Design of an Unmanned Tilt-Rotor Aircraft for Multi-Mission Applications

MEAC Presentation
Team 8

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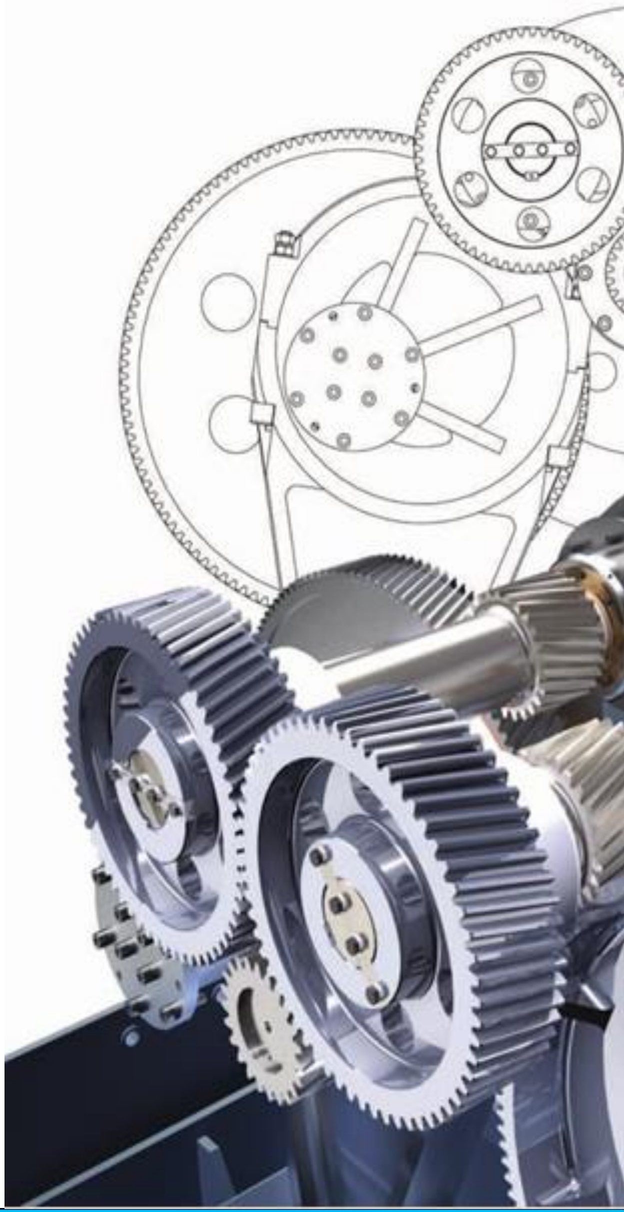
Outline

- **Project Overview**
- **Concept Evolution**
- **Product Selection**
- **Potential Challenges/ Resolution**
- **Progress**
- **Future Plans**



Project Overview
Background

- The Seafarer Chapter of Association for Unmanned Vehicle Systems International (AUVSI)
    - Student Unmanned Aerial System (SUAS) competition
- Challenges students to design a system capable of completing a specific and independent aerial operation.
- Stimulate and foster interest in innovation and careers in the aerospace industry

Project Overview
Competition Primary Objectives

- Autonomous Flight
  - Takeoff, waypoint navigation, and landing all done autonomously
- Search Area
  - Autonomous localization and classification, with imagery

Project Overview
Competition Secondary Objectives

- Automatic Detection, Localization, Classification
- Actionable Intelligence
- Off-Axis Standard Target
- Emergent Target
- Air-Drop
- Simulated Remote Information Center
- Interoperability
- Sense, Detect, and Avoid

Project Overview
Constraints & Requirements

Constraints (2016)

- Minimum 10 Hz communication
- Less than 55 pounds
- Max airspeed of 115 mph
- Flight altitude of 100ft – 750ft

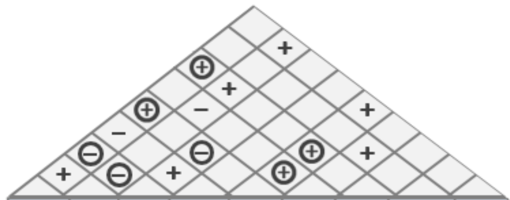
Requirements (2016)

- Capable of Vertical Take-off and Landing (VTOL)
- Autonomous path planning & obstacle avoidance
- Autonomous target detection & characterization

Project Overview
Objectives

- Research various forms of aerial vehicles that utilize VTOL flight
- Design and manufacture autonomous aerial vehicle capable of VTOL flight and target detection
- Assembly of vehicle for testing of functionality
- Optimize for acceptable competition parameters

House of Quality



Engineering Characteristics

Customer Importance Low(0) – High (5)

Direction of Improvement

Customer Requirements	Customer Importance	Weight	Energy Needed	Thrust	Material Strength	Flight Efficiency	Controls	Range	Bandwidth	Resolution
Direction of Improvement		↓	↓	↑	↑	↑	↑	↑	↑	↑
Autonomous Flight	5					⊙	●●			
Visual Feed	5	○	○					⊙	⊙	○
Payload Delivery	3	⊙	⊙			○				●
Obstacle Avoidance	2					○	●			●
Heavier-than-air Flight	5	●●	●	⊙	●	●●				
Cost	4	⊙			●			⊙		⊙
Time of Flight	3	⊙	●●	●		●●		●		
VTOL Flight	4	●	●●	●	⊙	●●	●			
Safety	4	○	⊙	⊙	⊙		●●	⊙		
Repeatability	4		○			○	⊙		○	⊙
Precision	3						⊙			●●
Reproducibility	4		○			○	⊙		○	⊙
Importance Rating Σ(Priority X Relationship)		127	146	89	95	153	176	73	28	118
Relative Importance		13	15	8	9	15	18	7	3	12
Rank Order of Engineering Characteristics Low (9) – High (1)		**4**	**3**	**7**	**6**	**2**	**1**	**8**	**9**	**5**

Correlations:
- ⊕ Strong Positive
- + Positive
- ⊖ Strong Negative
- – Negative

Relationships:
- ●● Strongest= 10
- ● Strong= 7
- ⊙ Fair= 4
- ○ Weak= 1

Project Overview
Needs Assessment

Needs Statement

- “There needs to be a solution to minimize human danger and improve overall quality of human life, in the aerospace industry.”

Goal Statement

- “The goal is to design an autonomous unmanned aerial vehicle able to meet competition parameter while emphasizing safety.”

Concept Evolution

Previous Years

Year 2012

- Purchased Fixed Wing Aircraft – Senior Telemaster

Year 2013

- Fixed Wing Aircraft – Senior Telemaster
- Firmware used was ArduPilot Mega 2.5
- Nitro powered motor

Concept Evolution

Previous Years

Year 2014

- Purchased a new fixed wing plane (Senior Telemaster Plus)
- ArduMega 2.5 autopilot system
- Used electric motor powered with batteries

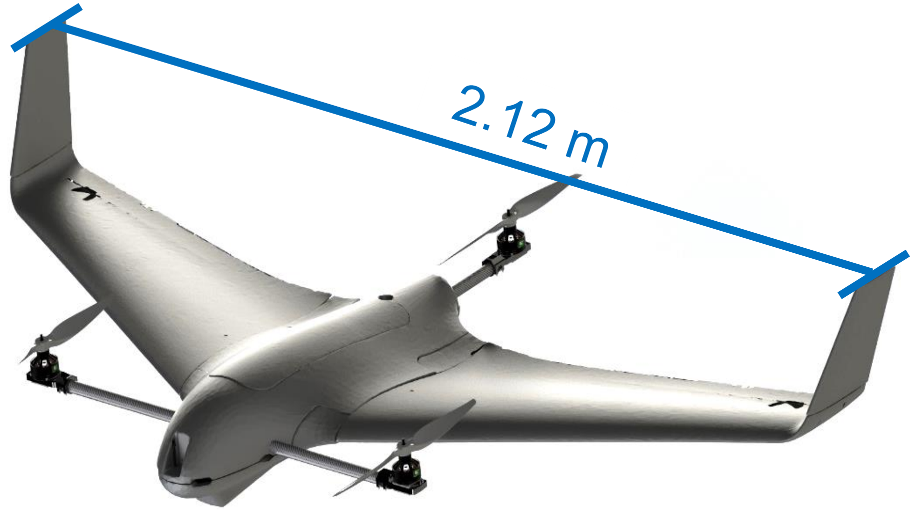
Concept Evolution
Previous Years

Year 2015

- Adapted Senior Telemaster plus with VTOL capabilities
- Used five motors
- Heavy (~8,300g)

