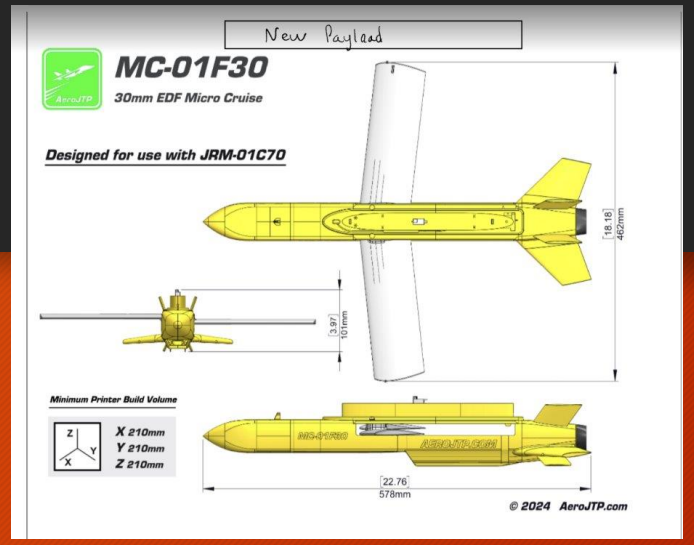
DORIS: Concept Generation and Evaluation

With Dylan Boeholt, Andre Bonillas, Connor Davidson, Jeremy Malmo, and Michael Zielinski

Overview

- Project Description
- Concept Generations
- Engineering Calculations
- Concept Evaluation
- Schedule
- Budget
- Bill of Materials
- Next Steps

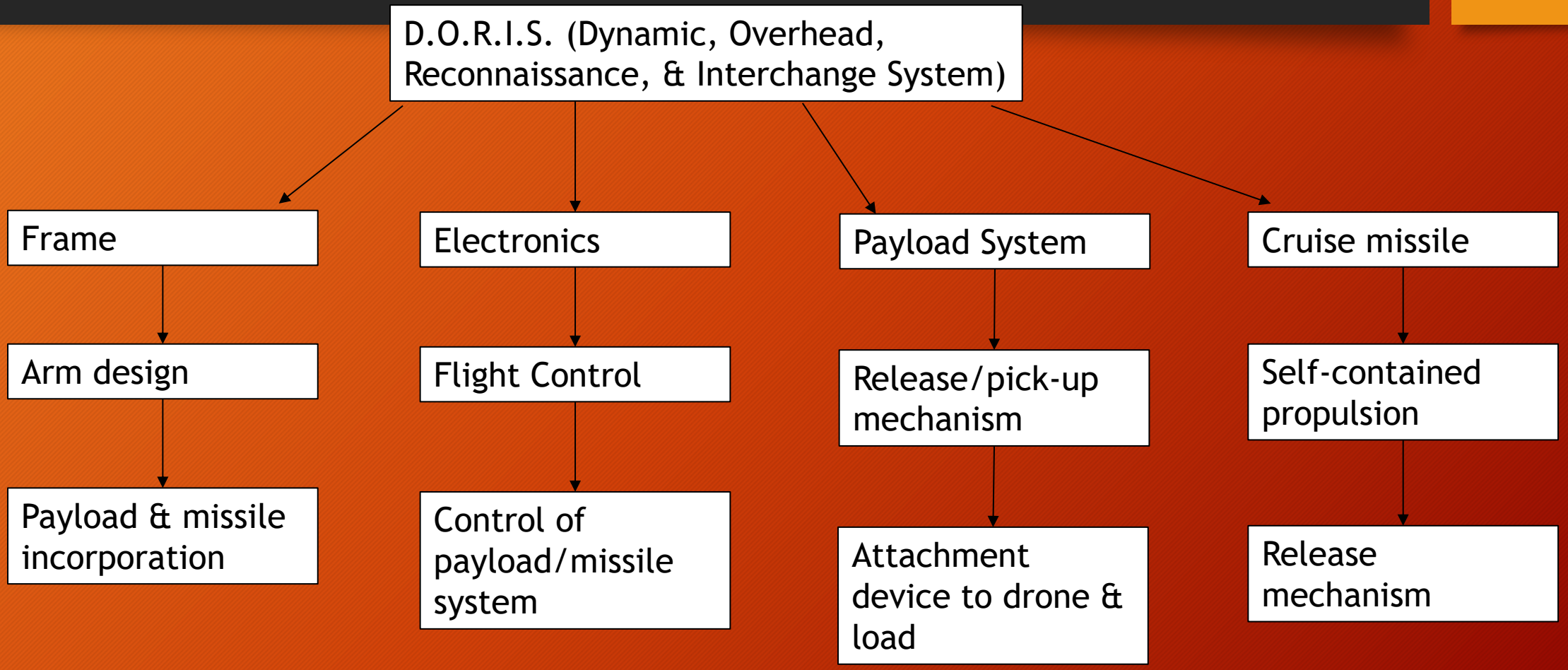
Project Description



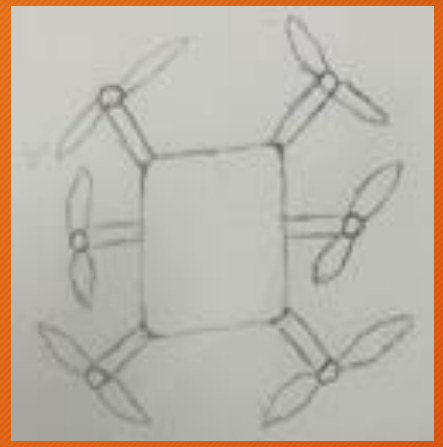
- Statement:
  - We will Develop a Utililty Drone with Variable Payload Capacity
- Description/Objective:
  - Design a drone frame utilizing commercially available parts
  - Engage and deploy different payloads, while remaining airborne
  - One payload will include a camera for potential surveying
  - One payload must be equal or greater in weight to 30% of the drone's empty weight
  - Another payload will include a MC-01F30 Cruise Missile that must be able hit a target after being deployed.
  - Drone must be able to return to user and deliver/retrieve a payload to/from a desired location/target
- Sponsor/Client:
  - Mechanical Engineering Department at Northern Arizona University
  - Contact: Professor David Willy
- Importance:
  - satisfies a need for a more affordable and easier to manufacture, payload capable drone
  - Drone could be used to deliver and receive any kind of package
  - Could also be used for emergency response to deliver first aid materials or other emergency supplies
  - Necessity for remote piloted drones that are durable, easy to fly, and can return to the user while performing tasks

