COMPARATIVE ANALYSIS OF RANS AND DDES METHODS FOR AERODYNAMIC PERFORMANCE PREDICTIONS FOR HIGH PERFORMANCE VEHICLES AT LOW GROUND CLEARANCES

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Abstract. Various assessments of RANS and Hybrid RANS-LES turbulence models have been conducted for automotive applications. However, their applicability for high performance vehicles which exhibit much more complex flow phenomena is not well studied yet. In this work, the predictive capabilities of RANS and DDES models are investigated through a comparative study on a high performance configuration of the *DrivAer* Fastback model at a low ground clearance in an open road computational domain. The results show much agreement in the general pressure distribution, except in areas of highly unsteady flow. Visualisation of the flow field depicts that the DDES simulation is able to capture a wider range of turbulent scales with a higher fidelity. Lastly, variation in the magnitude, distribution and decay of pressure losses in the wake are observed between both simulations. The presented results are used to illustrate the capabilities and limitations of these turbulence models for other academic or industrial users to make an informed decision on the turbulence model suited for their objectives.

Key words: *Hybrid RANS-LES; DDES; RANS; DrivAer; High-Performance*

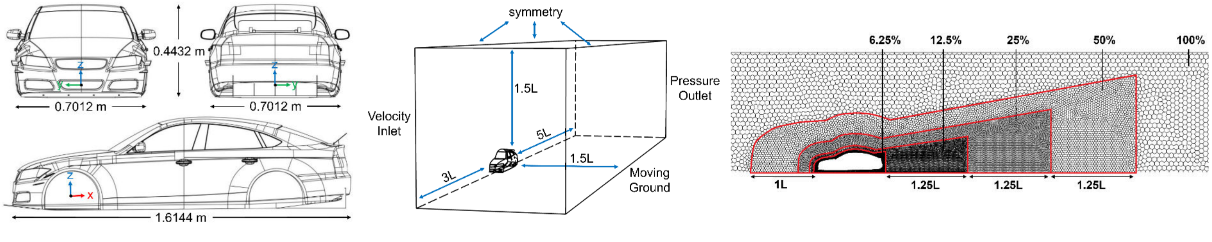
1 Introduction

The performance of automotive and motorsport vehicles is critically determined by their aerodynamic designs. The analysis and design process for more advanced and efficient aerodynamic concepts requires the use of Computational Fluid Dynamics (CFD) to complement the traditional wind tunnel experiments. Turbulence model selection is an important aspect in CFD which requires a trade-off to be made between accuracy and computational costs for specific design objectives. Reynolds-Averaged Navier-Stokes (RANS) turbulence models are well known for their low computational costs, but have limited capabilities to capture unsteady details in turbulent flows. In contrast, Scale-Resolving Simulations (SRS) like the Large Eddy Simulation (LES) are able to resolve complex turbulent flow structures, but require significant computational resources. Hybrid RANS-LES models like the Delayed Detached Eddy Simulation (DDES) are able to switch between a RANS model is the boundary layer to a LES model in regions of large flow separation and thereby improve overall computational efficiency. For ground vehicles, most prior research on the capabilities of these turbulence models has been devoted to automotive passenger vehicles. This paper provides a comparative study on the predictive capabilities of RANS and DDES simulations dedicated to high performance vehicles, which exhibit significantly more complex flow phenomena.

2 Problem description

Turbulence model selection is application and even case dependent, it should not only consider the trade-off in accuracy and computational costs but also the flow physics. In automotive applications, RANS models have shown adequate accuracy in drag predictions but an inability to produce detailed flow structures [1]. Hybrid RANS-LES models have shown promising results both in terms of the mean pressure distribution and velocity field, and also in capturing unsteady flow structures with a high fidelity [2]. Yet, the applicability of these turbulence models on high performance vehicles is not well studied. High performance vehicles exhibit much more complex flow phenomena through the use of downforce generating devices, especially at low ground clearances [3], which need to be accurately captured to asses the aerodynamic performance.

