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Computational Fluid Dynamics Analysis of the 1303 Unmanned Combat Air Vehicle

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Abstract

This paper examines the flow over the 1303 UCAV platform, with a focus on the behaviour that causes the onset of pitch break. The effect of applying wash in and wash out on the outer section of the wing are also examined. Simulations were performed using the commercial CFD package FLUENT, using an incompressible, steady solver with the $k-\omega$ SST turbulence model at a Reynolds number of 5.6 million and Mach 0.25. Water tunnel flow visualisation experiments were also performed to validate the numerical model and provide further understanding of the flow field.

Introduction

The 1303 Unmanned Combat Aerial Vehicle (UCAV) is a generic design representative of "typical" UCAV platforms. It is a tailless aircraft with a wing-sweep angle of 47°, that exhibits complex aerodynamic behaviour. It is useful for comparing numerical methods and testing flow control methods due to the availability of experimental ([1], [2]) and CFD results (such as [3], [4]) in the literature.

The experimental data ([1], [2]) shows that pitch break occurs at an angle of attack (α) of around 8°. Pitch break is a phenomenon in which the pitching moment of the aircraft increases with increasing α, causing the aircraft to pitch up at an increasing rate, which leads to stall if not brought under control. By gaining a better understanding of the flow over the 1303 UCAV the authors aim to facilitate the development of novel control mechanisms which allow good maneuverability without leading to loss of control.

Simulation Details and Validation

Numerical simulations were performed at a Reynolds number of 5.6 million, based on the mean aerodynamic chord, and a Mach number of 0.25. These values were chosen to allow the results to be validated against the experimental studies of Bruce and Mundell [1] and McParlin *et al.*[2] as well as the numerical simulation of Wong *et al.*[3]. The Mach number is sufficiently low that compressibility effects will be small. The numerical solver used was Fluent v12, with a steady, incompressible solver and the $k-\omega$ SST turbulence model. The SST model was chosen based on the comparison of different models over the 1303 UCAV by Arthur and Petterson[4]. The chosen pressure-velocity coupler was SIMPLEC and 2nd order discretisations were employed to give high accuracy while still being stable. Mesh independence studies showed that approximately 3 million cells was sufficient to resolve the flow well and obtain convergence with experimental data. To ensure good resolution of the boundary layer, 5 prism layers were used over the aircraft surface, with a maximum non-dimensionalised wall normal distance, y^+, of 210 for the first prism layer.

Figure 1 shows the coefficient of pitch moment plotted against angle of attack, for this study, together with the experimental results (of [1]) and CFD results published by Wong *et al* [3]. All

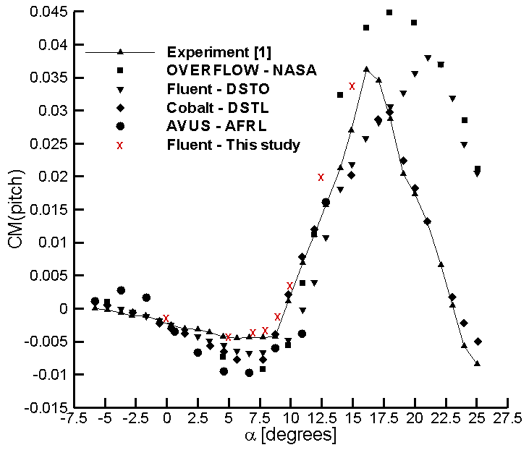

Figure 1: Coefficient of pitch at various angles of attack for the current study compared to experimental wind tunnel and CFD results published in [3]

moments were taken about the aerodynamic centre of the aircraft to coincide with the experimental results. Our simulations shows very good agreement at lower angle of attack, with the deviation becoming more significant as α is increased beyond 10°.

