# SAE Aero Design

## Project Proposal

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# Introduction

- Build an airplane that adheres to SAE requirements.
- Constraints include a maximum combined dimensions of 175 in, specific payload bay area volume, and must have a 1000 W power limiter
- Implementation of cutting edge design software
- The team has created decision matrices and concepts for the most critical functionalities to determine the best design alternatives
- The design phase has begun, starting with the wing and tail designs.

# Need Statement

Northern Arizona University does not have an airplane design to compete in the SAE Aero design competition, so the team is tasked with the design and construction of the airplane.

# Project Goals

- Design and build an aircraft that adheres to the SAE Aero competition requirements
- Gain valuable knowledge in the mechanical engineering design and manufacturing processes, specifically in airplane design
- Compile an excellent report detailing the design and manufacturing processes and orally present the final design
- Win the SAE Aero Regular class competition

# Objectives

| **Objective** | **Measurement** | **Units of Measurement** |
|---|---|---|
| Carry max payload | Weight | Pounds Force (lbf) |
| Carry a payload from point A to B | Distance | Feet (ft) |
| Small turning radius | Distance | Feet (ft) |

# Constraints

- Freestanding aircraft must not exceed a combined length, width and height of 175 in
- Aircraft must be powered by a commercially available lithium-polymer battery pack
- Must use a new 2015 version 1000 W power limiter provided by Neumotors.com
- Interior payload bay must be smooth and dimensions must be 10’’x4’’ x4’’ (length, width, height) with a tolerance of +0.125”

# Constraints

- Payload must be secured to an airframe, with payload plates
- Airplane must land and take off within 200 ft
- Must complete all tasks within 180 s

# Criteria

**Airfoil**

- Coefficient of Lift (max)
- Design Lift Coefficient
- Coefficient of Drag
- Lift-to-Drag Ratio
- Lift Curve Slope (max)
- Pitching Moment Coefficient
- Stall Quality

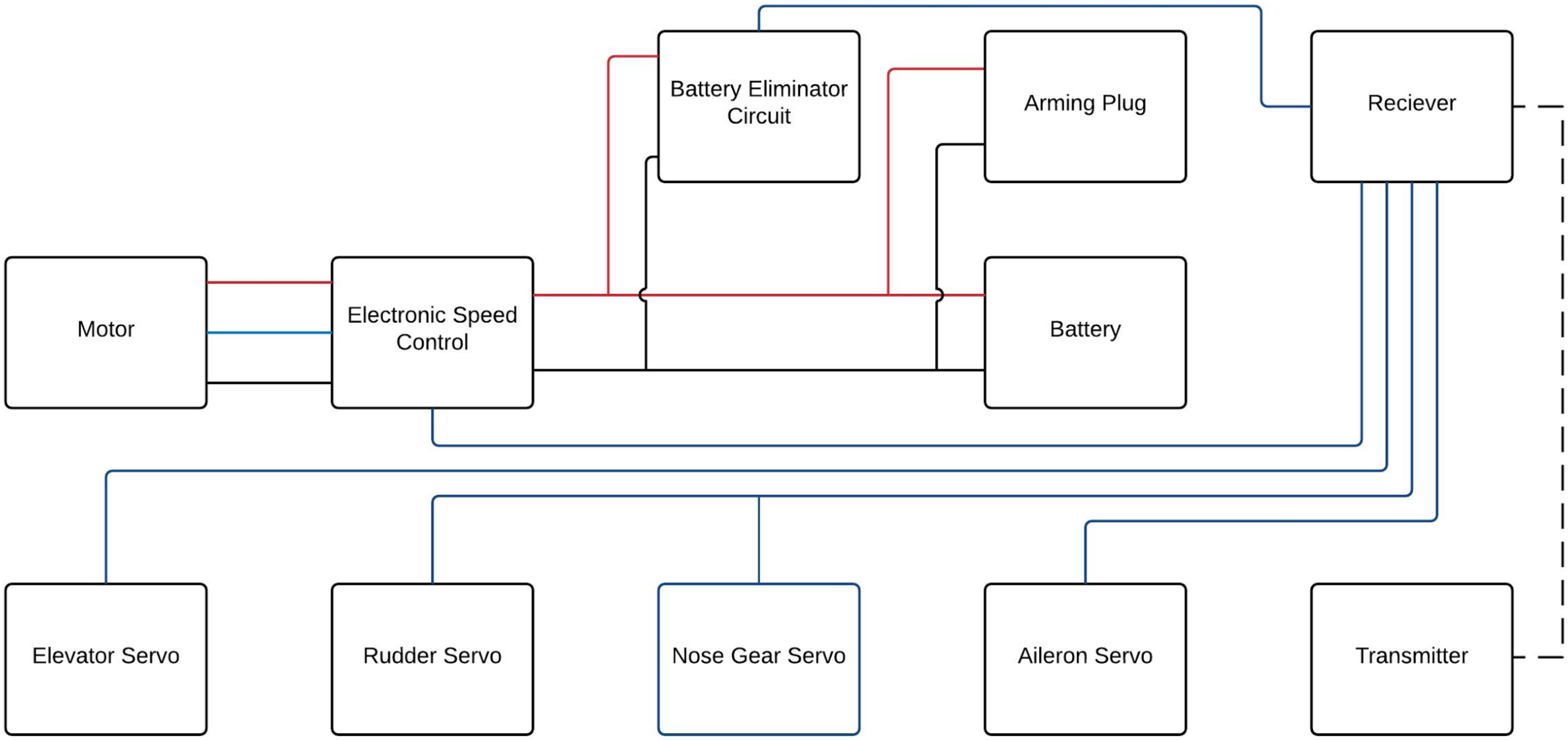
**Wing Placement Configuration**

- Weight
- Loading
- Coefficient of Lift (max)
- Coefficient of Drag (min)
- Lift-to-Drag Ratio