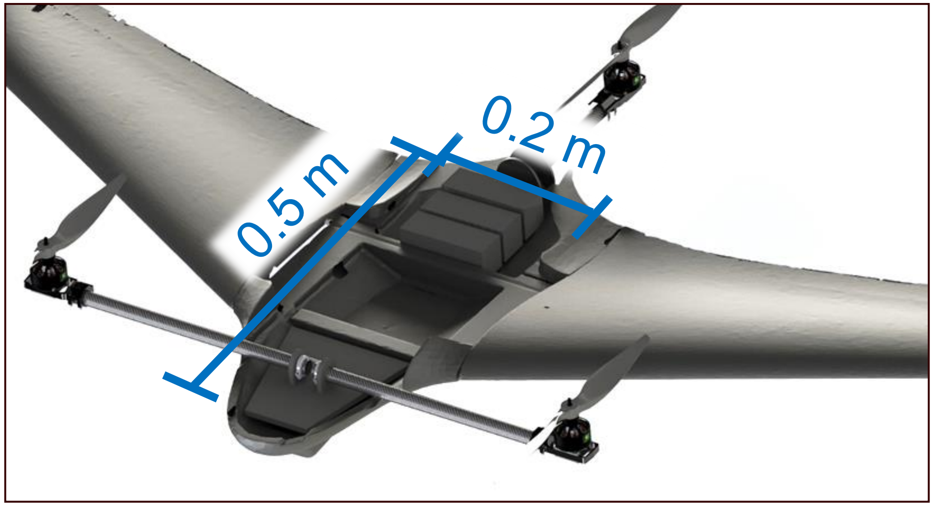
Concept Evolution

Skywalker Tri-copter



Skywalker X8

- Durable
- Easily replaceable parts
- Large internal capacity
- Suitable lift characteristics



Tri-Copter

- Lower power consumption
- Lighter (5,500g)
- Streamline Profile

Product Selection

Propulsion

Qty	Component	Manufacturer	Functional Parameter
3	Motor	Cobra	410kv
3	Electronic Speed Controller	Cobra	40Amp
3	Propeller	RC Timer	16” x 5.5”
2	Battery	Venom	22.2V , 5000mAh

Figure 5 – 4510/450kv Cobra Motor[4]

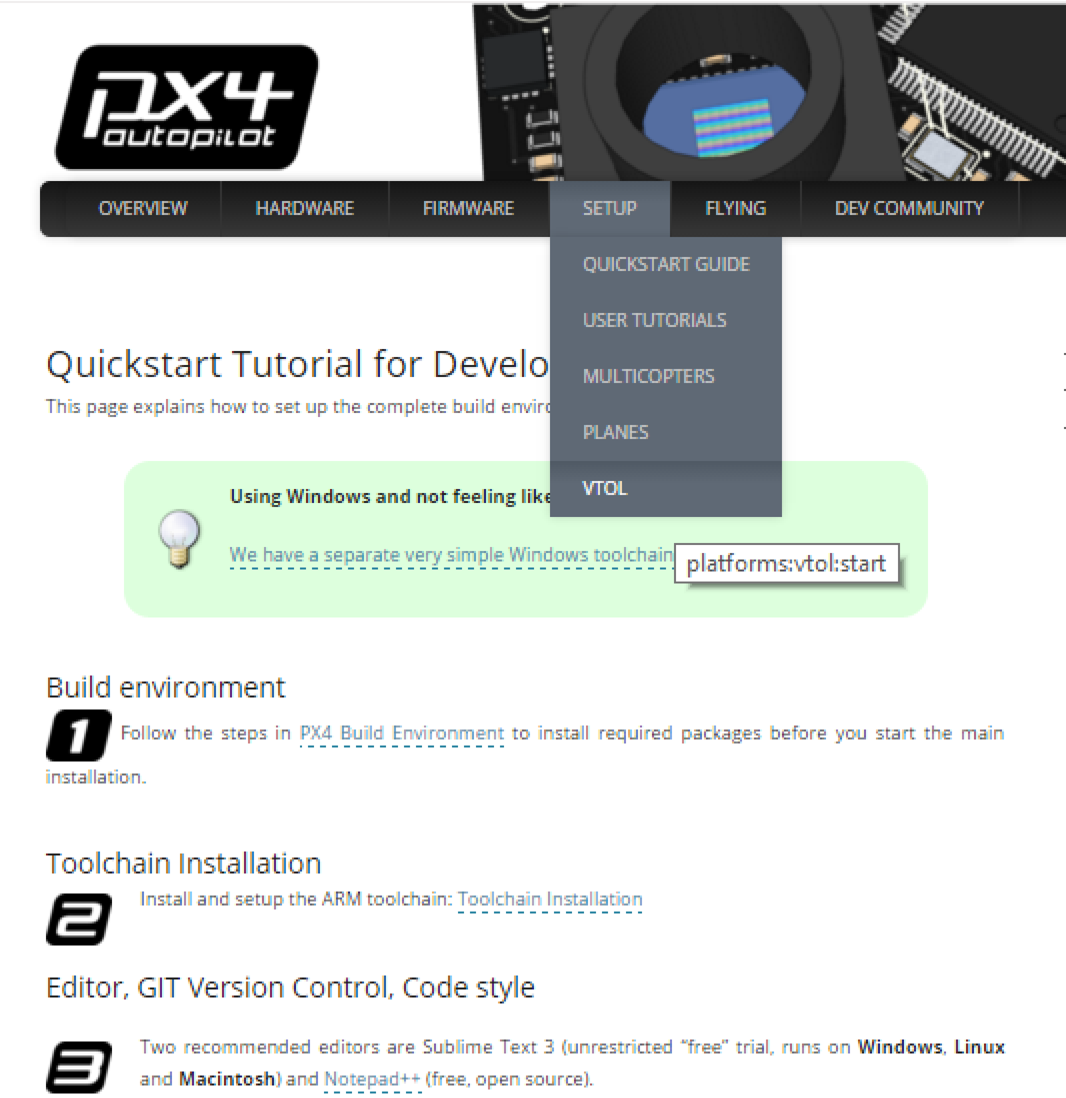
Figure 8 – Electronic Speed Controller[5]

Product Selection

Controls

<u>Flight Controller</u>

- Pixhawk
- Active VTOL development
- Open source development
- Development resources



Product Selection

Controls

Description	Front Tilt-Rotor	Tail Tilt-Rotor	Elevons (at 50 mph)
Max. Force (Newtons)	7.556	2.940	9.245
Min. Torque (oz-in)	87.091	33.845	59.902
Max. Torque (oz-in)	131	131	76

Front Tilt-Rotor & Tail Tilt-Rotor Servo

Elevon Servo

Product Selection

Sensor/Payload Package

Sensor Package

- Pixycam
- Characterization identification
- Capable of learning
- Open source development

Payload Package

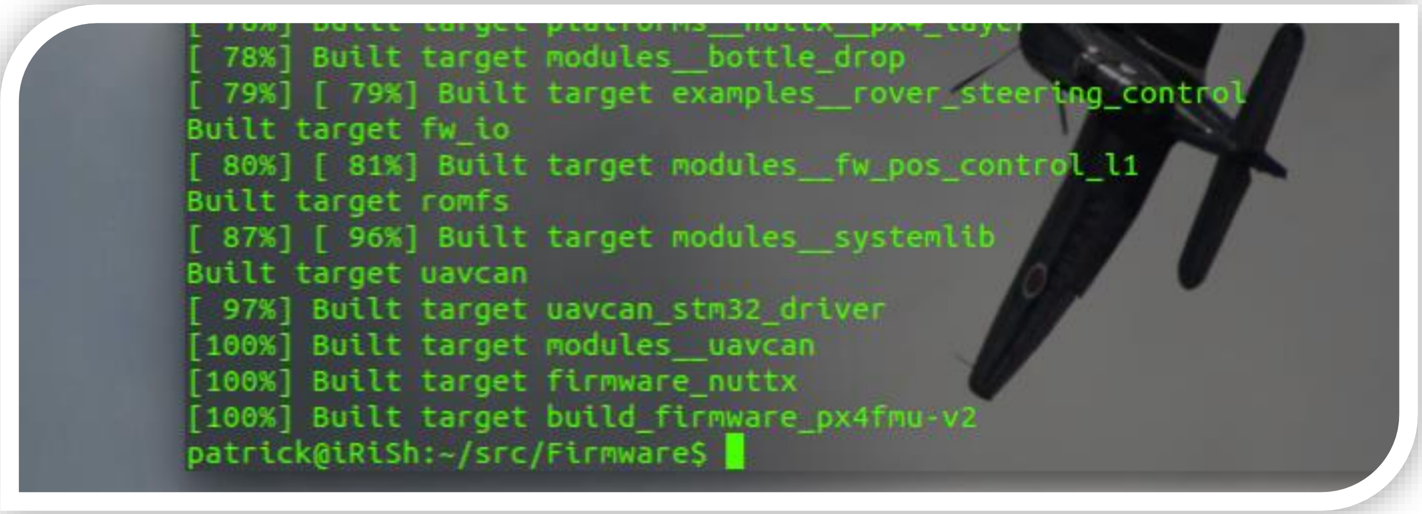
- Storage optimization
- Release mechanisms

