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Establishing Angle of Attach for NACA 6412 Twin-Wing on Take-off Downwash Influences on Lift and Drag

Ian R. McAndrew, Elena Visnehvskaya, and Kenneth L. Witcher

***Abstract*—This research paper investigates the aerodynamics of a twin-wing aircraft whilst taking-off and determines the influences of down wash from various angles of attacks with a positive stagger. The results identify that having different angles of attack allows more lift to be generated by the lower wing and maximizes the lift from the upper wing. Recommendations are made as to how twin-wings can be designed when low take-off speeds are needed, either by short runways, or heavy payloads.**

***Index Terms*—Aerodynamics, twin-wing, take-off speeds.**

I. Introduction

In this research paper, the basis of a twin-wing is researched and investigated. Its aim is to determine the possibility of use with Unmanned Aerial Systems, UAV. This line of research follows as a side topic of twin-wing designs to achieve high altitude at low speed. It also included the Angle of Attach, AoA, for certain phases of flight. Before that is possible, they need to be effective at take-off with either short runways or high payloads. Previous research by the authors have investigated the possibility of the height and AoA of the wing and stagger [1]. Take-off introduces more aerodynamic influences than any other stage of flight, for example the influence of the ground affecting and directing flow underneath the lower wing in this case.

Twin-wing design, commonly called Biplanes, used the extra wing to generate more lift with aircraft that had low power output and were initially designed without a full understanding of aerodynamics. These designs had lower stall speeds and high maneuverability than monoplanes, and characteristically other possibilities for current applications of UAVs. Their principal weakness was the struts used to make the system rigid by securing the upper and lower wing together and the upper wing to the fuselage. These struts were needed, and created additional drag, limiting its maximum speed. Various streamlining designs were used for the struts; however, the form drag was considerable and increased quadratically as speeds increases. Modern materials can now be used that eliminate the need for struts and produce a clean flow shape. Composites are rigid and it is possible to have twin-wings, which are independent. An additional feature, stagger, is the offset of the upper wing to the lower. Negative stagger has been typical to allow the pilot to enter the cockpit. There are four other demands, shown in Fig. 1.

1) Taxing and landing.
2) Vertically above to see other aircraft when increasing altitude.
3) Behind and
4) Below when descending.

Negative stagger is not the effective position aerodynamically and the pilots, which needs outweigh all other. With a UAV, this stagger can be modified to suit aerodynamic needs and not the pilot means that requirement is removed.

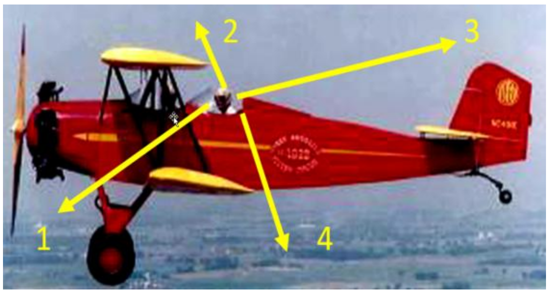

Fig. 1. Biplane with struts and negative stagger.

Struts can be clearly seen in this Figure above and overall the drag is much higher than ideal configerations. The lower wing is attached directly to the fuselage, as conventional commerical aircraft. The upper wing is held in place with these strtuts to the cockpit opening and also the lower wing too. Stagger (offset) may have the three classic configurations, and are shown in Fig. 2. Their interactions have been researched and suggested alternatives made [2]. Positive stagger is better for higher lift, zero stagger offers little more than negative. AoA at each configuration will influence both with advantages and disadvantges the effectiveness, and this research is comparing the relationship at take-off.

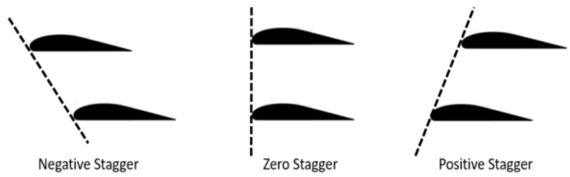

Fig. 2. Biplane with struts and negative stagger.

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Ian R. McAndrew FRAeS is with Embry Riddle Aeronautical University-Worldwide, College of Aeronautical Science, Earnley, UK (e-mail: McAnd4f1@erau.edu).

Elena Visnehvskaya is with Embry Riddle Aeronautical University-Worldwide, College of Arts and Sciences, Bitburg, Germany (e-mail: Navarroj1@erau.edu).

Kenneth L. Witcher, Embry Riddle Aeronautical University-Worldwide, College of Aeronautical Science, Daytona Beach, Florida (e-mail: Witchea8@erau.edu).