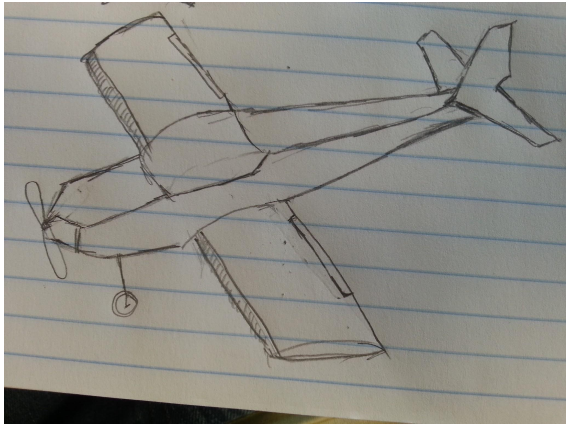
**Vertical and Horizontal Stabilizers**

- Stability Coefficient
- Pitching Control
- Yaw Control
- Weight

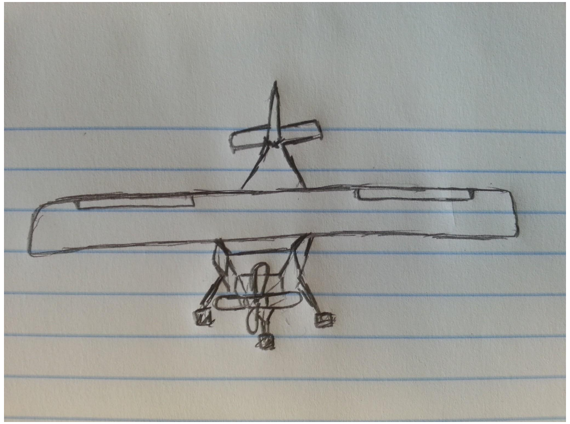
# Functional Diagram



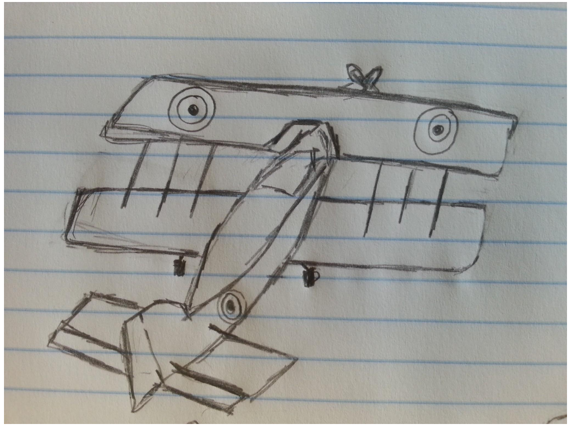
# Concept Generation - Wing Placement Configuration



