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TWIN-WING DESIGN OPTIONS USED FOR UNMANNED AERIAL VEHICLES TO ACHIEVE HIGH ALTITUDES AT LOW SPEEDS

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Abstract — The paper addresses the aerodynamic performance of twin-wing aircraft (biplanes) that are remotely piloted. While twin wing aircraft are acknowledged as to having greater maneuverability than monoplanes, they have inherent disadvantages based on the set position of the upper wing to meet piloting needs which induces significant levels of drag from the struts that link the upper and lower wings together. In this research, the aerodynamics of the wing position in relationship to the lower wing are analyzed with Computational Fluid Mechanics/Dynamics and simulation models. It will show that modern material can eliminate the strut drag and allow for greater lift at lower speeds. This proposed design is capable of achieving much higher altitudes with low speeds to offer advanced applications for Unmanned Aerial Vehicles, UAVs.

Keywords- Aerodynamics, Twin-Wings, High altitudes, Low speeds, UAVs

1. INTRODUCTION

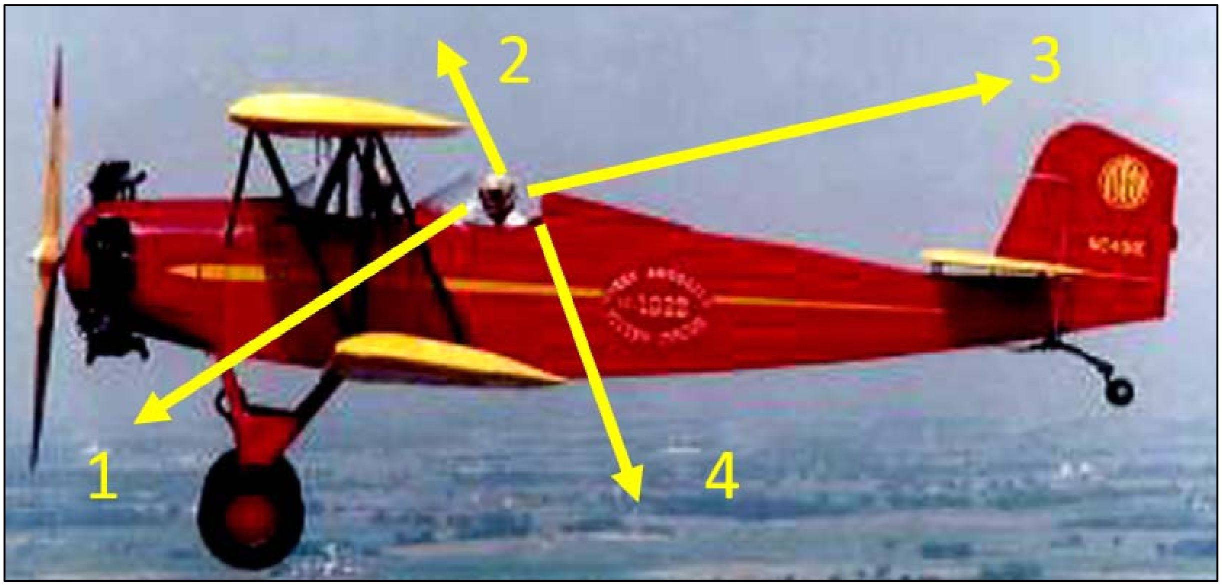
Of necessity, early aircraft designs were of a twin-wing configuration (biplanes) in order to generate sufficient lift at low speeds as the power units then available were not capable of delivering sufficient forward speed. Another contributing factor leading facilitating a biplane design is that the wing structure could be made to have greater rigidity and which assisted in enhanced flight stability. The materials used on the early aircraft have little or no resemblance to those used now and the way they overcame the low rigidity was to support the wings with struts to make a rigid structure. These struts allowed the wings to maintain profile and sufficient strength to generate lift suitable for flight [1]. This is illustrated in figure 1 which shows a classic biplane with struts between the upper and lower wings. However, even with streamlining these are considerable drag additions. Furthermore, this drag not only increases with speed, it also slows the maximum speed and affects the airflow over each wing; they also limit the possible flow and highlights the compound effect of biplanes. It is also important to note that biplanes do exhibit greater maneuverability than monoplanes [2]. At the start of World War Two, many biplanes were still in use as they were capable of smaller turning circles; a key in dog-fighting. As monoplanes flew mush faster this advantage quickly became insignificant in combat situations and soon biplanes were became obsolete. It is worth noting that aerobatic aircraft still use biplanes and exploit the advantages they exhibit.

