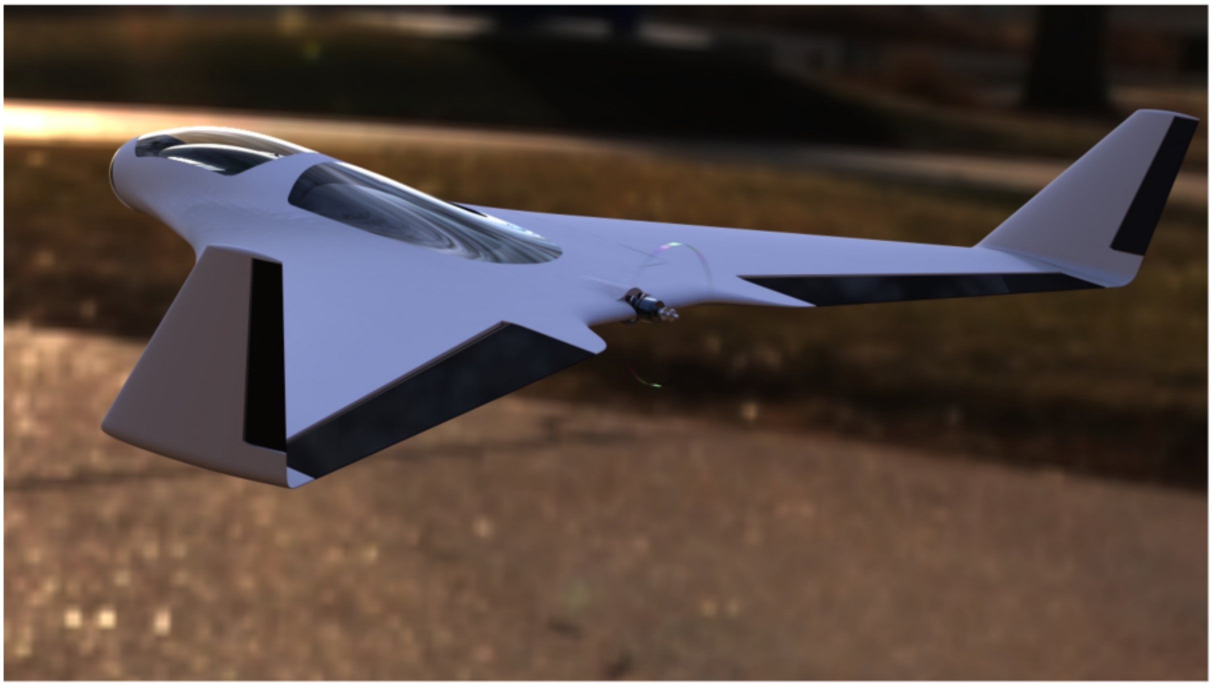
Aerodynamic and Stability Analysis
Aeronautical's P3.1



Summary

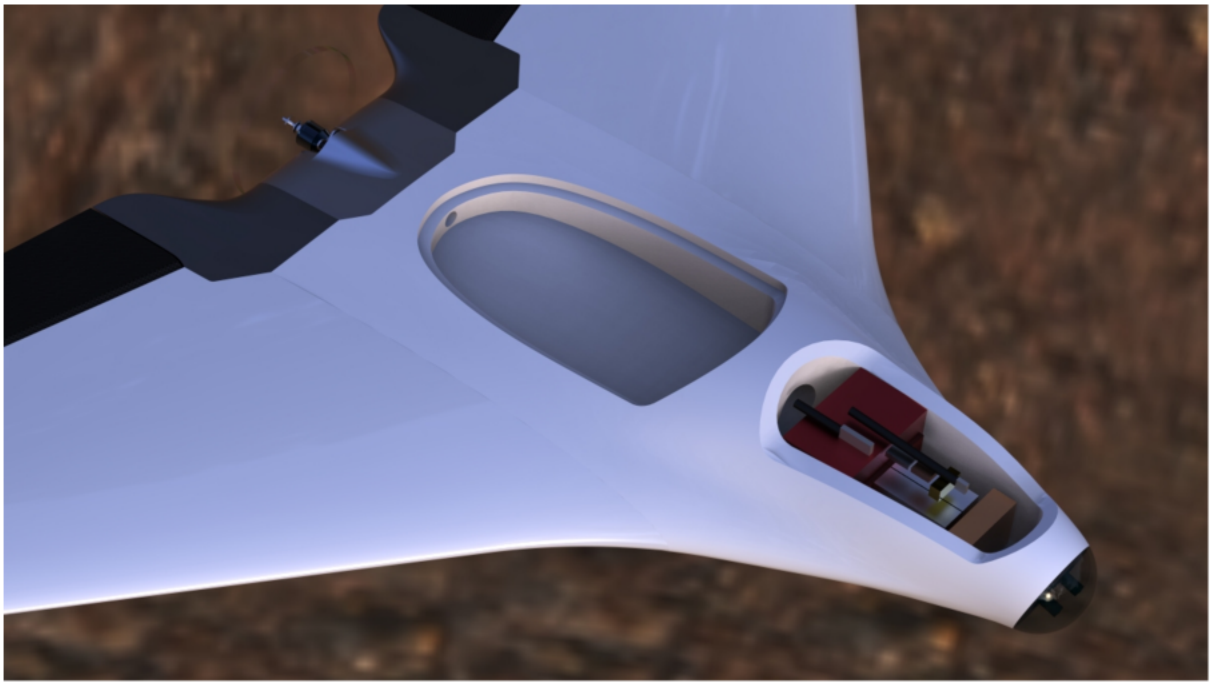
The main strengths of the current aircraft design are its low stall speed and gradual lift reduction with the onset of stall and vortex induced lift. This design was to provide a tough UAV platform with low speed stall and take-off. Economical manufacturing also ensures an effective platform for many applications.