**MONOWING LOW PLACEMENT**

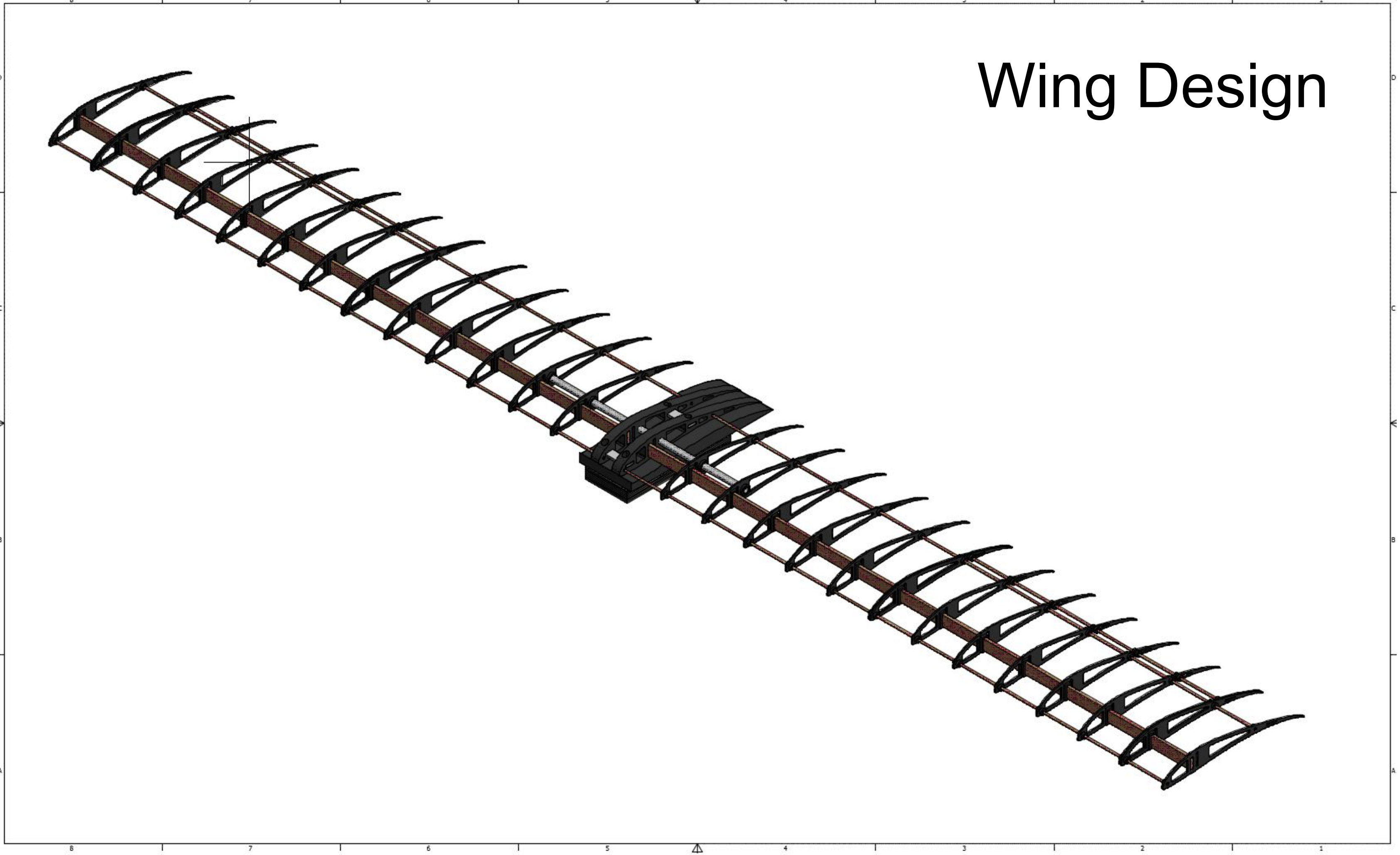


**MONOWING HIGH PLACEMENT**

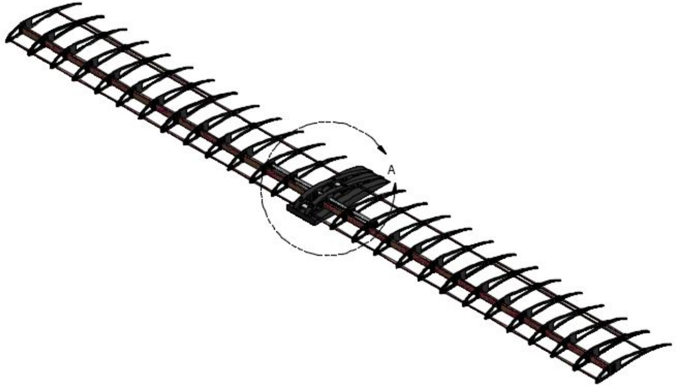


**BIPLANE**

# Wing Design

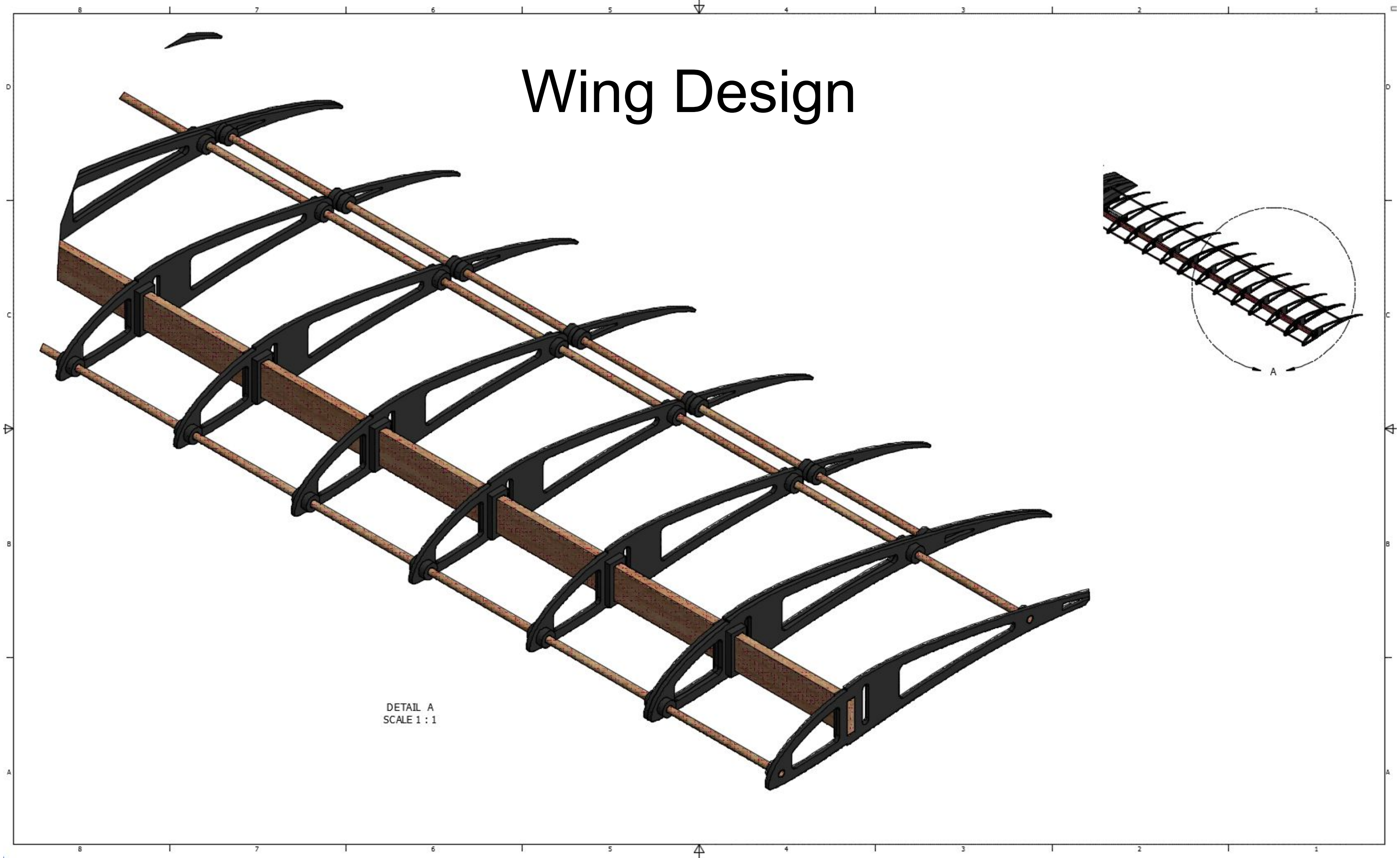