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II. Review of Literature and Theory

Lift and Drag are interrelated and depend on the design, profile and other factors [3]. An AoA has a significant influence on the lift and increases lift whilst also increasing drag, at the point where drag and lift balance stall occurs [4]. Aerodynamics is a balance between all requirements of flight from take-off to landing. Additional features, e.g. flaps and slats, allow specific stages to be accommodated without detriment to all stages. As such, there is a finite AoA achievable to suit take-off and including the aerodynamics of the surface prior to flight is needed. Additionally, the air that has passed over the wing will be a higher speed on the upper surface and its momentum will naturally flow downwards and is known as downwash [5]. When this air mixes with the air from below the trailing edge, vortices will be created that further increase drag [6]. Typically, these are minimized, for a twin-wing downwash may have the advantage of allowing linear flow without interference on the lower side of the upper wing [7]. This facet is part of the research and how AoA interact will show potential settings for take-off [8]. As UAVs tend to have take-off speeds lower than other aircraft the drag is also lower and influences indirectly.

III. Research Methodolgy

A NACA 6412 wing profile is used in these simulations for several reasons. First, it is a classic shape that has and still used for low speed applications, e.g. gliders [9]. Secondly, the lift characteristics are not unstable at AoA up to the stall conditions, which is an advantage for UAV. Finally, using a known aerofile profile allows for validation of the Computational Fluid Dynamics, CFD, of the simulation software run on MicroCDF ® 2D. Previous research has shown that a positive stagger of 50% of the chord length is close to optimum, and an AoA on the upper surface of 5^0 is the base feature, and will be the datum in this research. Changes to the lower surface AoA are investigated at 0^o, 5^o, 10^o and 15^0. Mach, density, pressure and temperature were modelled and these results are shown and discussed below. Each simulation is with a smooth surface option selected and the Ground Effect enabled to model this influence. Take-off speed is set at 0.1 Mach and at sea level this approximated to 32m/s or 72 mph. Other air properties are set at standard atmospheric levels and shown on the results.

IV. Results and Discussions

In Fig. 3 the upper AoA is as stated in the methodology at 5^o as this was shown to be a balance between lift and drag for level flight. UAVs are generally low speed and the influence of drag lower than that for normal flight requirements. Only the lower wing will be adjusted as compound changes to both would require sophisticated control and feedback mechanisms; far beyond the basis features of UAVs. . The lower wing is at AoA 0^o in this first simulation and used to see if the downwash is affected and to what degree in the most probably configuration, and to allow for comparison with the other simulations. This first run was calibrated from two stages. First, the wing was simulated as a mono application and its pressure profile and differential pressure were compared to a wing tunnel result with the same profile and corresponding Reynolds number. Secondly, the speed distribution compared. As both within acceptable experimental limits that has been used to validate and confirm the outputs.

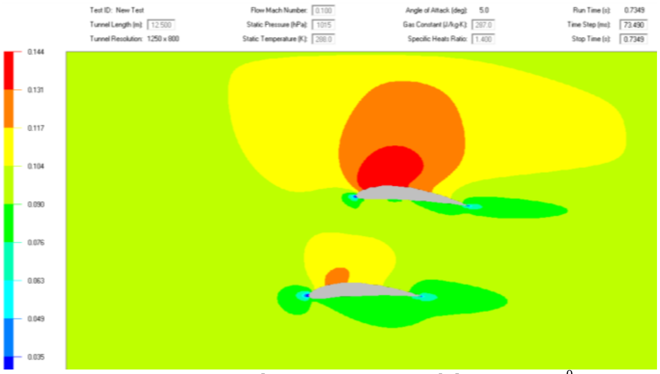

Fig. 3. Twin-wing and positive stagger with lower AoA 0^0.

The first simulation shows there is a significant difference between the results on the upper and lower wing. Air flowing over the upper wing will be unaffected by the configuration below. Underneath the pressure changes between the wings will alter the air speed, and hence pressure profiles in all areas. Nevertheless, this differential pressure and resulting lift to drag ratio, see Table I, clearly shows the top wing produces lift close to that expected if modelled as a mono-wing. Airflow over the lower wing is shown to be affected and the maximum speed of the air on its upper surface is visually lower. This is true for the underneath of the lower wing. Differential pressure is much smaller and its total lift is far below expectations and that on the upper wing. A combned lift of both wings is approximately only 1.28 of the theory prediction as if two separate wings were used independently of each other. The influence on the runway underneath the lower wing also plays its part in the reduced pressure differentials [10]. This air is categorized as not being clean air but dirty air, meaning that is is not laminar and reduces the pressure underneath, hence available lift. Fig. 4, shows the flow lines and the distance behind the trailing edges before the air returns to the normal condition is a long way downstream and this downwash influnce increases drag, lowers lift and requires higher speeds or lighter payloads for take-off.