Black Box Model

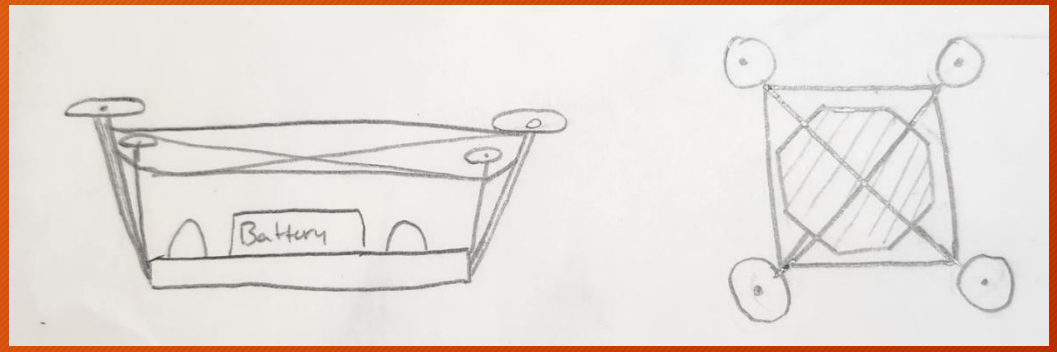
Hierarchy Chart



Concept Generation - Frame



Design 1



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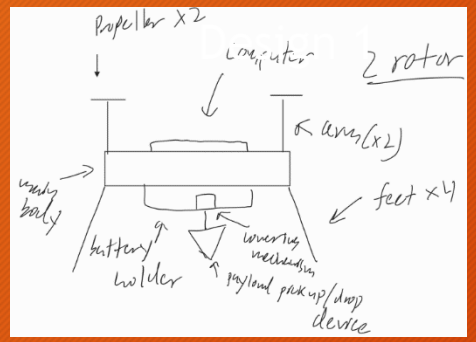
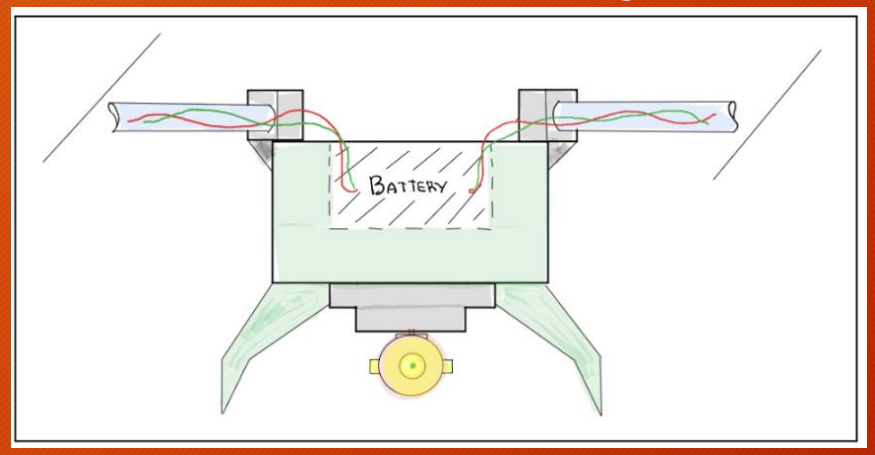
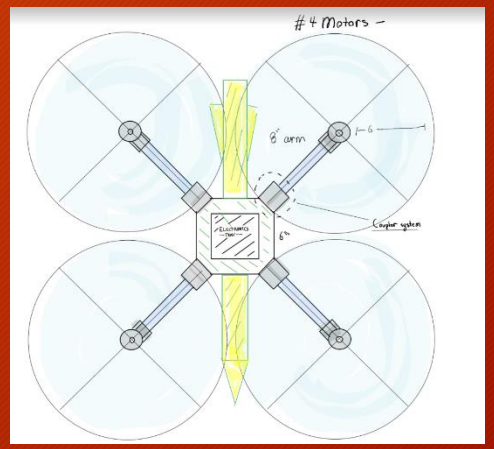
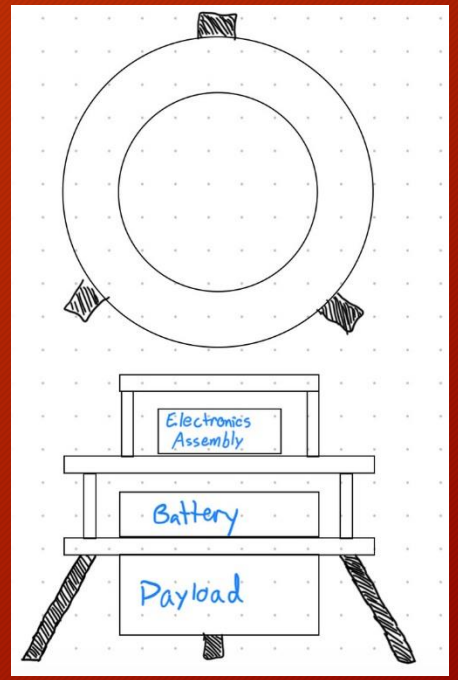


Design 4



Design 3



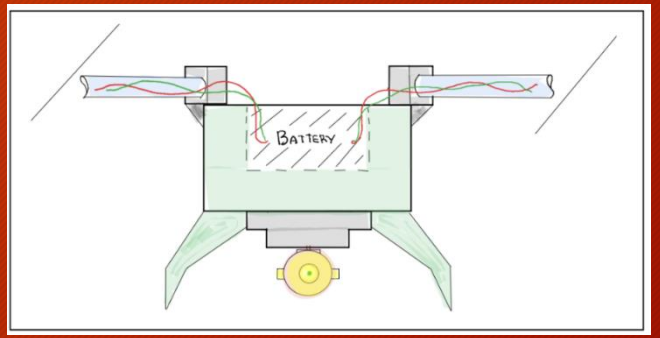


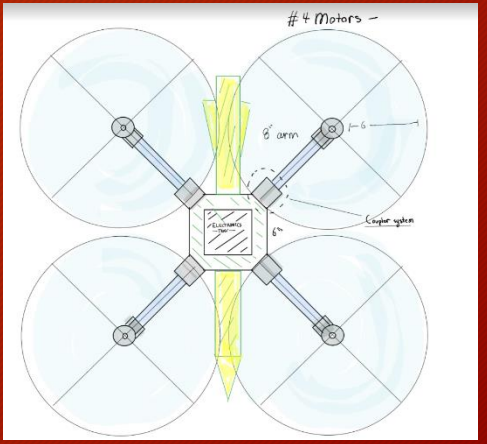
Design 5

Concept Evaluation

Frame (Main Body)