Figure 2 shows a comparison of our Fluent results for the coefficient of lift compared to the wind tunnel study by [1]. The results of the CFD studies published by [3] have been left off the plot for clarity, as the lines all agree well. The CFD CL results agree well with the experimental data, especially at 10° and below. The coefficient of drag comparison is shown in figure 3. The CFD results predict a slightly higher coefficient of drag, but the profiles of the curves are similar. It is believed that this drag increase may be partially due to the absence of the sting mechanism used to attach the aerofoil to the force balance in the wind tunnel studies. This creates a blunt trailing edge behind the body in the centre, which will change the flow field around the point of attachment.

Flow Features

As is typical for delta wings with moderate sweep angles the 1303 features a leading edge vortex, which can be seen in figure 4. As α is increased this vortex grows in strength and begins to detach from the leading edge, becoming a trailing vortex near the wing tip. This detachment occurs at around the same angle of attack as the onset of pitch break, with the point of detachment moving towards the nose as α is increased.

The region of the wing outboard of the vortex detachment point stalls. Due to the swept angle of the wing, the inner portion of the wing generates a positive (nose up) pitch moment which is

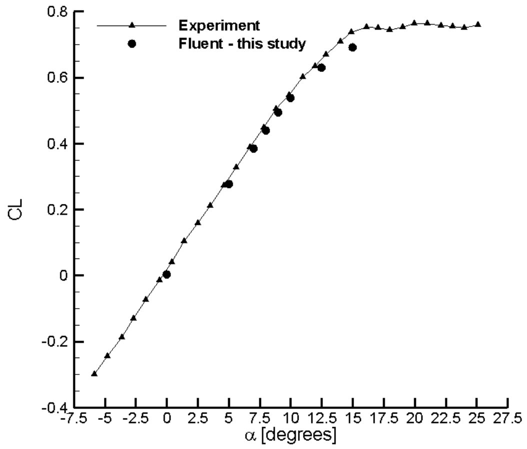

Figure 2: Coefficient of lift at various α for the current study experimental wind tunnel results published in [3]

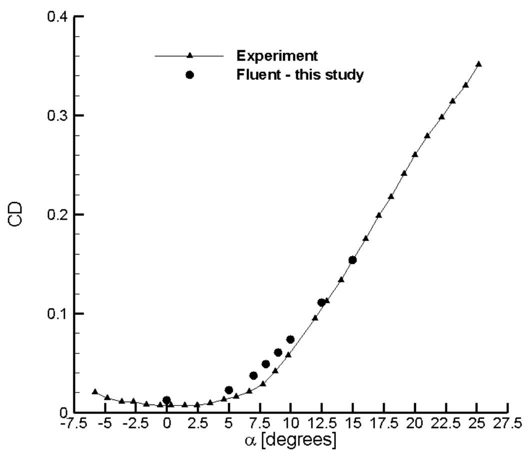

Figure 3: Coefficient of drag at various α for the current study experimental wind tunnel results published in [3]

balanced, at low angle of attack, by the lift from the wing tips that are behind the aerodynamic centre of the aircraft. Once the wing tips stall, the negative moment from the wing tips is greatly reduced, creating the positive pitching moment seen in figure 1. This results in the stability of the aircraft, for $\alpha < 8^\circ$, being disturbed by changes to the outer wings, and slight changes in geometry can potentially cause the vortex to detach and pitch break to occur earlier.

The separation of the flow is evident on the wall shear plots in figure 5. The results show a separated band on the outer wing, near the leading edge, which is consistent with the flow pattern seen on more simple, slender delta wings (see Gursul *et al.* [6] for example). Unlike the results seen for slender delta wings, the separation line begins a significant distance from the nose, this may be due to the rounded NACA profile of the 1303 UCAV wing. As the angle of attack is increased the thickness of the detached band increases and the starting point moves towards the nose of the aircraft. At $\alpha = 5^\circ$ the separation line occurs slightly downstream of the leading edge, but for $\alpha = 7^\circ$ or higher it lies very close to the leading edge.

