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Aerodynamic forces in deformed wings

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In this work, we carry out a detailed study of the change in aerodynamic forces due to wing deformation in flight. The results presented are for a wing model of a fixed semi aspect ratio $sAR = 4$, and different chord-based Reynolds numbers in the range of application of UAVs. Our results show that numerical simulations with turbulence models are able to accurately simulate these aerodynamic forces when compared to experimental results obtained in the wind tunnel.

1 Introduction

One of the advances in aeronautics in recent years has been the reduction of aircraft consumption in flight, with a view to complying with European energy saving regulations. In particular, Civil aviation accounts for 13,4% of total CO2 emissions from EU transport. The ReFuelEU Aviation initiative is part of the “Fit for 55 in 2030 package”, the EU’s strategy to reduce greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels, in line with the European Climate Law (ReFuelEU Aviation initiative , 2022). The solutions to this problem include the development of more efficient turbojets and the reduction of the aircraft weight. This weight reduction involves using lighter materials, increasing the wingspan, making them slimmer and lightweight. This reduction of weight means that in normal flight conditions, wings can have tip deformations of more than 10% of their wingspan. Rapid methods of predicting lift and drag, such as the panel method, do not usually include this possibility of wing deformation. For this reason, the aeronautic manufacturer is demanding an exhaustive knowledge through experiments and numerical simulations to determine the performance of these deformed wing surfaces in order to be able to compare with the fast methods used in the industry.

To obtain the results in a realistic case of deformed wings we have to solve a complex fluid-structure interaction (FSI) problem, where aerodynamic forces act on the wing, which, depending on the internal structure and its inertia, responds by deforming. To avoid the complexity of this FSI problem, we will assume an imposed deformation, obtained from literature results Farnsworth *et al.* (2015), and we will start from these results to perform the aerodynamic study.

2 Formulation of the problem and results

In this study we will use `OpenFOAM` to solve the Reynolds Averaged Navier Stokes equations (RANS) using different turbulence models ($k-\epsilon$, $k-\omega$ and $k-\omega\ SST$) around a straight and deformed wing with a NACA0012 wing profile (see figure 1). We generated a mesh using the utility `snnapyHexMesh`. Once the mesh is tested against previous 2D studies for very high Reynolds numbers Frost (1970), we perform the simulations for the 3D case for different Reynolds numbers and angles of attack, α, in the pre-stall region.

Figure 1: 3D schematic of the two configurations studied for a wing model: straight wing (light color) and deformed wing (dark color) with a NACA0012 airfoil.

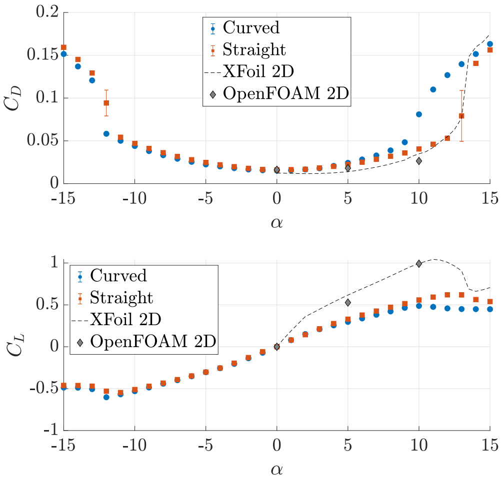

Figure 2: Experimental drag coefficient, C_D and lift coefficient, C_L for the case of $sAR = 4$ and $Re = 1.6 \times 10^5$. We have included as a reference the 2D results provided by XFoil and the 2D numerical results obtained from `OpenFOAM` for the same Reynolds number.

The main difference observed in the results is the loss of symmetry in the aerodynamic coefficients in the case of deformed wings (for positive angles of attack), along with an increase in drag force of up to 360% and a reduction in a lift of up to 30%. Likewise, the onset of stall appears at lower angles of attack.

3 Conclusions

In this research, we have performed a numerical simulation of the turbulent flow around straight and deformed wings. The aerodynamic forces are compared to experiments performed in the wind tunnel, allowing us to select the turbulence model and mesh to replicate the experimental data accurately. The effect of the curvature makes the aerodynamic coefficients lose symmetry, increasing the drag force, decreasing the lift force and advancing the stall to lower angles of attack. The simulations provide other interesting data as the pressure distribution over the wing and the detachment of the boundary layer, allowing us to physically explain the reasons for the differences between the experimental results.

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