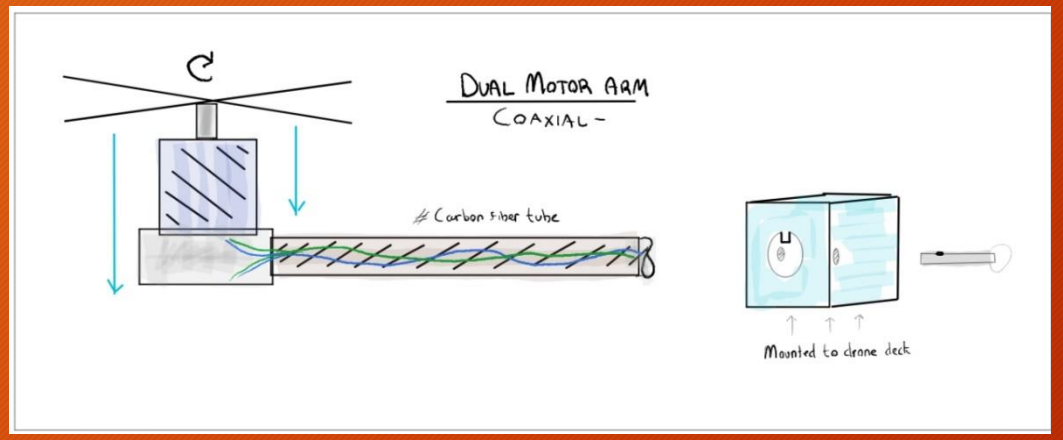
	Weight	Cost	Simplicity	Aesthetics	Durability	Repairability	Total
Weights	0.2	0.3	0.1	0.05	0.15	0.2	1
Design 1	2	2	3	4	3	4	2.75
Design 2	4	3	2	4	2	2	2.8
Design 3	5	4	4	3	4	4	4.15
Design 4	4	4	3	2	3	3	3.45
Design 5	3	4	4	3	3	4	3.6



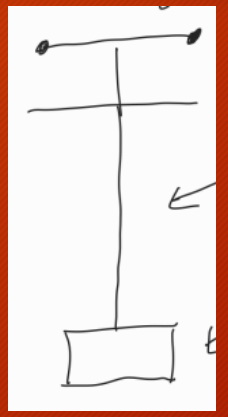


Concept Generation – Arm Design

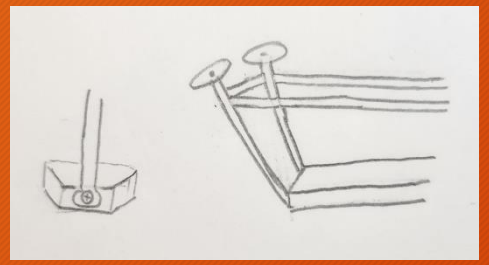
Design 1



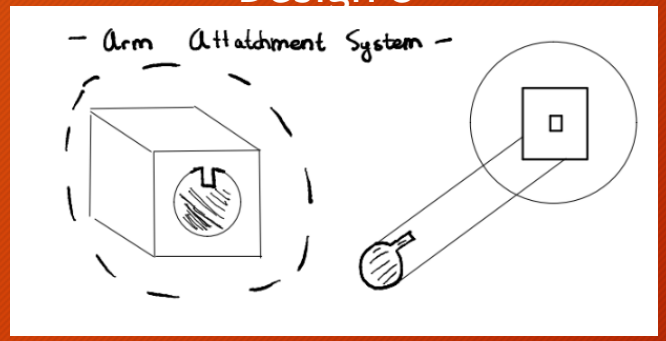
Design 3



Design 4



Design 1

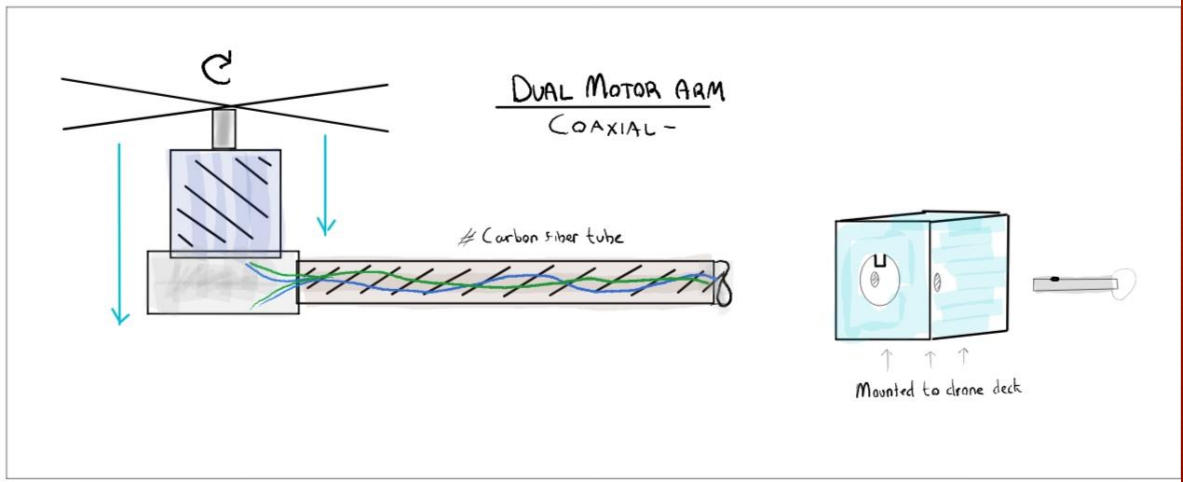


Design 5

Concept Evaluation

Arm Design

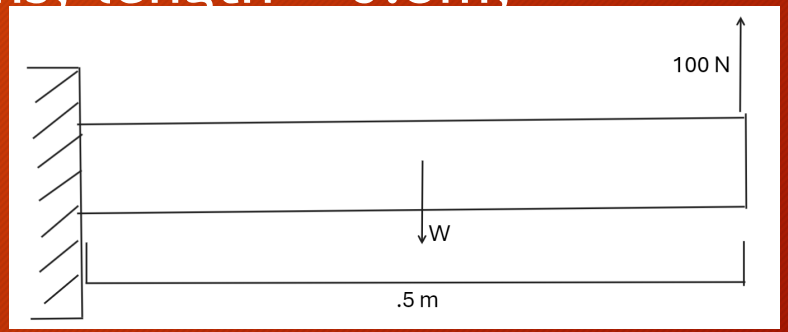
	Weight	Cost	Simplicity	Aesthetics	Durability	Repairability	Total
Weights	0.05	0.25	0.15	0.05	0.3	0.3	1
Design 1	4	2	3	4	4	2	3.15
Design 2	4	3	3	4	2	4	3.4
Design 3	5	3	4	3	4	4	4.15
Design 4	4	3	2	3	2	2	2.6
Design 5	4	1	3	5	4	2	2.9



Engineering Calculations (Arm Force Calculations)