Potential Challenges

- Autonomous flight
  - Path Planning Algorithms
  - Obstacle Avoidance Algorithms
- Vehicle Controls
  - Transitional flight
- Imaging software / hardware
  - Target recognition
  - Microcontroller communication

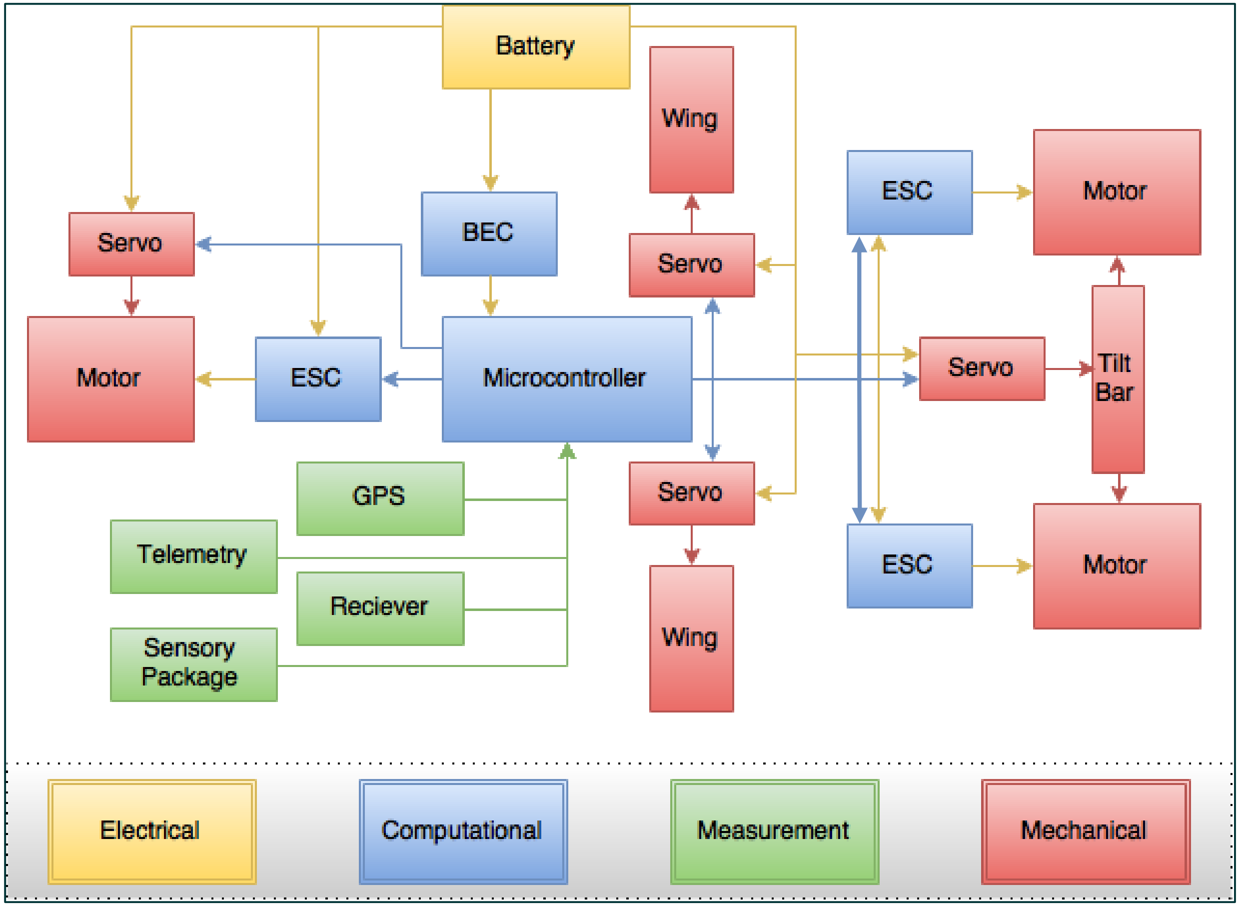
Problem Resolution

- Firmware complications
  - Switching to Ubuntu (Linux) operating system for firmware development
  - Using QGroundControl microcontroller interface

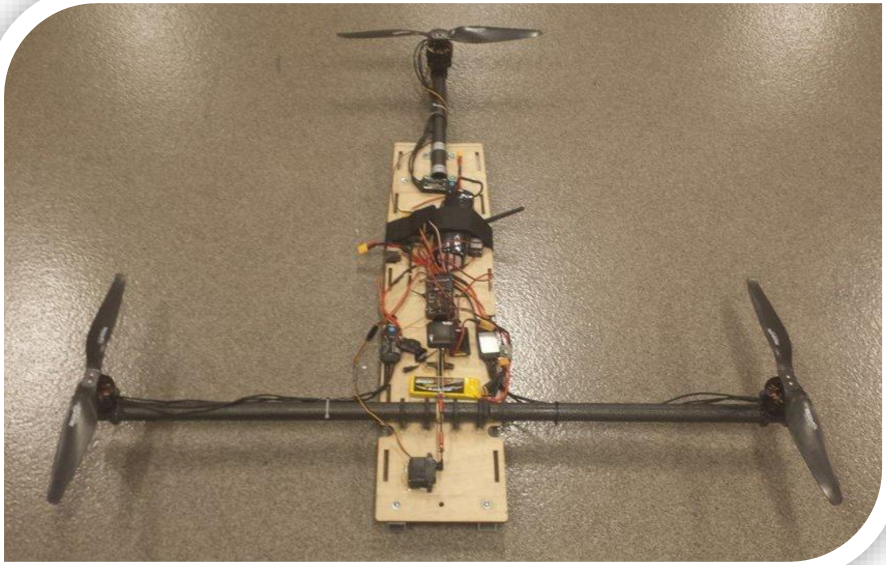


Progress
Ideal Final Design

Component Organization



Progress
Prototype I



Overall Design

- Rapid construction
- Re-use of material

Motor mounts

- ABS plastic
- Affixed with hot glue

Progress
Prototype I

Front tilt bar

- Driven by external servo
- Loose fit allows rotation
- Requires spring assist

Rear tilt mechanism

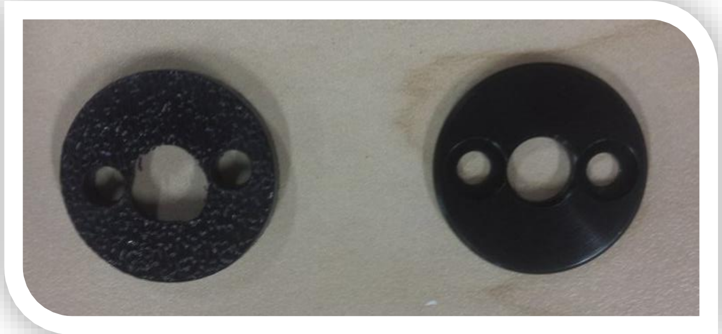
- Driven by internal servo
- Simple design
- Loose fit allows rotation