The current lift distribution is reasonable considering the high degree of sweep. This leads to a slight induced drag penalty. Some wing tip washout was introduced in order to reduce the wing tip loading, providing a more elliptic lift distribution.

The stall characteristics of the design are a strength with the low wing loading enabling low speeds during take-off and landing. Low wing loading means that the design has both a higher viscous and induced drag penalty due to increased geometry sizes. With the onset of stall for this design the lift reduction is gradual which maintains control authority and hence recovery.

Steep decent rates are possible as the combination of the major effect of low wing loading and a minor effect of the high wing sweep lead to the formation of vortex induced lift.

The region which the CG can be located is relatively constrained due to the flap deflection required in order to trim the aircraft. This is due to the flying wing design having a nose down moment.



Contents

General Notes

Unless otherwise stated the aircraft's mass is taken as 17 kg.
The angle of attack used to generate the results is 3.2 degrees as this is the optimal flight condition for C_L/C_D.

Lift Area

The current lift area is 2.74m^3 which is taken from the x-y projection of the aircraft due to the significant lift of the blended body. For scaling purposes the area used would be dependent on the desired scale of the entire aircraft or just the wings with the body section remaining constant.

For scaling purposes of the entire aircraft the projected area on the x-y plane should be used as the Trefftz plane, Figure 1, shows that the blended body creates a significant lift contribution.

The Trefftz plane also provides details on how closely the current lift distribution is to the ideal elliptic distribution. Figure 2 indicates that the wing tips are loaded in this design with an efficiency factor, e, of 0.79. This leads to a slight increase in the induced drag of the aircraft.

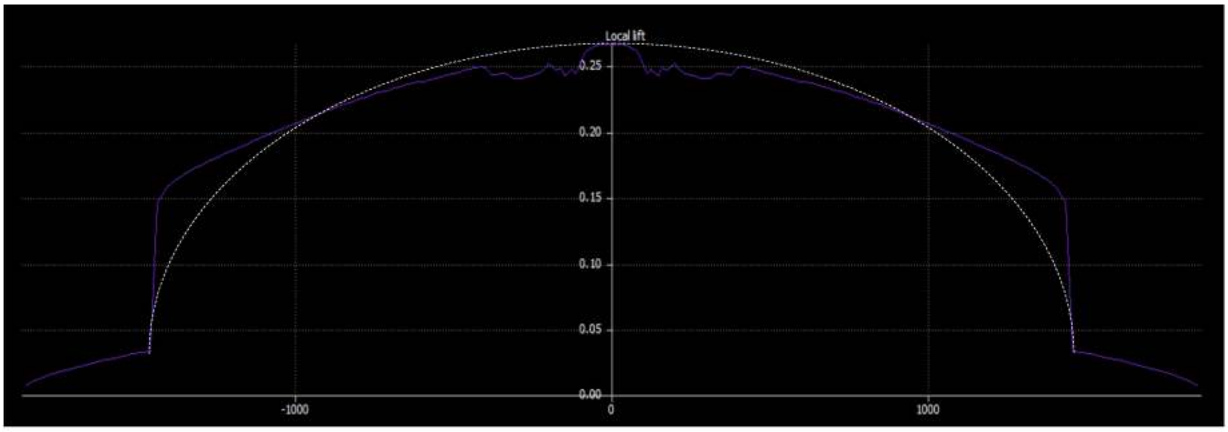


Figure 1: Trefftz Plane showing local lift distribution for $\alpha = 3.2^0$

For scaling of the wings only the x-y projection wing area should be used and is shown in Figure 2. The current wing only projected area is 2.63 m^3.