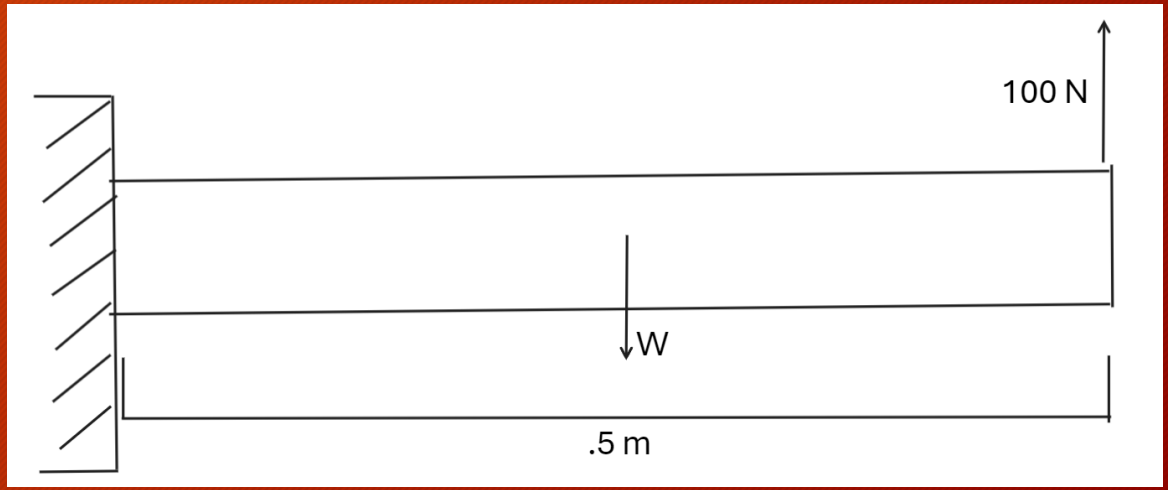
- Assuming carbon fiber cantilever beam style arms, length = 0.5m, mass = 0.04536kg, thrust force = 100 N,
- W = 0.04536kg * 9.81m/s^2 = 0.445N
- ΣF = 0 => 100N - 0.445N - Rf = 0 =>
- Rf = 100N - .445N = 99.555 N (shear force)
- (Target weight of drone is approximately 111N)
- ΣM = 0 => 100N * 0.5m - .445N * 0.25m + Rm = 0 =>

  Rm = -100N * 0.5m + .445N * 0.25m = -49.889 N*m (bending moment)

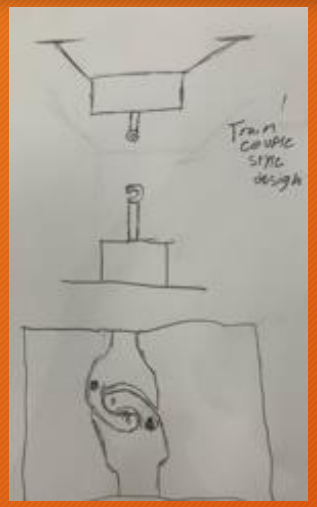


Engineering Calculations (Arm Deflection)

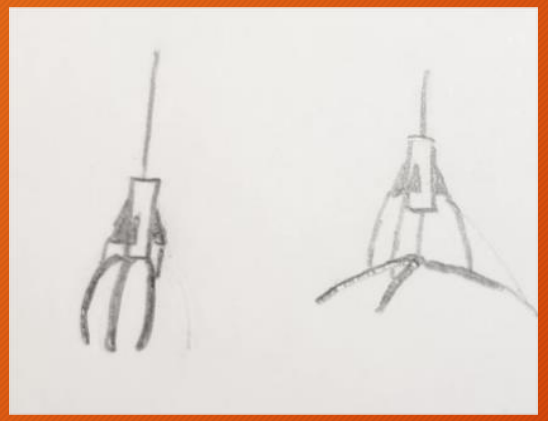
- E = 250–350GPa (1), ri = 20mm = 0.02m, ro = 22mm = .022m,
- I = π/4(ro^4-ri^4) = π/4[(0.022m)^4 - (0.02m)^4] = 5.832*10^-8 m^4
- Δmax = PL^3/3EI = [100N * (0.5m)^3] / [3 * (300*10^9Pa) * (5.832*10^-8m^4) =
- Δmax = 2.381*10^-4m = .2381mm ≈ 1/100th of an inch



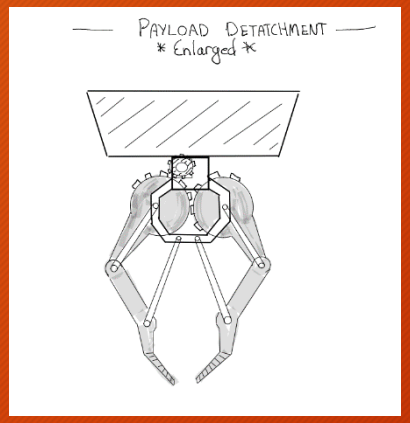
Concept Generation – Payload System



Design 1



Design 2



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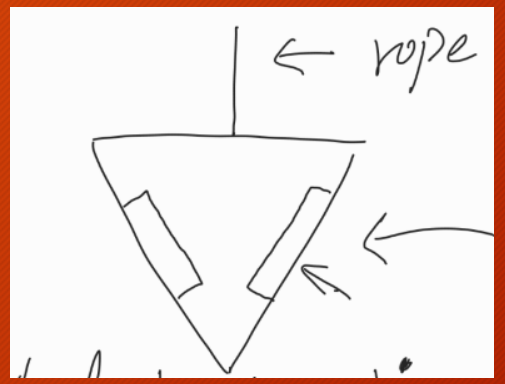

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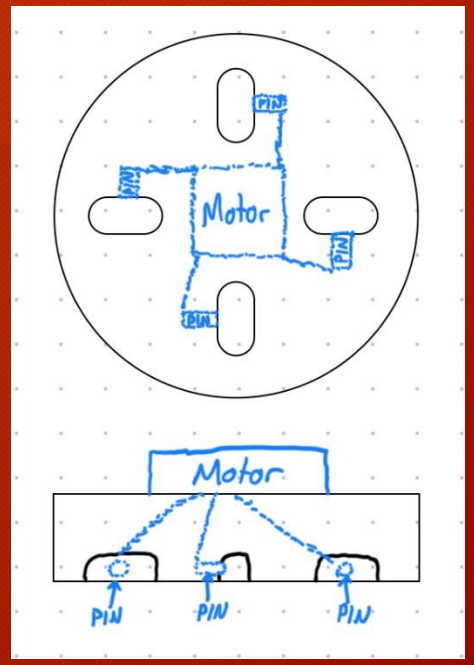
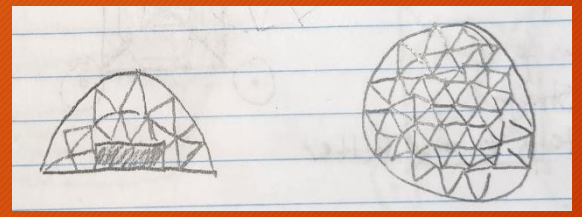
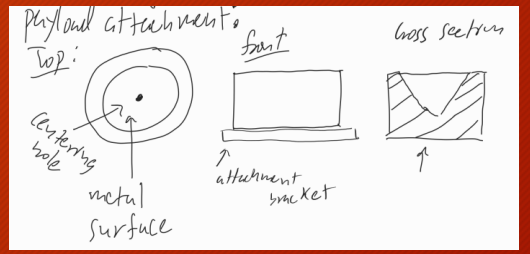