Figure 1. Biplane with struts.

Unmanned Aerial Vehicles (UAVs), have generally been designed for low cost reliable operation at slower speeds and manufactured using less complex mechanical technology. For example, fixed blade propellers are used in almost all UAVs, while general aviation moved away from such technology around a century ago [3]. Military UAVs may be considered as the exception. The last five years has seen a rapid expansion in the usage of UAVs across the globe with many individuals and corporate entities seeking to identify new roles and enhance existing applications that are commercially profitable, not just safety or enforcement [4]. The next significant challenge is to integrate UAVs into national airspace with the Federal Aviation Administration (FAA) taking the lead in the United States via the “Next Generation Air Transportation System” (NextGen) with research into the technologies and protocols that will enable UAVs to interact within the same operational airspace as conventional aircraft [5]. The research envisages that UAVs could be designed to fly above commercial airspace, thus reducing the possibility of collisions and augmenting the often overcrowded airspace seen in many parts of the world. These UAV would still capitalize on their original concepts of low cost, low technology and speed.

Biplanes have a parameter called stagger, which is the top wing is offset relative to the lower wing, regardless of the direction. If the top wing is forward of the lower this is called negative stagger, reverse and positive stagger and directly above and zero stagger. Figure 2 shows a classic case of negative stagger, with the upper wing forward of the lower. The amount of stagger is generally defined according to the percentage of the lower chord length. For example, 50% negative stagger is the top wing is 50% of the chord length forward. This is done for several reasons and the four ways are shown on figure 2. First (1) pilots can see the taxiway and runway for landing and taking off. Secondly (2) to see above and enter the cockpit. Thirdly (3) to see behind with good visibility. Finally (4) looking for the enemy that might be below. With a UAV, all these features are unnecessary and so do not feature in design requirements

Figure 2. Negative stagger on a biplane.



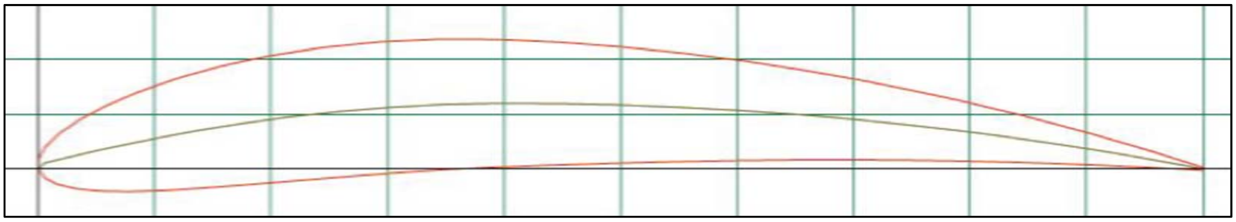
The principal aim of this research is to determine what influence stagger has on lift at high altitudes and drag, with a view to considering if a twin-wing is a feasible option for UAVs. The designs will be modelled and simulated for flight at 37,000ft with a static pressure of 217 hPa and speed of 0.3 Mach (approximately 200 mph).

2. EXPERIMENTAL STUDY AND THEORY

2.1 Wind parameters

The wing to be modelled is a NACA 6412 that is shown in figure 3. It is a Four-Digit profile, there are 5 and 6 series aerofoils and these have mainly been developed for M_{CRIT} speeds in transonic regions of flight. This has a maximum camber of 6% at 40% of the chord length from the leading edge and a maximum thickness of 12% of the chord length. It is of a simple profile and one that has seen widespread application on previous generations of biplanes and gliders [6]. While this design allows for the extra generation of lift, it does suffer more from drag and the thickness is deeper than many and the frontal cross-sectional area larger than average. The lift to drag rations are shown in Table 1. As this is not investigating high speeds, but relatively low, the thickness is not paramount for the drag.

