Assessment of Hybrid LES Formulations for Flow Simulation Around the Ahmed Body

Emmanuel Guilmineau, Ganbo Deng, P. Queutey, Michel Visonneau

► To cite this version:

Emmanuel Guilmineau, Ganbo Deng, P. Queutey, Michel Visonneau. Assessment of Hybrid LES Formulations for Flow Simulation Around the Ahmed Body. 4th International Conference on Turbulence and Interactions, Nov 2015, Cargèse, France. 10.1007/978-3-319-60387-2_18 . hal-02873798

HAL Id: hal-02873798

<https://hal.science/hal-02873798>

Submitted on 18 Jun 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Assessment of Hybrid LES Formulations for Flow Simulation Around the Ahmed Body

E. Guilmineau, G.B. Deng, P. Queutey and M. Visonneau

Abstract This paper presents numerical simulations for the prediction of the flow around the Ahmed body, with the 25° and 35° slant angles, obtained with the flow solver ISIS-CFD. A RANS (Reynolds Averaged Navier-Stokes) turbulence model, as EARSIM (Explicit Algebraic Stress Model) and two hybrid RANS-LES models, as DES (Detached Eddy Simulation) and IDDES (Improved Delay Detached Eddy Simulation) models, are used. All these turbulence models are based on the $k-\omega$ model. The use of a hybrid RANS-LES model, and more particularly the IDDES model, offers an advantage over RANS models in term of the force coefficients, and general flow field.

1 Introduction

The external aerodynamics of a car determines many relevant aspects of an automobile such as stability, comfort and fuel consumption at high cruising speed [6]. The flow around vehicles is characterized by highly turbulent and three-dimensional separations. There is a growing need for more insight into the physical features of these dynamical flows, on the one hand, and powerful numerical tools to analyze them on the other hand. Computations based on RANS equations are common in industry today. Although they are very successful in predicting many parts of the flow around a vehicle, they are unable to predict unsteadiness in the wake regions. The failure in predicting the base pressure is the major reason for large discrepancy in drag prediction between experiments and numerical simulations.

In an attempt to improve the predictive capabilities of turbulence models in highly separated regions, Spalart et al. [10] proposed a hybrid approach which combines

E. Guilmineau (✉) · G.B. Deng · P. Queutey · M. Visonneau
LHEEA, CNRS UMR 6598, Ecole Centrale de Nantes, 1 rue de la Noë, BP 92101,
44321 Nantes Cedex 3, France
e-mail: Emmanuel.Guilmineau@ec-nantes.fr

© Springer International Publishing AG 2018
M.O. Deville et al. (eds.), *Turbulence and Interactions*,
Notes on Numerical Fluid Mechanics and Multidisciplinary Design 135,
https://doi.org/10.1007/978-3-319-60387-2_18

171

emmanuel.guilmineau@ec-nantes.fr

features of classical RANS formulations with elements of Large Eddy Simulations (LES) method. This concept has been termed Detached Eddy Simulation (DES) and is based on the idea of covering the boundary layer by a RANS model and of switching the model to a LES mode in detached regions. Compared to classical LES methods, DES save orders of magnitude of computing power for high Reynolds number flows, due to the moderated costs of a RANS model in the boundary layer region, but still offers some of the advantage of a LES method in separated regions. A variant of the DES model, like Improved Delayed DES, IDDES, seems to be attractive. The numerical simulations, with these turbulence models, are carried out with the ISIS-CFD flow solver.

The purpose of this paper is to conduct a validation of the flow around the Ahmed body [1] to compare RANS model and hybrid RANS-LES methodologies. Both the 25° and 35° slant back angles are investigated in this study to assess the capability of each turbulence model to capture the important changes in flow physics. The flow is at a Reynolds number of 2.8×10^6 , based on the length of the model, L , and the upstream velocity $U_\infty = 40$ m/s.