Design 5

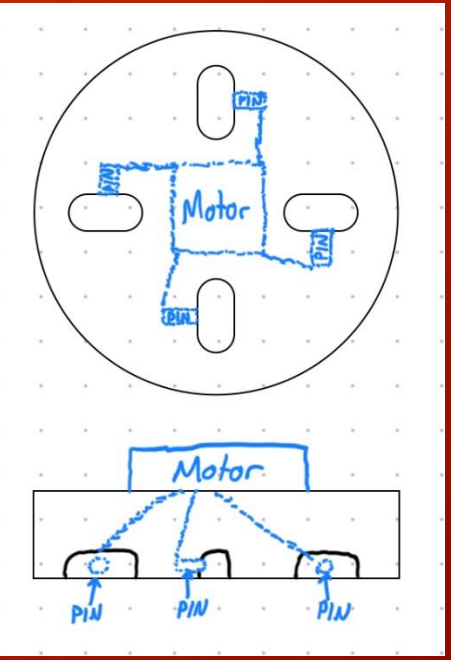




Concept Evaluation

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



Design 5

Evaluation: Magnet Comparison

- MAG-MATE AR1504

Class – shielded electro-magnet

Weight: 1 lb

Dimensions: 1.3" H, 2.5" D

Max hold force: 35 lbs

Price: 215$

- Target Drone Weight: 25 lbs
- Max Payload weight: 7.5 lbs

- 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 Evaluation: Motor Comparison

Propeller Configuration: 16 x 5.4

T-Motor f-1000	*iFlight XING X4214 660KV	SunySky X4120 650KV
Weight: 404 (g)	Weight: 213 (g)	Weight: 290 (g)
Max Thrust: 6875 (g)	Max Thrust: 7900 (g)	Max Thrust: 6592 (g)
Max Current: 125 A	Max Current: 98 A	Max Current:100A
Max Power: 4000 W	Max Power:2352 W	Max Power: 2750 W
Price: $119.90	Price: $82.99	Price: $136.65

Engineering Calculations (Motor Selection)

- MATLAB program to estimate flight times

Inputs

- Weight-motor efficiencies-motor thrust- motor #-

Outputs

Example Parameters

- Drone – 6 kg
- Payload – 4.5 kg

(43% of total)

```
>> UAVtoolboxtest
Total Weight: 103.01 N (10.50 kg)
Available Thrust: 31600.00 g (31.60 kg equivalent)
Thrust-to-Weight Ratio: 3.01
Design meets the thrust-to-weight requirement.

Throttle Required for Hover: 33.23%

Estimated Flight Time at Hover (Throttle: 33.23%): 863.40 seconds (14.39 minutes)

Estimated Flight Time at 100% Power (Throttle): 158.86 seconds (2.65 minutes)
Power consumed at 100% throttle: 9407.56 W

Estimated Flight Time at 75% Power (Throttle): 264.85 seconds (4.41 minutes)
Power consumed at 75% throttle: 5642.86 W

Estimated Flight Time at 50% Power (Throttle): 573.78 seconds (9.56 minutes)
Power consumed at 50% throttle: 2604.68 W
```

Concept Evaluation: Propeller Comparison

T-Motor P17x5.8

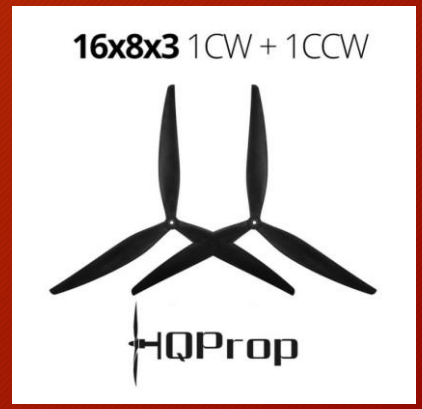
- **Diameter**: 17 inches
- **Pitch**: 5.8 inches
- **Material**: Carbon fiber
- **Weight: 26.5 g**
- **Thrust Limit**: 7.5 kg
- **Optimum RPM** : 3500-6000
- **Price** (2): $71.90

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**



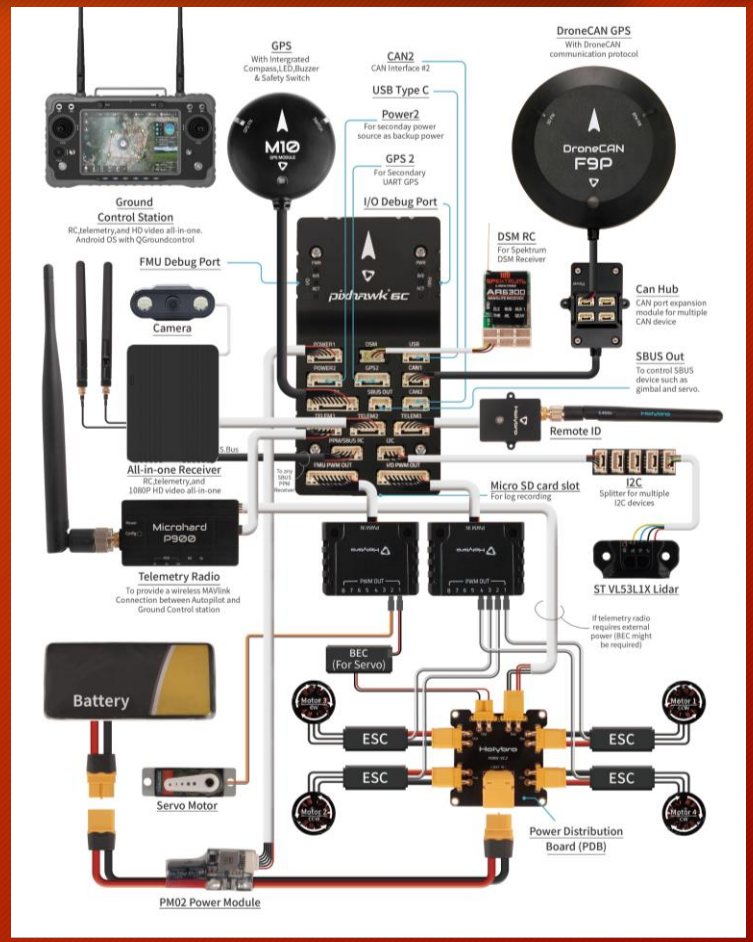
Concept Evaluation – Pixhawk 6C Flight Controller [2]

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

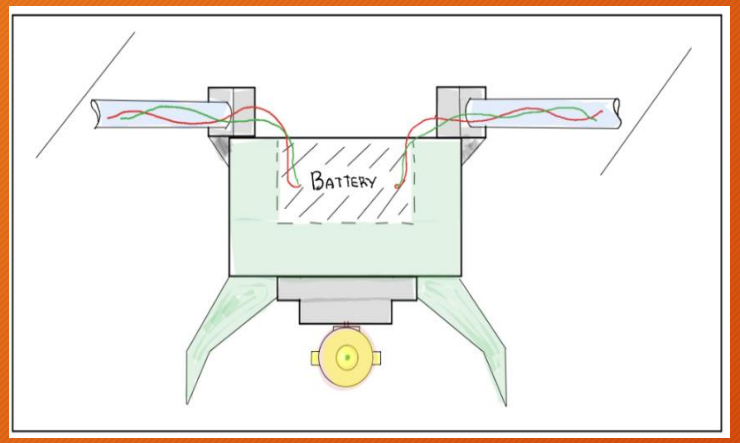
Electrical data
- Voltage Ratings:
- Max input voltage: 6V
- USB Power Input: 4.75~5.25V
- Servo Rail Input: 0~36V
- Current Ratings:
- Telem1 Max output current limiter: 1.5A
- All other port combined output current limiter: 1.5A