Progress
Prototype I

Conflict Resolution

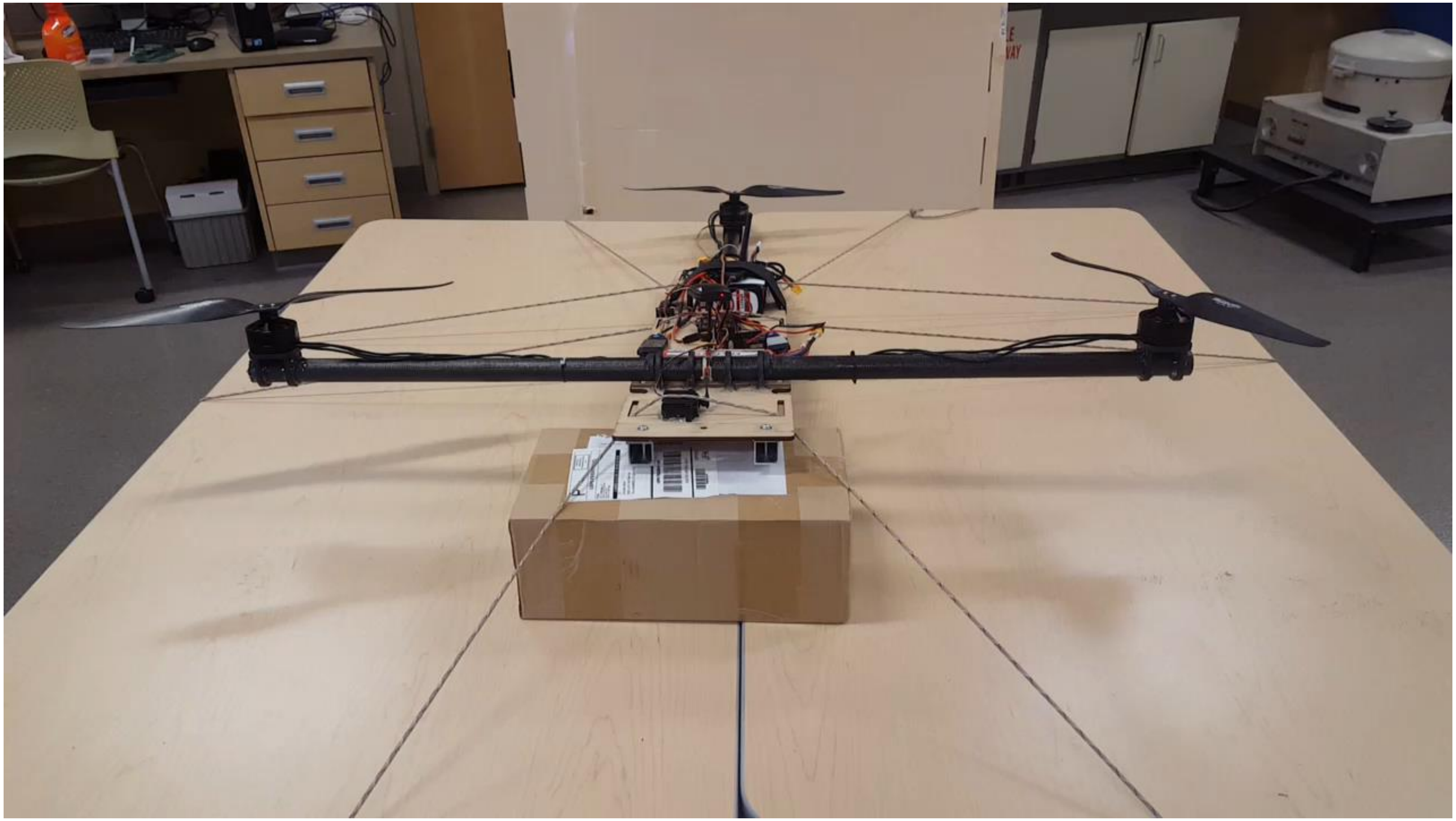
- Rear Servo Slippage
  - Epoxy reinforced

- Propeller Adapters
  - Replicas constructed



Progress
Prototype I

Front Tilt Bar and Rear Tilt Mechanism



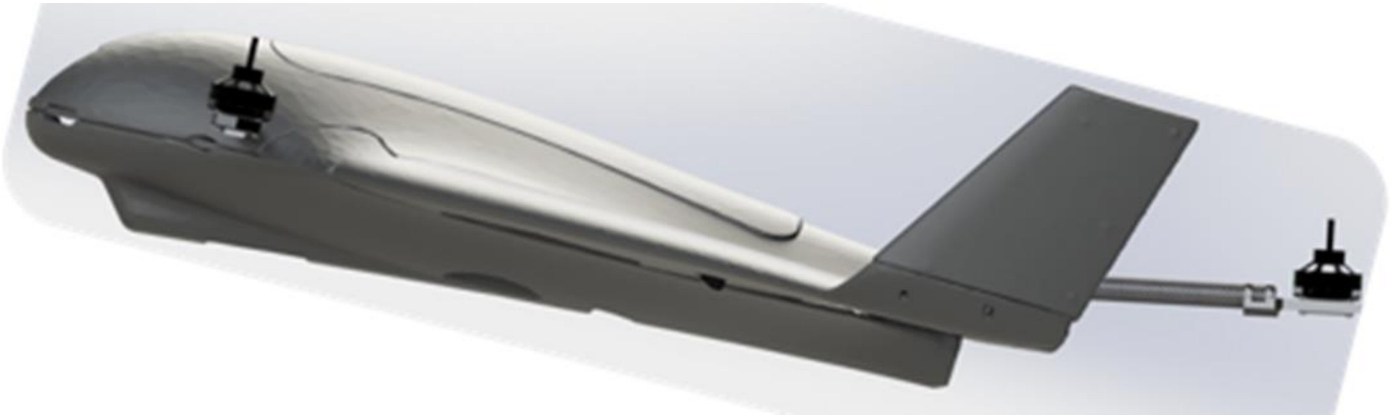
Progress
Prototype I

Manual Tricopter Flight

Progress
Prototype II

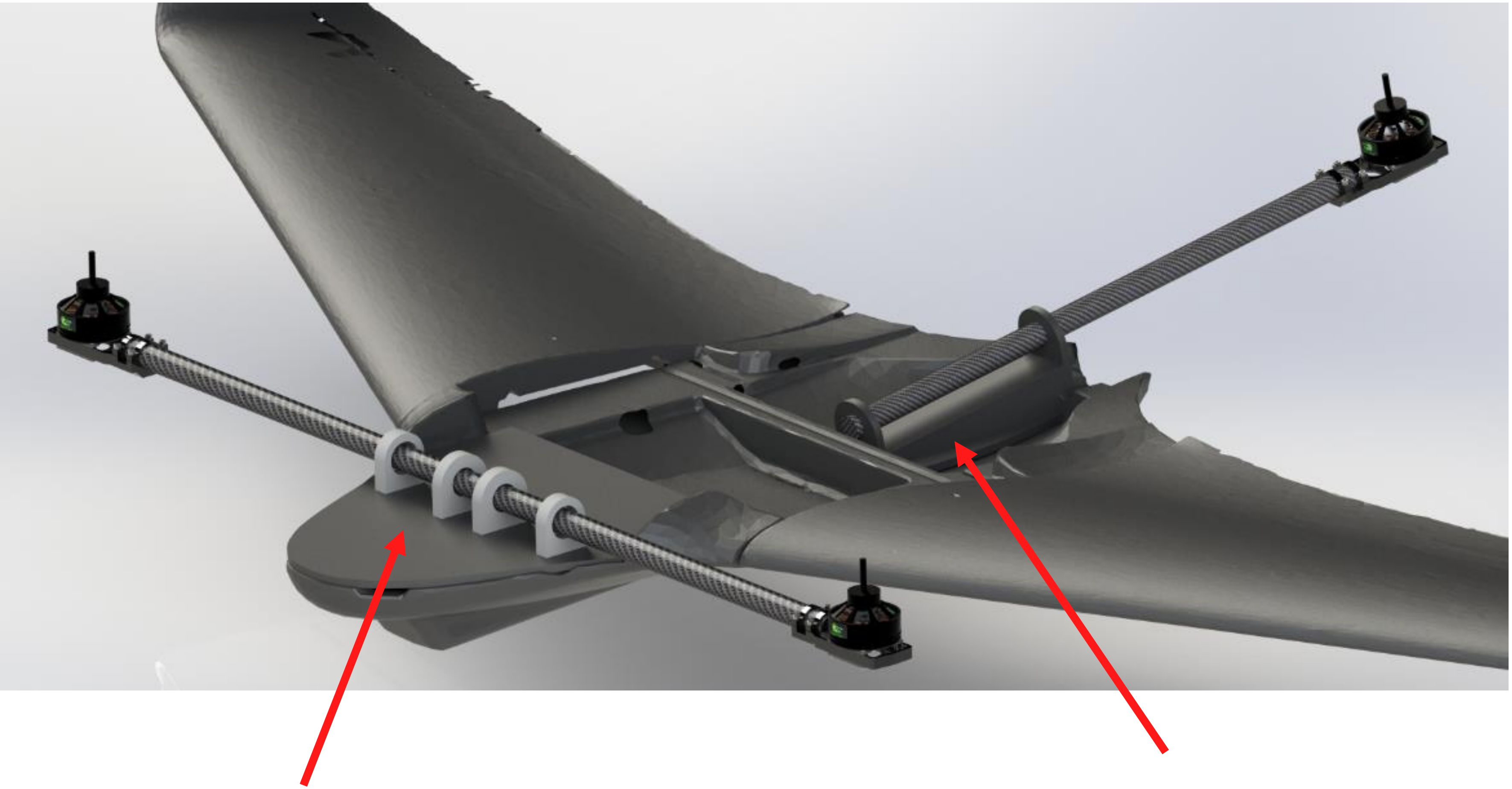
Tricopter Integration

- Needed to fix the prop arms to the foam structure
  - Front and Rear mounts designed
- Set at angle to offset initial forward motion