# Wing Design

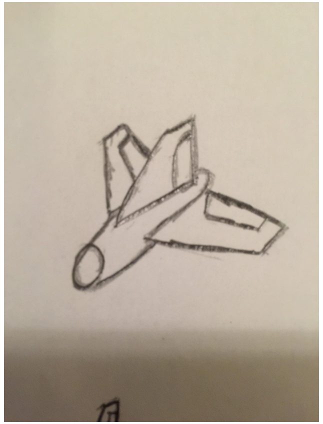



DETAIL A
SCALE 1 : 1

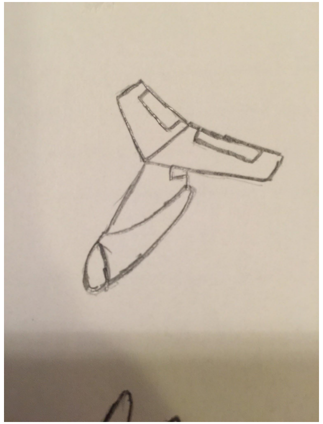
# Wing Design



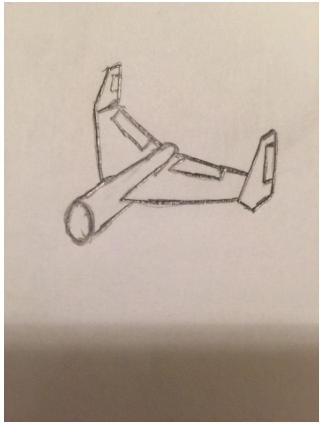
# Concept Generation - Vertical and Horizontal Stabilizers



