# Design
# The Vertical Take-Off Landing (VTOL) Aircraft for Land Surveying

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# Presentation outline

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# Project Background


- Geospatial information system (GIS)
- Aerial surveillance
- Point cloud land surveying
- Platform


# Problems statement

- Launching and landing access is difficult for fixed-wing platforms especially in the jungle.
- Crashes due to hard landing that will cause structure failure on the aircraft.

# Objectives

- To design a VTOL aircraft using parametric study and fundamental aircraft design.
- To find the aerodynamic characteristic of the VTOL aircraft.
- To make performance analysis of the VTOL aircraft.
- To prepare the preliminary design of the aircraft before fabrication process conducted.

# Research scopes

- Feasibility study on related existing aircraft.
- Conceptual and preliminary design process of an aircraft.
- Aerodynamic analysis using ANSYS Fluent.
- Performance analysis of VTOL aircraft.

# Literature reviews

- Aircraft design process
  - The fixed wing VTOL aircraft require different aspects of aerodynamic, propulsive and control methodologies for hover stability, transition and conventional flight phases (Oznalbant and Kavsaoglu, 2015).

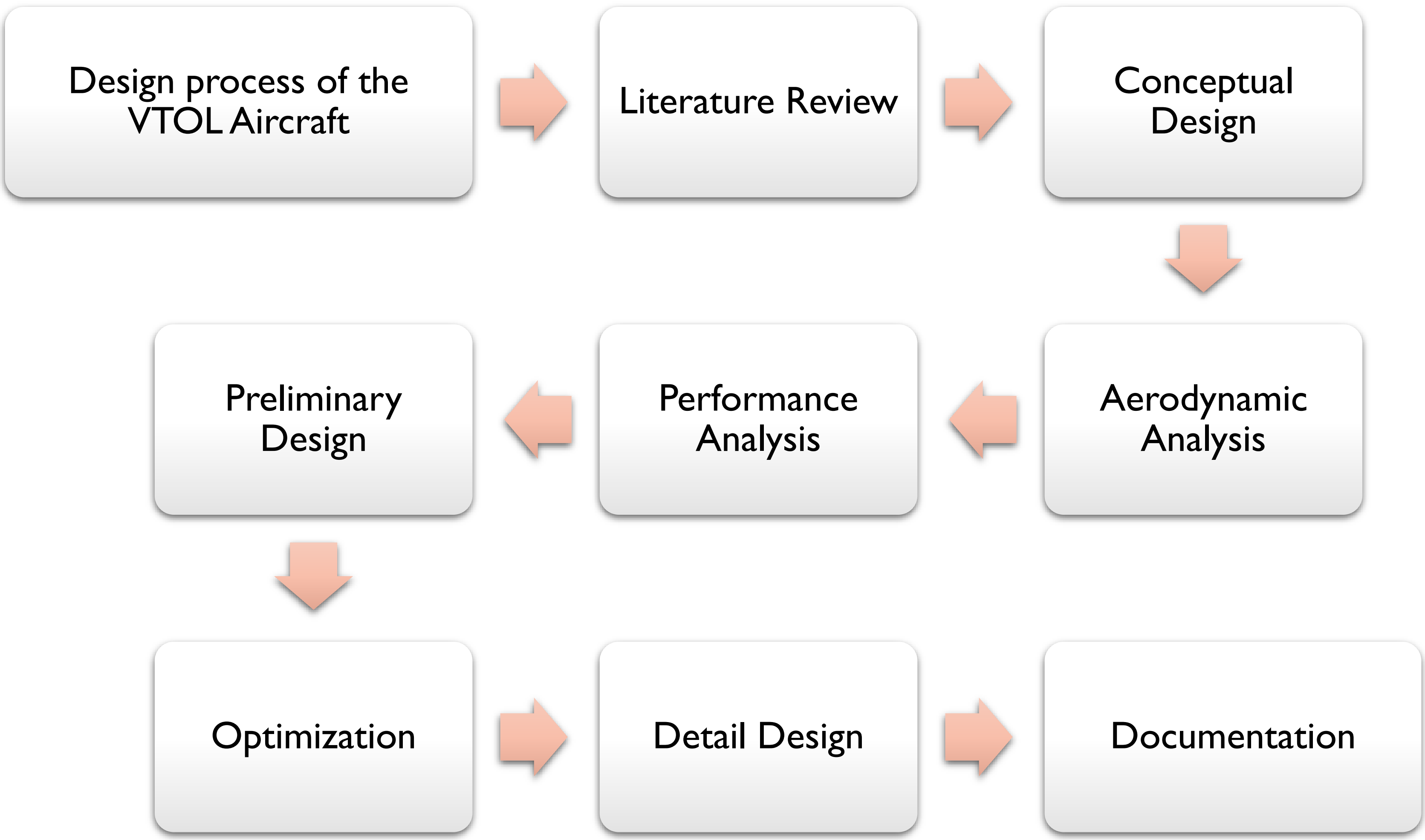
- VTOL design consideration
  - The total moment about the aircraft cg must be sustained zero together with aerodynamics and thrust forces considerations during transitions flight (Oznalbant and Kavsaoglu, 2015).

- Aerodynamic forces
  - Two forces that are considered as aerodynamic forces which are lift and drag as both are produced when the aircraft move through air mass (Pedro , 2005).

# Literature reviews

- Material
  - Foam's strength is lower than balsa's strength but the stiffness is comparable to balsa wood besides lower in density than woods (Carlos). Carbon fibre is a better solution but will increase difficulty in fabrication (Andrew et al., 2011).
- Propulsion system
  - More tailored propulsion system must be constructed to achieve the mission if the endurance requirement are more strict (Michael and Thomas, 2005).
- Test flight
  - The risks in the first flight can be reduced by having it tested on a loose cable from a tower crane (Seong et al., 2012)

# Schedule Planning



# Weight estimation

- The weight of electric-powered aircraft consist only two main type of load which are:

$$W_0 = W_{payload} + W_{empty}$$

# Parametric study

- Parametric study will be conducted based on several existing small aircraft used for land surveying.
- Equations obtained is used for aircraft initial sizing.

| Parameters | | Parameters |
|---|---|---|
| Maximum take-off weight | vs | Endurance |
| | | Wing Span |
| | | Fuselage length |
| | | Empty weight |
| | | Payload |
| Endurance | vs | Wing Span |

# Airfoil selection

- Airfoil selection is based on the existing aircraft airfoil shape.
- Selection is made based on the manufacturability of the airfoil.
- Approximately, N-10 is the closest profile to the existing aircraft.
- N-10 has flat surface at the bottom, easier to attach to the fuselage.

# Preliminary sizing

- Wing and tail configurations are chose based on its simplicity.
- Wing sizing will be based on the desired aspect ratio(AR).
- Tail sizing will be based on the required moment to control aircraft pitching behaviour.
- Fuselage sizing depends on the components required for the pilot's mission.

# Centre of gravity management

- All the basic centre of gravity ( empty weight cg, aft cg, forward cg and max cg) will be referred on Raymer (2006).
- Max cg will be located near as possible to the VTOL motor position.

# Aerodynamic Analysis

- ANSYS-Fluent is used to find the aerodynamic of the whole body of the aircraft.
- Simple meshing and Fluent default setting are used to reduce further considerations.

| Meshing | |
|---|---|
| Advanced size function | On: Proximity and curvature |
| Relevance centre | Medium |

| Fluid Flow (Fluent) | |
|---|---|
| Turbulence model | Standard k-epsilon (2 equation) |
| Iteration | 2000 |
| Reference velocity | 12 m/s |
| Density | 1.225 kg/m$^3$ |
| Kinematic viscosity | 1.7894 x 10$^{-3}$kg/ms |