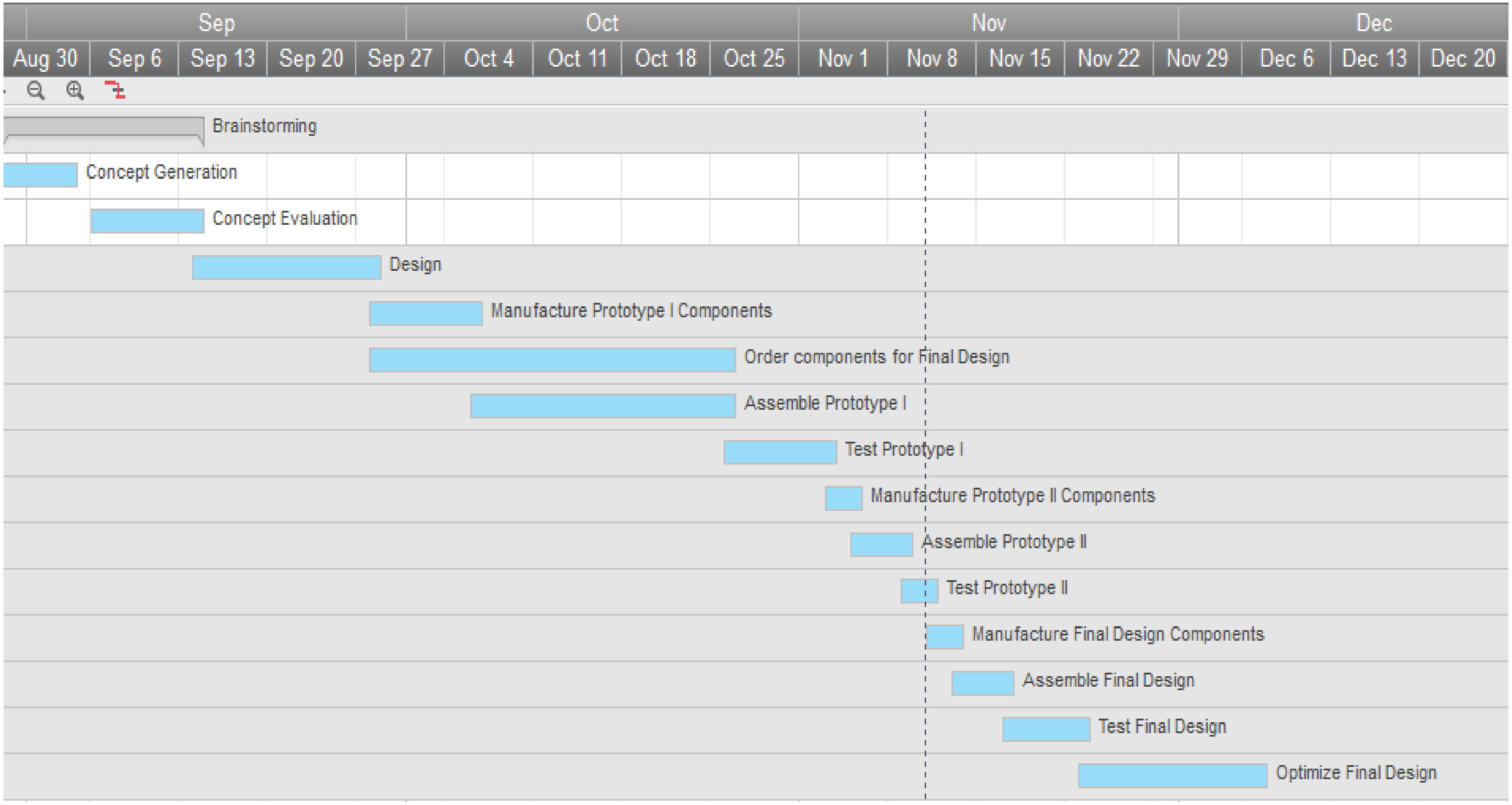


Progress

Prototype II



Gantt Chart



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Oct
Nov
Dec
Aug 30
Sep 6
Sep 13
Sep 20
Sep 27
Oct 4
Oct 11
Oct 18
Oct 25
Nov 1
Nov 8
Nov 15
Nov 22
Nov 29
Dec 6
Dec 13
Dec 20
Brainstorming
Concept Generation
Concept Evaluation
Design
Manufacture Prototype I Components
Order components for Final Design
Assemble Prototype I
Test Prototype I
Manufacture Prototype II Components
Assemble Prototype II
Test Prototype II
Manufacture Final Design Components
Assemble Final Design
Test Final Design
Optimize Final Design

Future Plans

End of Semester Goals

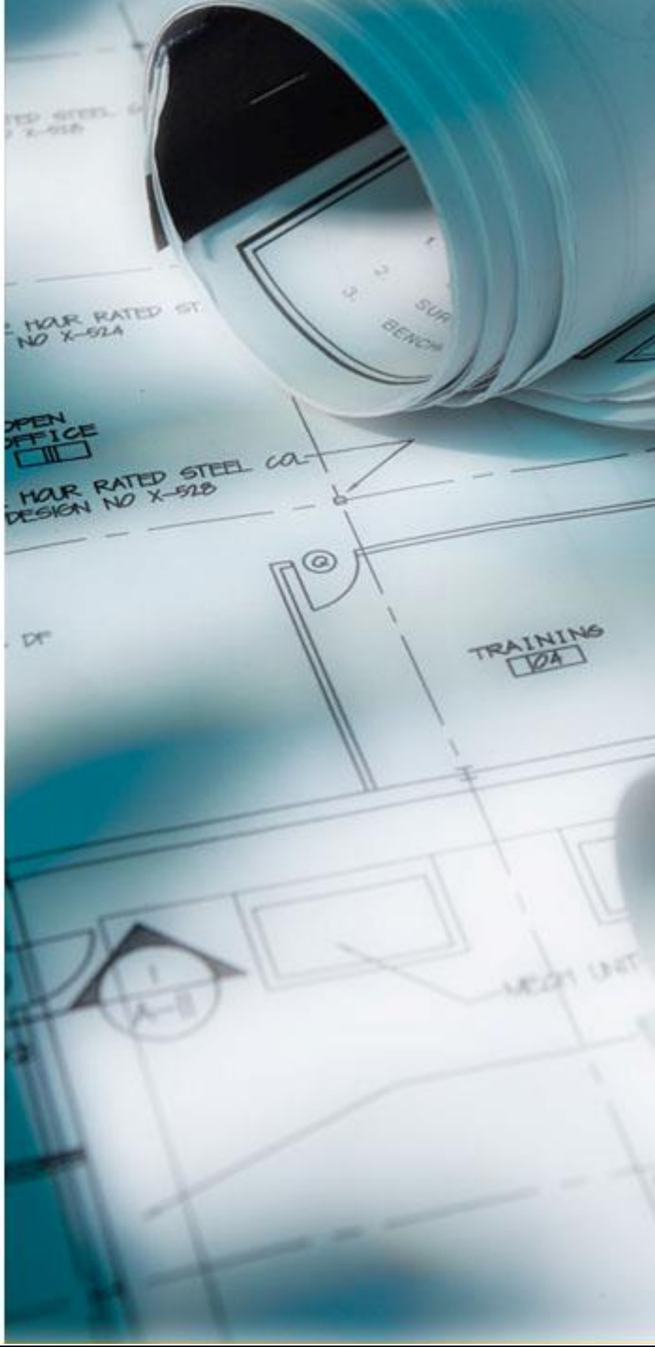
- Working autonomous vertical and horizontal flight
- Optimize gains for Pitch, Roll, Yaw control for Prototype II frame

2nd Semester - Competition Objectives

- Waypoint navigation
- Functioning sensor package
- Payload delivery

Summary

- Tri-copter
- Flying Wing
- Furthered Firmware Developement
- Tri-copter integration



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[1] - "FireFLY6 - Welcome to the Revolution." BirdsEyeView Aerobotics. N.p., 2015. Web. 20 Oct. 2015.

[2] - Hazelhurst, Jethro. "Pixhawk Graphic for Documentation." DIY Drones. N.p., 18 Dec. 2013. Web. 19 Oct. 2015.

