Unsteady RANS Calculation of Flow over Ahmed Car Model

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Abstract. Three-dimensional separated flow around Ahmed car model has been studied by numerical simulation to solve the unsteady Reynolds-averaged Navier-Stokes (URANS) equations. The simulation considers experimental model with two slant angles of 25^o and 35^o. After some priori tests, baseline meshes have been identified with $1.5 - 1.9 \times 10^6$ elements for each case. After the precursor steady flow calculation, unsteady simulation continued for further 2 shedding cycles. Both mean and instantaneous quantities of the flow are accumulated and compared with available test data at representative measurement planes/locations. It was found that for two slant angles considered the time-averaged mean streamwise velocity of URANS predictions are compared fairly well with the experimental data with correct profile and same magnitude of peak. It was also observed that the slant angle has considerable influences on the downstream flow, particularly the flow recirculation, turbulence kinetic energy (TKE) distributions. The separated shear layers from the slant edges are merging together to form large size trailing vortex. While the flow structures agree qualitatively well with the measurement, the TKE has been under-estimated in wake region. This is mainly due to the limitation of two-equation turbulence model for massive separated flow with strong vortex shedding. Further advancement to large eddy simulation will provide a solution for this kind of flow.

Key words: unsteady RANS, Ahmed model, separated flow.

1. Introduction

Massive flow separations often appear in many engineering flow problems and the flow over Ahmed car model with a slant back is one typical example. This generic model was first studied experimentally by Ahmed et al. [1] and more detailed experimental study has been carried out recently by Lienhart et al. [2]. Both studies revealed significant flow separation at the rear of the model with complicated wake vortex structures. Experiment provides measurements at various slant angles to analysis their influences, and angles of 25^o and 35^o have been particularly studied and analysed in more details.

Numerical study of Ahmed car model has been performed by Han [3] using RANS approach. The result has shown good qualitatively comparisons with the experiment, e.g. flow structures. Recently, Manceau and Bonnet [4] concluded that the classical RANS method cannot provide very promising predictions of both mean and turbulent intensities of this type of flow. It was suggested that more accurate method may be required, such as detached-eddy simulation (DES) [5] and large-eddy simulation (LES) [6], although both are still not ready for routinely industry applications. Nevertheless, the future trend seems to be more concerning on control of massive separated flow by either passive or active manner. Moin [7] has recently reviewed the development in this field by discussion two passive control modes splitter plate and varying slant angle with significant changes of flow structures being demonstrated. Following those researches, a research programme is proposed to re-visit the separated flow over Ahmed car model. This paper presents the first-step approach by performing unsteady RANS simulation to analysis the time-averaged and instantaneous flow field. The ultimate goal of the programme is to apply LES and various methods for separated flow control.

2. Problem Setup and Results Discussion

This study focuses on unsteady RANS with comparisons of numerical predictions and the experimental data. A computational fluid dynamics (CFD) package ANSYS-CFX is used and the simulation follows general procedure with a precursor steady calculation, followed by a transient unsteady calculation. Details are given in below.

2.1. CONFIGURATION AND MESHING

The configuration follows that used by previous researchers [1, 2]. Figure 1a is a sketch of geometry with dimensions. We consider two slant angles 25^o and 35^o. Domain size is taken from other studies [3, 5, 6] and it is sufficient. To capture the wall viscous layer, a hybrid grid is generated with stretched structured mesh near-wall and unstructured mesh away from wall. Grid dependency study has been carried out on a sequence of mesh and baseline meshes are identified which has 1.5×10^6 elements for 25^o case and 1.9×10^6 elements for 35^o case. For both cases, grid size is about 40-50 in wall unit in near wall and wake regions, which are recommended by the software for unsteady RANS run.