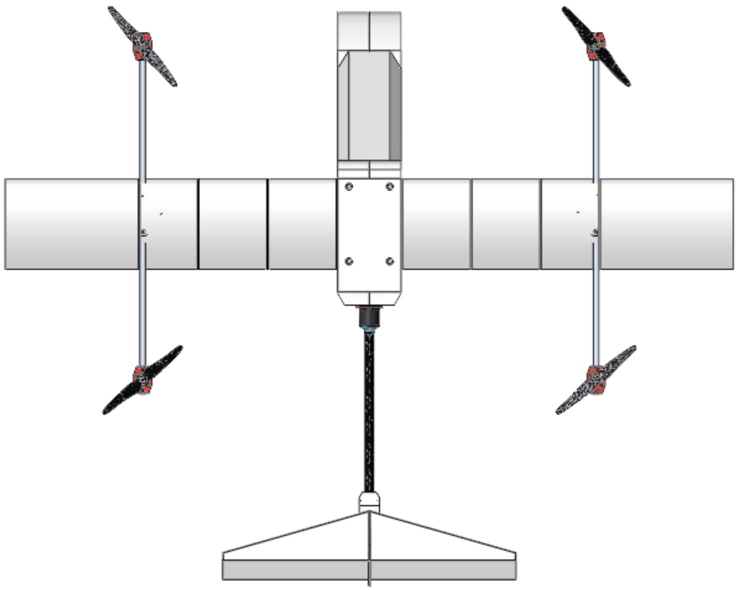
# Preliminary performance analysis

- Motor and battery technical specification is limited to the data provided manufacturer.
- Two type of performance analysis:

| Standard Take-Off Landing |
|---|
| Power available and Power required |
| Thrust available and thrust required |
| Rate of climb |
| Range and endurance |

| Vertical Take-Off Landing |
|---|
| Vertical take-off rate |
| Battery usage |
| Current selection |

# VTOL Motor Configurations

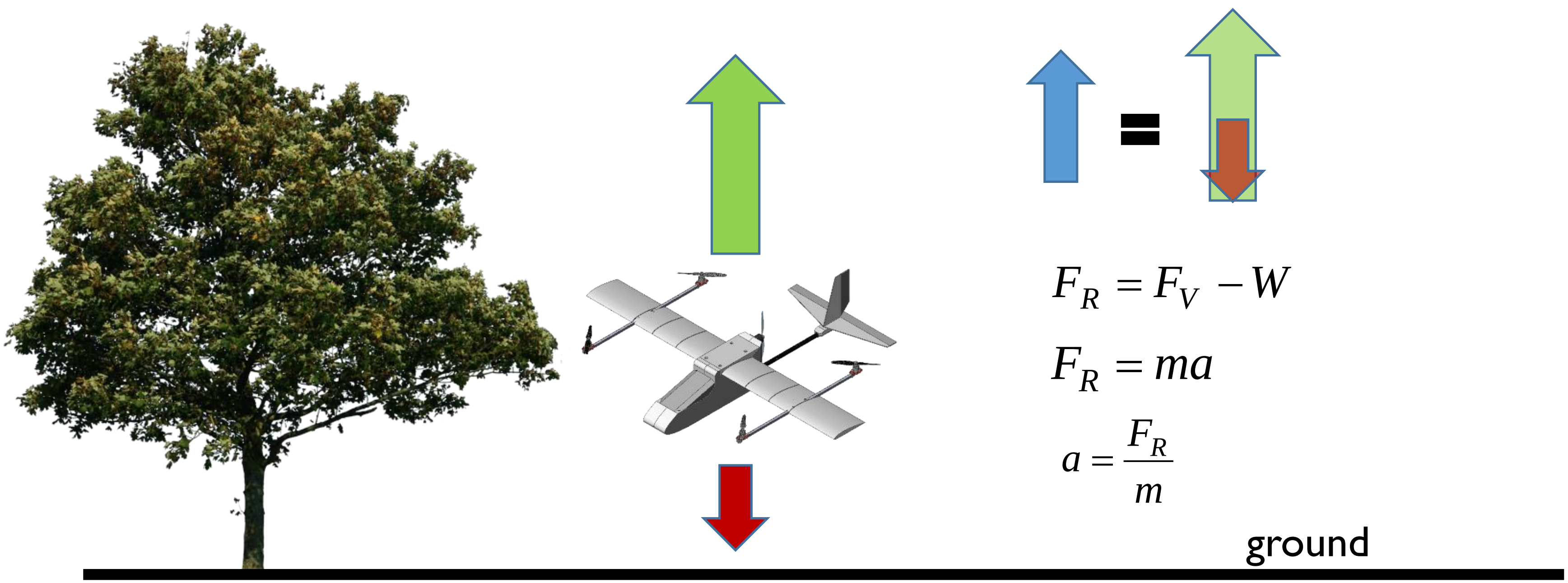


Quad-rotor has been chose as the flight condition is easier to understand and more reliable than bi-rotor and tri-rotor.

Quad-rotor produce more thrust and more stable.

# VTOL Analysis

Using Newton's 2nd Law of motion and equation of motion to find the take-off and landing rate.




$$F_R = F_V - W$$

$$F_R = ma$$

$$a = \frac{F_R}{m}$$

# Optimization

- The design of the aircraft will be optimized in order to achieve the desired specification set earlier.
- Using Solidworks to virtually position all the components in the aircraft.

| Considerations in optimization |
| --- |
| Components position |
| Material improvement |
| Structural modification |
| Power source variation |

# Detail design and fabrication process

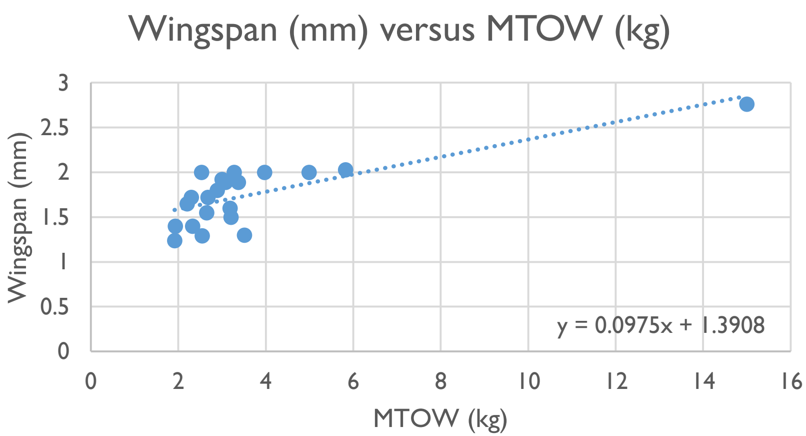
- All dimensions of the aircraft will be prepared through this process before it will be fabricate.
- Fabrication procedures will be prepared so the fabrication process will be conducted smoothly.

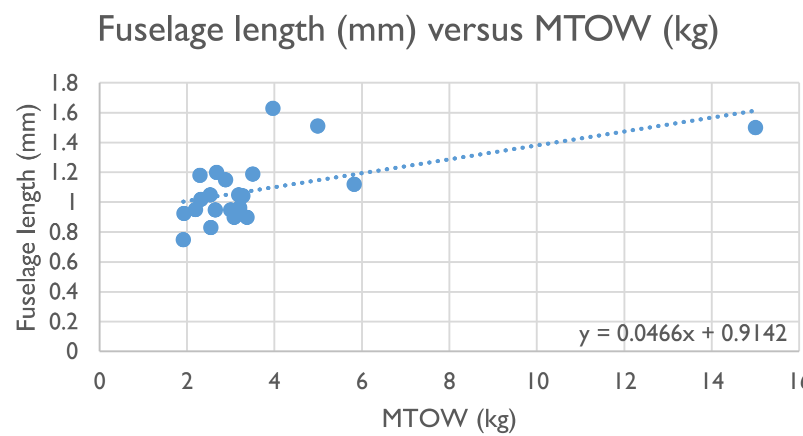
# Expected outcomes

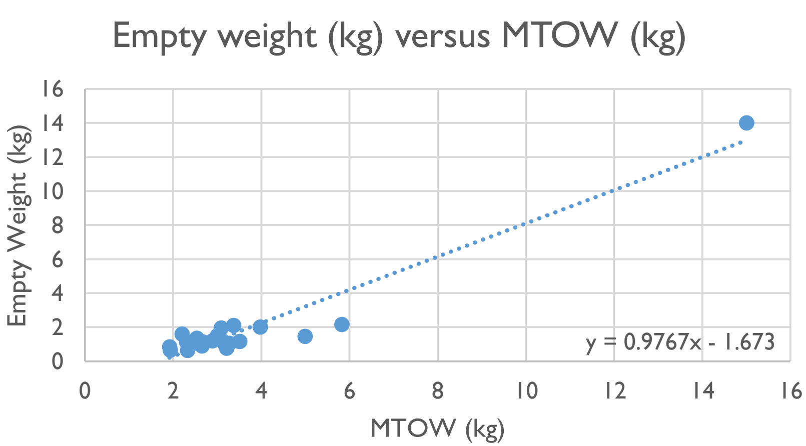
- A complete design of VTOL aircraft is prepared for the fabrication.
- Valid data obtained from analysis conducted compared to recent research.