[3] - Owenson, Gareth. "How to Build Your Own Quadcopter Autopilot / Flight Controller." Owenson.me. N.p., n.d. Web. 19 Oct. 2015. <http://owenson.me/build-your-own-quadcopter-autopilot/>.

[4] - "Cobra CM-4510/28 Multirotor Motor,KV=420." Cobra Motors USA. N.p., n.d. Web. 19 Oct. 2015. < http://www.cobramotorsusa.com/multirotor-4510-28.html>.

[5] - "Cobra 40A Opto Multirotor Esc" Cobra Motors USA. N.p., n.d. Web. 20 Oct. 2015 <http://www.cobramotorsusa.com/multirotoresc-40amp.html>.

[6] - "Cobra CM-4510/28 420Kv Motor Propeller Data" Innov8tive Designs. N.p., n.d. Web. 20 Oct. 2015 <http://innov8tivedesigns.com/images/specs/Cobra_CM-4510-28-420Kv_Specs.htm>.

Appendix

Reynold's Number:

$$Re = \frac{\vec{V} * L}{v} \quad [1]$$

Lift Equation:

$$F_L = C_L * \frac{\rho * \vec{V}^2}{2} * s \quad [2]$$

Flight Time:

$$Time = \frac{Battery\ Capacity}{Total\ Amperage} \quad [3]$$

Questions

Concept Evaluation

Quadcopter

- Inefficient with horizontal flight
- 4 motors, more power consumption

Concept Evaluation
Firefly Y6

- Payload weight is low
- Expensive
- 6 motors, even more power consumption

Concept Evaluation
Previous Year Design

- Heavy (8,238g)
- Firmware not supported
- Difficult to repair / modify
- Unstable horizontal flight
- Relatively high power consumption

Relevant Data
Motor Spec

Component	New Design
All up weight	5500g
Number of motors	3
Thrust needed per motor	~1850g or ~65oz
Thrust (n = 2)	~3700g or ~ 131oz
Size of props	16” x 5.5”

Figure 5 – 4510/450kv Cobra Motor[4]

Relevant Data

Motor Spec

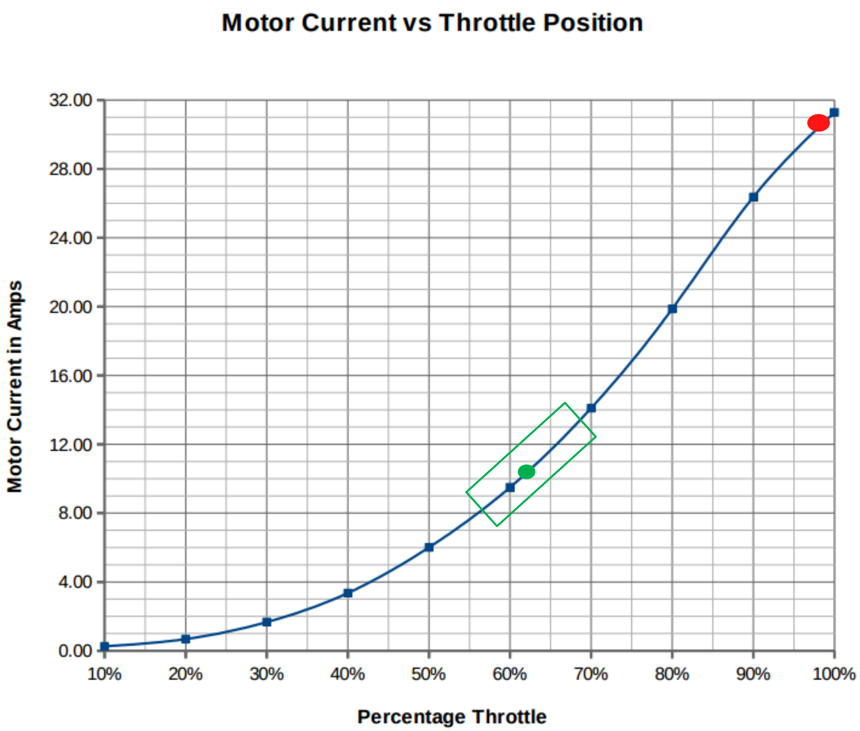


Figure 6 – Motor Current vs Throttle Position Graph

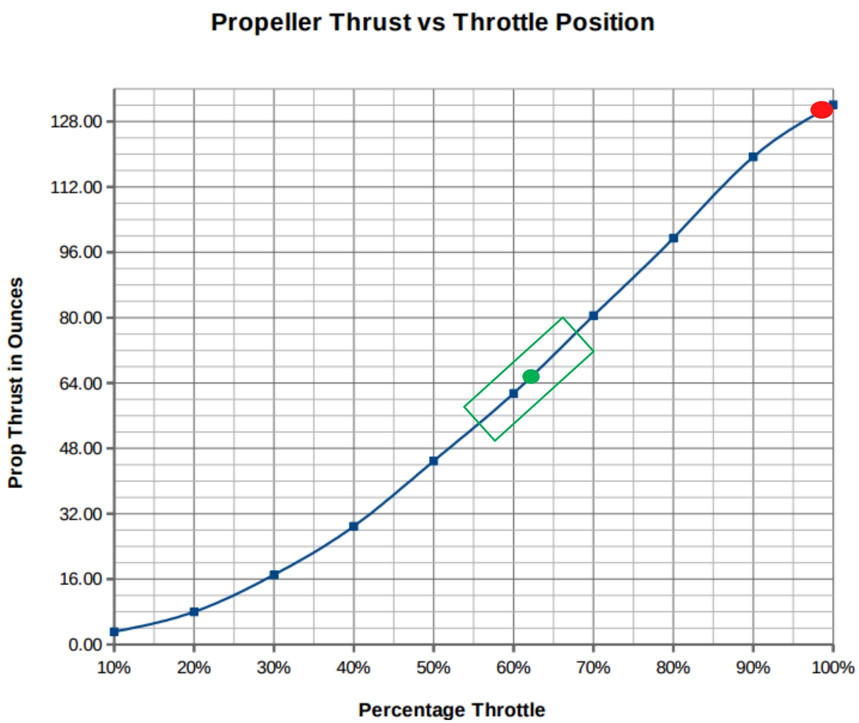


Figure 7 – Propeller Thrust vs Throttle Position Graph

- Desired weight

- Design Tolerance ($\pm 1kg$)

- Safety factor (n = 2)

Relevant Data

Prop Spec

Prop Manf.	Prop Size	Li-Po Cells	Input Voltage	Motor Amps	Input Watts	Prop RPM	Pitch Speed in MPH	Thrust Grams	Thrust Ounces	Thrust Eff. Grams/W
APC	14x5.5-MR	6	22.2	21.50	477.3	7,525	39.2	2788	98.34	5.84
APC	16x5.5-MR	6	22.2	31.29	694.6	6,915	36.0	3749	132.24	5.40
APC	18x5.5-MR	6	22.2	38.76	860.5	6,414	33.4	4468	157.60	5.19
GemFan	15x4.5-MR	6	22.2	19.73	438.0	7,638	32.5	2661	93.86	6.08
GemFan	16x4.5-MR	6	22.2	25.37	563.2	7,276	31.0	3220	113.58	5.72
RC-Timer	12x5.5-CF	6	22.2	16.44	365.0	7,874	41.0	1911	67.41	5.24
RC-Timer	13x5.5-CF	6	22.2	21.90	486.2	7,495	39.0	2417	85.26	4.97
RC-Timer	14x5.5-CF	6	22.2	29.31	650.7	7,021	36.6	2855	100.71	4.39
RC-Timer	15x5.5-CF	6	22.2	39.95	886.9	6,352	33.1	3375	119.05	3.81

Figure 9 – 4510 Cobra motor propeller comparison[6]

Propeller Chart Color Code Explanation

- (Blue) The prop is to small to get good performance from the motor. (Less than 50% power)
- (Green) The prop is sized right to get good power from the motor. (50 to 80% power)
- (Yellow) The prop can be used, but full throttle should be kept to short bursts. (80 to 100% power)

Relevant Data
Flight Time

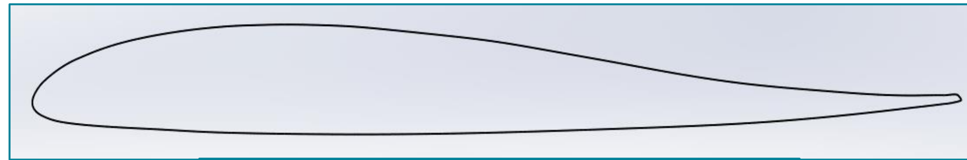
- Better flight time (65% increase) from previous year's design

