Comparison of CFD Methods to Wind-tunnel Data for a Class 43 High Speed Train

Justin Morden, Hassan Hemida, Chris Baker

School of Civil Engineering, University of Birmingham, UK., B15 2TT

jam239@bham.ac.uk

Abstract

This paper focuses on the application of computational fluid dynamics (CFD) to external aerodynamic flow around a 1/25th scale class 43 HST model. The CAD model of the train featured a high level of geometric detail within the under-carriage region to improve the accuracy of the simulation and to provide a more accurate simulation of under-body and wake flow structures. Two different CFD methods were used to study the flow around the HST. The obtained surface pressures are compared to wind tunnel data previously collected in order to determine the best practice when simulating external flows.

1 Introduction

Validation of the CFD approach is a critical stage prior to any investigation due to the sensitivity of the setup to a number of factors. With the power of computers following Moore's law the optimum setup used is constantly evolving. With current computational power high detail RANS (Reynolds-averaged Navier-Stokes) based simulations are becoming the normal, therefore a new more accurate approach needs to be investigated to continue pushing research forward. Research published for the LES (Large Eddy Simulation) approach has relied upon the use of highly simplified trains that omit under body detail and even the inter-carriage gap in some circumstances. This research approach provides a high level of insight into the fundamental flow regimes that occur around the body of a train at different yaw angles but fail to accurately study the effect of under body details. This paper looks at the application of a DDES (Delayed Detached Eddy Simulation) approach to a 1/25 scale class 43 HST train with a high level of geometric detail around the under-body. The surface pressure coefficients results of the two CFD approaches will be compared to data collected from a comparable wind-tunnel test to assess their accuracy and allow for a conclusion to be made.

2 Wind-tunnel experiment

Wind tunnel tests were conducted by RWDI on behalf of the research project, The tests were conducted on a 1/25th scale two car model of a class 43 train (Figure 1) on a scale ballast shoulder with rails (Figure 2) The power car, passenger carriage, inter-carriage gap and bogies were all included in the model. The train and ballast shoulder were mounted upon a raised platform 20cm above ground level to remove any effects created by the boundary layer on the wind tunnel floor. The power car was fitted with 313 pressure taps over its surface that were sampled for a time of 120 seconds for each run to provide time average results. The power car mount was fitted with a load cell to enable the measurement of lift and drag forces and the overturning moment. A total of 11 runs were conducted where the trains yaw angle was varied from 0^0 to 45^0 in 5 degree increments at a constant flow velocity of 13.2m/s, the Reynolds number for these simulations was to $1.0x10^5$ which is below the recommendations made in British Standards (2009) for the conducting of wind tunnel tests.

Figure 1: full scale HST.

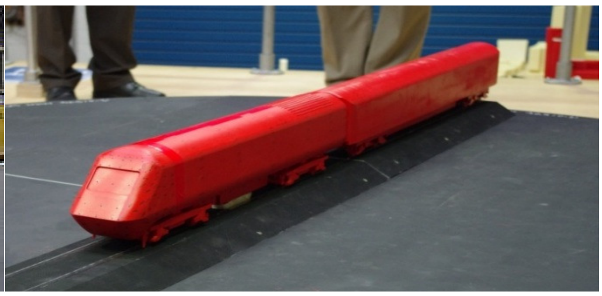

Figure 2: $1/25^{th}$ scale HST windtunnel model.

3 CFD

The initial step in conducting the CFD simulations was the simplification of the CAD geometry; this involved the removal of the windscreen and roof slats due to their minimal importance and complexities during the meshing process. The sensor umbilical cord was also excluded from the CAD geometry due to its exact dimensions being unknown.