Figure 3. NACA 6412 profile



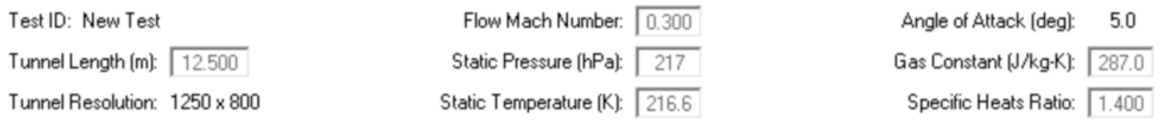
The simulation in this research uses a 5^0 Angle of Attacks, AoA, this is approximately mid-way between zero AoA and the start of stall, it also balances as the drag influence, table 1. Further research to optimize the root angle of incidence and twist is outside of the scope of this experiment and will be followed up subsequently, being the subject of future research work. As discussed above, this simulation will be set at 37,000ft as this is where the temperature remains constant above as it passes from the Tropopause to the Troposphere and then to the Stratosphere. A static pressure of 217 hPa is the value at this altitude and although not higher than most commercial flights, it is to determine the lift achievable at this level. Speed of 0.3 Mach (approximately 200 mph) where the temperature determines the value [7].

Table 1: Lift and Drag for NACA 6412 Aerofoil at Rey 50000.

Angle of Attack	**Lift C_L**	**Drag C_d**
1	0.3166	0.03657
3	0.2529	0.04426
5	0.7094	0.05375
7	0.8430	0.07193
9	1.2725	0.03391
11	1.3527	0.04742
13	1.3181	0.07194

Simulation is with 2D MicroCFD® and the parameters were set to those stated in figure 4. Wing length is ignored and tip drag and section vortices are only incorporated in 2D only. The flow was symmetrical and independent of ground surface influences. Surface flow was smooth and Gas Constants as altitude and standard atmospheric values [8].

Figure 4. Simulation parameters for 2D flow.



Test ID: New Test
Tunnel Length (m): 12.500
Tunnel Resolution: 1250 x 800
Flow Mach Number: 0.300
Static Pressure (hPa): 217
Static Temperature (K): 216.6
Angle of Attack (deg): 5.0
Gas Constant (J/kg-K): 287.0
Specific Heats Ratio: 1.400

3. RESULTS AND DISCUSSION

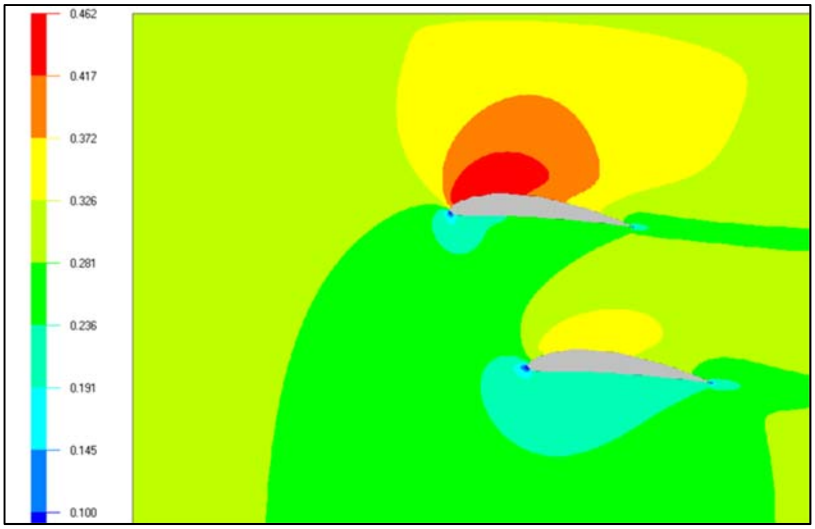
3.1. Simulation overview

Three combinations were simulated, those of negative, zero and positive stagger, stagger was 50% off set in both directions for both positive and negative stagger. The speed, pressure and flow are discussed, and shown for each simulation. Positive stagger results are expands to include the density and temperature profiles in support of the result and interpretations. These are also compared to combined lift and influences of drag.

3.2 Negative stagger for twin-wing

Simulation started with the upper and lower wings in the classic configuration of a negative stagger relation to 50% of the chord length off set. Figure 5 shows the result for the speed of flow measured in Mach numbers.

