



Technical note

On the implementation of a turbulence model for low Reynolds number flows

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ABSTRACT

Some aspects in the implementation of a turbulence model revealed critical for the correct prediction of the flow characteristics in the case of a low Reynolds number flow (10^4 – 10^5) around an airfoil. In particular the treatment of the transition point setting strongly influenced the computed solution. This effect was not found in case of high Reynolds number.

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The aim of the present short note is to report an experience describing how changes in an apparent detail of the implementation of a turbulence model provided unexpected large differences on the results. A discussion on this aspect has not been found in the literature, thus it has been considered worth to present it here.

Recently, a modification of the k – ω SST turbulence model (identified here as k – ω SST-LR) has been proposed to improve, by standard RANS CFD analyses, the simulation of the flow around airfoils in the low Reynolds number regime (10^4 – 10^5) [1]. A detailed comparison with LES results showed very good agreement up to and beyond stall [2], provided a correct setting of the transition point inside the laminar separation bubble (LSB). In the same paper an engineering criteria for identifying the transition location was also suggested.

The results proposed in [1,2] were obtained by CIRA³ RANS solver ZEN described in [3]. The solver is block structured with standard central space discretization and explicit adaptive 2nd and 4th order artificial dissipation. Pseudo time-marching is performed by a Runge–Kutta multistage scheme.

In Fig. 1 the skin friction and pressure coefficient distributions obtained for the SD 7003 airfoil at freestream Mach number

$M_\infty = 0.1$, Reynolds number $Re_\infty = 6 \cdot 10^4$ and angle of attack $\alpha = 4^\circ$ are proposed. The adopted input parameters are summarized in Table 1.

The transition position on the upper surface along the chord of length c was specified at $x_{tr}/c = 0.53$ as indicated by the experiments [4]. In the same figure a grid convergence study is also proposed (in the remaining of the paper all results are proposed for the 768×176 grid). The plots also show a very satisfactory agreement with a reference LES calculation, although in the turbulent reattached part of the flow the skin friction seems still under predicted.

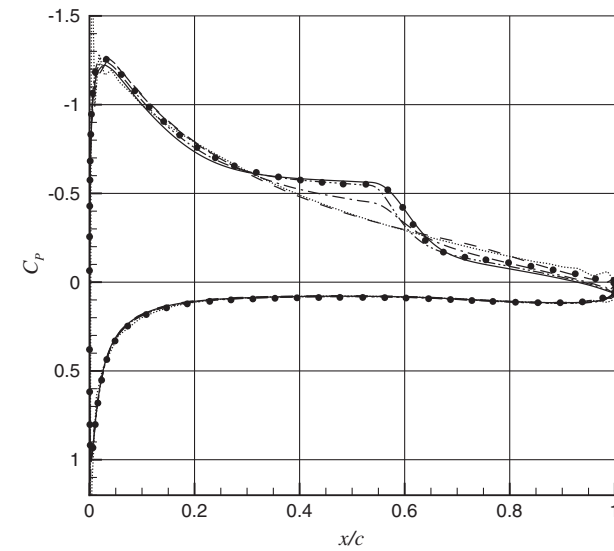
The modified turbulence model was also introduced in the RANS solver FLOWer developed by DLR⁴ [5] and widely adopted in the applied research and industrial community. The technical characteristics of this solver are very similar to CIRA ZEN code: block structured with standard central space discretization, explicit adaptive 2nd and 4th order artificial dissipation and pseudo time-marching by Runge–Kutta multistage scheme.

Quite surprisingly and despite of the same adopted test cases and inputs, FLOWer code provided a completely different description of the LSB. Why two flow solver codes, adopting the same numerical technique and turbulence models and using the same grid and input are providing different results?

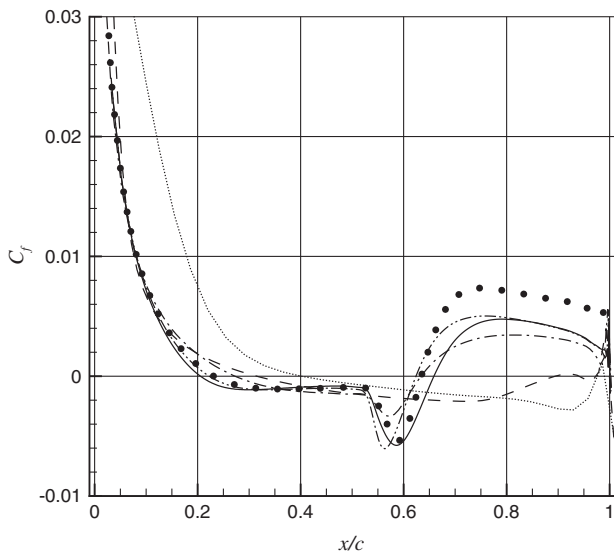
Previous comparisons in high Reynolds number conditions adopting the standard k – ω SST model showed satisfactory agreement between the two solvers; therefore the numerical

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(a) Pressure coefficient on the airfoil.



(b) Skin friction coefficient on the airfoil (upper).