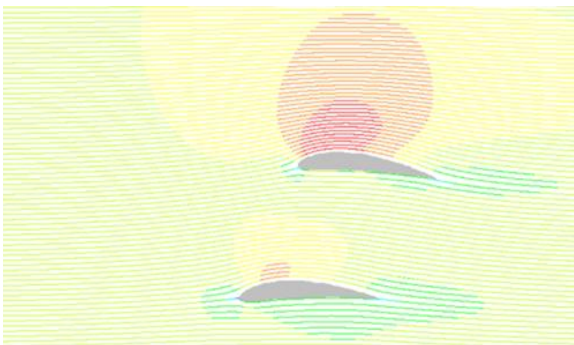

Fig. 4. Laminar flow and downwash.

The points where the air is affected and returns to normal flow can be seen by looking at the stream lines before and after. All changes in airflow create drag and at take-off for a twin-wing will have more drag than all other stages of flight [11].

Increasing the lower wing to an AoA 10^{o} is intended to create a larger downwash that does not influence the upper lift as much. The results, Fig. 5, are similar to those in Fig. 3, and the upper surface on the upper wing is very similar. Its differential pressure is higher by about 10% as the underneath is free to flow with a reduced influence from the lower downwash narrowing the airflow route. On the lower wing the speed increases in the upper surface and it too has a higher differential pressure resulting in a combined lift of approximately 1.65 that of the theory.

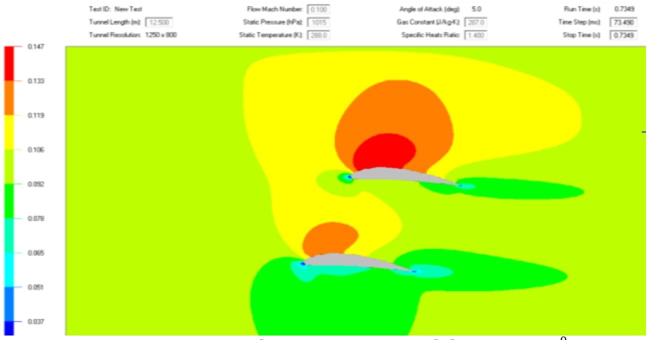

Fig. 5. Twin-wing and positive stagger with lower AoA 5^{0}.

The next simulation is with the lower wing set to 10^{o} AoA and repeated as the previous two simulation, see Fig. 6s. A trend can be seen with the Mach speeds and the upper wing's uper surface is identical to the previous two simulations. The differential pressure on this upper wing is only marginally higher that the previous. Downwash is likely to be reducing the funneling effect from the first simulation when the air flow is in effect a convergent nozzle, Fig. 6. The second created a parallel path and here the flow is more akine to a divergent and thus slowing the velocity post trailing edge and reducing the pressure accordingly. Therefore, it is highly likely the induced vortex drag will be lower as the further away from the trailing edge has a reduced quadraftic influence. At the trailing edge of the lower the speed wake is longer and flow returns to normal at a later stage. Nevertheless, the combined lift of this configuration is still higher and approaching 1.84 of the theory.

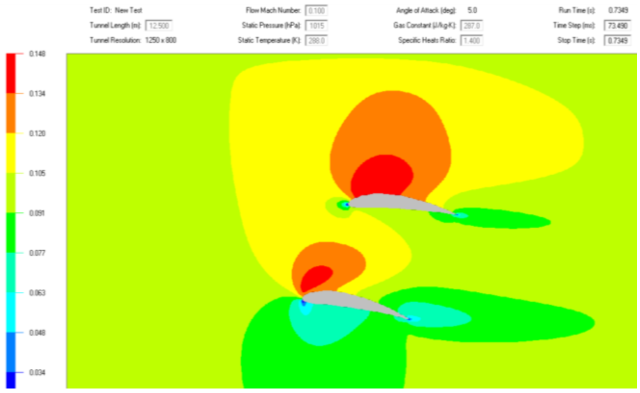

Fig. 6. Twin-wing and positive stagger with lower AoA 10^{o}.