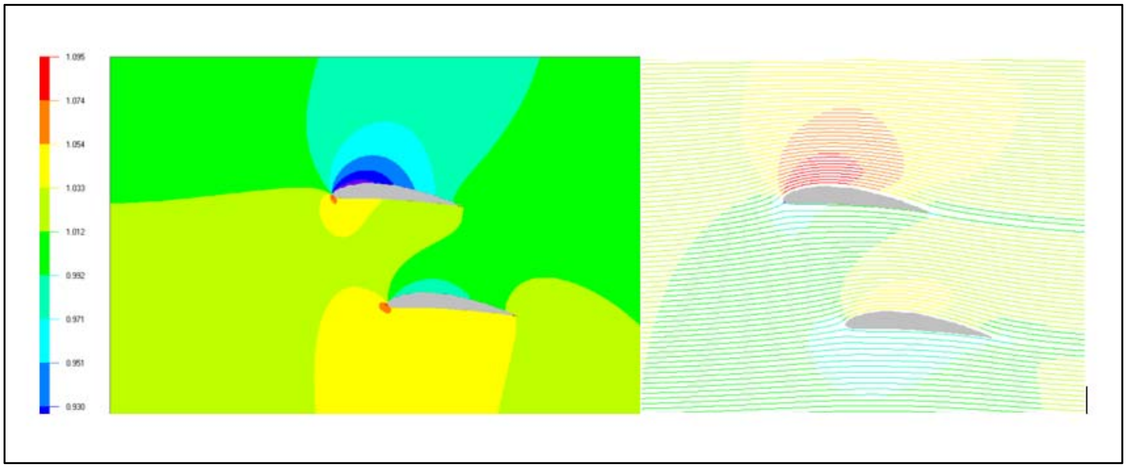
Figure 5. Flow over a negative stagger wing, speed in Mach.



Flow over the upper wing is not effected by the system constraints and high speeds are achieved easily on the profile as theory would predict. Leading edge dynamics is limited and a speed increase is achieved that follows backwards and results in a modest differential speed over the upper and lower wing. Speed profile differences between the two aerofoils is notably different and the upper surface of the lower wing is clearly limited by the wake of the upper wing. In effect, the lift that is generated by the differential speeds will be lower than the individual wings. When no influences or interactions the profiles should be identical.

This is validated in figure 6 below that shows the pressure distributions and flow lines [9]. The maximum speed on the upper profile of the lower wing is 0.37 Mach and compared the upper wing it is 0.46 Mach. The combined double wing system does not generate twice the lift of a monoplane with NACA 6412 and this is assuming no struts between the upper and lower. At best it can be argued that the twin-wing at best is only fractionally greater and at best 1.3 the lift on one wing; whilst the drag will not be double. Thus, why biplanes have a limited maximum speed and were not used for speed [10]. This is further supported by the flow lines and the upper wake influence on the lower [11].

Figure 6. Pressure and flow lines for negative stagger, pressure in hPa.



3.3 Zero stagger for twin-wing

Zero stagger was modelled and the simulation repeated with identical setting and figure 7 is the speed in Mach for this set of parameters. The chord lengths are parallel and vertically aligned. The upper aerofoil has identical flow speeds on the upper surface of the upper wing. Underneath the leading and trailing edges are limiter's to flow in those areas, not significantly, but moderately. On the underside of the lower wing, the flow is notably different to negative stagger and a greater differential flow over both surfaces of each wing [12]. The speeds of flow over each aerofoil are the same in magnitude but different in length and hence pressure achieved at static values, this can be clearly seen with the lower wing on the underside, a constant Mach 0.17 for most of the length. Also note, the trailing speed from the trailing edge on the upper surface, indicating good laminar flow and smaller wake as the lower wing up wash and indicating that pressure is being maintained.

Figure 7. Zero stagger flow speed in Mach.