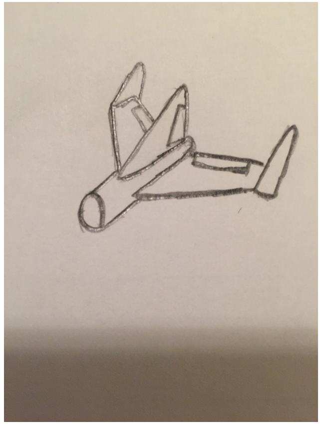
**Conventional Tail**



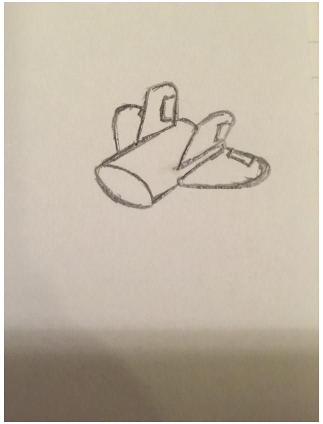
**T-tail**



**Dual Tail**



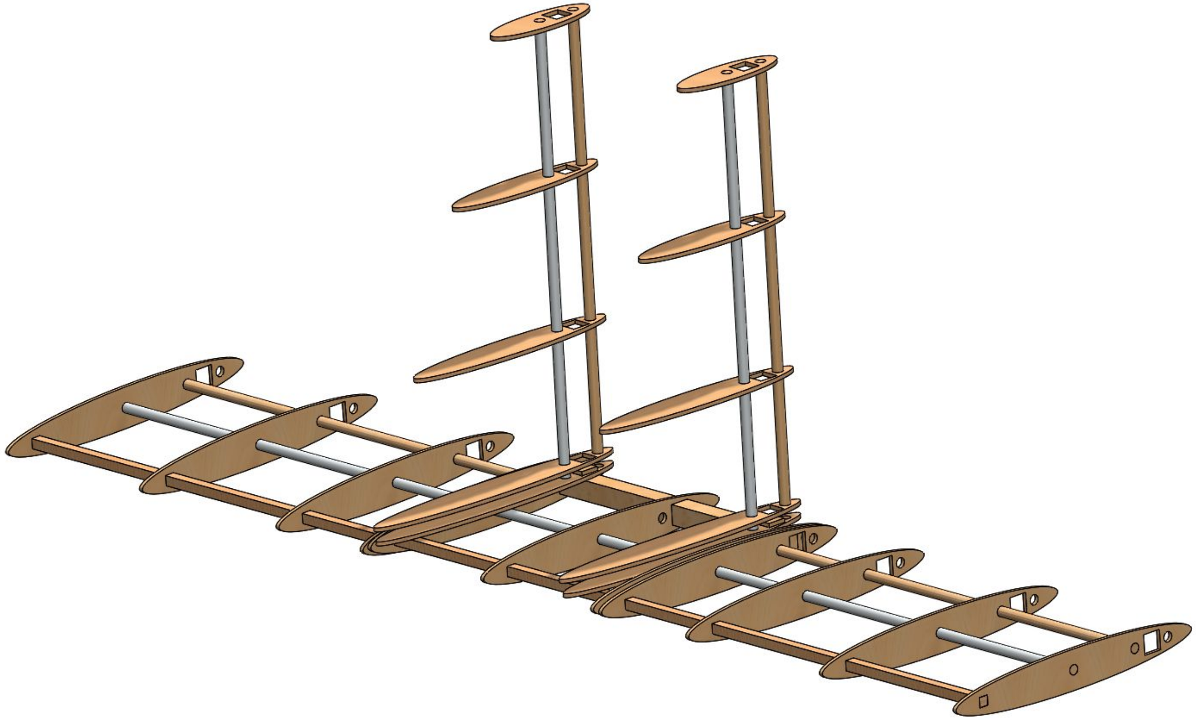
**Triple Tail**

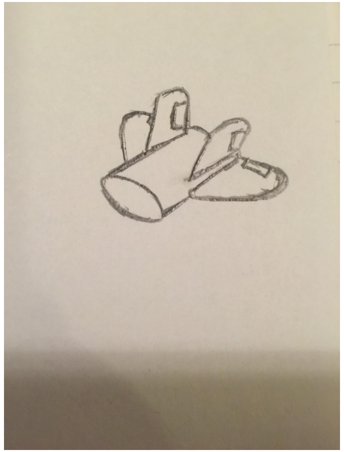


**Twin Tail**

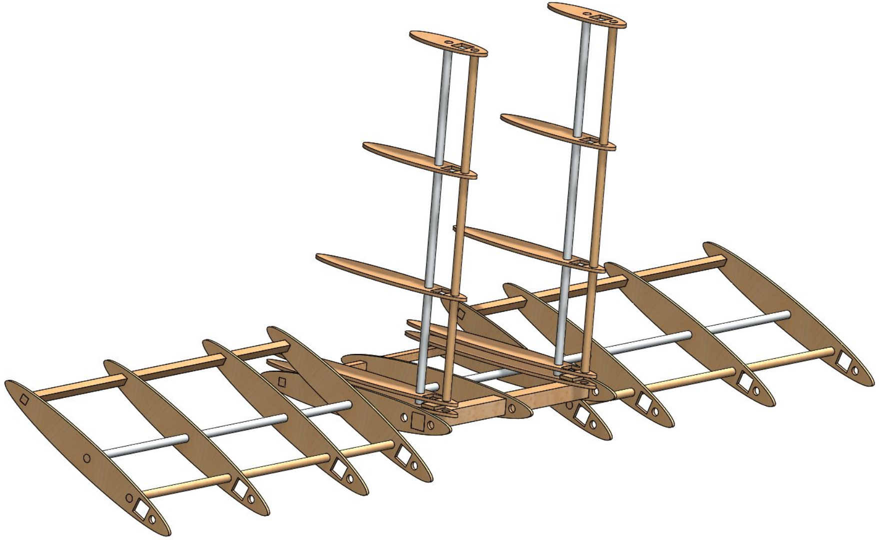
# Tail Design

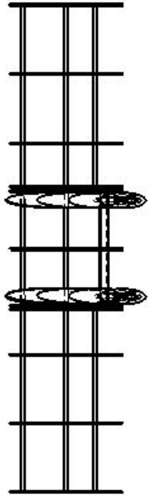
Twin tail

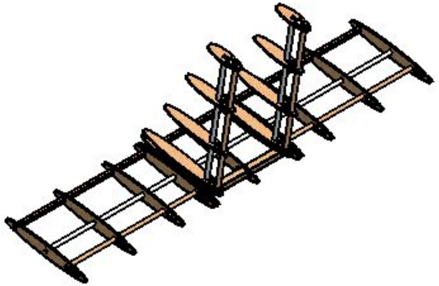


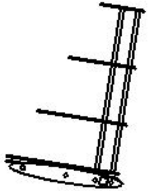


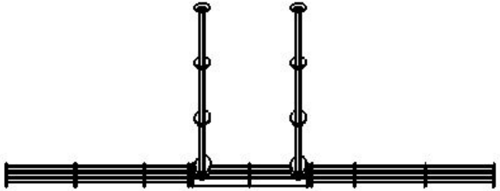
# Tail Design











# Final Components

- Motor - AXI 5325/16 GOLD LINE


- Propeller - APC 18x12WE

- ESC/BEC-CASTLE CREATIONS Phoenix Edge 75

# Final Components

- Battery-Eflight 3200mAh 6S 22.2V 30C LiPo, 12AWG EC3

- Receiver-AR610 6-Channel DSMX Aircraft Receiver (SPMAR610)

- Servos-Extra High Torque Servo (SPMS601H)