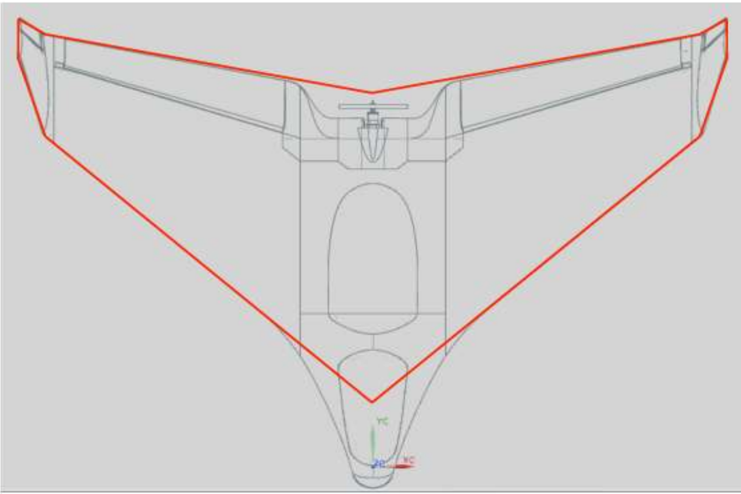


Figure 2: Wing projected area for scaling = 2.63 m^3

Wing Loading @ GTOW

Figure 3 displays the wing loading as a function of the take-off weight. For a GTOW of 17 kg the wing loading is 60.91 N/m^2

Prototype P3.1 profile, test flight Melbourne Australia.

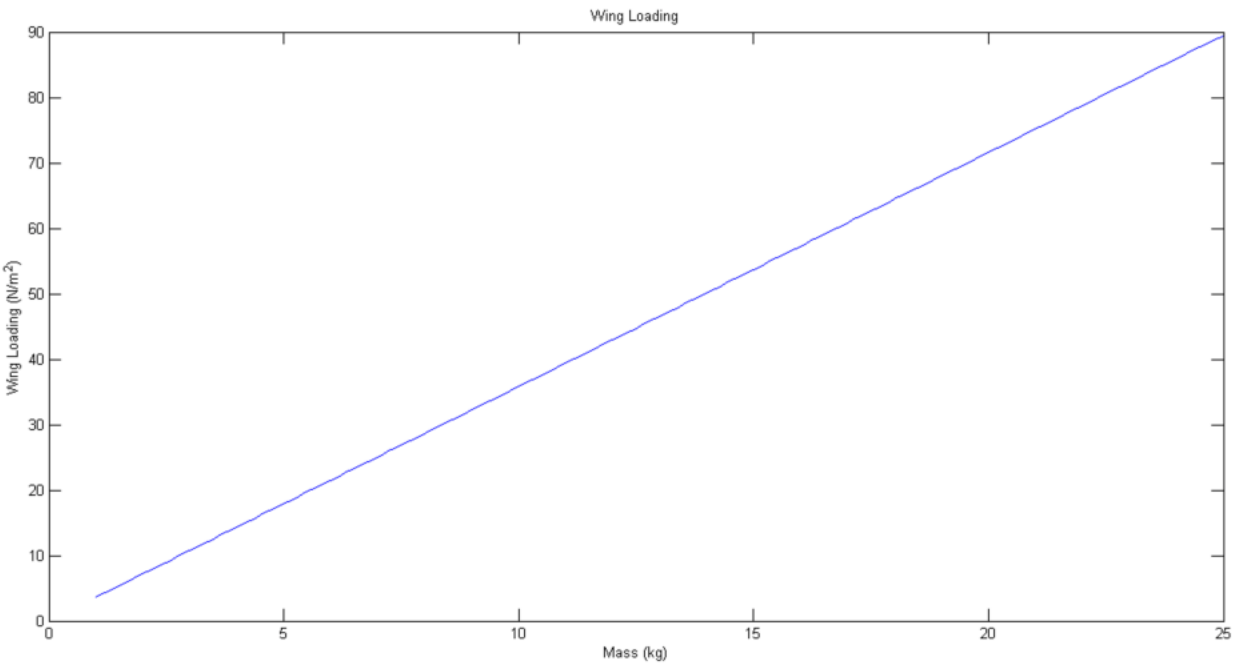


Figure 3: Relationship between wing loading and take-off weight

The current wing loading is low and due to the link between wing loading and the stall velocity, enables low landing speeds.

The stall velocity is tied to the wing loading which dictates the take-off and landing speeds. Typically 1.2 and 1.3 times V_{STALL} respectively. A lower wing loading will decrease the Vstall and hence decrease landing/take-off area requirements.

The Vstall of the current design is predicted using XFLR5 to be

$$V_{STALL} = \sqrt{\frac{2}{\rho}\frac{W}{S}\frac{1}{C_{L_{MAX}}}} = 9.55\ m/s$$

The low stall speed is a strength of this design which will reduce the likelihood of damage to the airframe during landing, as the probability increases with the velocity squared. The disadvantage of low wing loading is the required dimensions increase imposing structural limitations and a drag penalty or a reduced payload capacity.