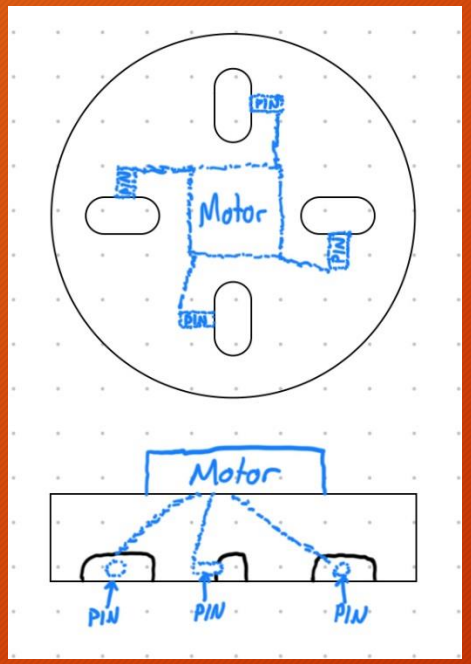
Mechanical data
- Dimensions: 84.8 * 44 * 12.4 mm
- Weight (Aluminum Case) : 59.3g
- Weight (Plastic Case) : 34.6g

Interfaces
- 16- PWM servo outputs (8 from IO, 8 from FMU)
- 3 general purpose serial ports
- Telem1,2,3 - Full flow control, separate 1.5A current limit
- GPS1 - Full GPS port (GPS plus safety switch)
- GPS2 - Basic GPS port
- 1 I2C port
- 2 CAN Buses
- Dedicated R/C input for Spektrum / DSM and S.BUS, CPPM, analog / PWM RSSI
- Dedicated S.BUS output
- 2 Power input ports (Analog)