Component	Old Design	New Design
Amp Draw (100%)	38.76	31.29
Number of Motors	4	3
Total Amp Draw	155.04	93.87
Flight Time (mins) [A.3]	3.87	6.39

** Based on 100% thrust, 22.2 volt system, and 10,000 mAh battery

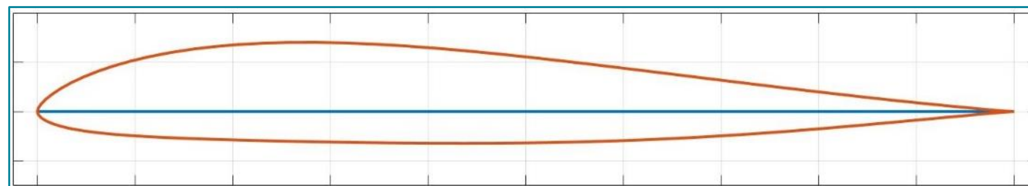
Figure 8 – Electronic Speed Controller[5]

Relevant Data
Airfoil Determination



Cross Section of Model

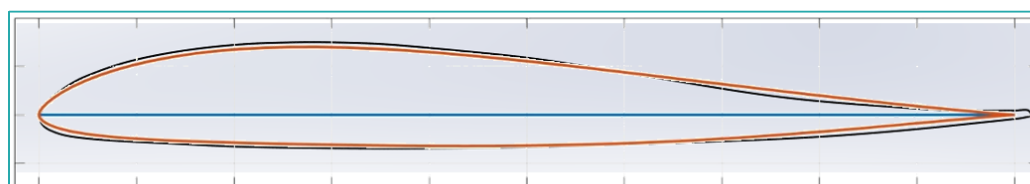
- Airfoil needed for aerodynamic characteristics



EH 2.0/10

- 2-D Sketch from 3-D model

- Tailless R/C Aircraft



Overlapping

Relevant Data
Lift and Drag Coefficients

- Airfoil Tools Analysis of EH 2.0/10
  - Based on Reynold's Number (200,000 Below)
  - Outputs lift and drag coefficients based on angle of attack (alpha)

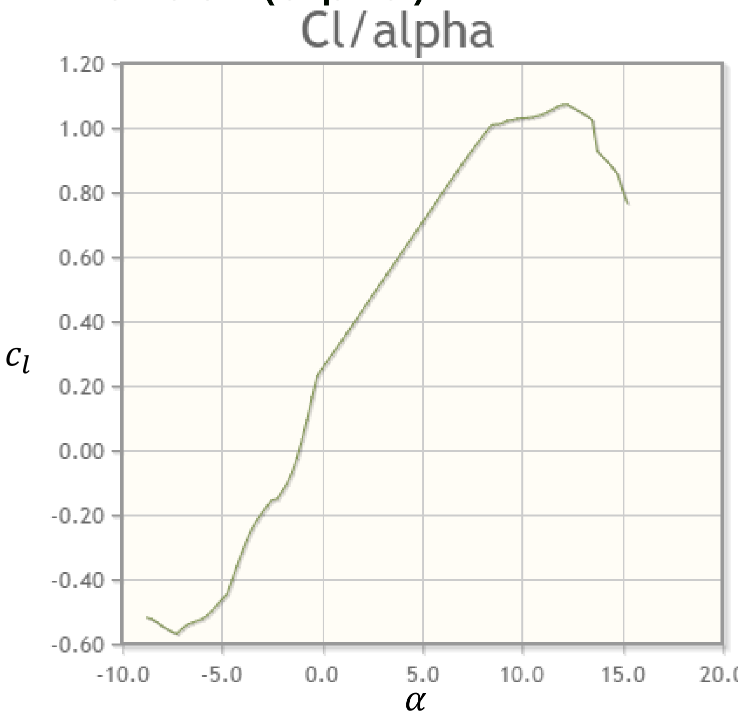


Figure 9 – Coefficient of Lift vs. Angle of Attack

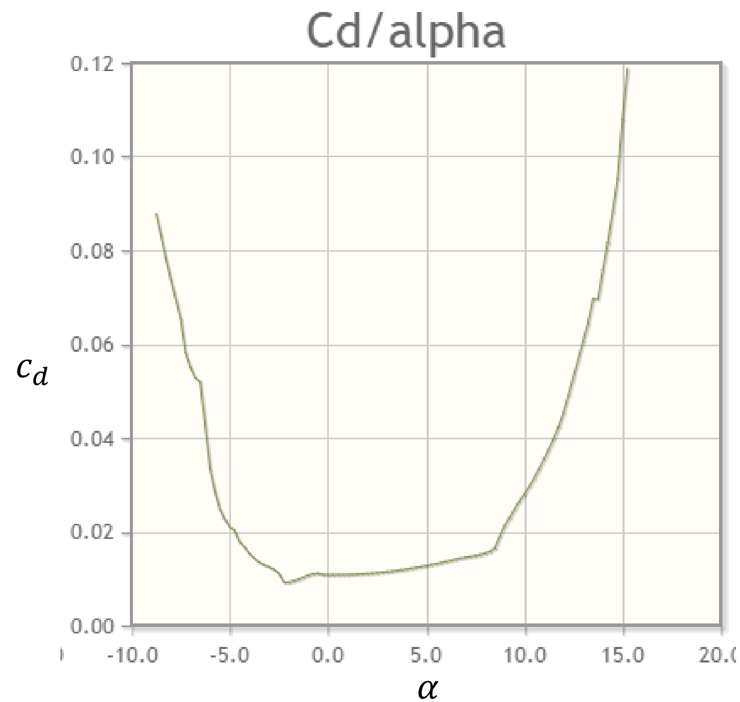


Figure 10 - Coefficient of Drag vs. Angle of Attack

Relevant Data
Lift Force

- Relationship formed from varying Reynold's Numbers (Re)
- Estimated Weight: 5500g
- Predicted Velocity: ~12.5 m/s[A.1-2]

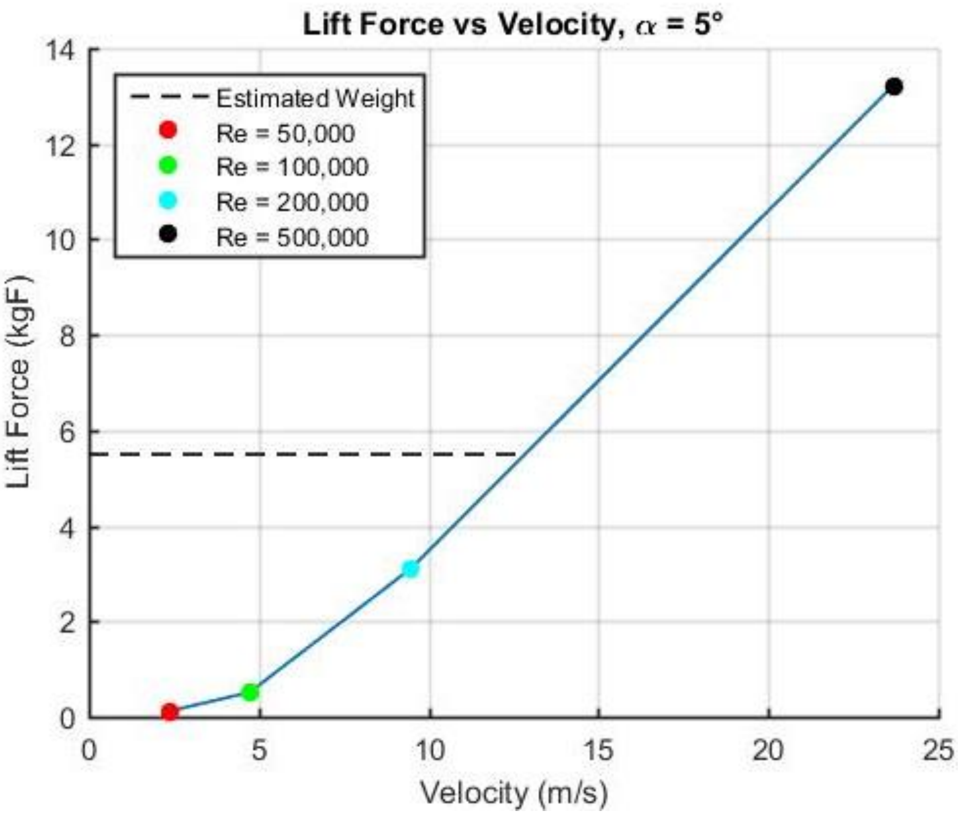


Figure 11 – Vertical Lift vs Horizontal Speed

Relevant Data
Current Firmware Code

- User-Friendly
- Open-source collaboration
- VTOL Firmware
- Diverse hardware compatibility