Therefore, a comparative study on the predictive capabilities between RANS and DDES models is conducted on the *DrivAer hp-F* model [4]; a high performance configuration of the *DrivAer* Fastback model (Figure 1a). The numerical simulations are performed on a half car model at a ride height of 15.015 mm in a rectangular computational domain with a blockage ratio of $\approx 1.3\%$, designed to resemble open road conditions (Figure 1b). The case is considered at a velocity of $U_\infty = 40\ m/s$ using an air density of $\rho = 1.1678\ kg/m^3$ and a dynamic viscosity of $\mu = 1.8377e^{-5}\ kg\ m^{-1}s^{-1}$. Two unstructured poly-hexcore meshes with a vehicle surface mesh size and base mesh size of around 0.45% and 7.25% of the vehicle's length (L) are created in ANSYS Fluent Meshing for the RANS and DDES simulations. The DDES mesh uses a low y^+ treatment of $y^+ \approx 0.8$ with 15 inflation layers whereas a higher y^+ treatment of $y^+ \approx 168$ with 4 inflation layers is used for the RANS mesh. Both meshes uses refinement zones, but the near-field element size is reduced from 6.5% to 2% of the base mesh size for the DDES mesh to allow a more gradual transition with the low y^+ treatment (Figure 1c). Both simulations are performed with the k-ω SST turbulence model using the standard settings in ANSYS Fluent. The RANS simulation is performed for 1000 iterations with force coefficients averaged over the last 500 iterations. The DDES simulation uses a fixed time-step of $3.125e^{-4}\ s$ with 10 inner iterations and is initialised using a RANS solution. The DDES simulation is performed for 2 s of flow time, equivalent to 49.6 convective time units (CTUs), including 24.8 CTUs to wash out the RANS initial condition, and the remaining 24.8 CTUs to average the flow field and collect unsteady statistics. These settings result in computational times of about 1 hour and 79 hours for the RANS and DDES simulations respectively.

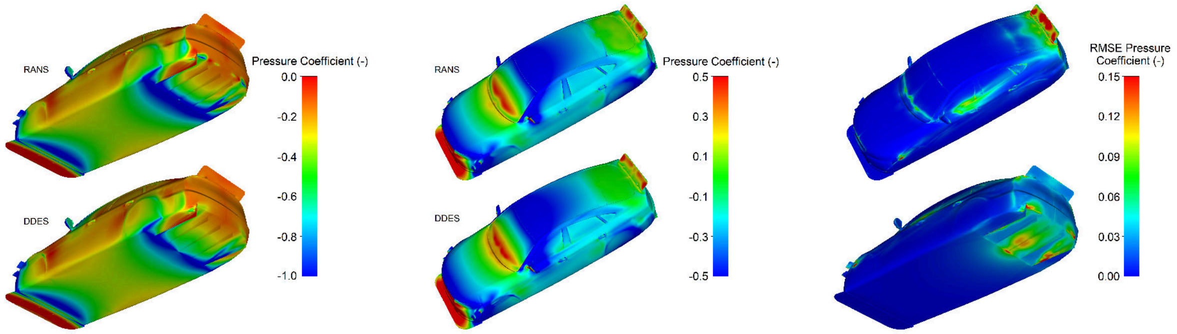


(a) (b) (c)

Figure 1: (a) *DrivAer hp-F* model with dimensions, adapted from [4], (b) computational domain with dimensions and boundary conditions, and (c) close-up of the mesh strategy with element sizes expressed as a percentage of the base mesh size