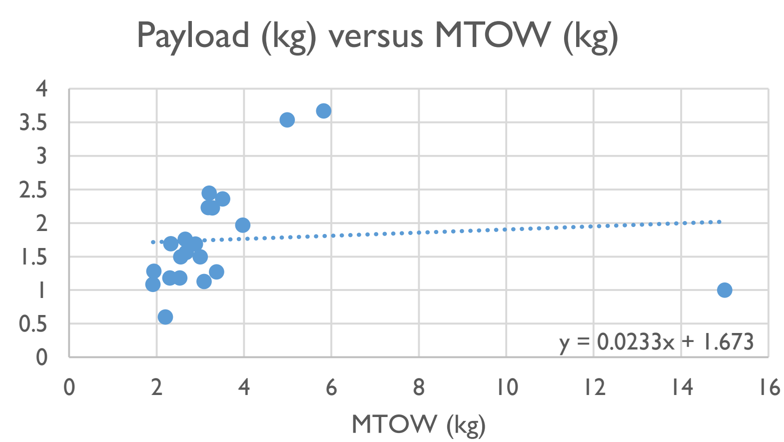
# Results and Discussions

# Parametric Study

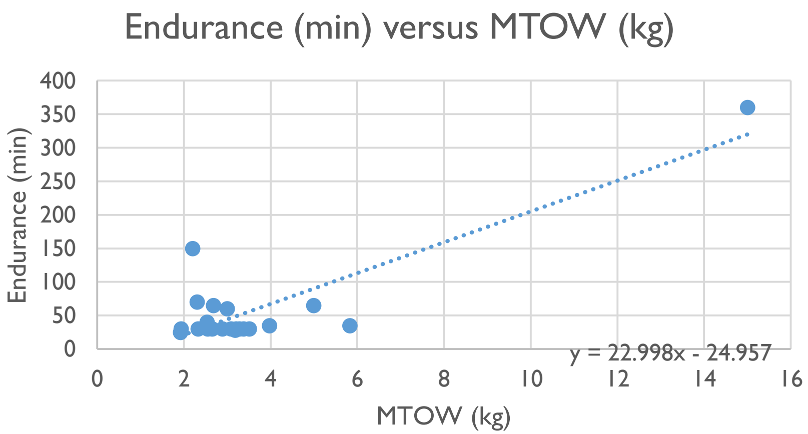


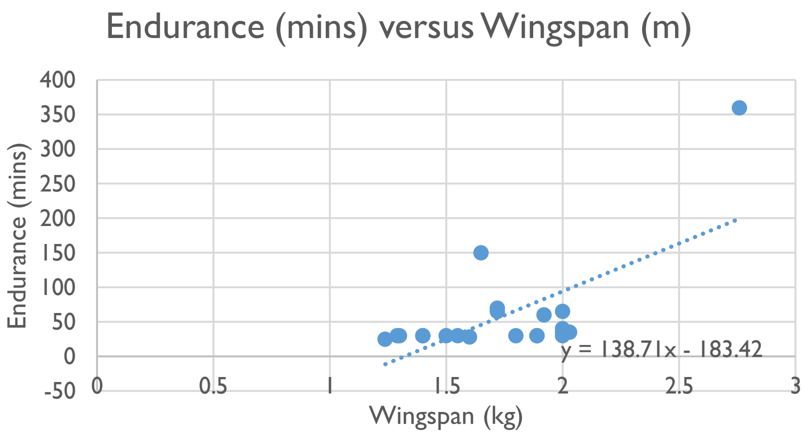



# Parametric Study




| Graph | | Linear equations derived |
|---|---|---|
| x-axis | y-axis | |
| MTOW | Wingspan | y = 0.0975 x +1.3908 |
| MTOW | Empty weight | y = 0.9767 x -1.673 |
| MTOW | Fuselage length | y = 0.0466 x + 0.9142 |
| MTOW | Payload | y = 0.0233 x +1.673 |
| MTOW | Endurance | y = 22.998 x – 24.957 |
| Wingspan | Endurance | y = 138.71 x – 183.42 |

# Initial sizing and weight estimation

- By referring to Raymer (2006), the initial sizing of the aircraft is presented in the table given.

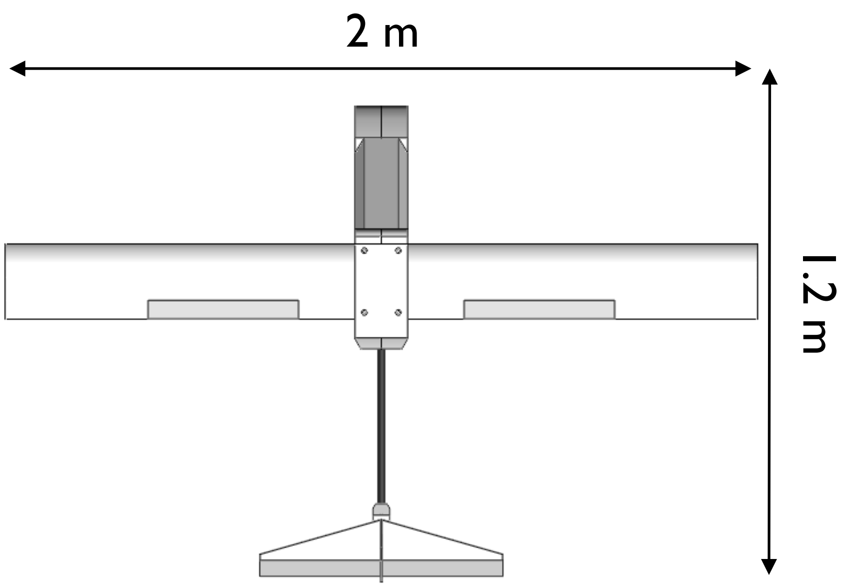
| Parameters | Values | Unit | Remarks |
|---|---|---|---|
| Aspect Ratio | 10.000 | - | Assumption |
| Wing mac | 0.200 | m | Testing |
| Wing Span | 2.000 | m | |
| Wing Area | 0.400 | $m^2$ | |

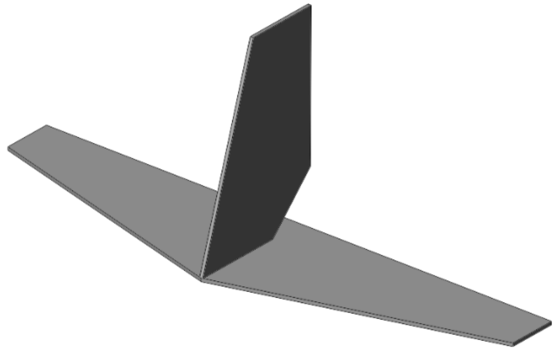
| Parameters | Values | Unit | Remarks |
|---|---|---|---|
| Fuselage Length | 1.206 | m | Raymer (2006) |
| Aileron Chord | 0.050 | m | |
| Aileron Span | 0.800 | m | |
| Elevator Chord | 0.043 | m | |
| Elevator Span | 0.647 | m | |
| Rudder Chord | 0.058 | m | |
| Rudder Span | 0.242 | m | |
| Maximum Take-off Weight | 6.256 | kg | Parametric study |
| Payload | 1.819 | kg | Parametric study |

| Parameters | Values | Unit | Remarks |
| --- | --- | --- | --- |
| Horizontal Tail Aspect Ratio | 6.000 | - | Raymer (2006) |
| Horizontal Tail Taper Ratio | 0.400 | - | Raymer (2006) |
| Horizontal Tail Root Chord | 0.154 | m | |
| Horizontal Tail Tip Chord | 0.062 | m | |
| Horizontal Tail mac | 0.108 | m | |
| Horizontal Tail Span | 0.647 | m | |
| Horizontal Tail Area | 0.070 | $m^2$ | |
| Horizontal Tail Arm | 0.573 | m | |

| Parameters | Values | Unit | Remarks |
| --- | --- | --- | --- |
| Vertical Tail Aspect Ratio | 2.091 | - | |
| Vertical Tail Taper Ratio | 0.500 | - | Raymer (2006) |
| Vertical Tail Root Chord | 0.154 | m | |
| Vertical Tail Tip Chord | 0.077 | m | |
| Vertical Tail mac | 0.116 | m | |
| Vertical Tail Span | 0.242 | m | |
| Vertical Tail Area | 0.028 | $m^2$ | |
| Vertical Tail Arm | 0.573 | m | |

- Aspect ratio is 10 to provide better lift-to drag ratio.
- Less airspeed needed for specific lift value.
- Wing shape is a straight wing without taper ratio and sweep angle because of fabrication limitation.
- Max aircraft weight adjusted to 2.6 kg due to components listing.
- Conventional tail has been used for the aircraft.
- High wing configuration for better stability and clearance for the propeller.