# Flight Calculations

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **General** | Motor Cooling: medium | # of Motors: 1 (on same Battery) | Model Weight: 4536 g / 160 oz; incl. Drive | | Wing Area: 96.8 $dm^2$ / 1500 $in^2$ | Field Elevation 500 m ASL / 1640 ft ASL | Air Temperature 25 °C / 77 °F | Pressure (QNH): 1013 hPa / 29.91 inHg |
| **Battery Cell** | Type (Cont. / max. C) - charge state: LiPo 3300mAh - 30/45C - normal | Configuration: 6 S 1 P | Cell Capacity: 3300 mAh | Total Capacity: 3300 mAh | Resistance: 0.0052 Ohm | Voltage: 3.7 V | C-Rate: 30 C cont. / 45 C max | Weight: 93 g / 3.3 oz |
| **Controller** | Type: CC Phoenix Edge 75 | cont. Curent: 75 A | max. Curent: 75 A | | Resistance: 0.010 Ohm | | | Weight: 114 g / 4 oz |
| **Motor** | Manufacturer - Type (Kv): AXI 5325/16 (350); search... | KV (w/o torque): 350 rpm/V | no-load Current: 2.1 A @ 30 V | Limit (up to 15s): 85 A | Resistance: 0.026 Ohm | Case Length: 59 mm / 2.32 inch | # mag. Poles: 14 | Weight: 575 g / 20.3 oz |
| **Propeller** | Type - yoke twist: APC Electric E - 0° | Diameter: 18 inch | Pitch: 12 inch | # Blades: 2 | PConst / TConst: 1.08 / 1.0 | Gear Ratio: 1 : 1 | Flight Speed: 32.2 km/h / 20 mph | calculate |

# Flight Calculations


Load:


Mixed Flight Time:


Current:


est. Temperature:


Thrust-Weight:


Pitch Speed:

**Remarks:**

**Battery**

| | | |
|---|---|---|
| Load: | 20.21 | C |
| Voltage: | 20.12 | V |
| Rated Voltage: | 22.20 | V |
| Capacity: | 3300 | mAh |
| Energy: | 73.26 | Wh |
| Flight Time: | 3.0 | min |
| Mixed Flight Time: | 5.2 | min |
| Weight: | 558 | g |
| | 19.7 | oz |

**Motor @ Optimum Efficiency**

| | | |
|---|---|---|
| Current: | 33.62 | A |
| Voltage: | 20.81 | V |
| Revolutions*: | 6725 | rpm |
| electric Power: | 699.8 | W |
| mech. Power: | 633.1 | W |
| Efficiency: | 90.5 | % |

**Motor @ Maximum**

| | | |
|---|---|---|
| Current: | 66.69 | A |
| Voltage: | 19.45 | V |
| Revolutions*: | 5927 | rpm |
| electric Power: | 1297.3 | W |
| mech. Power: | 1136.6 | W |
| Efficiency: | 87.6 | % |
| est. Temperature: | 75 | °C |
| | 167 | °F |

**Propeller**

| | | |
|---|---|---|
| Static Thrust: | 6615 | g |
| | 233.3 | oz |
| Revolutions*: | 5927 | rpm |
| Stall Thrust: | 3844 | g |
| | 135.6 | oz |
| Thrust @ 32.2 km/h: | 4650 | g |
| Thrust @ 20 mph: | 164 | oz |
| Pitch Speed: | 108 | km/h |
| | 67 | mph |
| Tip Speed: | 511 | km/h |
| | 317 | mph |
| specific Thrust: | 2.96 | g/W |
| | 0.1 | oz/W |

**Total Drive**

| | | |
|---|---|---|
| Drive Weight: | 1372 | g |
| | 48.4 | oz |
| Power-Weight: | 326 | W/kg |
| | 148 | W/lb |
| Thrust-Weight: | 1.46 | : 1 |
| P(in) @ max: | 1480.5 | W |
| P(out) @ max: | 1136.6 | W |
| Efficiency @ max: | 76.8 | % |

