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Turbulent wake characteristics of a simplified road vehicle: simulation vs experiment

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Abstract: A Simplified road vehicle (Ahmed body) with a square-backed shape was placed in a free-stream flow velocity 40m/s corresponding to a high Reynolds number $Re = 7.6 \times 10^5$ and experienced in a wind tunnel, in the same time in parallel a simulation was done in the same real conditions with different turbulence models. The main goal from this study was to examine the effectiveness of the DDES and $k - \omega$ SST turbulence models in presenting such complex flows. To certify the accuracy of the turbulent models many physical parameters were compared to experimental data, from boundary layer parameters to the wake characteristics, shear layer and mass entertainment. A great agreement were found between experiment and DDES model. In other hand a simulation was done to certify the effects of ground clearance and 5% of drag reduction was obtained by changing it from 50mm to 45mm.

Keywords: Aerodynamics, road vehicles, numerical simulation, experiments.

1 Introduction

The aerodynamics of road vehicles becomes nowadays a common interest for environmental and economical issues. Industries are directed towards developing strategies in order to improve aerodynamic performance [1]. Better understanding of the flow around a road vehicle could be the main goal for better designs. This flow has a great effect on parameters such as drag, lift and fuel consumption [2]. [3] introduced a well representative model for road vehicles called Ahmed body which attracted several designers to initiate their researches. In fact, numerical simulation is essential in analyzing bluff body flow mechanisms, where experiments may face difficulties. An example is the sensitivity of the near wake region to any probe that could perturb the flow. [4] and by using very large eddy simulation (VLES) have shown that numerical simulations is a well tool to estimate the aerodynamics of simple square-backed bluff body called Windsor body, see [5], [6].

Less computational calculation in the literature that shows the flow around squared-backed Ahmed body at high Reynolds number, [7] have done simulations for Ahmed body under similar condition (high Reynolds number) and analyzed the mean topology of the wake. This study will shed lights on the comparison between experimental and simulation analysis for the flow around Ahmed body, pointing that simulation done using real conditions similar to experimental ones. Deep discussion has been done to qualify the numerical simulation and turbulence models. In this abstract we focus on discussions on the mean flow properties. Additional results will be presented during the conference.

2 Experimental Setup

The experiment was held at PRISME laboratory in Orleans University (France) in wind tunnel of test section 2m by 2m wide, and 5m long. Full scale Ahmed body used in [3], with length $L=1044\text{mm}$, width $W=389\text{mm}$, height $H=288\text{mm}$, ground clearance $h=45\text{mm}$ (15% of the model height). The model was mounted via a plate located 0.47m from ground within a rotation ability in order to be aligned. The x-axis is aligned with

the streamwise direction, z-axis is vertical and positive upwards, and the y-axis followed the right handed coordinate system, the origin is at the bottom of the base of the model. An external strain gauge balance was used to measure the aerodynamic forces, located under the working section of the tunnel see figure 1a. The chosen sampling frequency is 1000Hz.

The pressure at the rear base was measured by covering the back-square face with an array of 81 pressure taps connected by tubing system to pressure scanner (length 600mm with internal diameter $d=1.56\text{mm}$) and with a manufacturer quoted accuracy of $\pm 6\text{Pa}$ with a sampling frequency 50Hz. In addition to that, 2D-2C PIV measurements were performed to analyse the topology of the flow downstream the body for x-z plane ($Y=0$), the windows size is $392 \times 603\text{mm}^2$ with spatial resolution around 2mm, the measurements obtained at 2.49HZ. The data were processed using DPIV software see [8] and [9].