L/D max

The L/D distribution is provided in Figure 4. A maximum L/D was found to be 22.86. It is important to note that simulation programs such as XFLR5 have a tendency to underestimate the drag due to the approximations made for the boundary layer transition location and neglecting gaps, joins etc present on the surface. It is suggested that the C_D values be increased by 10% for a more conservative estimate prior to the implementation of flight test data into the model. This yields a maximum L/D of 20.78 which occurs at an angle of attack of 3.2^0.

Note there is some instability in the solution as stall occurs as XFLR5 cannot model these effects accurately.

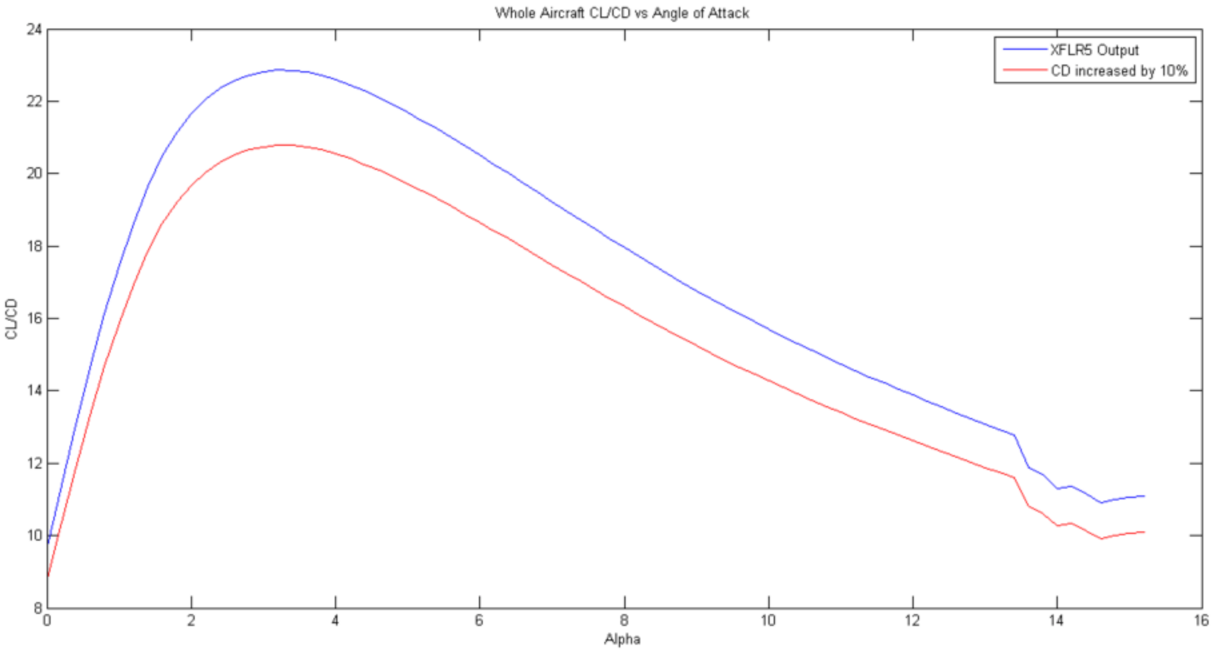


Figure 4: L/D distribution

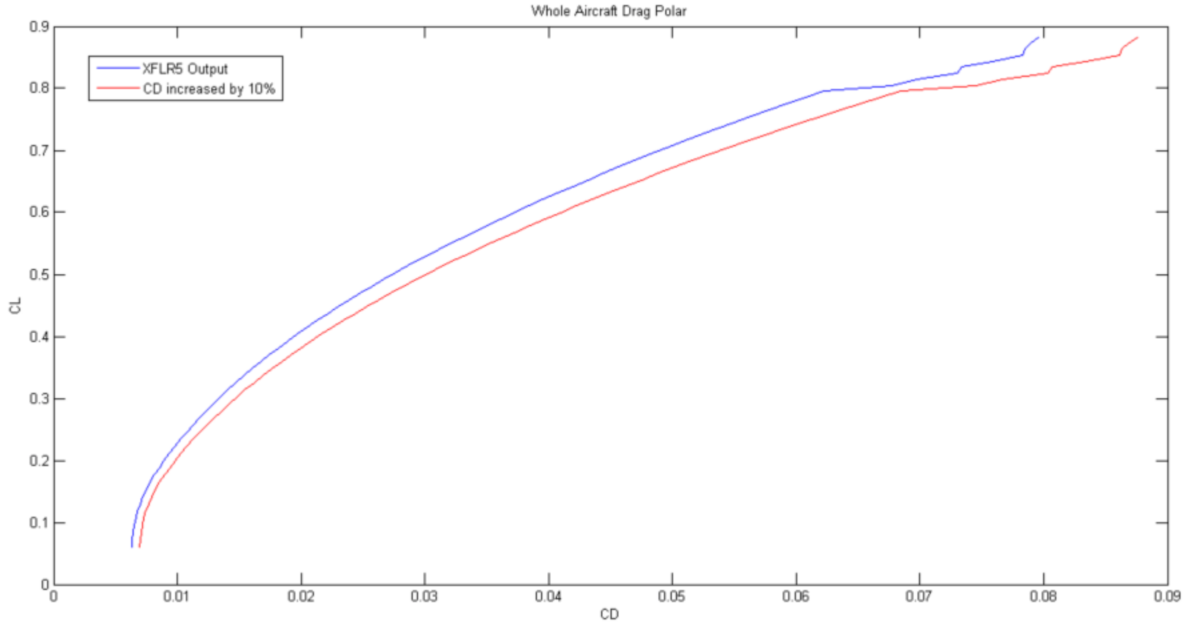


Figure 5: Whole aircraft drag polar

For maximum endurance for propeller powered flight is at $\frac{C_L^{3/2}}{C_D}$

For maximum range for a propeller powered aircraft flight is at $\frac{C_L}{C_D}$

CL

The coefficient of lift requirement will be dependent on the wing loading of the UAV and the freestream velocity. For the optimum flight angle of 3.2 degrees the freestream velocity, q = 20.14 m/s. At the current wing loading the C_L for trimmed flight = 0.25.