**Airplane**

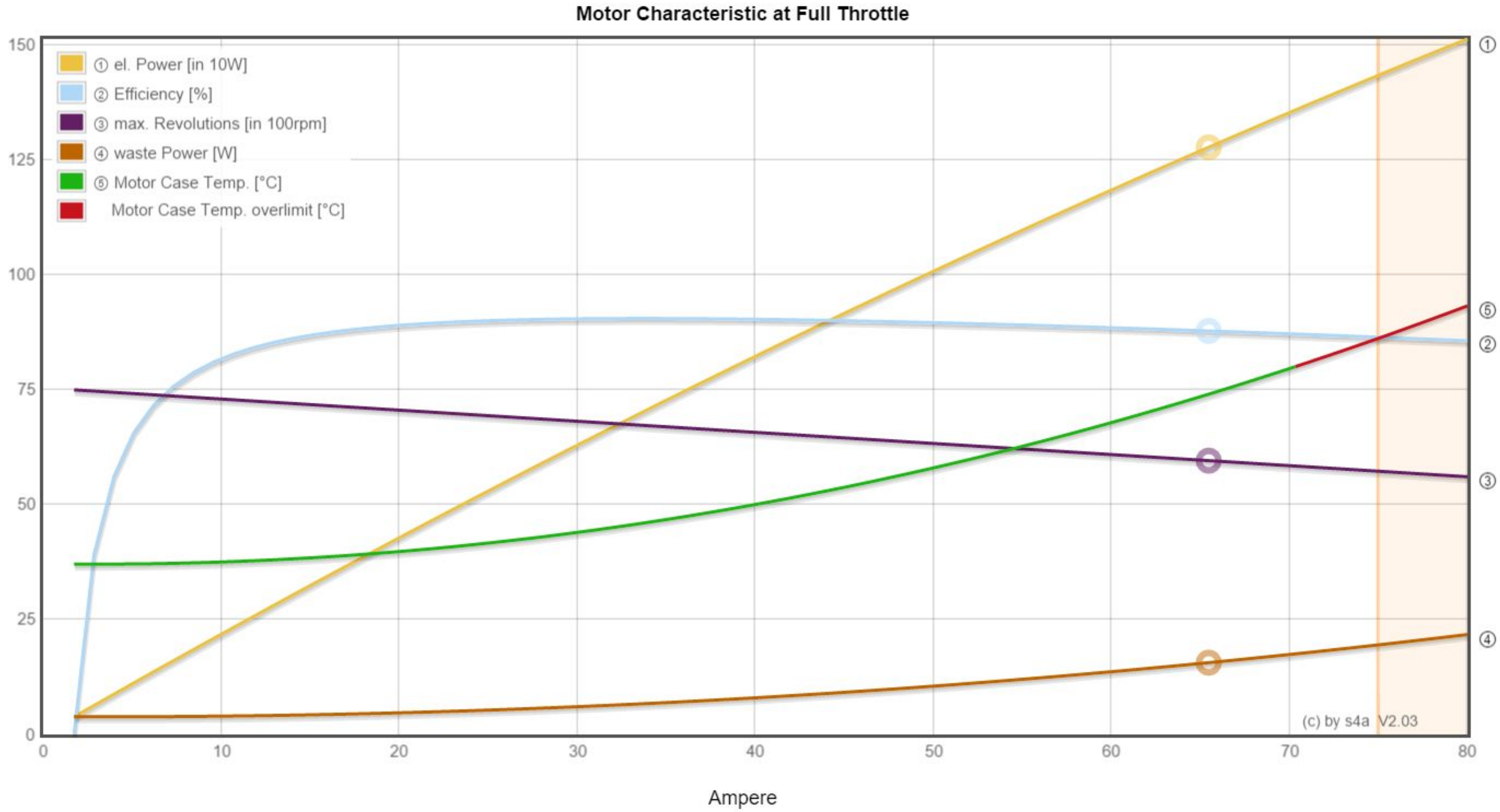
| | | |
|---|---|---|
| All-up Weight: | 4536 | g |
| | 160 | oz |
| Wing Load: | 47 | g/dm² |
| | 15.4 | oz/ft² |
| Cubic Wing Load: | 4.8 | |
| est. Stall Speed: | 33 | km/h |
| | 20 | mph |
| est. Speed (level): | 97 | km/h |
| | 60 | mph |
| est. Speed (vertical): | 33 | km/h |
| | 20 | mph |
| est. rate of climb: | 10.1 | m/s |
| | 1982 | ft/min |

# Flight Calculations

**Motor Partial Load**

| Propeller rpm | Throttle % | Current (DC) A | Volage (DC) V | el. Power W | Efficiency % | Thrust g | Spec. Thrust g/W | Pitch Speed km/h | Thrust oz | Spec. Thrust oz/W | Pitch Speed mph | Flight Time (85%) min |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 800 | 11 | 0.3 | 22.2 | 6.2 | 45.3 | 121 | 19.6 | 15 | 4.3 | 0.69 | 9 | 599.9 |
| 1200 | 17 | 0.7 | 22.2 | 14.8 | 63.9 | 271 | 18.4 | 22 | 9.6 | 0.65 | 14 | 250.2 |
| 1600 | 22 | 1.4 | 22.2 | 30.0 | 74.5 | 482 | 16.1 | 29 | 17.0 | 0.57 | 18 | 122.9 |
| 2000 | 28 | 2.5 | 22.1 | 54.1 | 80.6 | 753 | 13.9 | 37 | 26.6 | 0.49 | 23 | 67.8 |
| 2400 | 34 | 4.1 | 22.1 | 89.6 | 84.1 | 1085 | 12.1 | 44 | 38.3 | 0.43 | 27 | 40.8 |
| 2800 | 40 | 6.4 | 22.0 | 138.9 | 86.2 | 1476 | 10.6 | 51 | 52.1 | 0.37 | 32 | 26.2 |
| 3200 | 47 | 9.5 | 21.9 | 204.5 | 87.4 | 1928 | 9.4 | 59 | 68.0 | 0.33 | 36 | 17.7 |
| 3600 | 53 | 13.6 | 21.8 | 288.9 | 88.1 | 2440 | 8.4 | 66 | 86.1 | 0.30 | 41 | 12.4 |
| 4000 | 60 | 18.7 | 21.6 | 394.9 | 88.4 | 3013 | 7.6 | 73 | 106.3 | 0.27 | 45 | 9.0 |
| **4400** | **67** | **25.2** | **21.4** | **525.1** | **88.5** | **3646** | **6.9** | **81** | **128.6** | **0.24** | **50** | **6.7** |
| 4800 | 75 | 33.2 | 21.2 | 682.3 | 88.4 | 4339 | 6.4 | 88 | 153.0 | 0.22 | 55 | 5.1 |
| 5200 | 83 | 42.9 | 20.9 | 869.2 | 88.2 | 5092 | 5.9 | 95 | 179.6 | 0.21 | 59 | 3.9 |
| 5600 | 92 | 54.9 | 20.5 | 1088.9 | 88.0 | 5905 | 5.4 | 102 | 208.3 | 0.19 | 64 | 3.1 |
| 5927 | 100 | 66.7 | 20.1 | 1297.3 | 87.6 | 6615 | 5.1 | 108 | 233.3 | 0.18 | 67 | 2.5 |