2.2. SOLUTION PROCEDURE AND TURBULENCE MODEL

After a precursor steady calculation, transient unsteady run is followed for statistics. As lack of test data of shedding frequency, a bluff-body Strouhal (St) number 0.21 is used. The physical time is estimated based on this and characteristic length. Unsteady RANS is performed for 2 cycles with fixed time step, after sensitivity study. Two turbulence models (standard k-ε model and SST model) are considered and the performances are assessed. As expected, the SST model gives better performance in the separated region.

2.3. TIME-AVERAGED MEAN QUANTITIES

Figure 2 gives the time-averaged predictions at 15 measurement locations. The test data are plotted on the same graph for comparison. It is noted from 25^o case (Fig. 2a) that predictions from both k-ε and SST models are almost identical along the slant, but differences appear in near wake where k-ε model has poor performance with incorrect profiles. In contrary, SST model gives the correct shape and magnitude in comparison to test data at two wake locations. The experiment shows an incipient flow separation upstream of the upper rear corner, this has not been predicted by both models. Figure 2b shows SST model predictions for 35^o slant angle case and they are in good agreement with test data at all locations, including the upper rear corner with flow separation. Figure 3 shows the mean velocity vectors at mid-span plane with flow structures in near wake. The 25^o simulations (see Fig. 3a) do not capture incipient separation but 35^o

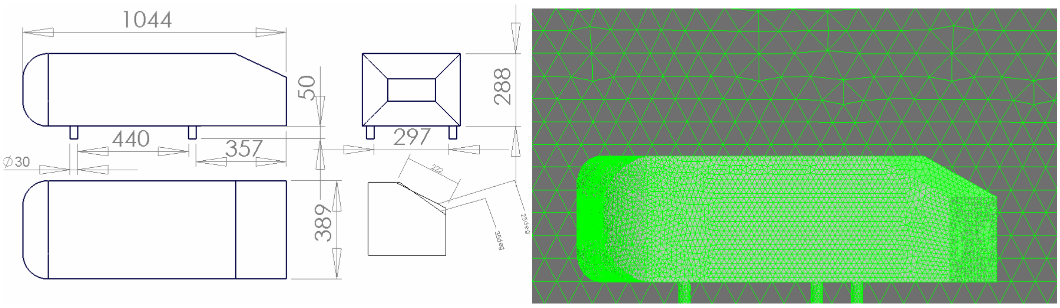
simulations (see Fig. 3b) capture separation well. As adverse pressure gradient increases at 35^o, the flow separated earlier on the slant, forming a much bigger vortex. This strong vortex entrains the fluids towards the ground and dominates the wake flow. A smaller vortex is visible in downstream, which is formed due to the shear layer of low surface.

2.4. INSTANTANEOUS FLOW FIELD

The instantaneous flow field has been visualized by iso-surface of vorticity as seen in Fig. 4a. The trailing vortex pair is originated from the shear layer of slant edges, progressively evolving downstream to form larger and enhanced structures. The counter-rotating vortex pair can also be seen in Fig. 4b. The transition from wall-bounded shear layer to free shear layer in near wake presents a great challenge for RANS modelling. It is widely accepted that most turbulence models are not working well in this region, simply because the models do not account for highly strained flow of this kind. Figure 5 shows comparisons of numerical predictions with PIV measurements at two wake planes. At x=80mm, simulation under-predicts the TKE value. It also shows a quite strong vortex pair, which is not recorded by the test, probably due to limited resolution of the PIV. Further downstream at x=200mm, simulation predicts a single vortex; qualitatively agree with the test, although the location and size of are slightly different. In this case, the predicted TKE are also lower compared to the test data. As in URANS modelling, the TKE comes from two contributions, k-equation of turbulence model representing small-scale fluid motions and accumulated large-scale fluid motions due to periodic shedding mechanism. It appears that although transient unsteady simulation has been performed, the vortex shedding is not as strong as expected for this kind of flow. Thus the contribution to TKE from vortex shedding has been largely under-estimated, causing the pitfall of overall TKE evaluation when comparing to the test data. The reason for this is probably due to a combination effect of capability of turbulence model and poor grid resolution in the wake region. To improve this in future, simulations will focus on refined wake grid resolution and applying the LES.