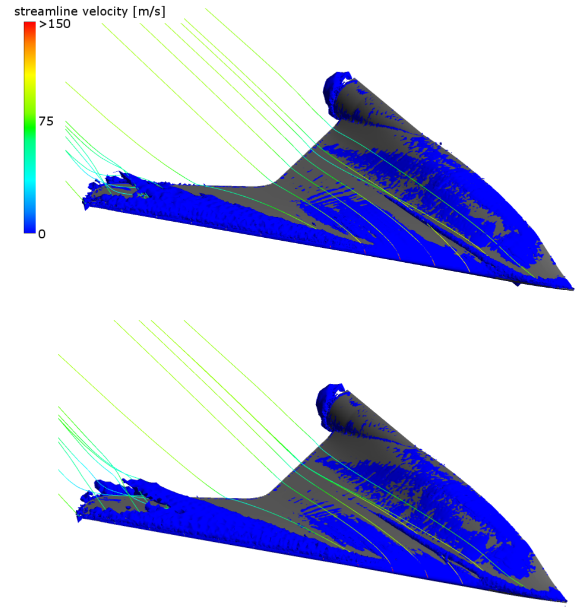

Figure 4: Streamline traces (coloured by velocity magnitude) and a vorticity isosurface using the Lambda-2 Criterion ([5]). The top image is at $\alpha = 7^\circ$, before the onset of pitch break, and the bottom image is at an $\alpha = 9^\circ$, after the onset of pitch break.

Unpublished dye streak line experiments were undertaken and results were compared to the CFD predictions. These experiments were conducted in a low Reynolds number (approximately 7200) water tunnel facility. The water tunnel has a water depth of approximately 470mm, and a working section 500mm wide and 1100mm long. The streamlines showed the same behaviour as the CFD results, with the vortex detachment that causes pitch break occurring at around the same angle of attack.

Modifications to the Basic Geometry

A linear wash out (decreasing local angle of attack by twisting the outer wing) and wash in (increasing the local angle of attack) were applied to the wing to investigate their effects on the pitching moment and resultant airflow. The twist was applied linearly, starting from the apex point on the trailing edge, and increasing to a maximum twist of 5 degrees at the wing tip. The axis about which it was twisted was in the span-wise direction, about the centre of the wing cross section where the twist began. The same transformation was applied to both the left and right wing. The effect on the pitching moment is shown in figure 6, for $\alpha < 10^\circ$ the wash out significantly increases the pitching moment due to the reduced lift created at the wing tips. The wash in reduces the overall pitching moment, but the general trend, including the pitch break, is not changed much. Plots of lift and drag coefficients are not included, however the effects were not large, with the wash out tending to decrease both the lift and drag coefficients slightly, and the wash in having the opposite effect.

These same modifications to the geometry were also investigated in the water tunnel. As expected, it was observed that the wash in caused the trailing vortex to detach earlier at low α, but at high α it had little effect as the outer wing had already separated. The wash out had a more interesting effect, it lowered the local α of the wing tip enough that at moderate angles of attack the leading edge vortex would still detach part way down the wing, but the flow on the wing tip appears to have reattached, with the vortex regrowing. This can be seen in the plots of iso

