

Comparison of RANS and scale-resolving approaches when modelling the turbulent flow behind a bluff body

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Abstract. In this paper, the results of a numerical simulation of the air flow in the vicinity of a parallelepiped fixed on a plate are presented. The 3D calculations were performed with the ANSYS Fluent software using scale-resolving DES approach. The obtained results are compared with the experimental data and with the results of the previous numerical calculation.

1 Introduction

Turbulence is a key physical factor in many industrial applications. The choice of the turbulence model significantly affects the accuracy of the prediction of aerodynamic and thermo-physical processes. It is known that the widely used Reynolds Averaged Navier Stokes (RANS) approach gives good results when solving engineering problems. However, it does not allow us to obtain a real spectrum of turbulent pulsations, especially in areas of flow separation behind bluff bodies. This leads to significant errors when solving problems dealing with heat transfer, aeroelasticity, impurity transfer, etc. At the same time, the application of the Large Eddy Simulation (LES) approach requires enormous computational resources, so more economical combined Detached Eddy Simulation (DES) and Scale Adaptive Simulation (SAS) models have recently been developed [1-3].

DES attracted much attention in the calculation of internal and near-wall flows with extensive separation zones. When using the DES turbulence model, the near-wall layers are described within the framework of the RANS approach, and the LES-like formulations is used in large separation (“detached”) zones where the dominant role is played by large nonstationary turbulence scales.

In this paper, the calculations of the flow in the vicinity of a parallelepiped fixed on a plate are performed under the condition of the experiment [4]. Earlier, the authors calculated the same flow using various RANS-based turbulence models [5]. The vortex structure of the flow was studied. It was shown that limiting the production of turbulence kinetic energy allows a reduction in turbulence viscosity level and improves the prediction accuracy for separation zones. The goal of the paper is to compare previous results with those obtained in a frame of DES approach.

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2 Formulation of the problem

The 3D transient isothermal calculations are carried with the ANSYS Fluent software[†] on the basis of pressure-based solver using the DES turbulence model.

The geometry of the problem under investigation presents a prism of square cross section ($b = 0.08\text{m}$) and height $H = 2b$ which is fixed on the wall (Fig 1). The calculation domain is restricted by the bottom wall and free boundaries from the other sides and has the sizes $1.72 \times 1.36 \times 1.1\text{ m}$. A structured grid with a total number of cells of about 3.5 million is constructed in the computation domain with the refinement to the bottom and prism walls. The condition $y^+ \sim 1$ is satisfied in the first near wall cells, which allows a resolution of the laminar sublayer.

At the entrance to the calculation domain, the profiles of velocity, turbulence kinetic energy, and turbulence dissipation rate are specified according to the experimental data [4]. The no-slip condition is accepted on the walls. On the top and lateral boundaries of the computational region, the symmetry condition is prescribed to ensure the absence of flow through these boundaries. The origin of the global coordinate system is on the plate, at the center of the lower section of the prism. In Fig. 1, b, the position of vertical $X1$ ($x/b=0.75$), $X2$ ($x/b=1.25$) and horizontal $Y1$ ($y/b=1$) planes are shown which are used below to present the simulation results.

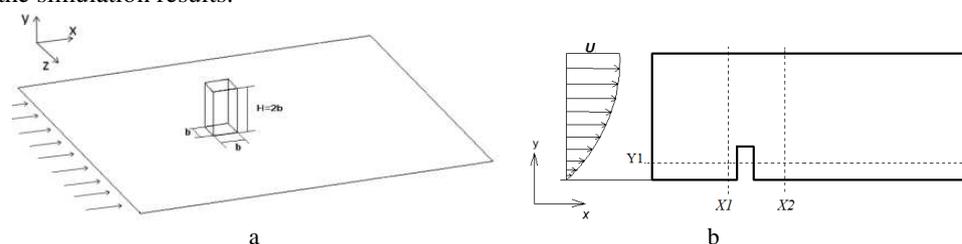


Fig. 1. The geometry of the problem (a) and the calculation domain in cross-sectional view (b).