# Aircraft weight

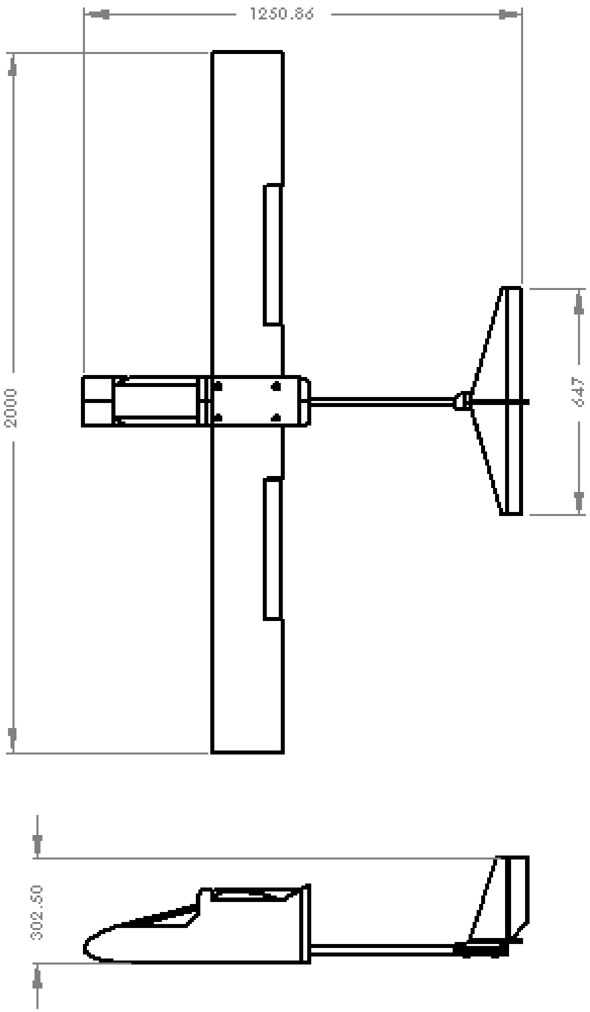
| Items | Weight (kg) | Remarks |
|---|---|---|
| Wing | 0.192 | EPF Foam |
| Frame | 0.564 | Aluminium |
| Emphennage | 0.193 | EPF Foam |
| Fuselage | 0.281 | EPF Foam |
| Servo | 0.040 | Towerpro |
| Propulse motor | 0.210 | SunnySky X3520 |
| VTOL motors | 0.312 | SunnySky X2212 |
| Camera | 0.263 | Sony RX100 iii |
| Battery | 0.380 | Infinity 4s 14.8V 5200mAh 35c Lipo Battery |
| ESC | 0.228 | Turnigy Plush 100 A<br>Hobbywing Skywalker 30 A |
| Receiver | 0.017 | FlySky |

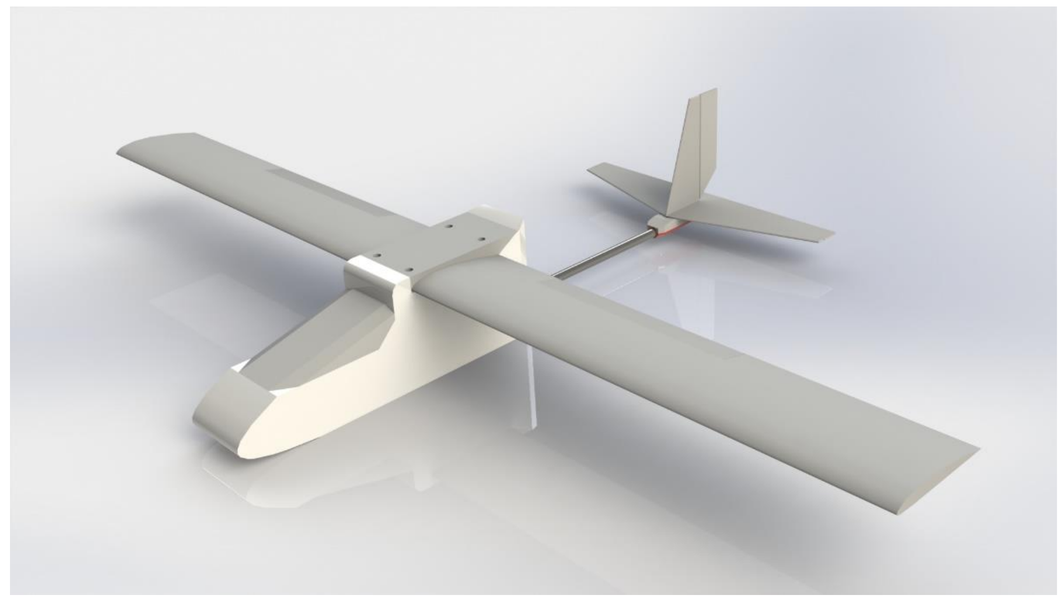
Maximum aircraft weight
= 2.68 kg

Difference compared to initial sizing weight
= 6.256 – 2.68
= 3.576 kg

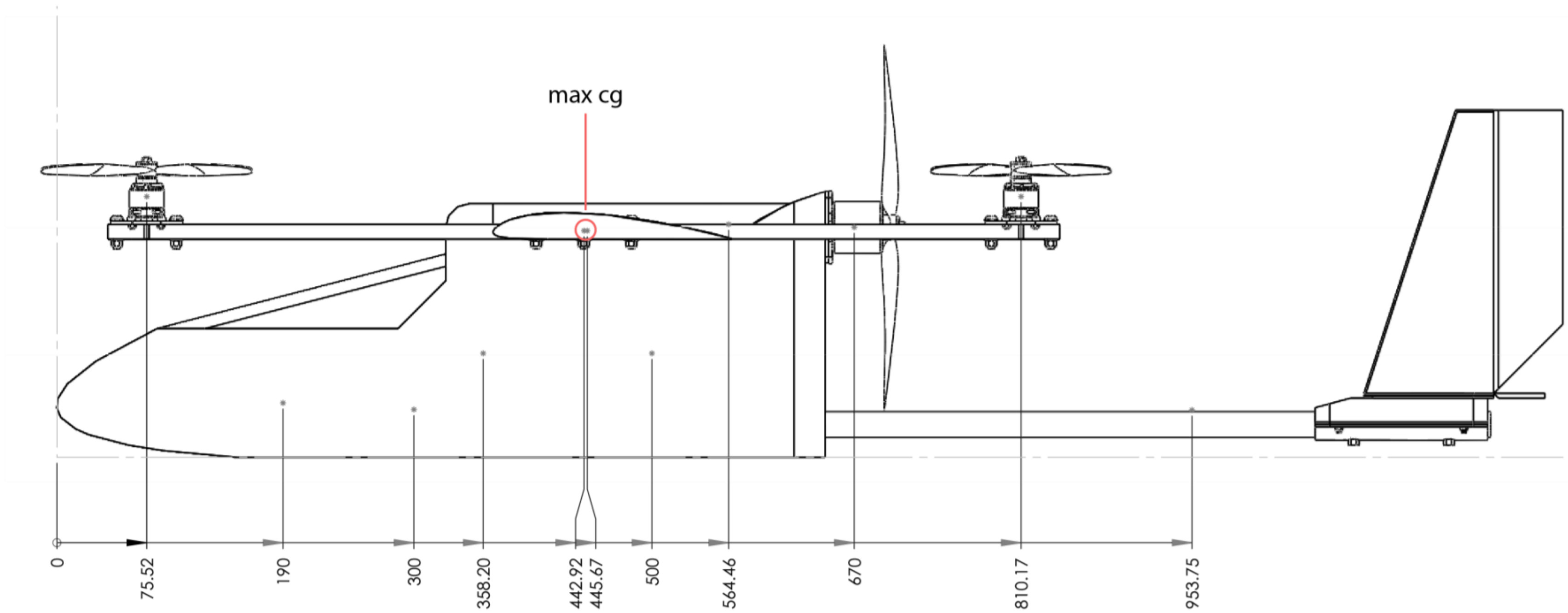
Reduce excess power by using optimized motor