CG Stability Plot

The neutral point of the aircraft is located at 1056 mm from the nose of the aircraft for a 0 degree flap angle. For the longitudinal static stability criteria the CG should be placed forward of this location.

Figure 6 shows the region in which stability and trim criteria can be met. As the CG location is moved forward the static margin increases and hence a larger aileron deflection is required in order to change the pitch rate. Figure 6 also shows that a small –ve flap deflection is always required in order to trim the aircraft. This increases the induced drag of the airfoil and hence reduces the efficiency. An alternative method which can be used to create an initial positive moment force is wing tip washout. This would have the benefit of preventing initial stall at the wing tips by reducing the wing tip loading and improving the spanwise lift distribution, Figure 1.

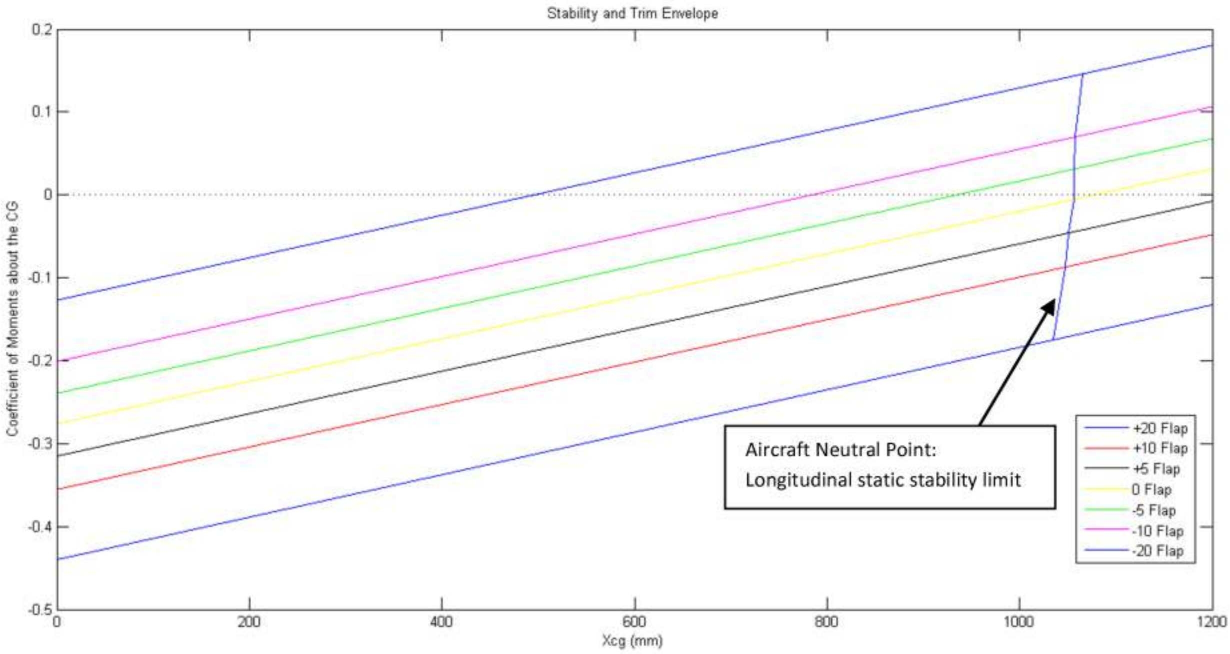


Figure 6: Stability and Trim envelope (+ve flap angle is downwards deflection)