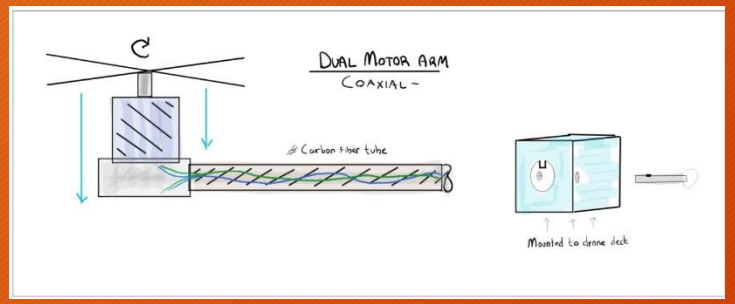
Final Design

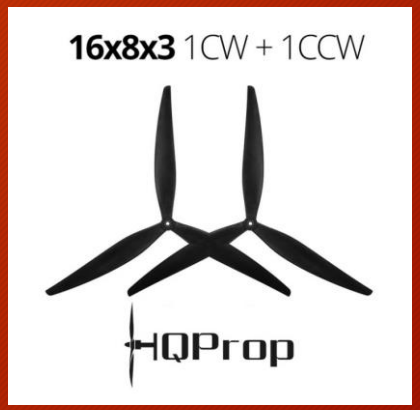




iFlight XING X4214
660KV Motor

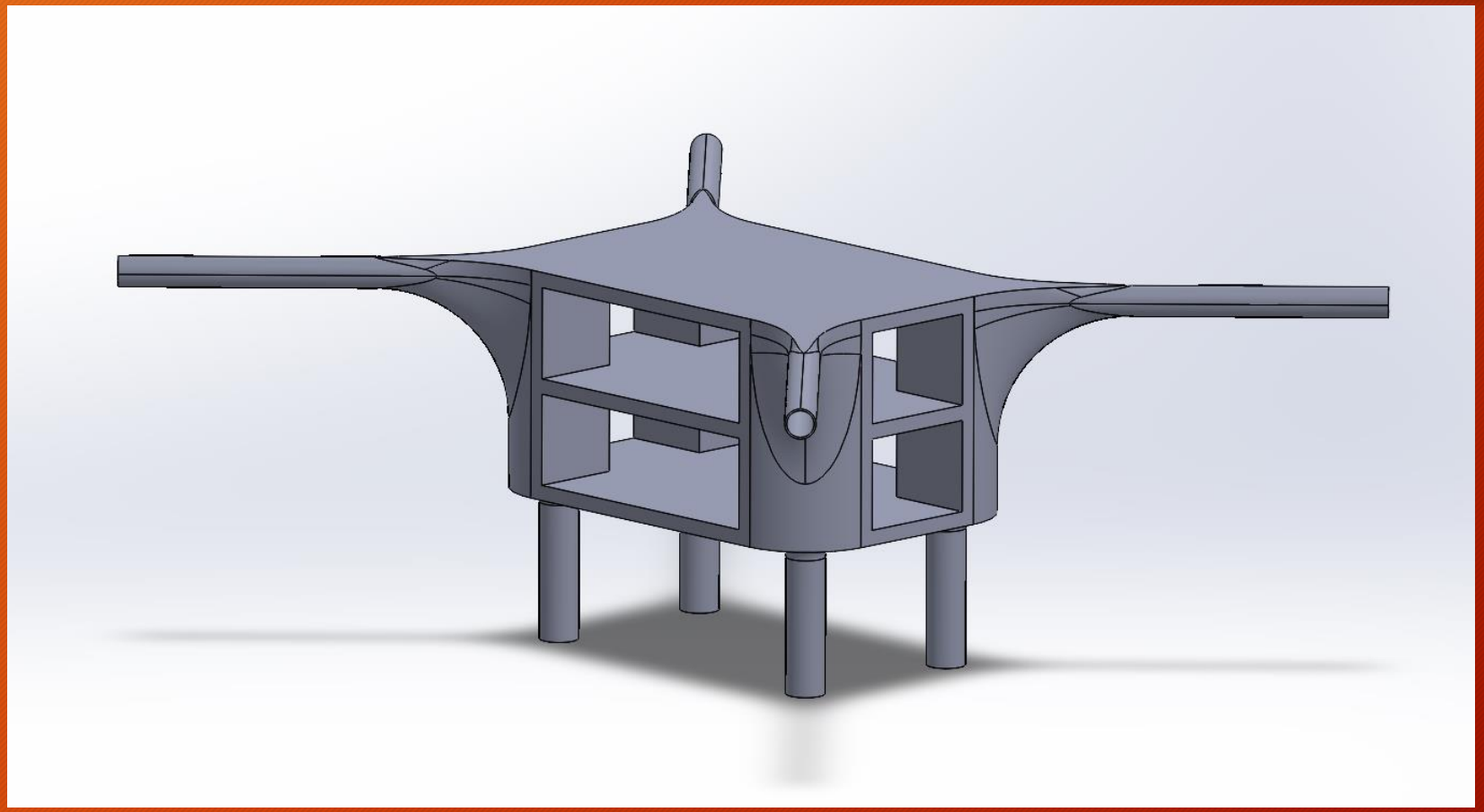
Magswitch MAGJIG 60



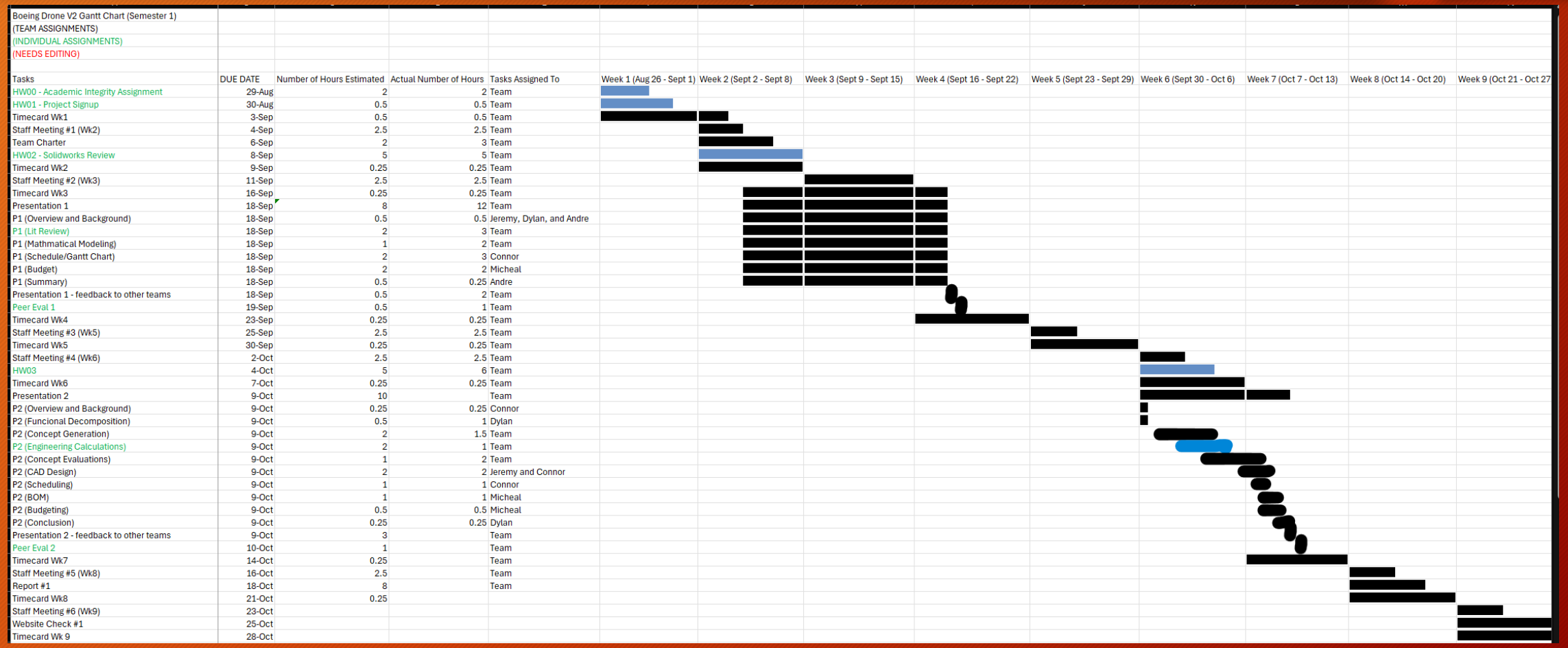


HQProp 16X8X3 (3 prop)

CAD Design



Schedule



Boeing Drone V2 Gantt Chart (Semester 1)													
(TEAM ASSIGNMENTS)													
(INDIVIDUAL ASSIGNMENTS)													
(NEEDS EDITING)													
Tasks	DUE DATE	Number of Hours Estimated	Actual Number of Hours	Tasks Assigned To	Week 1 (Aug 26 - Sept 1)	Week 2 (Sept 2 - Sept 8)	Week 3 (Sept 9 - Sept 15)	Week 4 (Sept 16 - Sept 22)	Week 5 (Sept 23 - Sept 29)	Week 6 (Sept 30 - Oct 6)	Week 7 (Oct 7 - Oct 13)	Week 8 (Oct 14 - Oct 20)	Week 9 (Oct 21 - Oct 27
HW00 - Academic Integrity Assignment	29-Aug	2	2	Team									
HW01 - Project Signup	30-Aug	0.5	0.5	Team									
Timecard Wk1	3-Sep	0.5	0.5	Team									
Staff Meeting #1 (Wk2)	4-Sep	2.5	2.5	Team									
Team Charter	6-Sep	2	3	Team									
HW02 - Solidworks Review	8-Sep	5	5	Team									
Timecard Wk2	9-Sep	0.25	0.25	Team									
Staff Meeting #2 (Wk3)	11-Sep	2.5	2.5	Team									
Timecard Wk3	16-Sep	0.25	0.25	Team									
Presentation 1	18-Sep	8	12	Team									
P1 (Overview and Background)	18-Sep	0.5	0.5	Jeremy, Dylan, and Andre									
P1 (Lit Review)	18-Sep	2	3	Team									
P1 (Mathmatical Modeling)	18-Sep	1	2	Team									
P1 (Schedule/Gantt Chart)	18-Sep	2	3	Connor									
P1 (Budget)	18-Sep	2	2	Micheal									
P1 (Summary)	18-Sep	0.5	0.25	Andre									
Presentation 1 - feedback to other teams	18-Sep	0.5	2	Team									
Peer Eval 1	19-Sep	0.5	1	Team									
Timecard Wk4	23-Sep	0.25	0.25	Team									
Staff Meeting #3 (Wk5)	25-Sep	2.5	2.5	Team									
Timecard Wk5	30-Sep	0.25	0.25	Team									
Staff Meeting #4 (Wk6)	2-Oct	2.5	2.5	Team									
HW03	4-Oct	5	6	Team									
Timecard Wk6	7-Oct	0.25	0.25	Team									
Presentation 2	9-Oct	10		Team									
P2 (Overview and Background)	9-Oct	0.25	0.25	Connor									
P2 (Funcional Decomposition)	9-Oct	0.5	1	Dylan									
P2 (Concept Generation)	9-Oct	2	1.5	Team									
P2 (Engineering Calculations)	9-Oct	2	1	Team									
P2 (Concept Evaluations)	9-Oct	1	2	Team									
P2 (CAD Design)	9-Oct	2	2	Jeremy and Connor									
P2 (Scheduling)	9-Oct	1	1	Connor									
P2 (BOM)	9-Oct	1	1	Micheal									
P2 (Budgeting)	9-Oct	0.5	0.5	Micheal									
P2 (Conclusion)	9-Oct	0.25	0.25	Dylan									
Presentation 2 - feedback to other teams	9-Oct	3		Team									
Peer Eval 2	10-Oct	1		Team									
Timecard Wk7	14-Oct	0.25		Team									
Staff Meeting #5 (Wk8)	16-Oct	2.5		Team									
Report #1	18-Oct	8		Team									
Timecard Wk8	21-Oct	0.25											
Staff Meeting #6 (Wk9)	23-Oct												
Website Check #1	25-Oct												
Timecard Wk 9	28-Oct												