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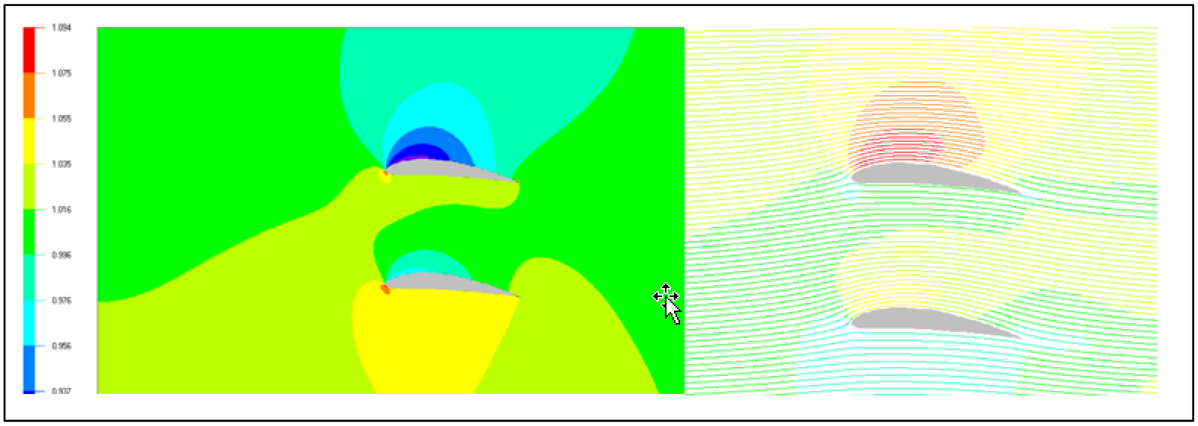
Figure 8. Pressure (hPa) and flow for zero stagger.



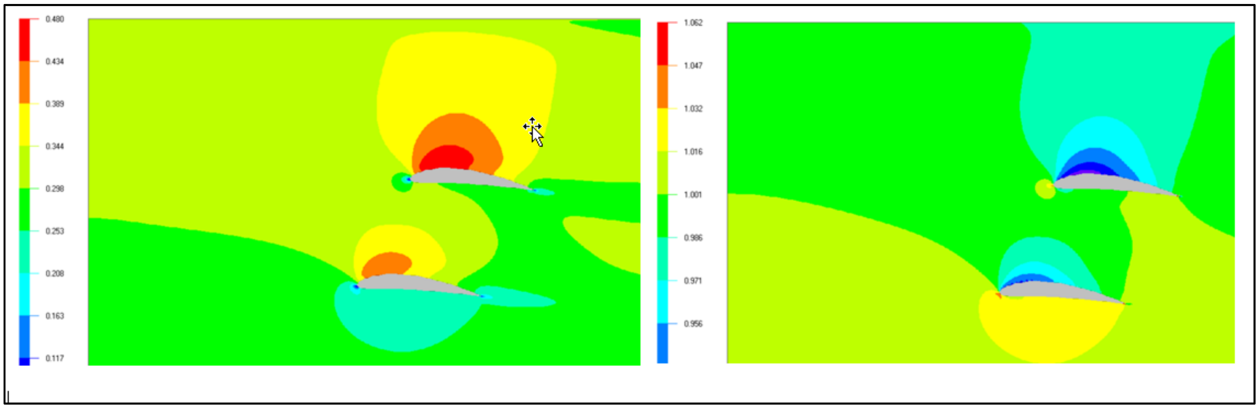
Above, figure 8, the pressure profile that the upper surface of the upper wing has static pressures as low as 0.990 hPa and the lower surface of 1.010 hPa; thus a reasonably improved differential pressure and achieved lift. These are similar to the negative stagger but marginally higher. On the lower wing, it is smaller than the upper for differential pressure; it is higher than negative stagger. Overall, the lift generated by this configuration is approximately 1.5 of the equitant of the first mono-wing in figure 5. This clearly shows zero stagger is aerodynamically more efficient under these parameters compared to negative stagger. This still ignores the maneuverability advantages over monoplanes which can be significant in remotely piloted aircraft for stability and level flight.

3.4 Positive stagger for twin-wing

Positive stagger in this case is with the upper wing offset backwards by 50% of chord length. The two profiles have identical chord lengths and the influence of different lengths is not part of this research.