2 ISIS-CFD at Glance

ISIS-CFD, developed by the Ecole Centrale de Nantes and CNRS and available as a part of the FINE/Marine computing suite, is an incompressible unsteady Reynolds-averaged Navier-Stokes (URANS) method. The solver is based on the finite volume method to build the spatial discretization of the transport equations. The unstructured discretization is face-based, which means that cells with an arbitrary number of arbitrarily shaped faces are accepted. A second order backward difference scheme is used to discretize time. The solver can simulate both steady and unsteady flows. The velocity field is obtained from the momentum conservation equations and the pressure field is extracted from the mass equation constraint, or continuity equation, transformed into a pressure equation. In the case of turbulent flows, transport equations for the variables in the turbulence model are added to the discretization. A detailed description of the solver is given by Queutey and Visonneau [9].

The solver features sophisticated turbulence models: apart from the classical two-equation $k-\varepsilon$ and $k-\omega$ models, the anisotropic two-equation Explicit Algebraic Reynolds Stress Model (EARSIM), as well as Reynolds Stress Transport Models, are available, see Duvigneau et al. [3] and Deng and Visonneau [2]. All these are RANS models. A Detached Eddy Simulation (DES) approach has been introduced, see Guilmineau et al. [5]. Recently, some modifications of this formulation proposed by Griskevich et al. [4] includes recalibrated empirical constants in the shielding function and a simplification of the original Spalart-Allmaras-based formulation. This new model is called Improved Delayed Detached Eddy Simulation (IDDES).

3 Numerical Simulation Set-up

The computational domain starts $2L$ in front of the model and extends to $5L$ behind the model. The width of the domain is 1.87 m and its height is 1.4 m . These dimensions are recommended for the ERCOFTAC workshop on Refined Turbulence Modelling [8]. The mesh is generated using Hexpress, an automatic unstructured mesh generator. This software generates meshes containing only hexahedrals. For the surface of the car model and the floor, a no-slip boundary condition is used and the wall normal resolution is set 0.0007 mm , i.e. $y^+ \leq 0.7$. For the 25° slant angle, the mesh consists of 23.1×10^6 cells and the model is described by $384,090$ faces. For the 35° slant angle, the mesh consists of 22.2×10^6 cells and the model is described by $379,358$ faces.

For the RANS simulations, the time step is $\Delta t = 0.001\text{ s}$ while with the hybrid RANS-LES models, the time step is $\Delta t = 2.5 \times 10^{-4}\text{ s}$. With the RANS simulations, the numerical simulation converge to a steady flow while with the hybrid RANS-LES models the flow is unsteady and the averaging time, $t \times U_\infty/L$ is 40 .

4 Results

4.1 35° Slant Angle

Figure 1 shows a comparison of the streamwise velocity in the symmetry plane for the Ahmed body with the 35° slant angle. The experimental profiles are those obtained by Lienhart et al. [7]. All turbulence models predict the correct flow, a fully separated flow, in the symmetry plane. The IDDES model gives a better agreement at the shear layer region.

Fig. 1 35° slant angle—streamwise velocity on the rear slant and in the wake

Fig. 2 35° slant angle—turbulent kinetic energy on the rear slant and in the wake

Table 1 35° slant angle—drag and lift coefficients

Model	C_D	C_L
EARSIM	0.260	−0.039
DES	0.316	−0.015
IDDES	0.355	−0.014
Experiments [1]	0.256	n/a

Figure 2 presents the turbulent kinetic energy (TKE) in the symmetry plane. Each model gives a good agreement with the experimental data. At the shear layer, the IDDES model overpredicts TKE while the other models underpredict TKE. In the wake, a better agreement with the experimental data is obtained with the hybrid RANS-LES models.

A comparison of the drag and lift coefficients is given in Table 1. The numerical results represent the total force, i.e. the force obtained on the model and the feet, while in experiments [1], it is only the model. For the lift coefficient, the value obtained with the EARSIM turbulence model is lower than the values obtained with the hybrid RANS-LES models which give similar values.