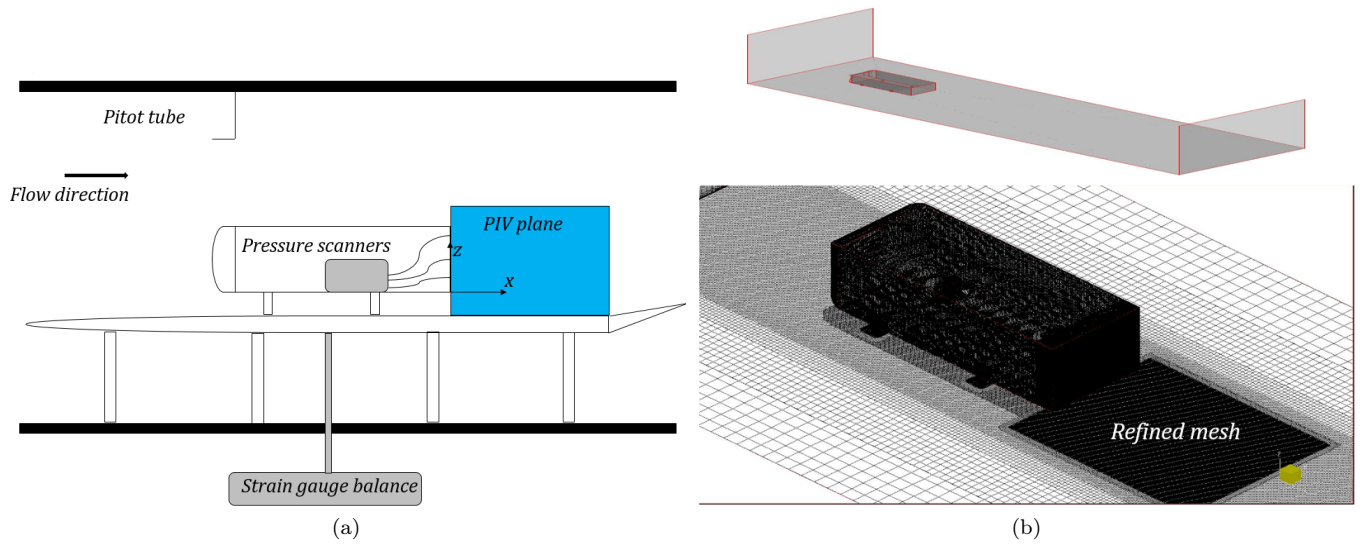


Figure 1: Experimental setup (a) Simulation mesh and domain (b) DDES

3 Simulation

In the present work the simulation done using ISIS-CFD flow solver. This solver was developed by the EMN (Equipe Modélisation Numérique), uses the in-compressible unsteady Reynolds-averaged Navier Stokes equations (RANS).

Numerical setup: Same simplified vehicle model was used with computational domain dimensions $13.2L \times 1.7L \times 1.9L$ see figure 1b, setting 40m/s at the inlet, which leads to $Re_H = 7.6 \times 10^5$ based on height and free-stream velocity, no slip condition was chosen for the body and the road in order to enable the boundary layer's growth. Two full unstructured hexahedral meshes done using HEXPRESS, the first with 32 million cell and second with 56 million cell, 2% of drag reduction confirmed us the convergence of our mesh. In order to have better capturing near the wall a special refinement done by defining three boxes covering the whole body and zooming on the rear part in which cell size reached 1.7mm. Note that the computational time is around $t^*=278$, where $t^* = tU_\infty/H$, t time in seconds, 480 processor were used in the simulation. Two turbulence models were used, $k - \omega$ SST (SST, shear stress transport) RANS model, in addition to the Delayed Detached Eddy Simulation (DDES), which is a hybrid RANS-LES model that used the $k - \omega$ SST at the boundary layer for a less consumption and switch into LES in the rest of the region. Further information can be found in [10] and [11].

4 Results and discussions

Global values: Table 1 shows the mean values for the pressure coefficient (using ??) for the three studied cases. 4% and 11% is the difference that observed between the reference case (experiment) with DDES and $k - \omega$ SST models respectively. Same for the drag coefficient at the base estimated using equation ??, while the total drag coefficient difference is 1.2% for DDES, while 7% for $k - \omega$ SST . Its interesting to have comparable results between both models and experiment, but in the same time looking into the physics near the simplified vehicle will give more significance for the comparison, especially the wake which is important in the square-backed bodies, the recirculation region length l_r^* was estimated and shown in figure 1, 2% and 22% difference for DDES and $k - \omega$ SST models respectively. DDES model is more comparable than $k - \omega$ SST in terms of characteristic lengths for the wake. Moreover, these results gave a sign to look at the boundary layer profile in order to check effects of boundary layer on these differences, the boundary layer was discussed at the rear top of the simplified vehicle and will be presented at the conference.

	<i>experiment</i>	<i>dDES</i>	<i>kω - sst</i>
C_{pb}	-0.2735	4%	11%
C_{db}	0.273	4%	11%
C_d	0.333	1%	7%
l_r^*	1.5709	2%	22%

Table 1: Pressure coefficient(C_{pb}) and pressure drag (C_{db}) at the base, and total drag (C_d), l_r^* : recirculation region length.

