ON THE LOW-FREQUENCY BEHAVIOUR OF THE LAMINAR SEPARATION BUBBLE ON A NACA0012 NEAR STALL

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Abstract Mechanisms of quasi-periodic flow oscillation observed in airfoils near stall and stall behavior, which affect airfoil efficiency, remain still not fully understood. In this sense, numerical simulations using large-eddy simulations can be useful in order to shed some light into the underlying complex physics. In this sense, the flow over a NACA0012 at Reynolds number of $Re = 50000$ and angles of attack in the range $AOA = 8.25^\circ - 12^\circ$ have been considered. In order to obtain credible solutions, first numerical results have been compared to results from DNS at $AOA = 9.25^\circ$. The results have shown that LES models are capable of capturing the complex flow phenomena present at these AoA such as the low frequency fluctuations near stall and the vortex shedding produced at higher AoAs.

INTRODUCTION

The flow around airfoils in full stall is a problem of great interest in aerodynamics and specifically for the design of turbomachines (turbines, propellers, wind turbines, etc.). Stall on airfoils is caused by the massive separation of the flow, which deteriorates their performance leading to a sharp drop in the lift and an increase in the drag over the airfoil surface. It is well known that the NACA0012 airfoil exhibits two types of stall: i) a trailing-edge stall at all Reynolds numbers and, ii) a combined leading-edge/trailingedge stall at intermediate Reynolds number. The latter is characterised by the presence of a turbulent boundary layer separation moving forward from the trailing-edge as the angle of attack (AOA) increases and, a small laminar bubble in the leading-edge region failing to reattach. The combination of these two mechanisms complete the flow breakdown. In addition near stall, the flow is highly unsteady and oscillates with a very low frequency (see for instance [2, 6]). However, mechanisms of quasi-periodic oscillation observed near stall and stall behavior, which affect airfoil efficiency, remain still not fully understood. The advances in computational fluid dynamics have made possible to tackle complex problems at high Reynolds numbers thanks to the development of modeling techniques such as Large-Eddy Simulation (LES) methods.

This paper aims at studying the flow behaviour at near stall and stall angles in order to shed some light into the physics of this complex flow. To do so, the Wall-Adapting Local-Eddy viscosity model [5] within the variational multi-scale framework (VMS-WALE) [3] has been used for modeling the flow past a NACA0012 at $Re = 50000$ and angles of attack (AOA) in the range of $AOA = 8.25 - 12^\circ$.

MATHEMATICAL AND NUMERICAL MODEL

The governing equations have been discretised on a collocated unstructured grid arrangement by means of second-order spectro-consistent schemes [10]. Such schemes are conservative, i.e. they preserve the symmetry properties of the continuous differential operators and ensure both, stability and conservation of the kinetic-energy balance on any grid and even at high Reynolds numbers and with coarse grids. For the temporal discretisation of the momentum equation a two-step linear explicit scheme on a fractional-step method has been used for the convective and diffusive terms, while for the pressure gradient term an implicit first-order scheme has been used. This methodology has been previously used with accurate results for solving the flow over bluff bodies with massive separation [4, 7, 8]. By filtering the Navier-Stokes system of differential equations, the subgrid-scale (SGS) stress term appears in the momentum equations which must be modelled in order to close the formulation. In this work, the wall-adapting local-eddy viscosity model within a variational multi-scale formulation (VMS-WALE) [5, 3] has been used. The meshes used for solving the domain considered have been generated by a constant step extrusion of a two-dimensional (2D) unstructured grid. The algorithm used for solving the resulting Poisson equation is explained in detail in [1].

RESULTS

First, results obtained with the VMS-WALE model at $AOA = 9.25^\circ$ have been compared to those obtained by Direct Numerical Simulations [9]. In Figure 1, the local distribution of the pressure on the airfoil surface obtained with a computational mesh of $138276x32$ (about 4.4MCVs) is compared to that obtained from DNS computations (about 50MCVs). As can be seen, LES modeling is capable of reproducing the aerodynamic data obtained with DNS. Thus, computations with the 4.4MCVs mesh have been performed for the different AOAs.

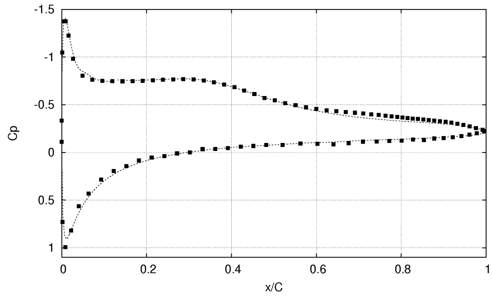
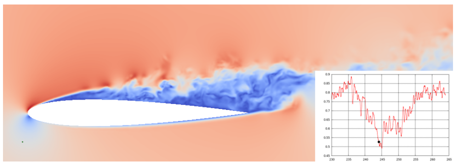
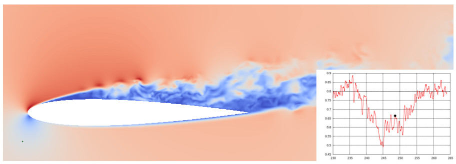


Figure 1. Pressure distribution on the airfoil surface at $AOA = 9.25°$. Comparison with DNS data (solid squares).



(a)



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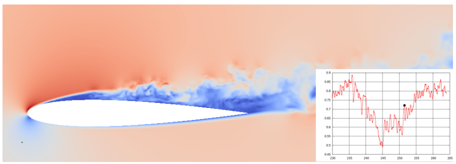

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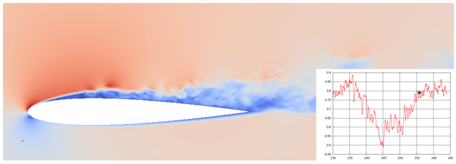

(d)

Figure 2. Transient evolution of the flow at AoA=9°. Taken every 4 TU approximately, from flow fully separated (a) and minimum lift to flow reattachment (d).

For AOA near stall, low-frequency fluctuations in the lift coefficient occur. The unsteady behaviour is observed as a sudden decrease of the lift coefficient produced by the flow detachment from the airfoil surface (see figure 2). In the figure, instantaneous velocity profiles every 4TU are plotted. It is shown how after reaching a local minimum in the lift, the recirculation zone gradually decreases and the flow reattaches to the airfoil surface, where the lift attains a maximum. In the final version of the paper, this oscillation mechanism will be studied in detail.

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