CL/ α

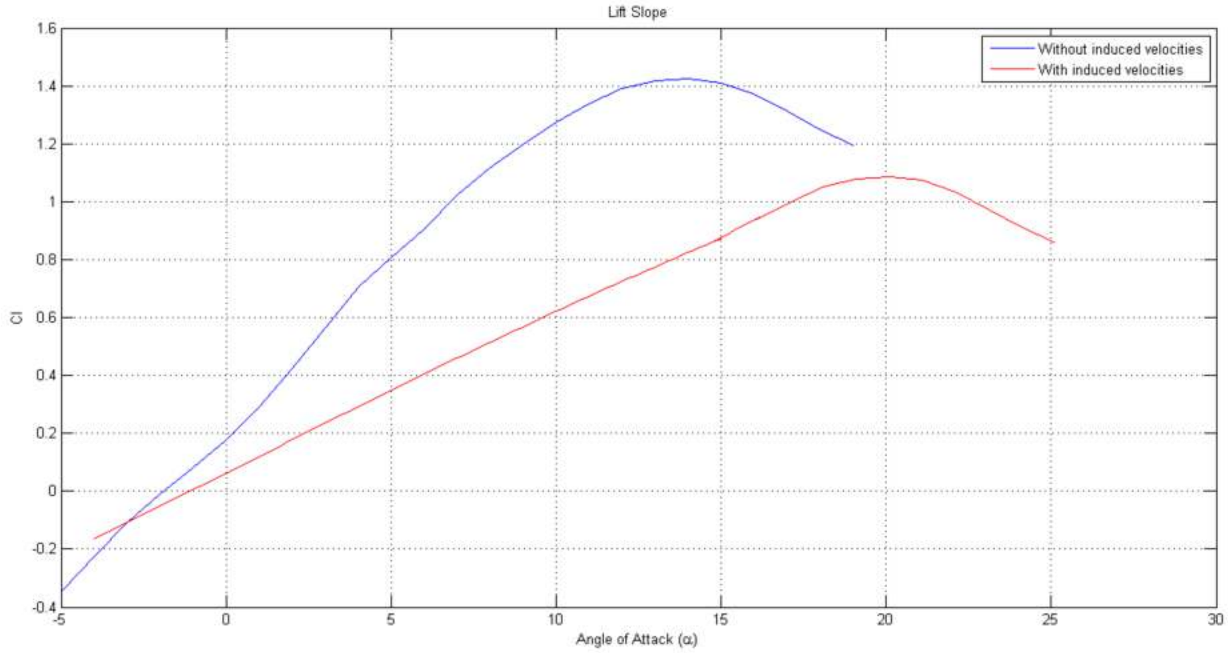


Figure 7: Lift slope for aircraft under induced and non induced velocity conditions.

Figure 7 displays the lift slope for the aircraft with and without induced velocities. This shows the loss in maximum high lift potential due to the three dimensional flow effects and hence the importance of induced drag reduction in order to design an aircraft with a short take off and landing area. A positive attribute of this design is the gradual stall characteristics of the aircraft which makes recovery easier.

The Clmax for the whole aircraft under the more accurate induced velocity condition is 1.09.

Inverted Flight Characteristics

Under inverted flight conditions the aircraft would able to maintain steady level flight through an inverted positive angle of attack of 5 degrees. From Figure 8 it is evident that for this small angle under inverted conditions the aircraft will be close to stall. This is unfavourable as the aircraft geometry is more inclined to create a nose down pitching moment which would increase the angle of attack and lead to stall.

