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CFD analysis of the low Reynolds S1223 airfoil

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Abstract

The Low Reynolds S1223 airfoil has been modeled and performance has been evaluated numerically through CFD open source OpenFOAM suite. The numerical results have been validated with available experimental data at Re = 2e05 obtained by means of wind-tunnel tests. Results are also reported at Re = 2e04 and Re = 2.06 in terms of lift and coefficients, streamlines, pressure coefficient and velocity distributions, at 3 different AOA. The main original aspect of this numerical research has been the sensitivity analysis of the aerodynamic performance of the S1223 airfoil over a wide range of Reynolds number. In particular, the effects at low Reynolds number 2e04 have been investigated.

Keywords: S1223 airfoil, Low Reynolds number airfoil, High-lift airfoil, CFD simulations, OpenFOAM.

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1. Introduction

The beneficial effects of improved low Reynolds airfoil aerodynamics suitable for high-lift conditions represent the answers for several applications, facing today challenges like increased payloads, shortened takeoff and landing distances, reduced aircraft noise, and lowered stall speeds. For these reasons this topic has been acquiring considerable interest (Mueller, 1985; Selig et al., 1989, 1995, 1996, 2001). The importance of the low Reynolds airfoils has been mainly pointed out for the UAV, High-Lift and Log-Endurance aircraft applications (Foch and Ailinger, 1992; Liebeck, 1978; Liu and Li, 2006; Zhu, 2006). The purpose of this paper is to present a numerical analysis of the S1223 airfoil (Selig and Guglielmo, 1997), which has shown several and practical applications at low Reynolds number regimes. In particular small unmanned aerial vehicles (UAVs) usually operate in this fluid dynamics conditions. The high lift performance is not the only desired feature. The airfoil lift-to-drag ratio, endurance parameter, thickness, pitching moment, stall characteristics and sensitivity to roughness are also important factors, among others, that should be taken into account for selection of an airfoil at the design stage. This study mainly focuses on the lift and drag coefficient characterization of the high-lift low Reynolds number S1223 airfoil, using the open-source CFD suite OpenFOAM (2022). The originality of this numerical investigation is its focus on the sensitivity analysis of the S1223 aerodynamic performance with respect to Reynolds number, in particular at values as low as 2e04.

Preliminary simulations have been performed, using different turbulence models, roughness and turbulence intensity values. In this paper the results with standard k-epsilon turbulence model (Wilcox, 1998; Wang, 2004) only are reported, since they represent the best matching with the experimental data (Selig and Guglielmo, 1997). Once the CFD model has been validated, the CFD analysis have been repeated at Re = 2e04 and Re = 2e06. The flow conditions at AOA = 4°, 8°, 12° have been then investigated in terms of velocity and pressure distributions.

2. Validation of the CFD Model

In Fig. 1 the lift coefficient Vs AOA at Re = 2e05 is reported. The CFD results are compared with experimental data from wind tunnel tests (Selig et al., 1997). A very good accordance is seen up to AOA = 14°, then the CFD overestimates the stall. From Fig. 2, showing the airfoil polar curve at Re = 2e05, it is also seen an acceptable agreement between CFD results and experimental as far as drag coefficient is concerned. The CFD results have been obtained with standard k-epsilon model (Wilcox, 1998; Wang, 2004) and inlet turbulence level Tu = 0.1%. It is observed that, even though the CFD overestimates the drag coefficient, the trend of the airfoil polar is well reproduced.