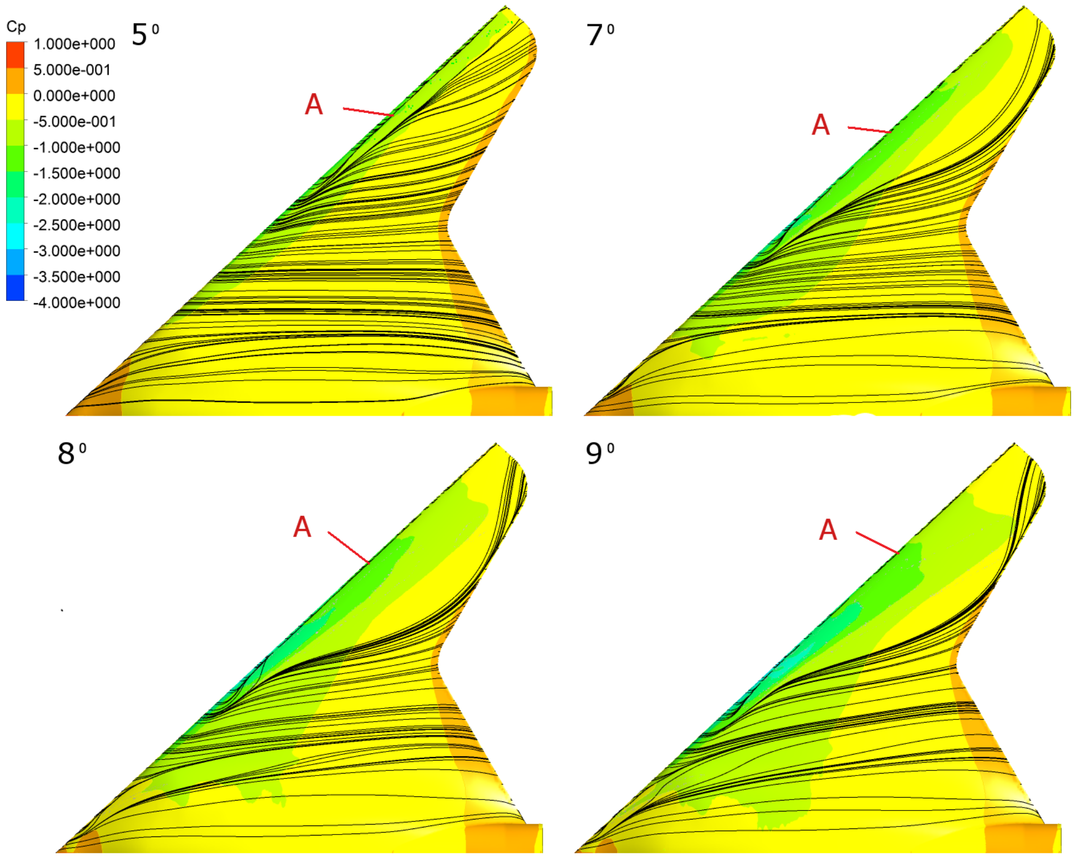

Figure 5: Wall shear lines on the top surface of the wing, coloured by contours of coefficient of pressure at $\alpha = 5°$, $7°$, $8°$ and $9°$. The location of the separation line is marked by A.

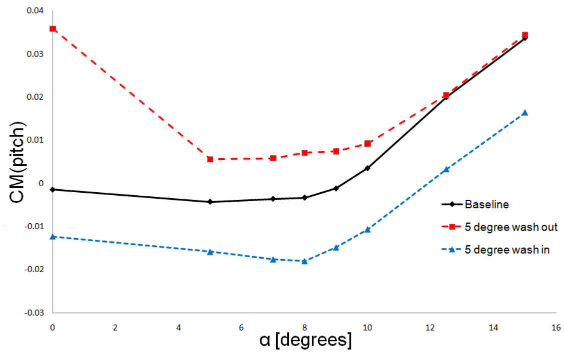

Figure 6: Coefficient of pitching moment at various α for the baseline case compared to the cases with wash out and wash in.

surfaces of Lambda-2 criterion ([5]) at an $\alpha = 9°$ (figure 7) and the dye streaks from the experiments in figure 8.

Conclusions

The flow over the 1303 UCAV was investigated, with particular attention paid to the behaviour around the pitch break point. The simulations agreed well with the experimental studies of [1] and water tunnel experiments. A large separated region over the outer wings was observed, coinciding with the detachment of the leading edge vortex. Applying wash out and wash in to the outer wing was found to present a possible form of pitch control at low to moderate angles of attack. The authors hope this understanding of the flow will better enable attempts to provide flight control to the platform without loss of stability.