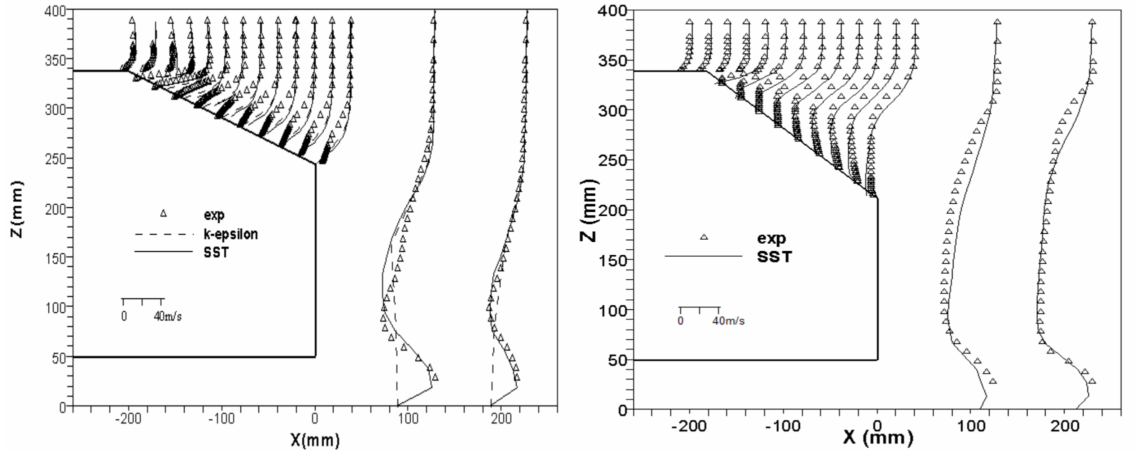
3. Conclusions

Unsteady RANS simulations have been carried out in this study, in order to analysis the separated flow over Ahmed car model. The simulation considers two representative slant angles of 25^o and 35^o. Numerical predictions are compared with available test data at same conditions. For both cases, streamwise mean velocity profiles are in good agreement with the measurement data, with the SST model performs better than the k-ε model particularly in the near wake region. The slant angle also has significant influences on wake flow structures as seen from the velocity vector field. The trailing vortex structure originating from the slant edge shear layer dominates the entire wake region. Numerical predictions are compared qualitatively well with the measurement at two wake locations, but the TKE has been under-estimated significantly, which is attributed to the RANS model weakness for such massive separated flow and strong vortex shedding in this kind. Future study will focus on refine the wake grid size and distribution and also apply the LES, which is more suitable for this type of flow.



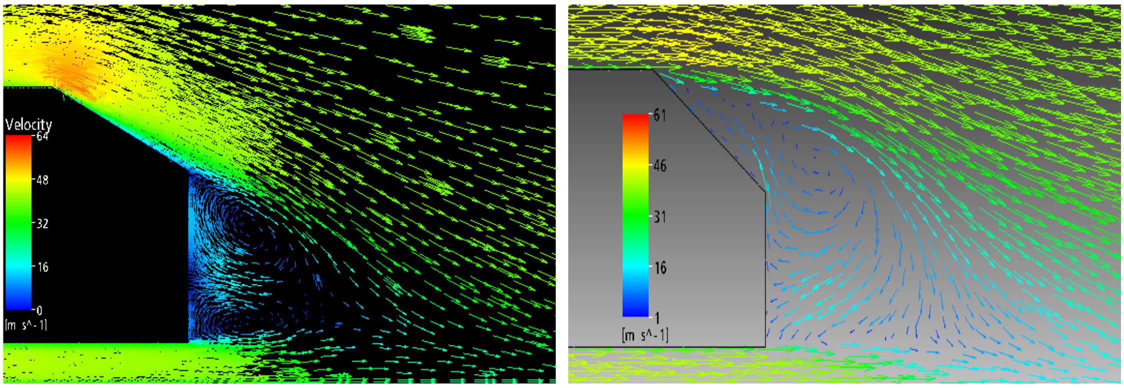
(a) (b)

Figure 1: Ahmed car model. (a) geometry, dimension and slant angle; (b) snapshot of background mesh and surface mesh.