3 Results of 3D calculations and Discussion

As a result of the calculation, instantaneous and mean values of all the gas-dynamic and turbulent parameters are obtained. The velocity (Fig. 2) and Turbulent Kinetic Energy (TKE) (Fig. 3) fields at the $Y1$ plane are shown.

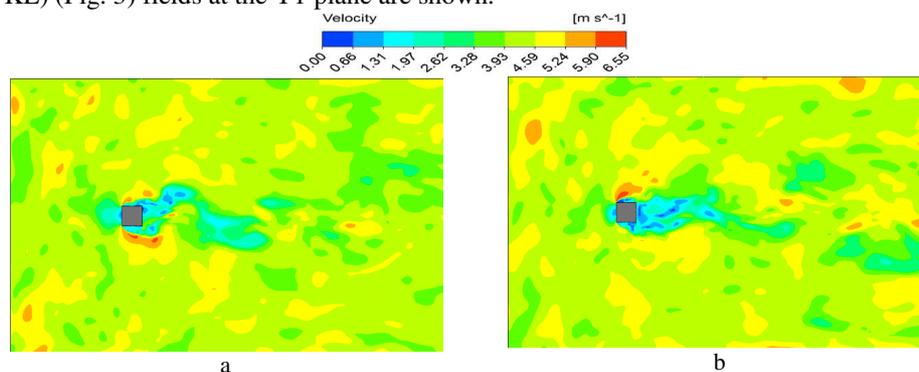


Fig. 2. The instantaneous velocity fields at $Y1$ plane for time moments $t = 5.2$ (a) and 6.2 s (b).

[†] ANSYS academic research custom number 610336

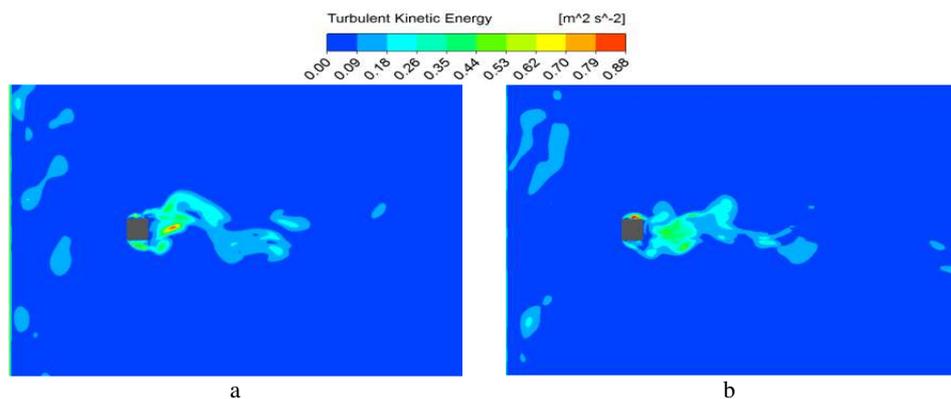


Fig. 3. The fields of the turbulence kinetic energy (k) on the plane Y1 at different instants of time (t): a) 5.2 s, b) 6.2s.

In figures, the pulsations of velocity and TKE are visible. Incoming velocity at $y/h = 1$ level is $U = 3.87$ m/s, and TKE maximum is $k = 0.65$ m^2/s^2 . Near the prism, lower velocity and higher TKE values can be seen testifying on the Karman vortexes shedding from the prism edges.

During the calculation, the statistics of the turbulent flow were processed in Fluent, by recording the averaged data of velocities, TKE and other parameters. Average statistics which consists of mean values and RMSE values are collected in internal cells in each sample interval. In these calculations, statistics were taken in the time interval $t = 5 \div 6.4$ s.

The profiles of the mean x -velocity (U_x) and TKE (k) are presented in Fig. 4 and 5 at the intersection of the X1 and X2 planes with the symmetry plane. In figures, symbols stand for experimental results. Lines 1-3 present the results of previous computations [5] with the standard $k-\epsilon$ (1), $k-\omega$ (2) turbulence models and the $k-\omega$ model with the Kato-Launder limiter (3). Line 4 denotes the results of present DES calculations.