# Conceptual Design



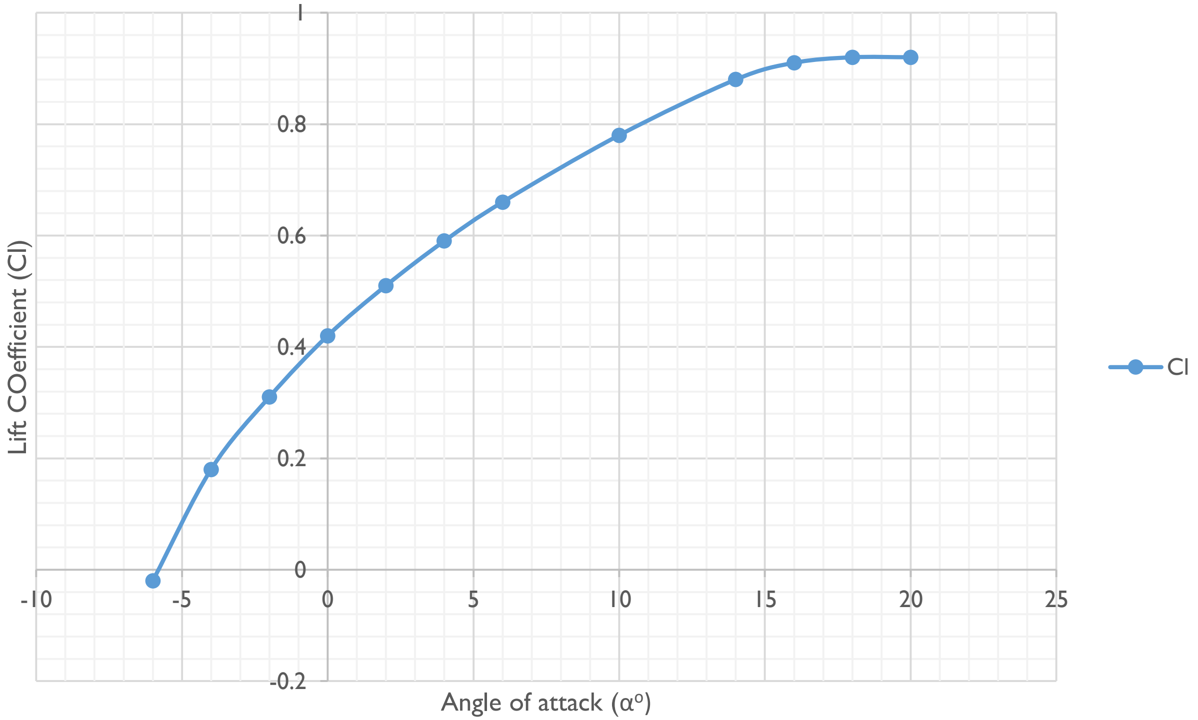



# Centre of gravity management



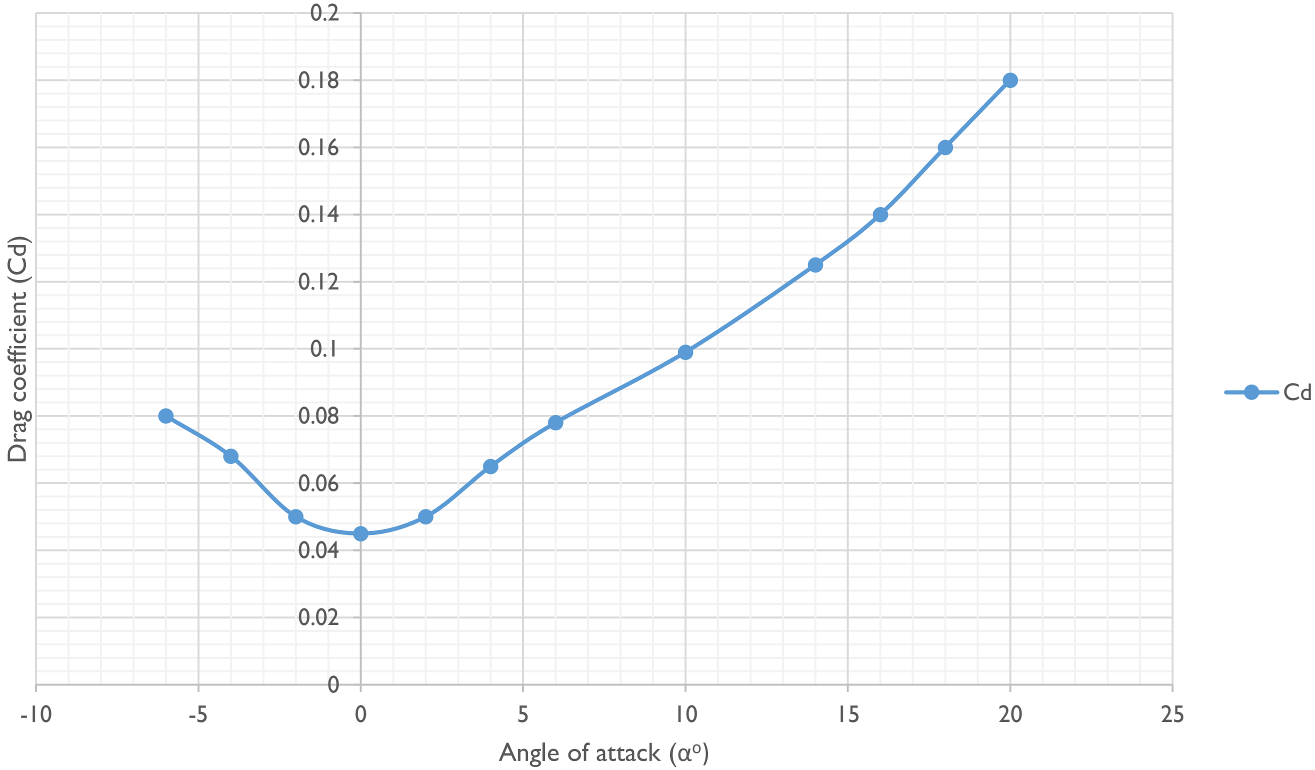

Maximum CG is at 442.11mm from the aircraft nose.
It is aligned with the position of VTOL mechanism.

