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EFFECT OF INVERTED AEROFOIL GEOMETRY ON AERODYNAMIC PERMORMANCE IN GROUND EFFECT

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Summary A two-dimensional Computational Fluid Dynamics (CFD) study was undertaken to examine the effect of various inverted (downforce generating) aerofoil geometry configurations on the ground effect phenomena seen at low ground clearances. Simulations were conducted and comparisons made between a NACA4412 aerofoil, a Tyrrell aerofoil and three modified Tyrrell aerofoils. The results indicate underwing ground effect suction is heavily influenced by the curvature on both sides of the aerofoil.

INTRODUCTION

The aerodynamic behaviour of an aerofoil, inverted or otherwise, changes dramatically when the aerofoil is brought into close proximity to the ground. This behaviour has been well known for many years and has been put to use in several disciplines; the aerodynamics of racing cars probably the most prominent example. General observation of the changes in the aerodynamic behaviour of wings and aerofoils when brought into close proximity to the ground has been performed by many authors, e.g. [1], however, little attention has been paid to the influence of some of the finer geometric features of aerofoils when operating in ground effect.

This paper uses Computational Fluid Dynamics (CFD) to compare the performances of two quite different downforce generating aerofoils, the Tyrrell [2] and the inverted NACA4412, and tries to ascertain the reasons for those differences by examining the effect of the main geometric differences between them. This is done by creating three hybrid aerofoils which are based upon the Tyrrell aerofoil but each substitutes one distinct feature of the Tyrrell aerofoil with the corresponding section of the NACA4412.

NUMERICAL MODEL

The numerical model has been used previously by the same authors and has been rigorously validated [3]. It consists of a two-dimensional aerofoil near a moving ground plane. The inlet and outflow boundary conditions were located 15c and 20c away from the aerofoil, respectively. The upper boundary condition, located 15c from the aerofoil, was designated a symmetry plane which allowed no fluxes across the boundary and thus specifying a horizontal velocity field at the top of the domain. The aerofoil was surrounded by a structured boundary layer mesh of 20 layers with a total (wall normal) height of 0.03c. An implicit, steady RANS solver was used employing the SIMPLEC pressure-velocity coupling, QUICK discretisation scheme and RSM turbulence model.

RESULTS AND DISCUSSION

There are three primary areas of difference between the Tyrrell and NACA4412 aerofoils: the leading edge (LE) curvature; the significant camber on the upper surface of the Tyrrell aerofoil near the trailing edge (TE); and more rearward location (and smoother curvature) of the lowest point on the NCA4412 aerofoil. The modified Tyrrell aerofoils replace, respectively, the LE with that of the NACA4412, the top surface with the NACA4412 top surface and the bottom surface with the NACA4412 bottom surface (moving the lowest point of the aerofoil back to the NACA4412 position). All five aerofoil configurations are shown in Figure 1. The five aerofoils were simulated at an angle of attack of 6 degrees and a ground clearance of h/c = 0.30, where h is the distance from the lowest point of the aerofoil to the ground plane.

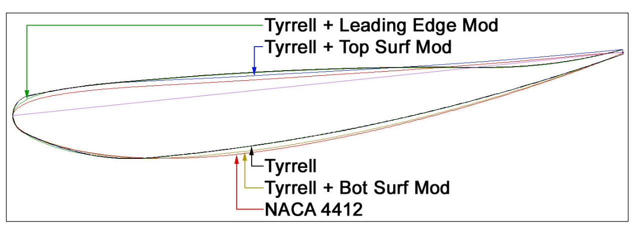

Fig 1: All aerofoil geometries simulated, AOA = 6 degrees

Pressure coefficient distributions

A plot of the pressure coefficient distribution for all aerofoils is shown in Figure 2. The plot of the Tyrrell aerofoil shows the existence of a 'suction spike' near the leading edge on the underside of the wing. This is followed by a large suction region (x/c = 0.1-0.2) at the lowest point on the aerofoil. This is followed by a fairly consistent adverse pressure gradient region. The top surface features a small 'suctions spike' and an increase in pressure close to the TE.

The NACA4412 does not feature a 'suction spike' or an increase in pressure near the TE on the top surface. It also does not feature any increase in suction near it lowest clearance point. Consequently, its lift performance is 13.9% lower than the Tyrrell aerofoil.

The LE modification does away with the suction spike but the large suction region remains almost unchanged, which suggests that the sharp curvature on the Tyrrell LE (that causes the suction spike) does not influence the large suction region downstream. The change in lift coefficient produced by this aerofoil is a reduction of only 0.9%.