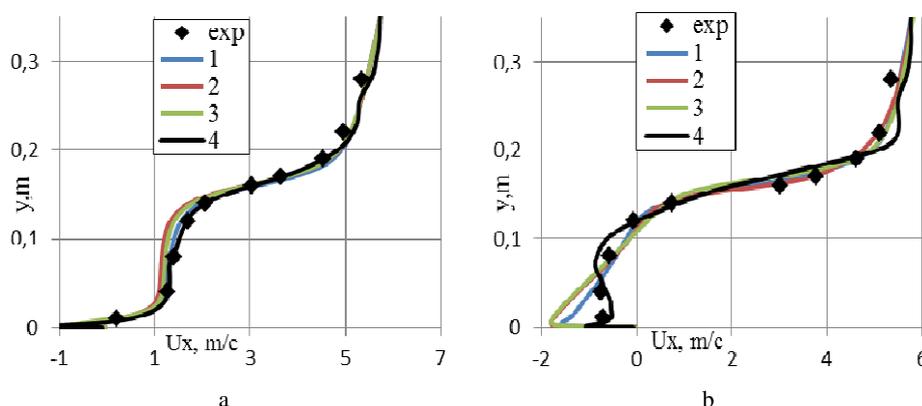


Fig. 4. Profiles of mean velocity U_x in the sections (a) X1 and (b) X2 obtained from experimental data and in numerical calculations with the various turbulence models.

As it can be seen in figures, DES turbulence model gives better results than results of [5] for the mean velocity profile at both sections and TKE profile at the X1 section. The classical $k-\epsilon$ and $k-\omega$ turbulence models yield several times overestimated turbulence levels in the separation zone before the prism. In the zone behind the model, the KTE profile has a nonmonotonic behavior due to the presence of vortexes. At the same time, DES overpredict the TKE level in the near-wall region after the prism compared to other results, which may

be due to the insufficient grid quality in this region. Also, a larger time interval for collecting the statistics is required.

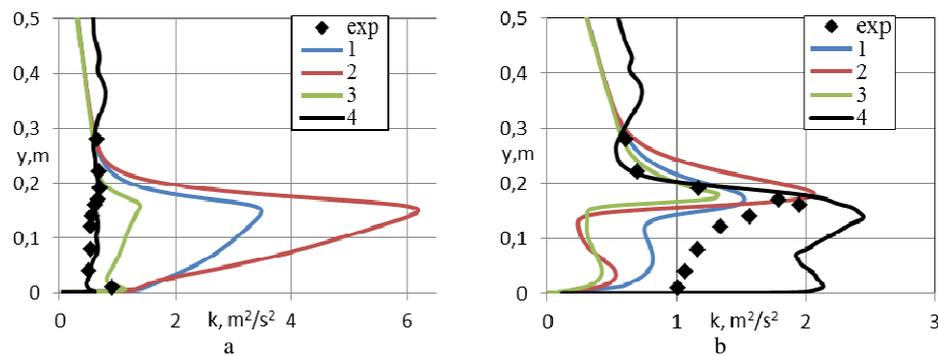


Fig. 5. Profiles of the turbulence kinetic energy (k) in the sections (a) X1 and (b) X2 obtained from experimental data and in numerical calculations with the various turbulence models.

4 Conclusions

The results of the simulations are presented of the air flow in the vicinity of the prism of the square cross section using the DES turbulence model. Analysis of the instantaneous velocity and TKE fields show the unsteady flow behavior after the prism that cannot be simulated in a frame of RANS-based models.

Comparison of the simulation results has shown better agreement with the experimental data in the terms of the mean velocity and TKE profiles at the sections located before and behind the prism comparing to those obtained it the previous work using RANS-based approach.

Further work is necessary to improve grid quality in the region behind the prism and enlarging the sample tame interval for collecting the statistical data.

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