Fig. 7, the density profile with a lower wing AoA 10^{o} and the downwash is clearly shown at the trailing edge. Surprisingly, is that its influence ahead of both wings is great. Although it does not appear to influence the upper wing, it might slow the flow over the upper surface of the lower wing; this will require separate simulations. At this configuration the downwash is consistant and will eventualy reach the runway at a considerable distance behind the taking off aircraft. The consistency in density also supports the theory of its maintaining laminar flow under these conditions. Downwash from the upper wing is least apparent and that would be expected given an AoA half that of the lower surface.

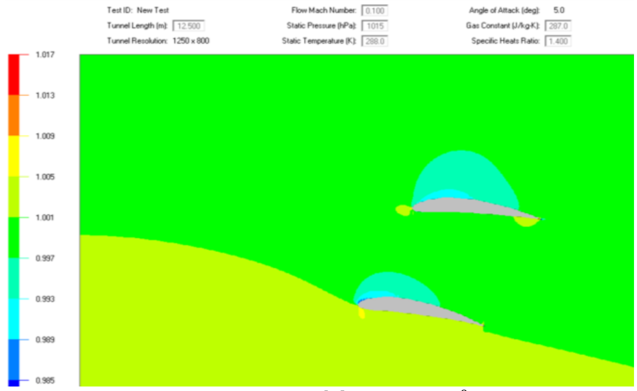

Fig. 7. Density with lower AoA 10^{o}.

In the last simulation, Fig. 8, shows a 15^{o} AoA, which is very high and depending on forward speed may be past its maximum and in the stall range [12]. During acceleration this would mean that there is a greater down force and that dictates the point of take-off. The maximum speeds on the lower wing is now considerably greater than the other configurations. Differential pressure is higher and the overall lift from both is about 1.84 the theoretical lift. AoA of each is a large divergant nozzle and reducing the downwash implications more than before. A disadvantage of this is at take-off the stability is sensitive to changes and for accent the pitch needs raising; thus stall is a real possibility. It would depend on speed and not practical for remote piloted.

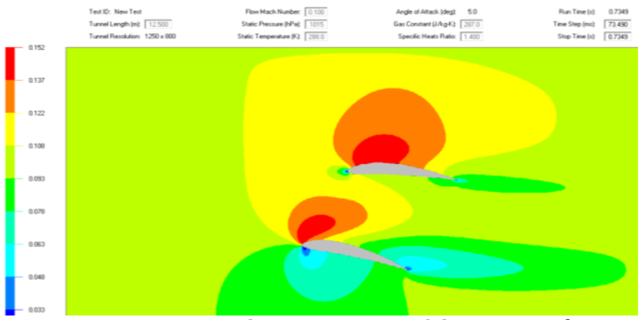

Fig. 8. Twin-wing and positive stagger with lower AoA 15^{o}.

Downwash is shown in Fig. 9 and that the point behind the trailing edges is where air returns to initial conditions and is considerably downstream. Any vortices from this will be minimal and low enough not to be a concern. The increased drag is discussed more with Table I. On the upper wing this is behavouring similarly as the previous results. The upper wing is the principal lift generator and when not affected by the lower they both increase the total lift. Downstream vortices that are close behind the trailing edge may disturb the surface on a grass runway and further compound the disturbed air.

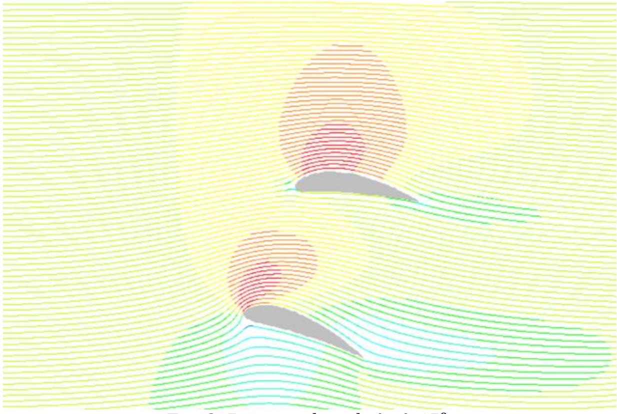

Fig. 9. Downwash with AoA 15°.

The individual configurations naturally effects the combined point of lift, force and direction. Fig. 10 collectively shows all four parameters and how they change with the AoA on the lower wing.

First, on the left, the collective force is near the trailing edge of the lower wing and approximately at the maximum thickness for the upper wing. A clockwise moment is pushing the nose up, albeit slightly. This is what is needed at take-off. However, this scenario would not be used as the simulation was to determine how downwash works for twin-wing and in particular a convergent nozzle flow between the wings.