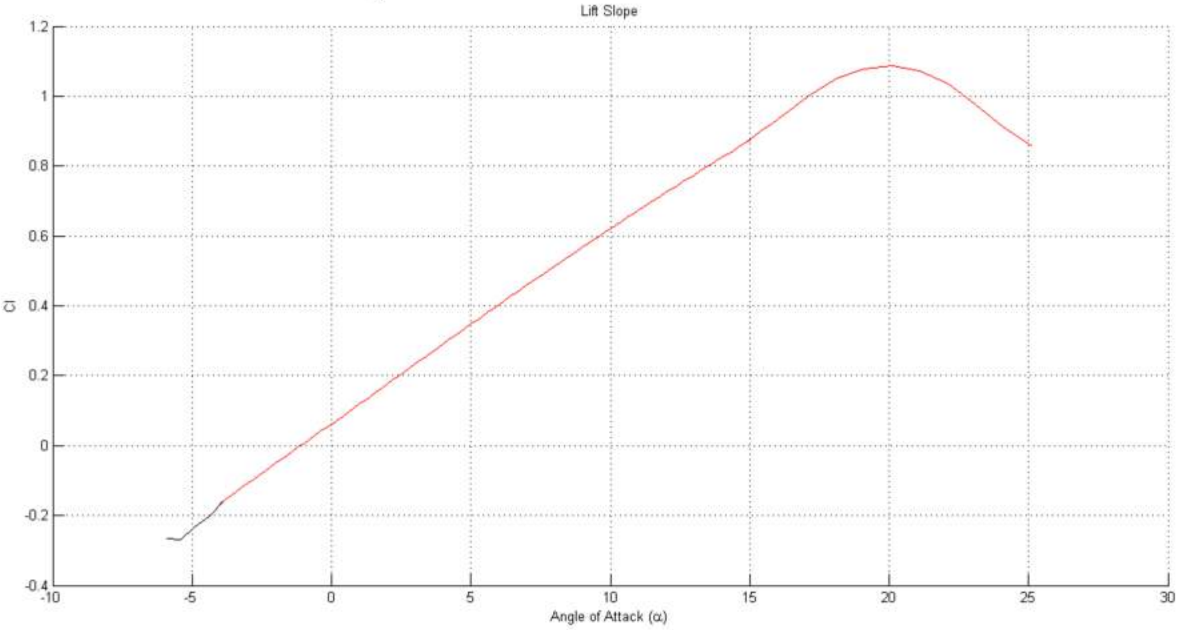


Figure 8: Lift slope for the region of flight under inverted conditions shown in black.

Power Estimates

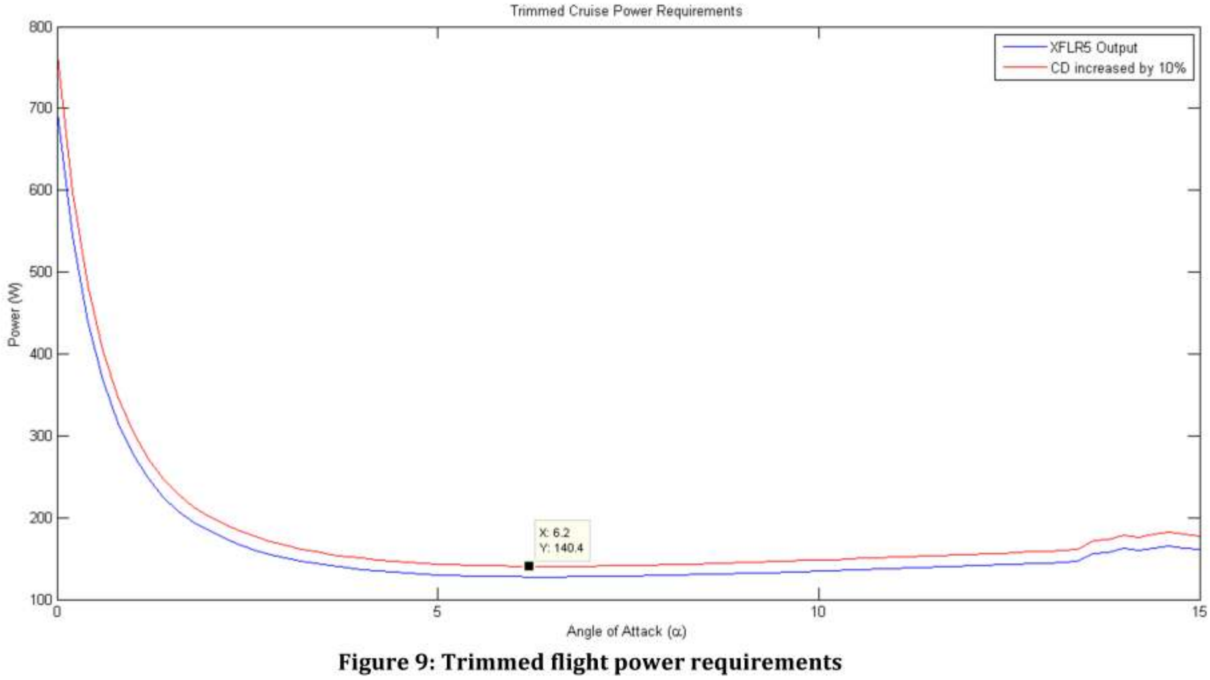


Figure 9: Trimmed flight power requirements

Figure 9 shows estimates of the power requirements to maintain trimmed cruise conditions. Excess power available is used to increase the climb rate. Further information about the climb rate is required to estimate climb requirements. The minimum power required is 141 W at $\alpha = 6.2^0$. This low power requirement stems from the low flight speed which is governed by the wing loading.

It should be noted that all these predictions are performed without the propeller and power unit fitted to the aircraft which would require additional power to overcome its self induced drag.