# VTOL Model Lift Coefficient, $C_L$



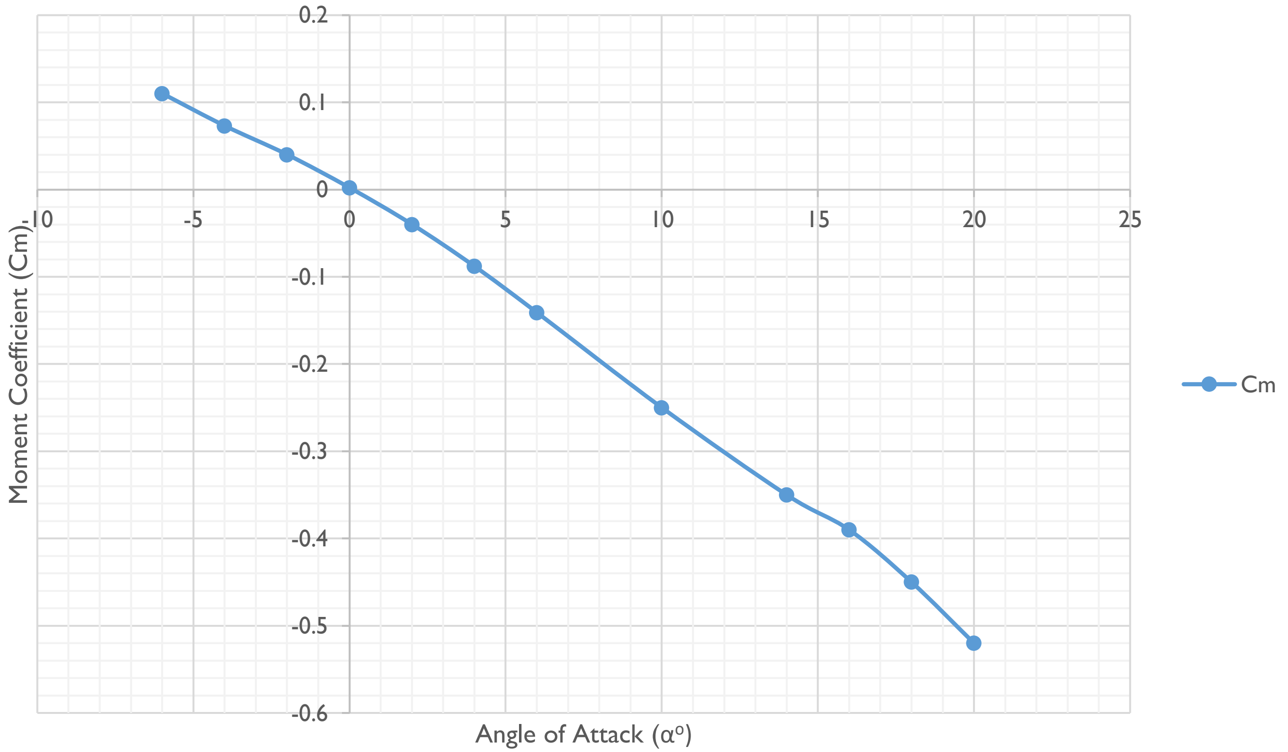

- Aircraft stalling angle is at 18º.
- Max $C_L$ is 0.92.
- Zero-lift angle of attack is at -5.8º.
- Cruising speed of aircraft is 16.044 m/s at 0º angle of attack.
- Min airspeed is 10.84 m/s at max $C_L$.

# VTOL Model Drag Coefficient, $C_D$

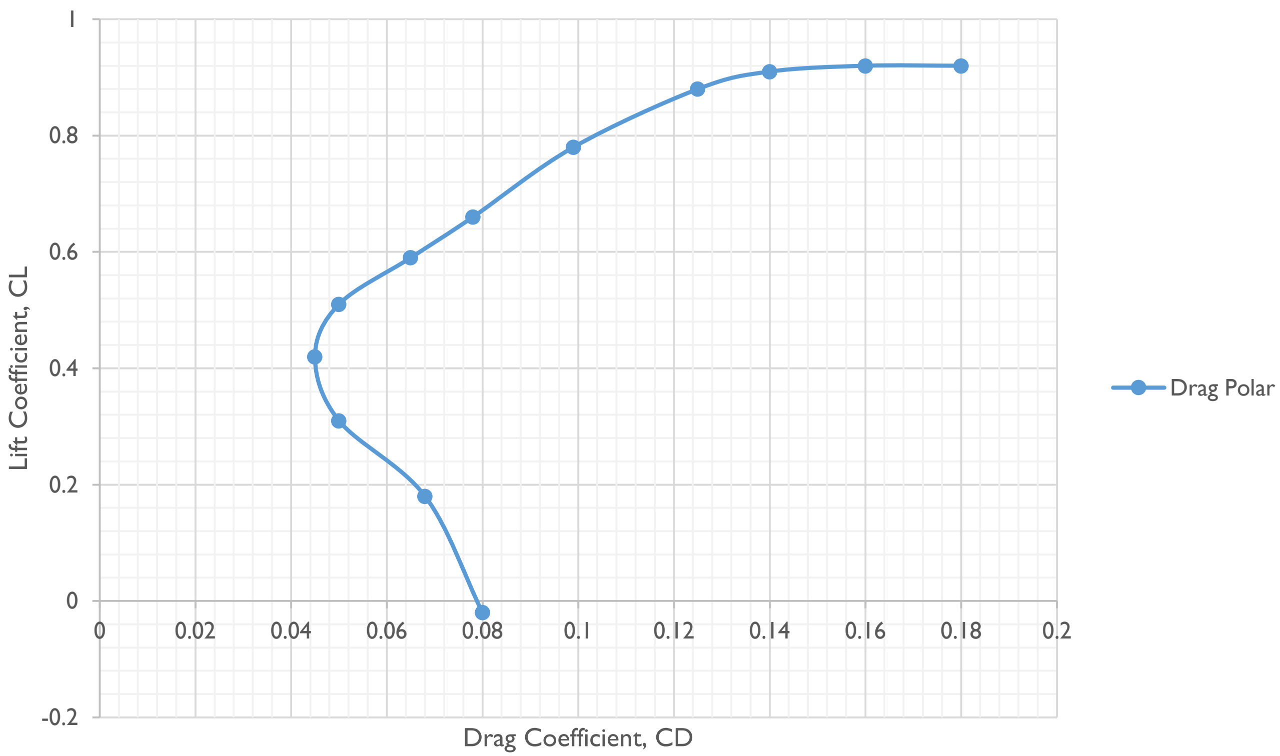



- Minimum drag is on zero angle of attack.

# VTOL Model Moment Coefficient, $C_M$



# Drag Polar




- Minimum drag occur at angle of attack 0° with positive lift coefficient.
- Theory by Anderson, 1999 stated that in real case, zero lift drag would result slightly higher parasite drag than minimum drag

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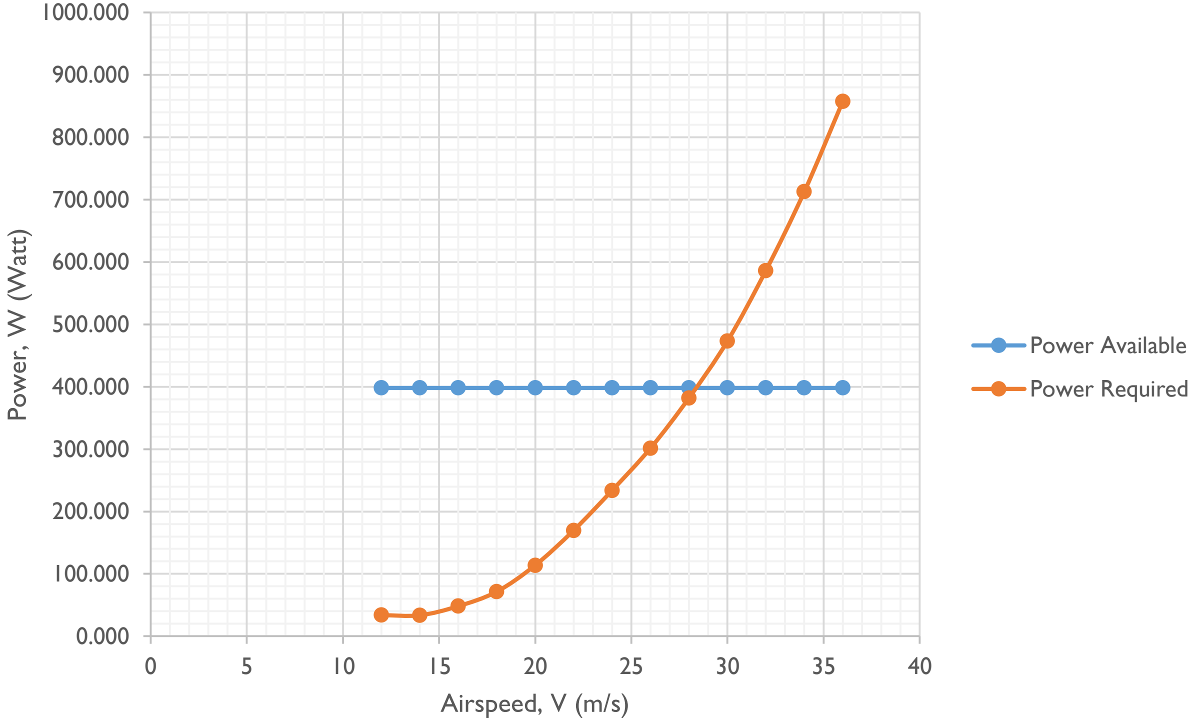
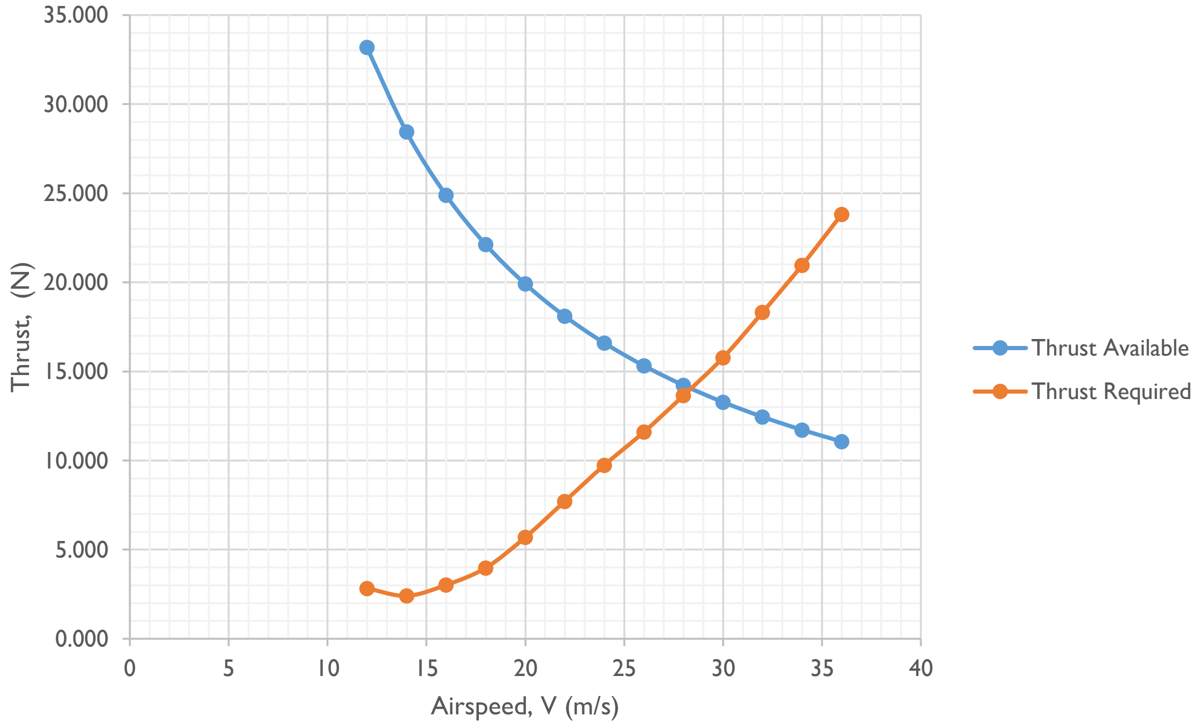
# Power available and required