3 Numerical results

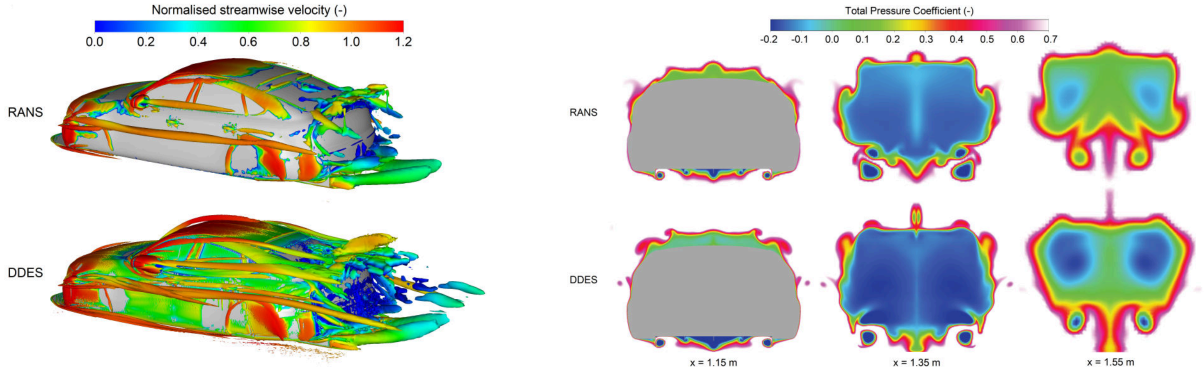
The RANS simulation predicts nearly 10% more downforce, but only over 3% more drag compared to the DDES simulation, resulting in 6% higher aerodynamic efficiency. Even though the RANS simulation shows slightly earlier pressure recovery in the diffuser, it also displays a lower pressure on the floor and diffuser inlet, resulting in a nearly 6% lower average pressure coefficient on the underbody (Figure 2a). Furthermore, the RANS simulation depicts less pressure build up on the windscreen, caused by the larger recirculation zone in front of the windscreen which acts as an air deflector that redirects airflow from the hood more smoothly to the windscreen (Figure 2b). More variation is observed on the spoiler where the RANS simulation shows a centralised high pressure region whereas the DDES simulation depicts a high pressure region around the periphery (Figure 2b). The diffuser, windscreen, slant and spoiler are also areas with high surface pressure fluctuations (Figure 2c) caused by large separation and unsteady flow behaviour. These effects are typically less accurately captured by RANS models, causing the dissimilarities in surface pressure to the DDES simulations in these areas.



(a) (b) (c)

Figure 2: Mean pressure coefficient at the (a) underbody and (b) upper surface, and (c) Root Mean Square Error (RMSE) for the mean pressure coefficient of the DDES simulation

Other concentrations of pressure fluctuation are seen in the wakes of the strakes and mirrors. The RANS simulation succeeds to capture these main turbulent structures, but the DDES simulation provides much more detail and further propagation (Figure 3a). This provides more insights into the downstream development, as seen for the vortices formed at the side of the splitter which move towards the low pressure region underneath the vehicle and exit out of the diffuser. Furthermore, the DDES simulation captures more turbulent structures like the one running over the centre line which is formed at the centre of the splitter, and the one formed at the A-pillar which moves towards the slant. Moreover, the DDES is able to resolve smaller structures in the separated flow on the slant and in the wake, which translates into a lower total pressure in those regions (Figure 3b). Increased separation on the slant and diffuser in the DDES simulation creates a more squared primary near-wake region at x = 1.35 *m* compared to the RANS simulation. Further downstream at x = 1.55 *m*, both simulations depict two circular concentrations of high pressure losses which corresponds to the two counter-rotating vortices formed at the spoiler and vehicle base. The DDES simulation shows less decay of pressure losses and the distribution is concentrated higher in the wake. Similarly, the DDES simulation shows more intense traces of the vortices and flow separation of the diffuser in the lower region of the wake.



(a) (b)

Figure 3: (a) Visualisation of coherent turbulent structures (Q = $8 * 10^4\ s^{-2}$) of the averaged flow colored by normalised streamwise velocity (U_x/U_∞), and (b) total pressure contour plots on a plane through the slant (x = 1.15 *m*) and two planes in the near wake (x = 1.35 *m* & x = 1.55 *m*)

4 Conclusions

A comparative study between RANS and DDES approaches intended to study their applicability for external aerodynamics simulations of high performance vehicles is conducted on the *DrivAer hp-F* model. Both simulations show a similar pressure distribution, bar from areas with highly unsteady flow where the RANS simulation predicts less separation resulting in 10% and 3% more downforce and drag compared to the DDES simulation. Dominant turbulent structures are captured by the RANS simulation, however the DDES simulation resolves a wider range of turbulent scales with a higher fidelity. Furthermore, the DDES simulation depicts a larger near-wake with higher pressure losses that decay slower compared to the RANS model. Considering the nearly 80 times faster computational time, the RANS simulation provides adequate information for analysis of the mean flow field and force coefficients. However, in depth analysis of specific devices and turbulent structures would benefit of the additional detail provided by the DDES simulation, especially in regions of unsteady flow and large separation.

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