Budget

Team:	DORIS		Budget:	$ 3,300.00	Amount of 10%:	$ 717.70	
Team Number:	F24toSp25_13		Expense:	$ 3,300.00			
Speedchart:	2920381F25		Remaining:	$ 0.00			
Sub-Debt:	CP19						

Date	Vendor	Item	Quantity	Per Unit Cost	Cost	Status	Notes
9/10/2024	Amazon	PLA Filament	1		$ 15.26	Delivered	Jeremy Paid
9/17/2024	Staples	64GB EliteX CL10 microSD (2 pack)	1		$ 16.46	In-Store	Jeremy Paid
9/25/2024	Online	MC-01F30 Cruise Missile Design	1		$ 42.52	Downloaded	Michael Paid
	Amazon	Tattu 6S LiPo Battery 1050mAh	1		$ 29.25	Delivered	Connor Paid
9/26/2024	Aliexpress	50pcs M3 12mm hex heads	1		$ 1.87	Delivered	Michael Paid
		10pcs 150mm extension wires	3		$ 15.87	Delivered	
		1350pcs Set C Black screws	1		$ -	Delivered	Refunded (case damaged)
		3-axis Gyro	1		$ 14.26	Delivered	
		7000KV 30mm motor	1		$ 23.64	Delivered	
		2g motor servo	3		$ 20.54	Delivered	
10/1/2024	Venmo	Direct Donation	1		$ (150.00)	Not Used	In Dylan Venmo
	GoFundMe	Transfer	1		$ (303.76)	Not Used	In Michael Ravalli
10/2/2024	Amazon	Lightweight PLA	1		$ 36.02	Delivered	Jeremy Paid
10/3/2024	Amazon	Magswitch MagJig 60	1		$ 84.60	Delivered	Capstone PO#1
		Lipo Battery Charger	1		$ -	Delivered	
		2-4S 20A Brushless	1		$ 25.10	Arriving 10/11-10/22	
	AliExpress	Iflight XING T4214	1		$ 251.74	Estimated 10/20	
		TATTU 22000mAh 22.2V	1		$ 238.48	Estimated 10/17	
10/7/2024	GoFundMe	Transfer	1		$ (48.25)	Not Used	In Michael Ravalli

Date	Vendor	Item	Quantity	Per Unit Cost	Cost	Status	Notes
		Pixhawk 6C Flight controller	1	$ -	$ -		Salvaged
		Holybro PM07	1	$ -	$ -		Salvaged
		Holybro M8N GPS/Compass	1	$ -	$ -		Salvaged
		Xing 2814 880KV Motor	4	$ -	$ -		Salvaged
		EFlite EFLA1040A EFC	4	$ -	$ -		Salvaged
		FlySky IA6B 6-channel Receiver	1	$ -	$ -		Salvaged
		RC Controller	1	$ -	$ -		Salvaged
		6000mAh battery	1	$ -	$ -		Salvaged
		Other electronic components (for drone flight only, not payload)	1	$ -	$ -		Salvaged
		Donated 3D filament (ABS & PLA)	1	$ -	$ -		Donated
		Propellers	4	$ -	$ -		Salvaged
		GoPro Hero (the little one)	1	$ 217.26	$ 217.26		GoPro.com
		New ESCs	6	$ 25.00	$ 150.00		Based on research experience
		New props	6	$ 60.00	$ 360.00		Based on SwellPro Fisherman Max 16" carbon fiber props (high end)
		Various hardware pieces	1	$ 75.00	$ 75.00		Based on hardware prices
		Frame Materials (filament, carbon fiber, etc.)	1	$ 1,000.00	$ 1,000.00		Estimate based on 3D printing from Hi Jacks
		Payload attachment system	1	$ 300.00	$ 300.00		Servos/design materials
		Discretionary Budget	1	$ 884.14	$ 884.14		Leftover

Bill of Materials

Item	Quantity	Cost Per Unit	Total Cost
DRONE ONLY		**Total Cost:**	**$ 1,193.46**
22Ah 6S LiPo Battery	1	$ 240.00	$ 240.00
Flight Controller (Pixhawk 6C)	1	$ 231.46	$ 231.46
GPS/Compass (M10, included w/ FC)	1	$ -	$ -
Motors	4	$ 62.75	$ 251.00
6-channel RC receiver	1	$ 35.00	$ 35.00
Power Distribution Module (PM07, included w/ FC)	1	$ -	$ -
Electronic Speed Controller (60A)	4	$ 30.00	$ 120.00
RC Controller	1	$ 50.00	$ 50.00
Wiring kit	1	$ 25.00	$ 25.00
LiPo Battery Charging Kit	1	$ 52.00	$ 52.00
Carbon Fiber Tubing (6')	2	$ 25.00	$ 50.00
3D Printing Filament (ABS)	2	$ 20.00	$ 40.00
3D Printing Filament (PLA)	1	$ 24.00	$ 24.00
Various hardware (screws, bolts, etc.)	As Needed	$ 75.00	$ 75.00

Item	Quantity	Cost Per Unit	Total Cost
MISSILE PAYLOAD		**Total Cost:**	**$ 208.41**
3D Printing Filament (LW PLA)	2	$ 35.00	$ 70.00
3D Printing Filament (PLA)	1	$ 24.00	$ 24.00
50pcs M3 12mm hex heads	1	$ 5.00	$ 5.00
10pcs 150mm extension wires	3	$ 5.29	$ 15.87
1350pcs Set C Black screws	1	$ 10.00	$ 10.00
3-axis Gyro	1	$ 14.26	$ 14.26
7000KV 30mm motor	1	$ 23.64	$ 23.64
2g motor servo	3	$ 6.85	$ 20.54
2-4S 20A Brushless ESC	1	$ 25.10	$ 25.10
REGULAR PAYLOADS		**Total Cost:**	**$ 450.00**
GoPro/similar camera	1	$ 220.00	$ 220.00
Magswitch MagJig Magnet	1	$ 30.00	$ 30.00
Payload attachment build materials	1	$ 200.00	$ 200.00
TOTAL OVERALL COST:			**$ 1,851.87**

Summary and Next Steps

- Mathematical analysis provided us with the best motors, propellers, and design
- Order Parts
  - ESC (electronic speed controllers X4) 100A
  - Carbon fiber tube length - 500mm Diameter - 20 mm X 4
  - Simnet Drone Design Program
  - HQProp 16X8X3 (3 prop) X 4
  - Electromagnet release system
- Report 1
- Update website
- Build Prototype and Test

Sources

[1] S. Mirdehghan, “Carbon Fiber Properties - an overview | ScienceDirect Topics,” www.sciencedirect.com, 2021. https://www.sciencedirect.com/topics/materials-science/carbon-fiber-properties

[2] “Pixhawk 6C Technical specification,” Holybro Docs, https://docs.holybro.com/autopilot/pixhawk-6c/technical-specification (accessed Oct. 9, 2024).

Questions?