4.2 25° Slant Angle

Figure 3 offers a comparison of the streamwise velocity in the symmetry plane for the Ahmed body with the 25° slant angle. The EARSIM turbulence model fails to describe correctly the velocity field and overestimates the size of the recirculation region. The hybrid RANS-LES models provide an improved prediction. With the DES model, the separation covers the whole slant while, with the IDDES model, the reattachment point is located at $X = 168$ mm, from the upstream edge of the slant,

Fig. 3 25° slant angle—streamwise velocity on the rear slant and in the wake

Fig. 4 25° slant angle—turbulent kinetic energy on the rear slant and in the wake

Table 2 25° slant angle—drag and lift coefficients

Model	C_D	C_L
EARSM	0.280	0.008
DES	0.437	0.376
IDDES	0.382	0.327
Experiments [1]	0.285	n/a
Experiments [12]	0.384	0.422

which is in good agreement with the experimental measurement of Thacker [11] for which the value is $X = 160$ mm.

A comparison of TKE is presented in Fig. 4. The TKE obtained with the EARSM turbulence model is underestimated on the slant which means less turbulent mixing and thus a greater recirculation region. With the hybrid RANS-LES models, TKE is larger than the values obtained with the RANS model. In the initial separated region, TKE predicted with the IDDES model is in good agreement with the experimental value.

Table 2 presents a comparison of the drag and lift coefficients. Compared to the previous slant angle, the drag and lift coefficients have increased. The drag coefficient is dependent to the turbulence model while the lift coefficient is similar for the hybrid RANS-LES model and higher than the value obtained with the EARSM turbulence model. If we compare the drag coefficient measured by Thacker et al. [12], the IDDES model gives the better agreement. However, the lift coefficient is underestimated.

5 Conclusions

In this paper, an investigation of RANS and hybrid RANS-LES models for the Ahmed car body at 25° and 35° slant angle cases has been conducted. It has been shown that the use of a hybrid RANS-LES model, in particular the IDDES model, offers an advantage over RANS model in terms of the force coefficients and general flow field, even for the 25° test case where the reattachment of the flow is correctly predicted.

Acknowledgements This work was granted access to the HPC resources of CINES/IDRIS under the allocation 2015-2a0129 made by GENCI

References

1. Ahmed SR, Ramm G, Faltin G (1984) Some salient features of the time-averaged ground vehicle wake. SAE World Congress, Paper No 840300
2. Deng GB, Visonneau M (1999) Comparison of explicit algebraic stress models and second-order turbulence closures for steady flow around ships. In: 7th symposium on numerical ship hydrodynamics, Nantes, France, pp 4.1–4.15
3. Duvigneau R, Visonneau M, Deng GB (2003) On the role played by turbulence closures in hull ship optimization at model and full scale. J Mar Sci Technol 8:11–25
4. Gritskevich MS, Garbaruk AV, Schütze J, Menter FR (2012) Development of DDES and IDDES formulations for the $k-\omega$ shear stress transport model. Flow Turbul Combust 88:431–449
5. Guilmineau E, Deng GB, Wackers J (2011) Numerical simulation with a DES approach for automotive flows. J Fluids Struct 27:807–816
6. Hucho WH (1998) Aerodynamics of road vehicles. SAE International
7. Lienhart H, Stoots C, Becker S (2000) Flow and turbulence structures in the wake of a simplified car model (Ahmed model). In: DGLR fach symposium der AG STAB, Stuttgart University
8. Manceau R, Bonnet J (eds) (2002) 10th joint ERCOFTAC/IAHR/QNET-CFD workshop on refined turbulence modelling
9. Queutey P, Visonneau M (2007) An interface capturing method for free-surface hydrodynamic flows. Comput Fluids 36:1481–1510
10. Spalart PR, Jou W, Strelets M, Allmaras S (1997) Comments on the feasibility of LES for wings and on a hybrid RANS/LES approach. In: Liu CZ (ed) 1st AFOSR international conference on DNS/LES, Advances in DNS/LES. Greyden Press
11. Thacker A (2010) Contribution expérimentale à l'analyse stationnaire et instationnaire de l'écoulement à l'arrière d'un corps de faible allongement. PhD thesis, Université d'Orléans
12. Thacker A, Aubrun S, Leroy A, Devinant P (2012) Effects of suppressing the 3D separation on the rear slant on the flow structures around the Ahmed body. J Wind Eng Ind Aerodyn 107–108:237–243