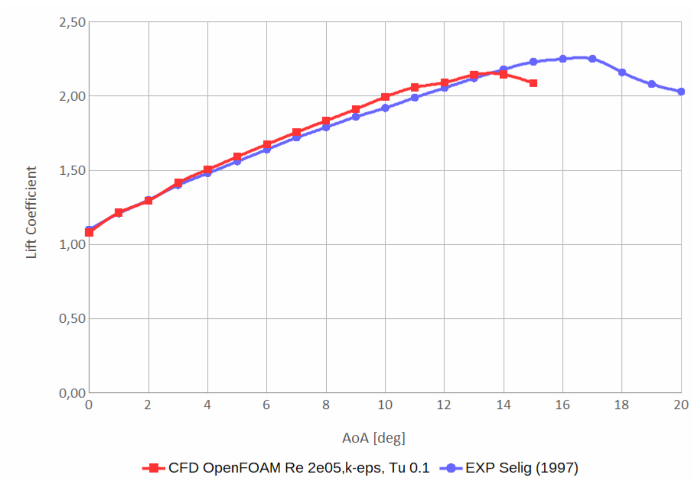

Figure 1. Lift coefficient at Re = 2e05. CFD Vs Experimental

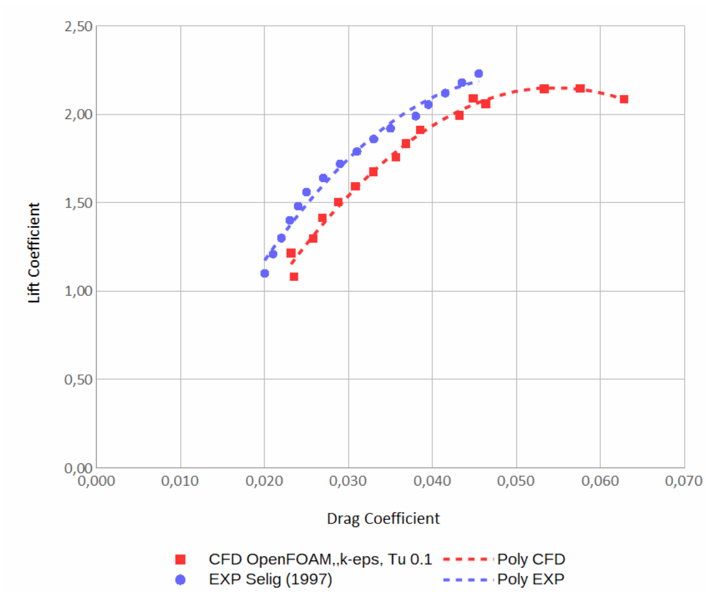

Figure 2. Airfoil polar at Re = 2e05, CFD Vs Experimental data

3. Results at different Reynolds and AOA

The CFD analysis on the S1223 airfoil have been repeated at Re = 2e04 and 2e05. The comparison of the lift coefficient curves is reported in Fig. 3. It is observed that the curve slope in the linear part (i.e. far from the stall condition) is practically not affected by the Reynolds number. On the other hand the lift curve, with increasing Reynolds number, is shifted upwards and the AOA of maximum lift is increased (see Table 1). It is worth to notice that by increasing to Re = 2e06 there is an increase of 17% of the lift coefficient, compared to the case Re = 2e05. On the contrary, by reducing the Reynolds number from 2e05 to 2e04 there is instead a reduction of about 32% in the maximum lift coefficient. This aspect is regarded as of great interest when designing a wing with the S1223 airfoil at low Reynolds numbers.

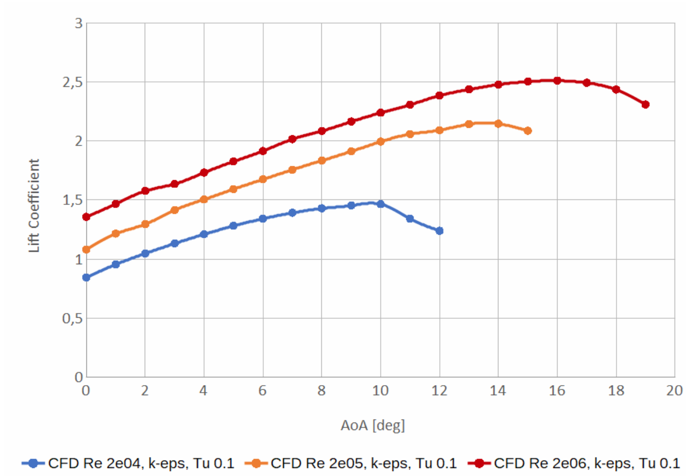

Figure 3. Lift coefficient (CFD) at Re = 2e04, 2e05, 2e06

Table 1. AOA at the maximum lift coefficient (results from CFD)

Reynolds number	AOA of maximum lift coefficient	Maximum lift coefficient
Re = 2e04	**10°**	**1.47**
Re = 2e05	**14°**	**2.15**
Re = 2e06	**16°**	**2.51**

For the considered Reynolds number flow conditions, the streamlines (Fig. 4), the pressure coefficient (Fig. 5) and the velocity magnitude contour (Fig. 6) have been obtained and compared considering AOA = 4°, 8°, 12°. From these visualization it can be observed that, increasing the AOA, the position of the separation point is moved to the LE. That is more evident for the Re = 2e04 case and can explain the lower AOA of maximum lift and the more abrupt stall behavior.