In the second from left, the effective point of pressure has moved forward on both wings and applying a moment approximately higher than the previous. In effect, the pitch would have to be establish upwards for accent. The lift of by natural genertion is sufficent for some altitude movement.

Thirdly, the second from right, the point of pressure has moved forward a little more on both wings. The lower wing possibly acting as an upward turning moment to add to lift. These, of course, depend on the centre of gravity and this may add to lift at take-off.

Finally, the one on the right, is a false and unusable configuration. The risk of stall and low stabiltiy would not be acceptable. The point of lift is now further forward on the upper surface, marginally, interestly, the lower point has now reversed slightly to the trailing edge.

Overall, this visually shows how lower wing changes alter lift at take-off. It does not, here, account for the underneater disturbances or changes in drag. They are discussed fully below.

Fig. 10. Biplane with struts and negative stagger.

A summary of the key data is in Table I, below, was taken from each simulation run and collated. 2D Aero coefficient Lift has been related previously to each of the above detailed descriptions with respect to the theoretical lift possible for the twin-wing design and is not discussed further here. Starting with the 2D Force, N/m Lift, as the AoA increases to 10° the lift increases approximately by 40% for each 5^0 of increase. At 15° the increase tails off as this is in the stall zone. 2D Drag nearly doubles with in 5° increase in AoA up to 10° and when 15° increases by approximately 150%, as could be expected in the stall/separation zone [13].

Coefficient Lift (2D) increases up to 10° and starts to reduce, again the theory matching practice as discussed in the theory. This zone is sensitive to take-off speed and needs more analysis, beyond the scope of ths research work, see future work section. Interestingly, this might be non-influential if take-off has been achieved and the beneath boundary conditions will alter to allow smoother airflow, as desired. Pre take-off conditions will vary considerably with head wind, payload and even if a UAV if on a tarmac or grass runway. These will all influence and need addressing to determine the practical and safe AoA possible. Note that with UAVs safety conditions and acceptance is related to the surrounding and not human passengers.

TABLE I: LIFT AND DRAG FOR INDIVIDUAL EXPERIMENTS

	1	2	3	4
Upper Wing AoA	5	5	5	5
Lower Wing AoA	0	5	10	15
2-D Force N/m Lift	3.03E3	3.84E3	4.36E3	4.66E3
2-D Force N/m Drag	1.05E2	2.2E2	3.19E2	4.97E2
2-D Aero Coefficient Lift	1.28	1.61	1.84	0.8304
2-D Aero Coefficient Drag	0.064	0.093	0.087	0.0886
Pitch	0.1863	0.134	0.1015	0.0147

V. Conclusions and Future Work

Twin-wings can be designed to be more aerodynamic for UAVs than manned aircraft, as the stagger can be set as needed and not to suit the pilot. The AoA of both wings can influence both lift and drag greatly at the take of stage and has been shown to be sensitive to small changes at higher AoA. Wing AoA position can act in several ways. First, as a convergent nozzle with opposing AoA, that creates unnecessary downwash and negative effect. Secondly, as a continuous flow in a pipe, an identical AoA, which offers no downwash improvements of magnitude. Finally, as a divergent nozzle with reduced downwash. This latter case is sensitive to the absolute configuration and at take off the boundary conditions become sensitive. At this stage the stability is concerning and needs finalizing.

Overall, this research has shown there are considerable advantages to using twin-wings for UAVs and if low speeds in flight are practical it offers two applications. First, high altitude flight with low speed. Secondly, lower altitude flight with battery powered propulsion that could be more efficient than current designs.

Future work will focus on this region of parameters and how they can be influenced, set and supported with theory. These future models needs to be 3D with absolute wing conditions set; and this includes any angle of incident at the root and tip. Furthermore, various take of speeds, payloads and operational requirements.

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Ian R. McAndrew is the Department Chair for Embry Riddle Aeronautical University – Worldwide, College of Aeronautics. He has a PhD, Master's and undergraduate degree in mechanical engineering. In addition, a Master's in Education and another undergraduate degree in manufacturing. He lives and works in the UK, where all his degrees were awarded. Dr McAndrew is also a Chartered Electrical Engineer. His current research interests are in low speed aerodynamics and the statistics of reliability in design.

Before entering education, he worked in the Automotive industry where he held several patent for automation of engine assembly and manufacture. He is the author of several books and conference proceedings. Additionally, he has examined PhD globally and has taught in more than 20 countries during his academic career.

Dr. Ian R. McAndrew PhD FRAeS is a Professor of Aeronautics at his university and tenured. He is a member of several institutions and external examiner at two UK Universities.