Wake topology: To go further in the comparison, wake is analyzed in the following section. For that, the time averaged flow downstream the simplified vehicle is shown in figure 2. Separation of flow localized at the rear of the body causing a large recirculation region, experimental results are well compared to DDES in terms recirculation length as discussed before and in also the shape of the mean wake is similar, the mean separation line is well estimated in the DDES model as well, while SST $k\omega$ is not well presenting the wake in comparison with experiment, the vertical plots of figure 3, confirmed this comparison. The vertical wake asymmetry appearing in figure 2 came from the presence of the ground perturbing the flow, which leads to flow features that is different from the upper and lower part of the wake. An agreement was obtained in comparing drag coefficients and characteristic lengths of the wake between the experimental data and DDES. Moreover, statistical and dynamical analysis will be shown in the presentation at the conference.

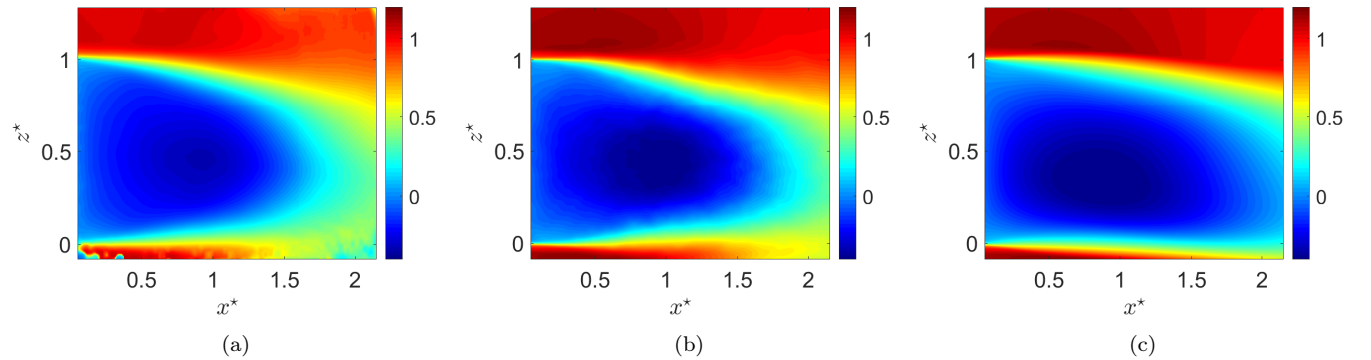


Figure 2: Mean velocity field U^* normalized by free stream velocity along Z-plane for (a) PIV experiment, (b) DDES , (c) SST- $k\omega$

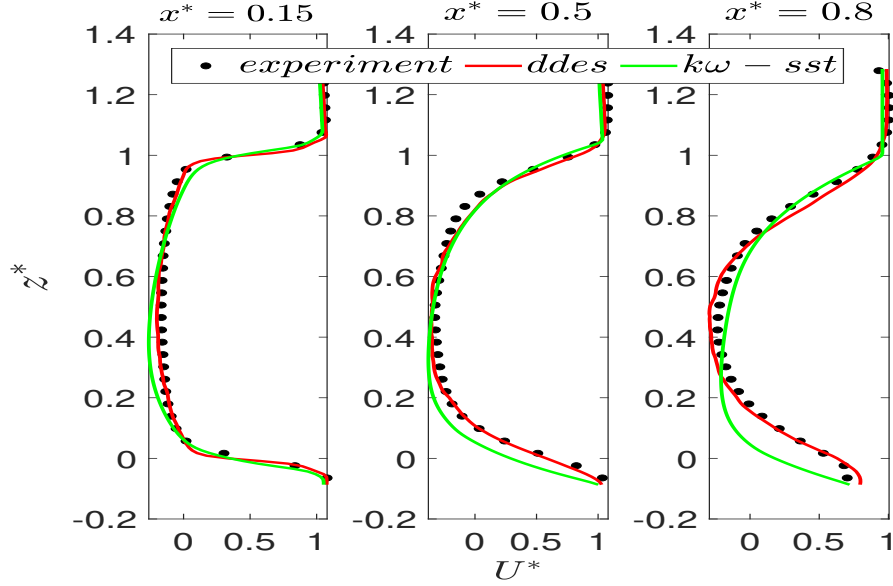


Figure 3: velocity vertical plots for plane $Y=0$ $x^*=0.15$, $x^*=0.5$ and $x^*=0.8$ (a)

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