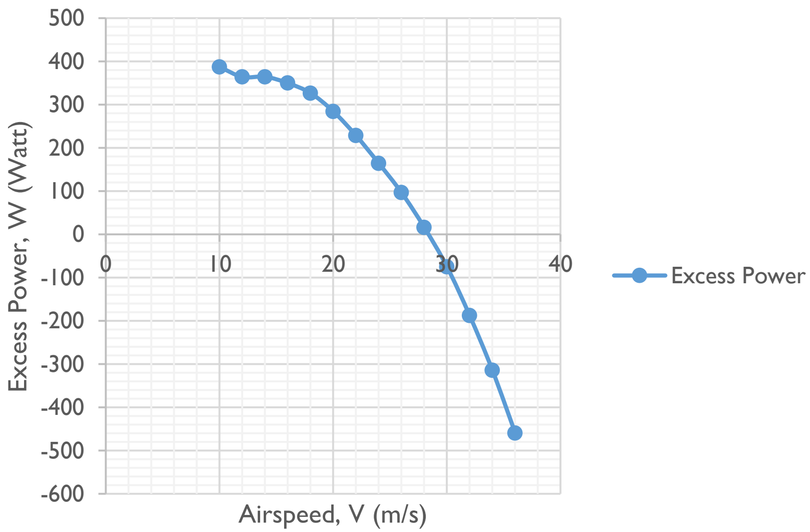

Airspeed limit of the aircraft's horizontal flight is 28.4 m/s.

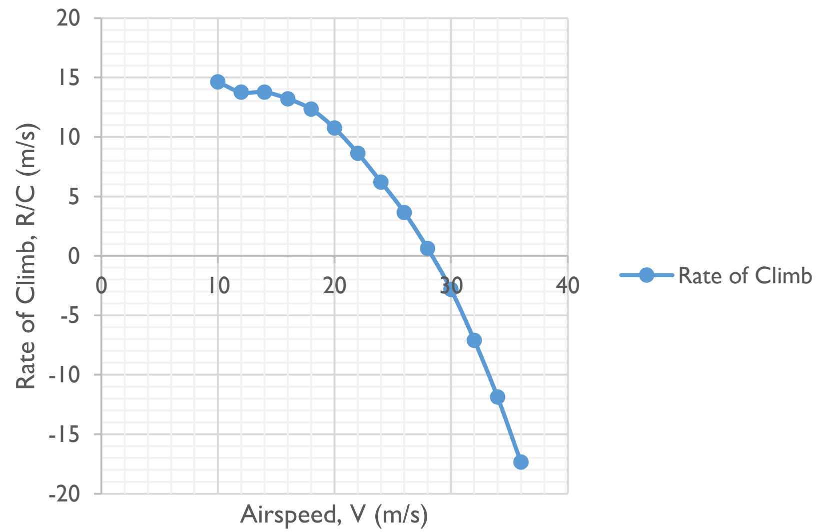
# Thrust available and required




Minimum thrust required is 2.4 N at airspeed of 14 m/s.

# Rate of climb

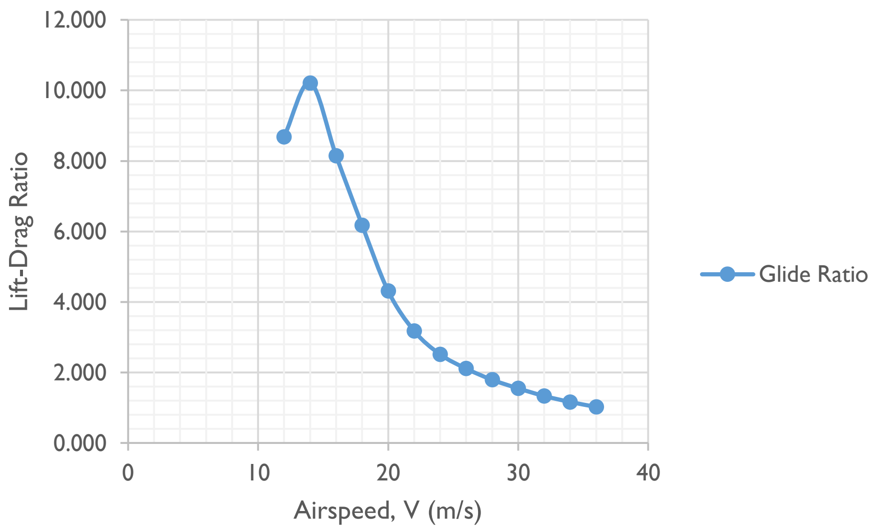


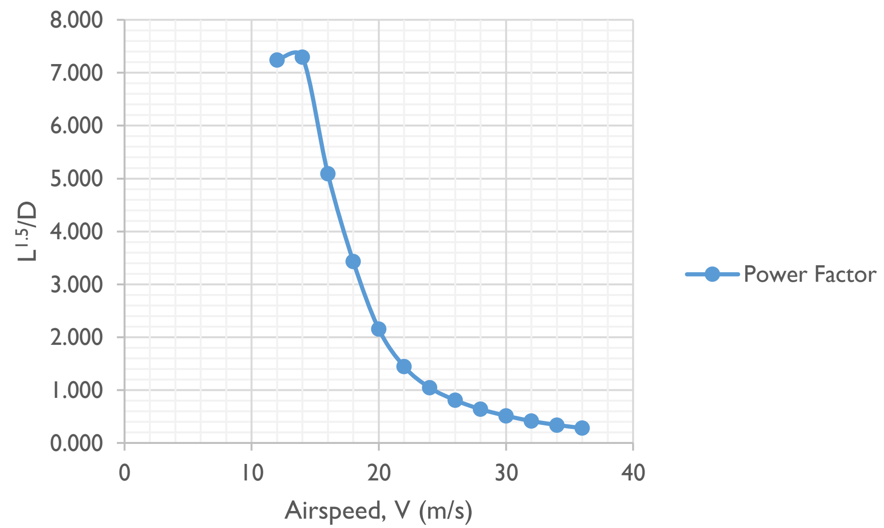




- Maximum excess power is 395.77 Watt at 100% throttle.
- Maximum rate of climb is 14.9 m/s due to maximum excess power.