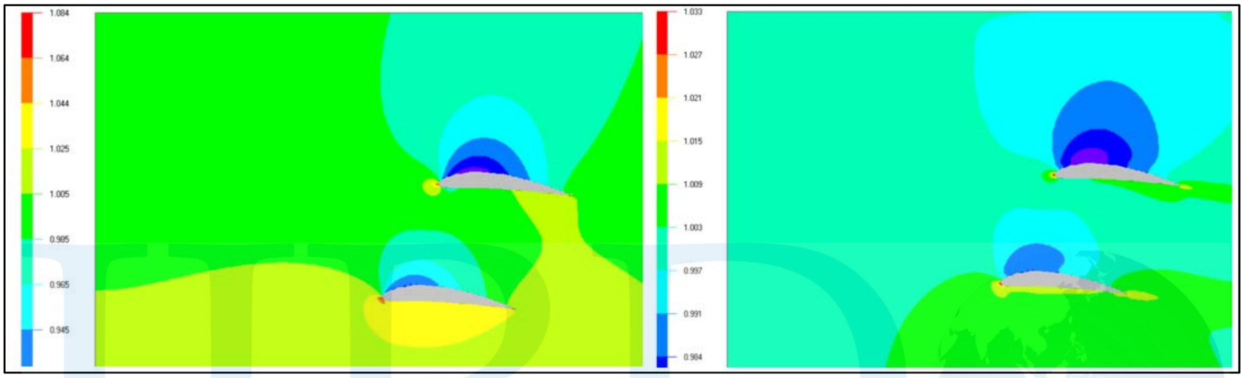
Figure 9 shows the Mach and Density for this simulation with positive stagger. The profiles distributions show a marked difference compared with the zero and negative and the difference sets this apart from the other two to produce a pattern of differential comparisons apart.

Figure 9. Speed (Mach) and Density (1.000 datum at altitude) with positive stagger, Density on the left.



The upper wing experiences the speed on the top surface similar to the other two configurations, its underside also resulting in a greater differential difference and this is shown in the density on the right hand side. The density comparisons between the two shows lower density on both and this is greater when compared amongst the three stagger configurations. Both upper surface have densities in the region of 0.995 kg/m^3 region, lower than nominal for the density at this altitude, recorded as 1.00 for comparisons. More importantly, the maximum speed on the upper surface of the lower wing reaches speeds close to those of the maximum of the upper wing, approaching Mach 0.434 with its forward speed of Mach 0.300. There is a clear difference with the positive stagger than the other two configurations in stagger. Pressure and temperature are shown below in figure 10, with temperature shown on the right.

Figure 10. Pressure (hPa) and Temperature (K) for positive stagger, Temperature on right.



Differential Pressure is actually higher on the lower wing and that on the upper is less than 10%, which is in contrast to those of negative and positive stagger. This is replicated with the temperature profiles that are interlinked to pressure under Charles and Boyles Laws [13]. From this juxtaposition it can be argued that the upper wing still generates the greatest lift from the under wing flow speeds. If this is compared to a monoplane with the NACA 6412 profile the twin-wing is now generating approximately 1.7 times, not double as would be required, something that needs to be reviewed for robustness in parameter design [14]. The positive stagger is different to negative and zero stagger; in particular the lower wing is less influenced by the upper for the majority of the chord length. In addition, the compound lift of each is closely followed. Drag is still influential in the total lift and figure 11 identifies the flow lines and hence the up-wash and down-wash of this configuration. However, at lower speeds it is less influential and at this level of analysis the relationship to stall cannot be precisely determined.

Figure 11. Flow distribution with positive stagger.

The left side of figure 11 where the darker green lines become the lighter green is where the influence of the height of the wings can be identified. In both cases, the down wash is greater than the up wash at each of the trailing edges. They both have a similar angle and direction; this, and the vortices generated, will be significant in the level of drag, as speeds would increase. The height does offer sufficient space and the flow lines under the upper wing are of a similar spacing compared to those approaching the leading edge, suggesting the height is sufficient to minimize the influence. This height too needs fully clarifying for chord length ratio. Currently, there is a lack of an adequate conceptual theoretical framework to determine the relationship and parameter setting. Any such analysis would also need to incorporate stability of flight and influences for all inputs.

4. CONCLUSION

The classic biplane design has largely been regarded as obsolete by designers for many practical reasons and technology has progressed to allow aircraft to achieve their needs with mono wing designs. However, the limitations of biplanes, negative stagger and struts are no longer a problem when UAVs with modern materials are employed and opens up possibilities for a reconsideration of twin wing configurations. This allows for changes and the position of stagger to be adapted for different flights situations. This research has shown that positive stagger offers considerably more lift for the same wing profile in this simulation.

Future work will be directed to how the angle of attack, varying chord lengths and position of stagger influence the exact lift and drag. Additionally, to determine the altitude possible with 3D modelling of an aircraft with defined aspect rations, and possible speed implications for stall. The angle of Incidence will also be considered as a way of enhancing flight stability for UAV beyond the Visual-Line-of-Sight.

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