repeatable lift force across test runs

**Magnetic Payload Engagement**

- **Purpose:**
  - Test reliability of magnet-based payload attachment and release
- **Engagement Method:**
  - Electromagnet or magnetic latch triggered onboard switch
  - Engage during takeoff, release on landing
- **Testing Focus:**
  - Confirm payload stays securely attached during lift
  - Test repeatability of magnetic engagement and release
  - Observe any shifts or instability during hover and movement
- **Pass Criteria:**
  - Payload remains attached during full-thrust lift
  - Clean and controlled disengagement when triggered
  - No interference with drone balance or control

# Final Testing

## 8.2 Detailed Testing Plan - Results

**Flight testing (exp. 1,2,4)**

**Issue:**

Two diagonal motors overheated and one failed during flight testing.

**Cause:**

Misconfigured motor directions in the flight controller caused the CW motors to overcompensate, leading to overheating.

**Fix:**

- Corrected motor rotation settings in software
- Verified direction and prop orientation
- Replaced damaged motor and retested successfully

### Thrust Dynamometer Testing (exp. 3)

| 16x8 Propeller | | |
|---|---|---|
| Percent Thrust (%) | Average Thrust (g) | Average Current (A) |
| 0 | 0 | 0.31 |
| 15 | 339 | 3.65 |
| 30 | 2714 | 12.5 |
| 45 | 5647 | 29.89 |
| 60 | 6779 | 54.61 |

Figure 34: Table: Thrust Test Results

### Payload Deployment test (exp. 5)

- **Payload Deployment System – Success**
- Magnetic switch system fully integrated and operational
- Payload deploys reliably on command
- Simple, lightweight mechanism with no mechanical failures observed

# Final Testing

## 8.3 Specification Sheets

| Engineering Requirement | Target | Tolerance | Measured/ Calculated Value | ER met? | Client Acceptable |
|---|---|---|---|---|---|
| ER1 - Thrust to Weight Ratio | 3:1 | +/- 100 g | | | |
| ER2 - Compact Design | 5X5X5 ft / <50 lbs | 1 in/ 5lbs | 4x4x4 ft / 23.6 lbs | Yes | Yes |
| ER3 - Complete Course in Time Limit | 9 minutes | +/- 1 minute | | | |
| ER4 - Payload Weight | 30% weight of the system | +/- 1 pound | 6.9 lbs | Yes | Yes |
| ER5 - Time of Flight | 10 minutes | +/- 30 seconds | | | |
| ER6 - Total Cost | $3000 | +/- $717.70 | $3,434.61 | Yes | Yes |
| ER7 - Meet FAA Requirements | Met | N/a | N/a | Yes | Yes |

Figure 35: Engineering Requirements Specification Sheets

| Customer Requirement | CR met? | Client Acceptable |
|---|---|---|
| CR1 - High Mobility | TBD | TBD |
| CR2 - Small | Yes | Yes |
| CR3 - Complete Recon Mission | TBD | TBD |
| CR4 - Payload Weight | Yes | Yes |
| CR5 - Battery Capacity | TBD | TBD |
| CR6 - Cost Efficiency | Yes | Yes |
| CR7 - Thrust Efficiency | Yes | Yes |

Figure 36: Customer Requirements Specification Sheet

# Future Work

## 9.1 Next Step & Iterations

- Redesign for autonomous navigation
- Replace fiberglass frame with lighter carbon fiber
- Expand payload capability
- Add remote FPV camera system
- Add telemetry tracking

# Acknowledgments


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- Professor James Clark III
- Graduate TA Connor Gaudette
- Northern Arizona University ME Department
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