# Flight Calculations



## Bill of Materials

| Items | Quantity | Description | Cost |
|---|---|---|---|
| Motor | 1 | AXI 5325/16 GOLD LINE | $299.99 |
| Motor mount | 1 | N/A | |
| Propeller | 1 | APC 18x12WE | $11.72 |
| Nose gear | 1 | Nose Gear with Nose Gear Mount Block (HAN1306) | $4.99 |
| Landing gear | 1 | Constructing at machine shop | |
| ESC/BEC | 1 | CASTLE CREATIONS Phoenix Edge 75 | $101.96 |
| Battery | 1 | Eflight 3200mAh 6S 22.2V 30C LiPo, 12AWG EC3 | $99.99 |
| Arming plug | 1 | SAE 2016 Arming Safety Harness | $30.00 |
| Power limiter | 1 | SAE Limiter V2 2016 | $50.00 |
| Receiver | 1 | AR610 6-Channel DSMX Aircraft Receiver (SPMAR610) | $49.99 |
| Servos | 5 | Extra High Torque Servo (SPMS601H) | $44.99 |
| Y-harness | 2 | Y-Harness: Telemetry (SPM1516) | $5.99 |
| Wheels (2 orders) | 4 | Big Wheels, 4" (DUB400RV) | $15.49 |
| Balsa dowels | 10 | 3/16" x 3' balsa dowels | $57.80 |
| Balsa sheeting | 6 | Balsa Sheet 3/16 x 12 x 36 | $112.59 |
| Pine spar | 2 | 2in.x4in.x10ft Kiln-Dried Heat Treated Spruce-Pine-Fir Lumber (161659) | $4.05 |
| Aluminum tubing | 1 | 36 in. x 1/2 in. x 1/16 in. Aluminum Round Tube | $10.67 |
| Aluminum sheeting | n/a | 3/16" Aluminum Scraps | Donated |
| 1/32-in nylon-coated cable | 1 | Loos Galvanized Steel Wire Rope, Nylon Coated, 7x7 Strand Core | $12.16 |
| ABS | 29.58in^3 | $250/52in^3 | $142.22 |
| **TOTAL** | | | **$1,054.60** |

# Project Plan

| Task | W 1 | W 2 | W 3 | W 4 | W 5 | W 6 | W 7 | W 8 | W 9 | W 10 | W 11 | W 12 | W 13 | W 14 | W 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Client meeting | | ■ | | | | | | | | | | | | | |
| Define problem and layout project plan | | | ■ | ■ | | | | | | | | | | | |
| Research design | | | ■ | ■ | | | | | | | | | | | |
| Research protocol writing | | | ■ | ■ | | | | | | | | | | | |
| Research parts of design | | | | | ■ | | | | | | | | | | |
| Functional diagram | | | | | ■ | ■ | ■ | | | | | | | | |
| Concept Generation | | | | | ■ | ■ | | | | | | | | | |
| Decision Matrix | | | | | | ■ | ■ | ■ | | | | | | | |
| Sketch Parts | | | | | | | | ■ | | | | | | | |
| Pick a final design (decision matrix) | | | | | | | | | ■ | ■ | ■ | | | | |
| Proof of Concept Discussion | | | | | | | | | | | ■ | ■ | | | |
| Project Proposal Discussion | | | | | | | | | | | | | ■ | | |
| Finalize design | | | | | | | | | | | | | ■ | ■ | ■ |
| Problem Definition and Project Plan Presentations | | | | ◆ | | | | | | | | | | | |
| Concept Generation and Selection Presentations | | | | | | | | ◆ | | | | | | | |
| Proof of Concept Demonstrations | | | | | | | | | | | ◆ | | | | |
| Project Proposal Presentations | | | | | | | | | | | | | | ◆ | |

# Conclusions

- The wing design has been finalized and will be submitted for printing in the next week
- A tail design has been presented and will be finalized
- Final components of the aircraft, such as the motor and propeller have been decided
- An estimate of the cost of the aircraft has been proposed with a bill of materials
- The team will finish design and construction into next semester

# References

[1] *What-When-How, “Tail design”, Conventional Tail, T-tail, Dual Tail, Triple Tail and Twin Tail. Available: what-when-how.com.*

[2] *National Aeronautics and Space Administration, ”structures and materials”, aircraft background, P3-4.*

[3] *P. J. Pritchard, Introduction to Fluid Mechanics 8th Edition. Fox and McDonald. Wiley, 2011.*

[4] *M. H. Sadraey, Aircraft design: a systems engineering approach. Hoboken, New Jersey: Wiley, 2012.*

[5] *“Airfoil Tools,” Airfoil Tools. [Online]. Available at: http://airfoiltools.com/. [Accessed: 2015].*

*[6] Flight calculations. Ecalc Calc for Airplanes. [Online]. Available at: [http://www.ecalc.ch/](http://www.ecalc.ch/)*