Figure 12 – Pixhawk Microcontroller[2]

Product Selection

Controls-Servo Torque Calculations

Front Tilt-Rotor

Force on servo

F = m*a

F = 0.772g * 9.8 m/s

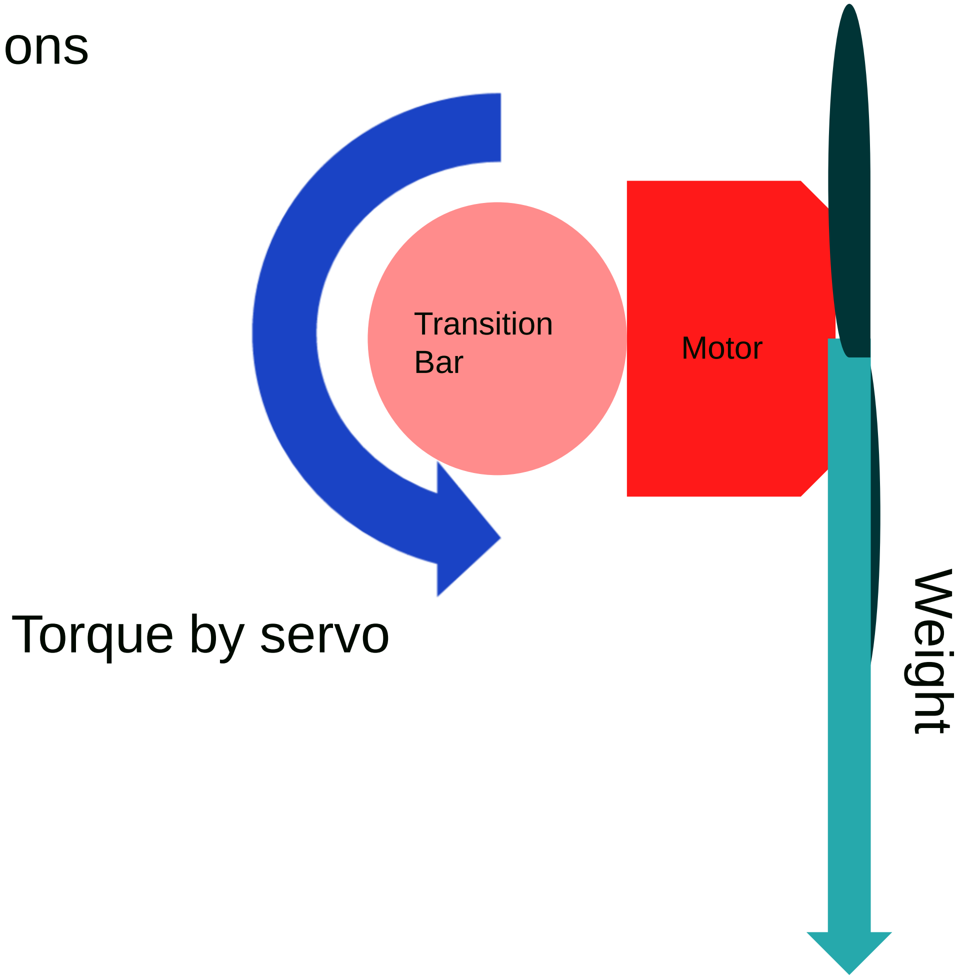
F = 7.566 N

Torque on servo

T = r*F

T = 0.08128m * 7.566N

T = 0.615Nm = 87.091 oz-in



Front Tilt-Rotor & Tail Tilt-Rotor Servo

Product Selection

Controls-Servo Torque Calculations

Tail Tilt-Rotor

Force on servo

F = m*a

F = 0.300g * 9.8 m/s

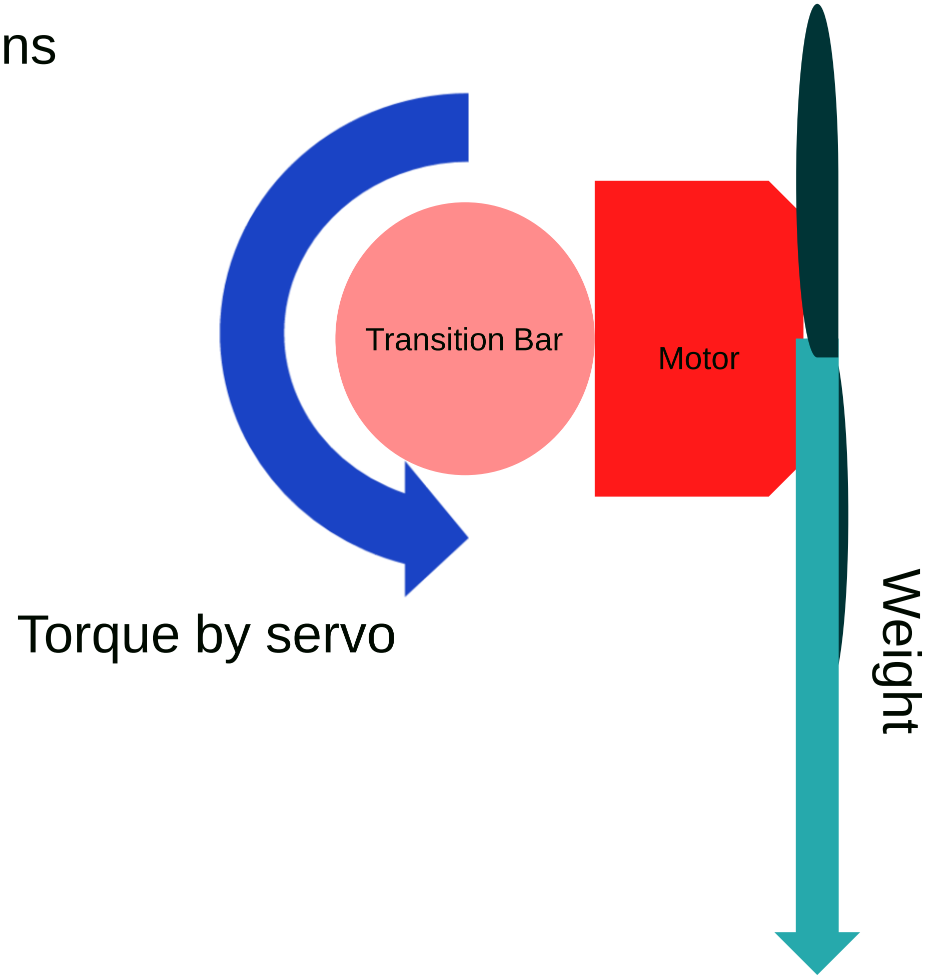
F = 2.940 N

Torque on servo

T = r*F

T = 0.08128m * 2.940N

T = 0.239Nm = 33.845 oz-in



Front Tilt-Rotor & Tail Tilt-Rotor Servo

Product Selection

Controls-Servo Torque Calculations

Elevon

Elevon Servo

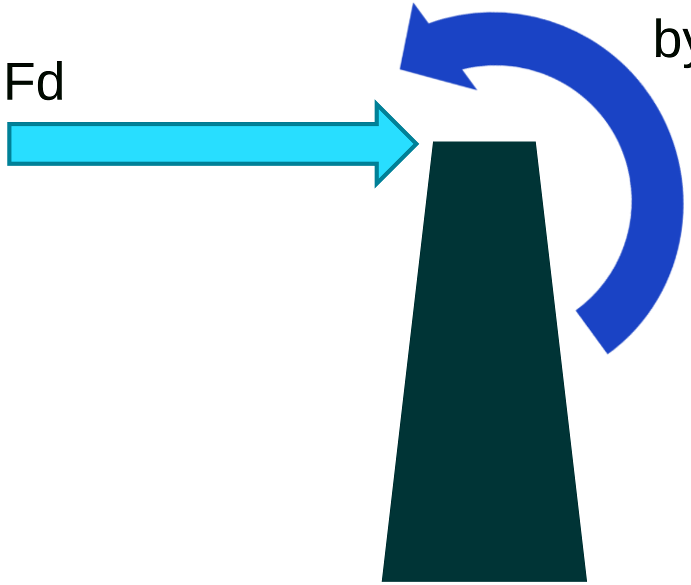
Force on servo

Force of Drag = F_D

$F_D = \frac{1}{2}\rho V^2 A C_D$

F_D = ½ * 1.225kg/m^3 * (22.35 m/s)^2 * 0.02288m^2 * 1.3206

F = 9.245 N



Torque on servo

T = r*F

T = 0.04537m * 9.245N

T = 0.423Nm = 59.902 oz-in