Basic Flow Analysis & Plot

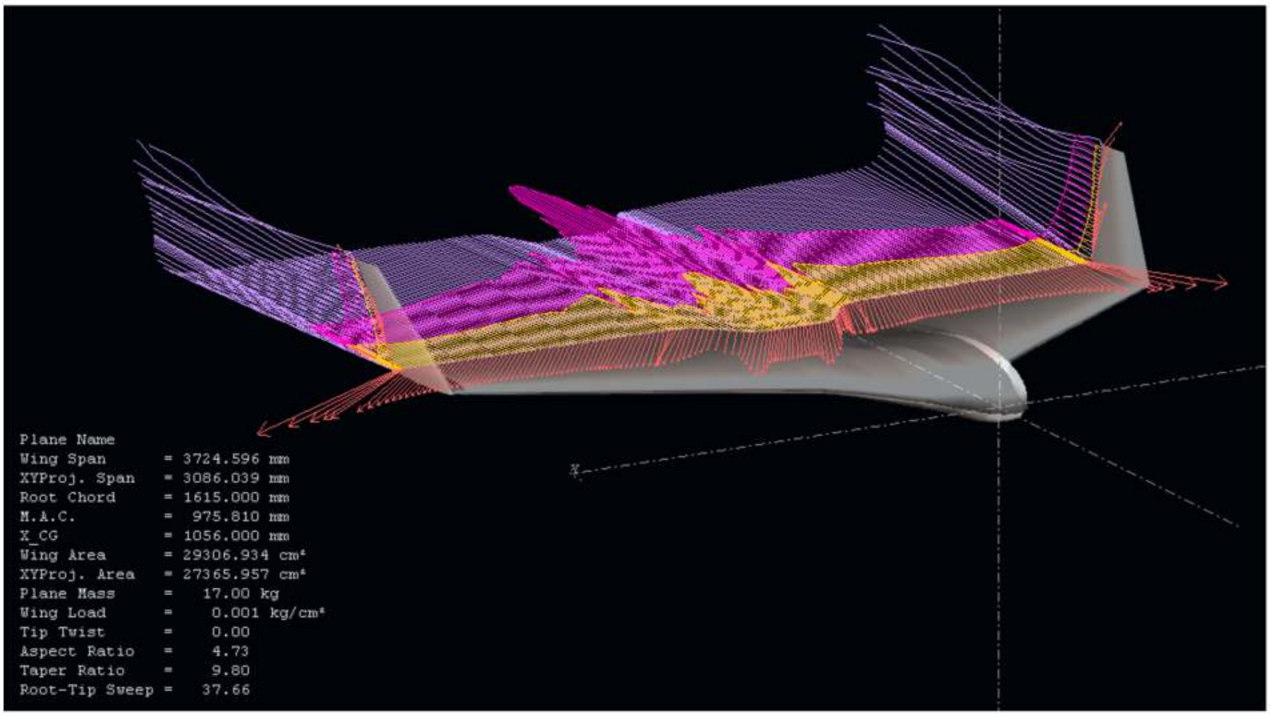


Figure 10: Plot form XFLR5 which provides an indication of the flow conditions at $\alpha = 3.2^0$

Purple = Viscous Drag
Yellow = Induced Drag
Orange = Down Wash
Grey = Streamlines

From the results of XFLR5 I will provide a basic analysis of the flow characteristics of the geometry referring to the results of Figure 10

Firstly the results aft of the central body section would be significantly altered by the presence of a power unit. What can be inferred from the downwash produced in this area is that the curvature in this region leads to a component of spanwise flow from the body. While this would only be a minor contributor when compared to the swept wing spanwise flow mechanisms a more discontinuous join would prevent this flow across the control surfaces in particular and reduce boundary layer thickening. Around the body section the viscous drag component dominates due to the large surface area.

Moving out along the span we can see that the viscous and induced drag components are similar. Approaching the winglets the induced drag increases due to the boundary effect of the winglet at the swept wing design enabling flow from inboard wing panels to induce velocity on outer panels.
From the streamlines it is seen that the winglets have shifted the trailing tip vortices away from the main wing surface which reduces the induced velocity at the tips and hence the induced drag. Figure 10 indicates that the viscous drag off the winglets is significantly higher than the induced drag. This is due to their large depth but relatively minor profile.

Variation in the design
Some variation in the design include a petrol EFI version and wing fuel tanks and a robust camera version that has the ability to carry an under noise mounted camera turret for high quality capture. These designs have been modelled in CAD and a centre of gravity calculation has been designed into each variation ensuring stability.
Planned use of our 3D printer will enable cost effective parts to be produced enabling unique low volume construction that is best of class in manufacturing. There are also plans to develop custom electronics for mining, photographic and SWARM mapping applications. Aeronautical is already working with Monash University, Swarm Robotics Department to develop hardware for special sensors in each specialist field.

Funding and market profile

Aeronautical is seeking project supporters and funding for this project.
Aeronautical Pty Ltd is an Australian registered private company with a share issue of 5000 shares. Additional shares can be issued to interested parties. Please contact Mario Carpeggiani at mario@aeronautical.com.au for more details.

Team Aeronautical, researchers, contractors and collaborators...

Mario Carpeggiani
Electronics Engineer

John Powell
Aerospace Engineer

Tom Carpeggiani
UAV operator in training

Craig Burton
Senior Industrial Designer

Herbert Briers Keable
Mechanical CAD engineering & prototypes