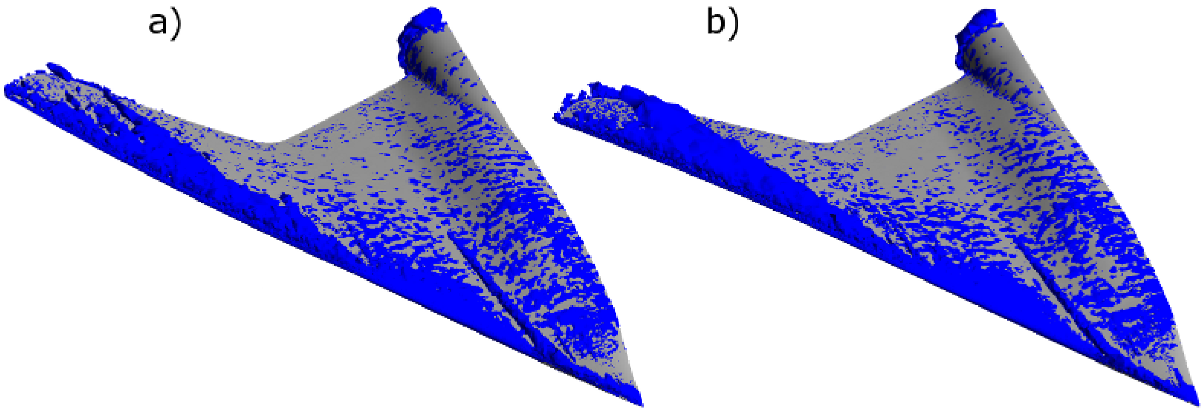

Figure 7: Vorticity isosurfaces using the Lambda-2 Criterion at an $\alpha = 9°$. a) shows the case with a wash out of 5°, b) shows the case with a wash in of 5°.

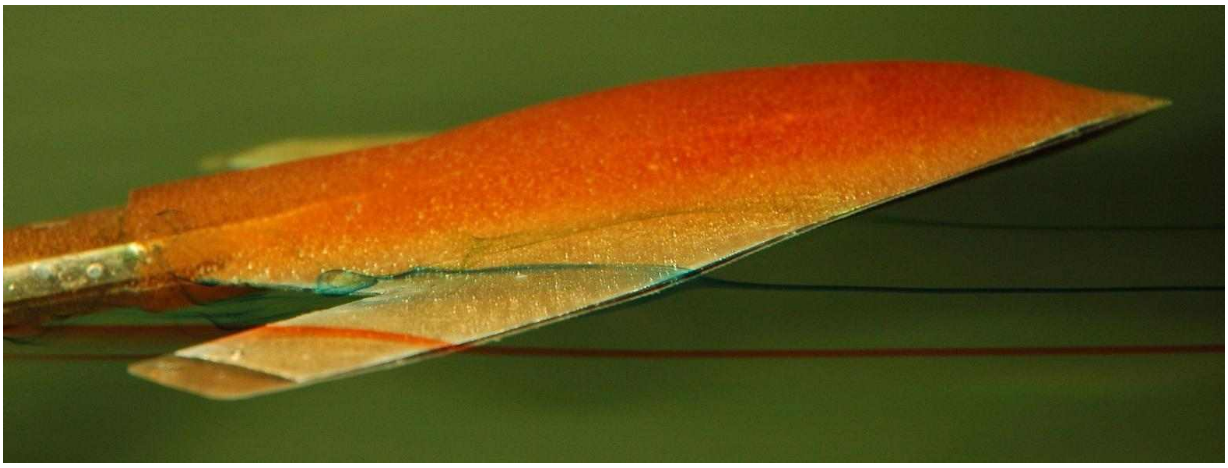

Figure 8: Water tunnel image for the wash out case at an $\alpha = 9°$. The less disturbed nature of the flow near the wing tip can be seen by comparing the red and blue dye streaks.

Acknowledgements

The authors would like to acknowledge the TTCP for supplying the aerodynamic model of the 1303 UCAV

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