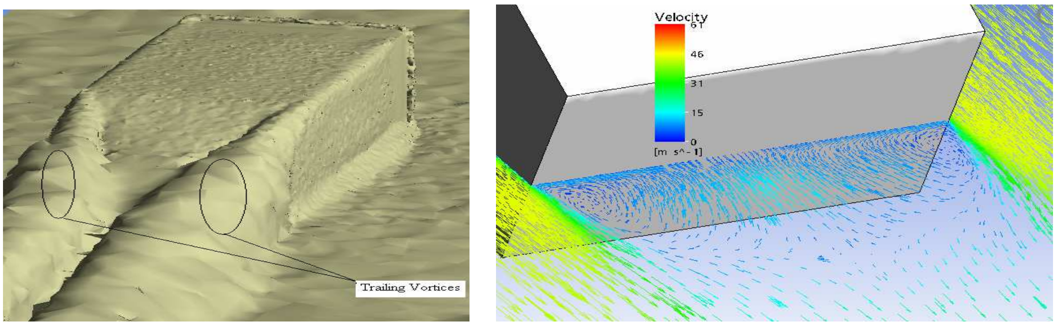
(a) (b)

Figure 2: Time-averaged mean streamwise velocity profile at 15 successive stations from top corner of the car to downstream wake field. (a) slant angle of 25°; (b) slant angle of 35°. Symbols: experiment; Lines: URaNS + SST model.



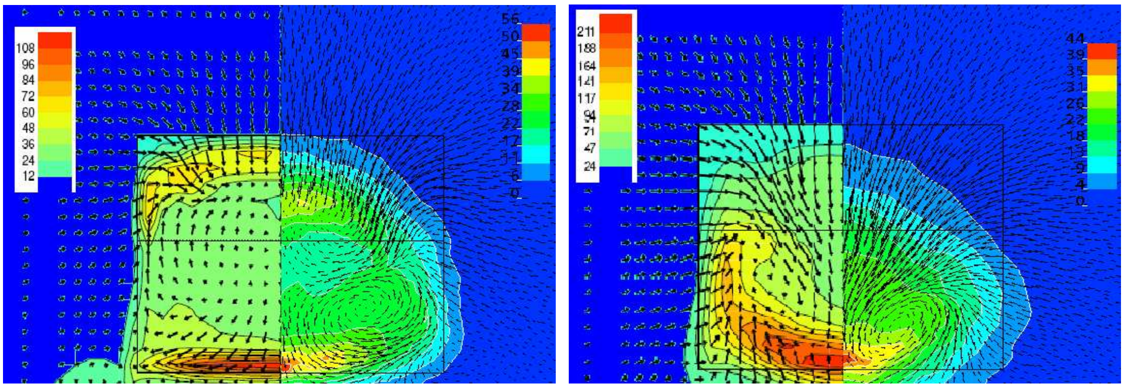
(a) (b)

Figure 3: Time-averaged mean velocity vectors at mid-span plane showing large recirculation bubbles. (a) slant angle of 25°; (b) slant angle of 35°. URANS + SST model



(a) (b)

Figure 4: Simulation results of 25° slant angle case. (a) iso-surface of voticity showing trailing vortex; (b) velocity vector at a horizontal plane showing flow recirculation at back of the model.



(a) (b)

Figure 5: Comparison of flow structure and TKE distributions at two successive vertical planes in the wake region for 35° slant angle case. (a) x=80 mm; (b) x=200 mm. Left: experiment; Right: URANS + SST model. Background colour contours show TKE level.

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