- The airspeed for maximum rate of climb is 10 m/s at angle of attack 18°

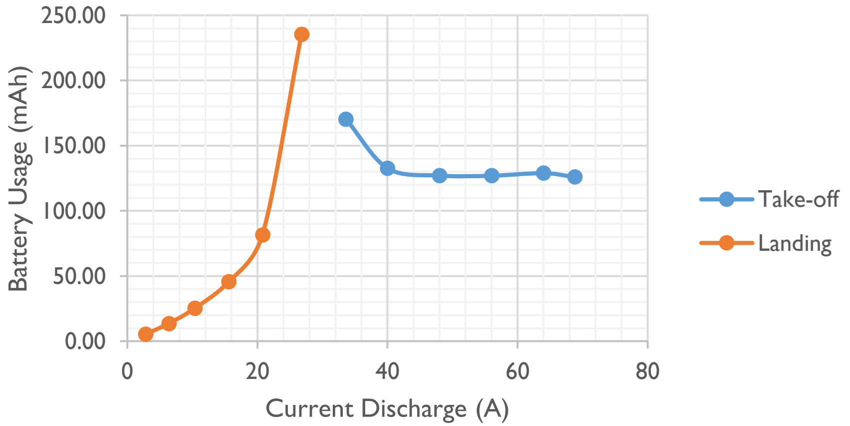
# Range and Endurance

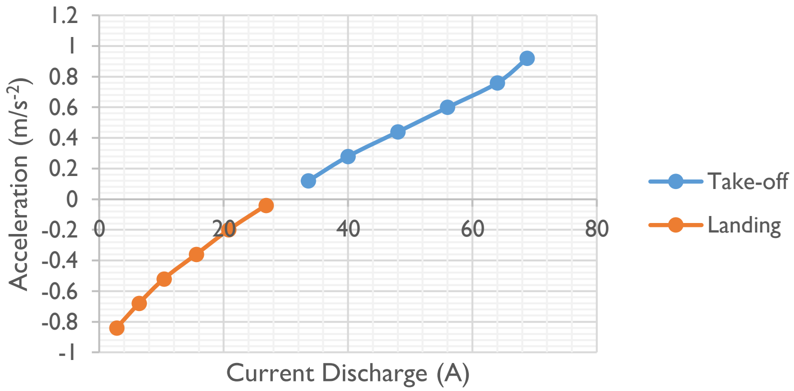


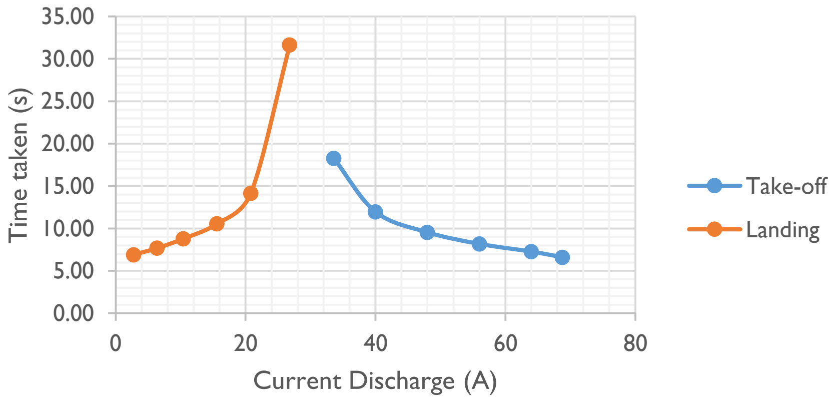




| | Distance |
|---|---|
| Cruising range (at 16.04 m/s) | 73.62 km |
| Cruising endurance (at 16.04 m/s) | 115.09 mins |
| Max range (at 14 m/s) | 92.31 km |
| Max endurance (at 14 m/s) | 128.88 mins |

# VTOL Analysis



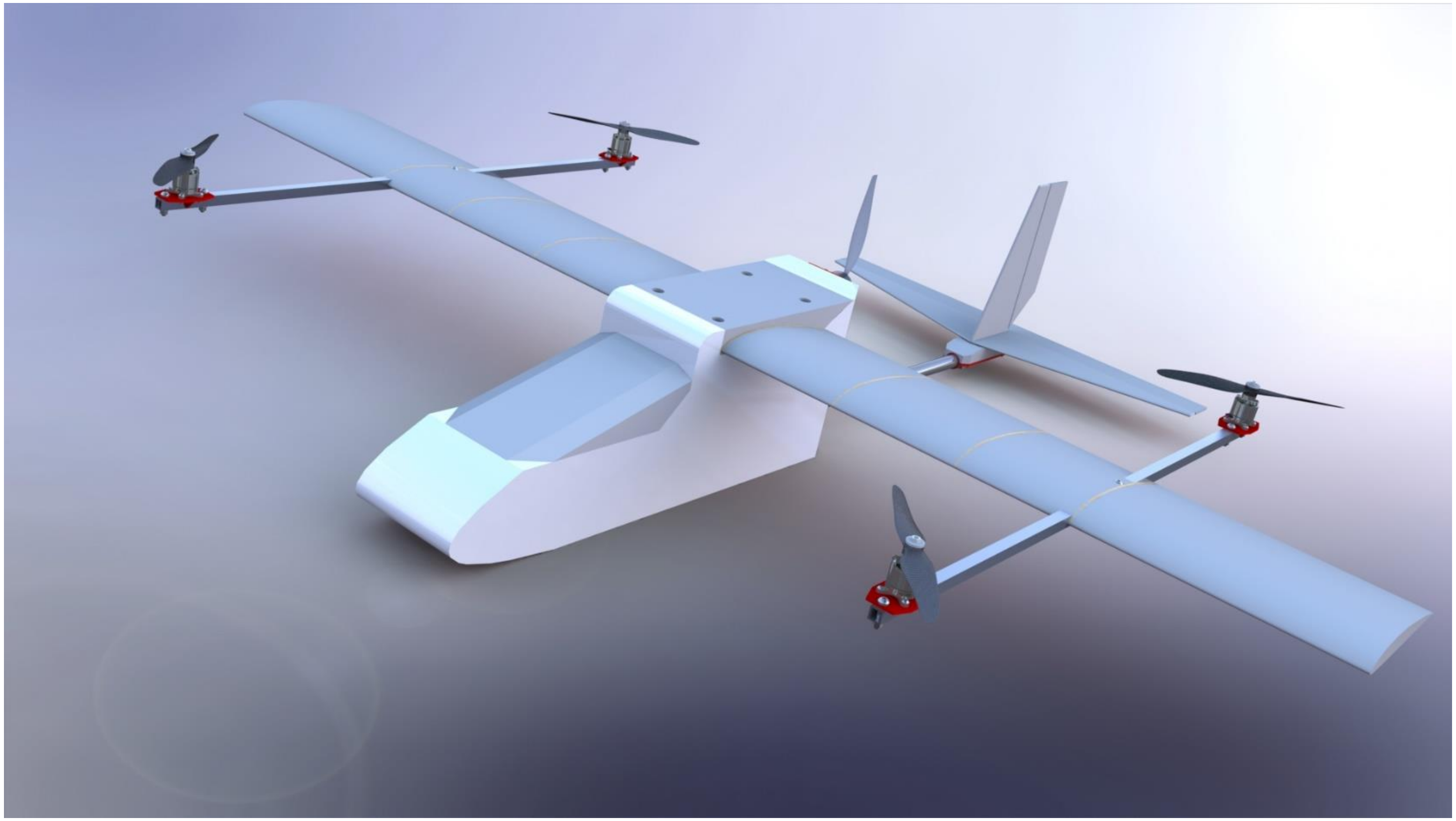




| | Vertical Take-off | Vertical Landing |
|---|---|---|
| Current discharge (A) | 68.8 | 10.4 |
| Battery usage (mAh) | 126.01 | 45.68 |
| Time taken (s) | 6.59 | 10.54 |

# VTOL Analysis

- More battery charge used during vertical take-off.
- Less battery usage during vertical landing with less current discharged but increase impact force.

# Detail Design



# Recommendations

- Transition flight analysis for better VTOL analysis.
- Optimized the propulsion system since too much of excess power.
- Wind tunnel testing for precise aerodynamic characteristic.
- Stability analysis to study aircraft's flight condition especially during transition flight.

# Conclusion

- Feasibility study and initial done by using Raymer 's approach in aircraft design.
- Preliminary design and detail design done by using Solidworks.
- Aerodynamic characteristic of VTOL aircraft obtained through ANSYS software.
- VTOL motor used is sufficient since not much of battery being used.
- Feasible result of horizontal flight performance analysis.

# THANK YOU