The top surface modification eliminates the increase in pressure near the TE because it no longer features the strong camber in this region. This seems to reduce circulation about the aerofoil as a distinct and consistent reduction of suction (relative to the Tyrrell) can be observed for the entire bottom surface of that aerofoil. This results in a 12.8% reduction in lift.

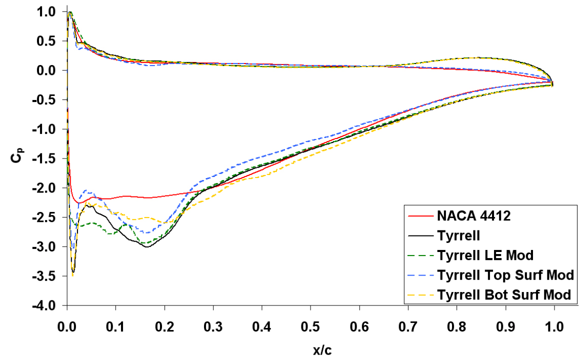

Fig 2: Pressure coefficient distribution of aerofoil geometries at h/c = 0.30 and AOA = 6º

The bottom surface modification maintains the suction spike (as the LE is unchanged), however, the large suction region has been reduced in size significantly – although, it is still a great deal stronger than on the NACA4412. The immediate curvature of the underside of this aerofoil, just downstream of its lowest point, is smoother than the Tyrrell and so the sudden increase is pressure is less severe. After this point, the adverse pressure gradient follows the NACA4412 trend, albeit at a slightly higher suction. Despite the lower suction in the x/c = 0.1-0.2 region, the aerofoil manages to regain much of that lost suction over the remaining length of the aerofoil and, as a result, loses only 0.6% lift in comparison to the Tyrrell case.

As the 'suction spike' was previously shown to have little effect on the large suction region behind it, the performance gain of the bottom surface modified aerofoil (over the NACA4412) is mainly attributable to the increased circulation offered by the high camber on the top surface. The main contributions to the superior performance of the Tyrrell wing is due to the contribution of the extra circulation resulting from the cambered upper surface and also due to the forward position of the lowest point of the Tyrrell wing – visible from the reduction in suction on the bottom surface modified aerofoil.

Velocity Contours

The velocity contours for all aerofoil configurations are shown in Figure 3. The bottom surface modification shown in Figure 3(c) shows a reduction in the velocity of the air travelling under the aerofoil, indicating the significance of the positioning of the lowest point under the wing and the following curvature. The reduction in speed under the top surface modified aerofoil in Figure 3(d) is more dramatic, even if its peak velocity is greater than in Figure 3(c). This reduction in speed in all areas under the aerofoil is entirely due to the reduced circulation. Finally, as was demonstrated in the pressure coefficient plots, the effect of changing the LE is quite minimal. This is also evident in Figure 3(e) as it is very similar in appearance to the Tyrrell's contour plot in Figure 3(b).

CONCLUSIONS

The simulations conducted indicate that the ground effect performance characteristics of an inverted aerofoil depend heavily on the circulation that can be generated about the entire aerofoil and also on the location of the aerofoil's lowest point and its curvature. The geometry of the leading edge seems to have had a fairly minimal effect in this circumstance.

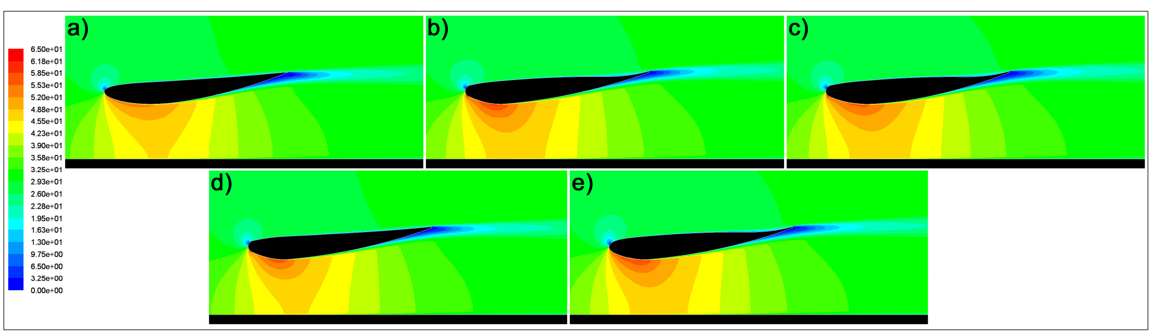

Fig 3: Velocity contours (m/s) at h/c = 0.30, AOA = 6º: a) NACA4412; b) Tyrrell; c) Bot Surf Mod; d) Top Surf Mod; e) LE Mod

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