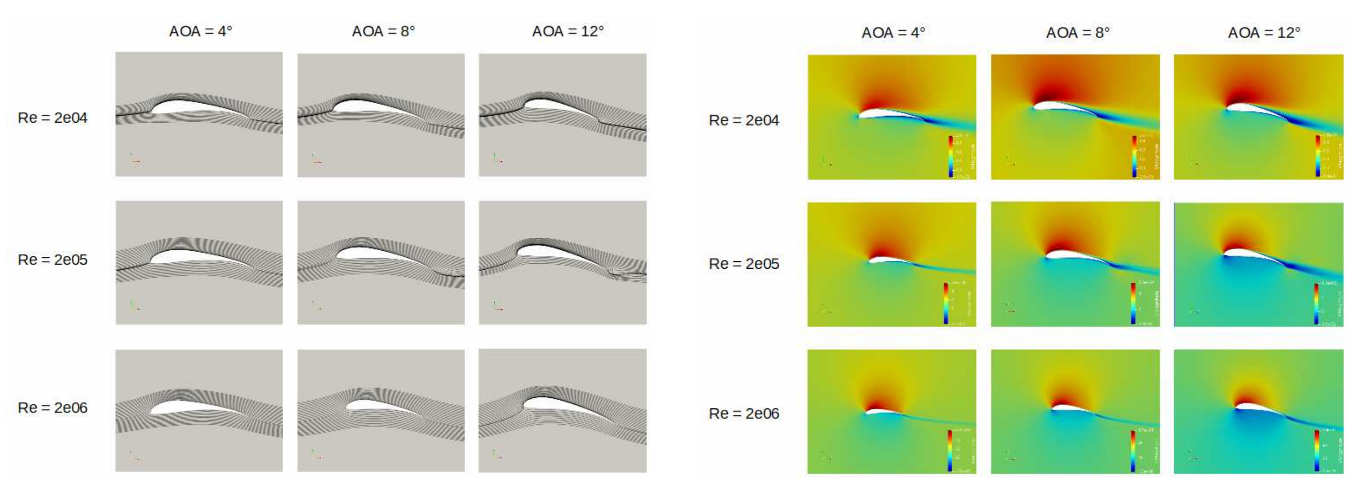

Figure 4. Streamlines at different Reynolds number and AOA

4. Conclusions and future works

The low Reynolds number / high lift S1223 airfoil has been investigated in terms CFD analysis using the OpenFOAM suite, with standard k-epsilon turbulence model and turbulence intensity Tu = 0.1%, in order to match the available experimental data. The results at Re = 2e05 show a good agreement with the wind tunnel test data, especially for the lift coefficient, validating the CFD model. The drag coefficient is over-estimated but it still shows the correct trend compared with the experimental data. The CFD analysis have been then repeated at Re = 2e04 and Re = 2e06 to perform a sensitivity analysis. It is observed that, reducing the Reynolds from Re = 2e05 to Re = 2e04, the maximum lift coefficient is reduced of 32%. Streamlines as well as pressure coefficient distribution and velocity contour have been evaluated for Re = 2e04, Re = 2e05 and Re = 2e06, at three different AOA (4°, 8°, 12°). From this visualizations it is observed that, increasing the AOA, the separation point moves to the LE. This is more evident for the Re = 2e04 case, getting insight into the stall behavior of the S1223 airfoil at this low Reynolds number flow conditions. The interesting outcomes of this numerical study have pushed the authors to a further investigation of Eppler (1990) airfoils and NACA airfoils at such low Reynolds number values since there is a lack of literature as far as the lift and drag coefficients at low Reynolds are concerned.

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