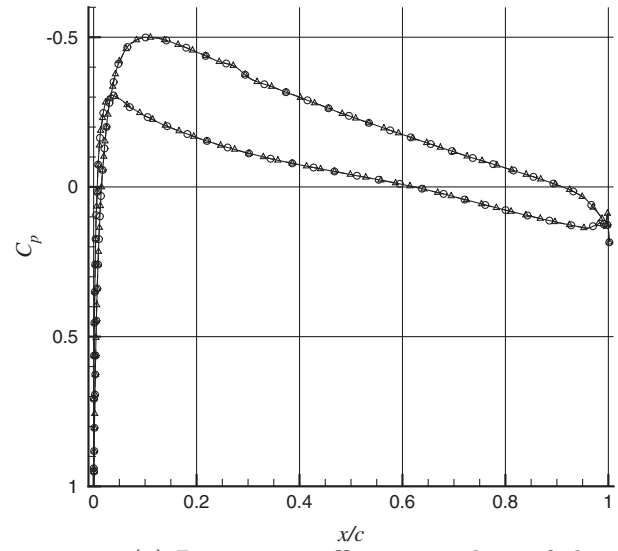
Fig. 1. SD 7003 airfoil. $M_\infty = 0.1$, $Re_\infty = 6 \cdot 10^4$, $\alpha = 4^\circ$, transition at $x_{tr}/c = 0.53$. ---: RANS $k-\omega$ SST-LR [1]. Mesh sensitivity study. ...: 96×22 grid. ---: 192×44 grid. - - - : 384×88 grid. - · - : 768×176 grid. - · - : 1536×352 grid. •: LES [1].

implementation of the $k-\omega$ SST-LR model in both codes was analyzed, looking for significant differences.

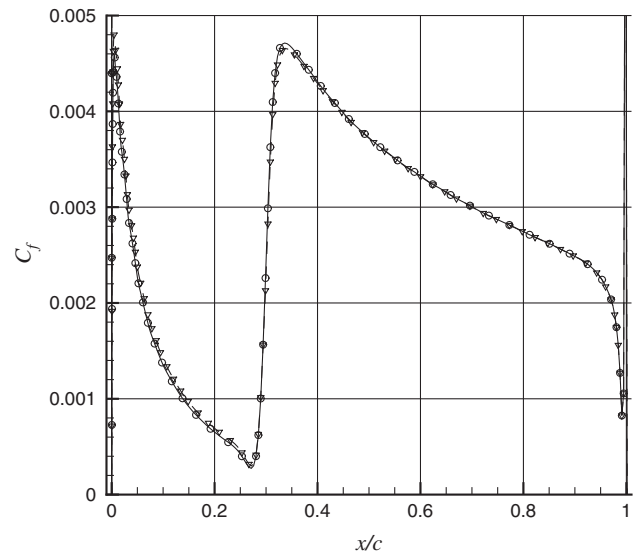
The difference was found in the treatment of the explicit setting of the transition point.

- (a) In ZEN code, the turbulence equations were also integrated in the laminar region taking care to set to zero the terms related to the turbulence production (in both k and ω equations). In this way the transport of turbulence kinetic energy and dissipation was, at least partly, taken into account in the first laminar part of the LSB.
- (b) In FLOWer code, the eddy viscosity was explicitly set to the given freestream value in the laminar part of the flow upstream of the assigned transition point.

Both procedures are standard and in the authors' experience never provided significant differences, at least in the case of high Reynolds number flow, as shown in Fig. 2, where the result for



(a) Pressure coefficient on the airfoil.



(b) Skin friction coefficient on the airfoil (upper).

Fig. 2. SD 7003 airfoil. $M_\infty = 0.1$, $Re_\infty = 6 \cdot 10^6$, $\alpha = 0^\circ$, transition at $x_{tr}/c = 0.30$. - · - : transition treatment (a) - - - : transition treatment (b).

the SD 7003 airfoil at $Re_\infty = 6 \cdot 10^6$ ($M_\infty = 0.1$, $\alpha = 0^\circ$) are presented. Very popular CFD commercial codes leave to the user the choice of implementation of the transition setting.

The effect of both transition treatments (a) and (b) for the low Reynolds number test in ZEN code are shown in Fig. 3. As in FLOWer code, transition treatment (b) provides large differences, both separation and reattachment points are modified, also implying a rear shift in the pressure recovery.

Calculations were repeated adopting a different case as reference: the DNS of the flow around the NACA 0012 airfoil [6] at $\alpha = 5^\circ$ with $Re_\infty = 5 \cdot 10^4$ and $M_\infty = 0.4$ (input parameters summarized in Table 1). The adopted grid is C-type (768×176 cells), the transition position on the upper surface is $x_{tr}/c = 0.485$ as found by the engineering criteria described in [2]. The comparison, shown in Fig. 4, substantially confirms the previous result: a good agreement between RANS and DNS by transition treatment (a) opposite to significant differences by transition treatment (b). Hence, the adoption of the eddy viscosity as computed by the turbulence model with the production terms switched-off in the laminar part

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