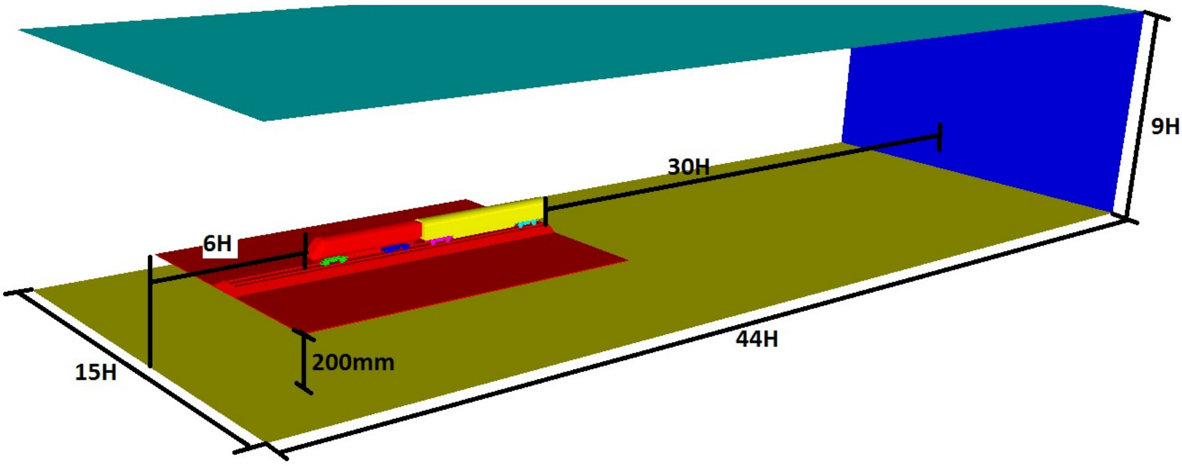

Figure 3: Computational domain sizes (H is height of train)

Figure 3 shows the overall domain size. The blockage ratio calculates to be 6% including the raised platform, this is below the recommendations in section 5.3.4 of the BS EH 14067-4:2005+A1:2009 guidelines which recommends 10%. The blockage ratio of 6% is also lower than the blockage ratios used in Ekeroth (2009) and Hemida (2009).

3.1 CFD setup

Both the RANS and DDES setups were initially run using first order upwind schemes before being switched to 2nd order central differencing schemes, this approach was chosen to improve the initial stability of the simulation and to reduce the time required to achieve convergence. The DDES simulation used a Crank-Nicholson 2nd order scheme for the time integration.

Convergence for the simulation was determined by monitoring the drag and lift forces of the leading carriage until there was no more change against time when plotted using line of best fit using a polynomial of two.

For the RANS simulations the SIMPLE algorithm proposed in Szablewski (1973) was used for the pressure-velocity coupling. The DDES experiments used the PISO algorithm proposed in Issa (1986) for pressure-velocity coupling.

3.2 *Computational Mesh*

Multiple meshes were produced using the Ansys Tgrid software to conduct a mesh sensitivity study (Figure 4), results of the study showed that a fine mesh of 34 million cells (Figure 5) would provide the highest accuracy whilst still ensuring suitable hardware requirements.

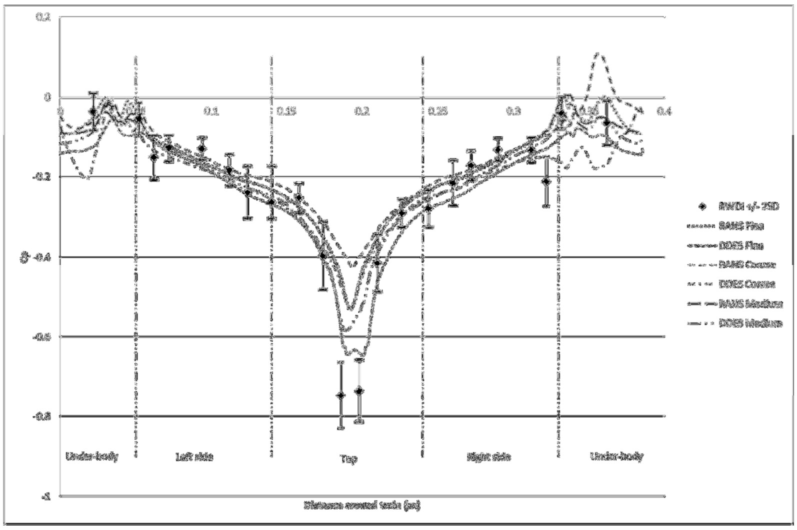

Figure 4: Mesh sensitivity study

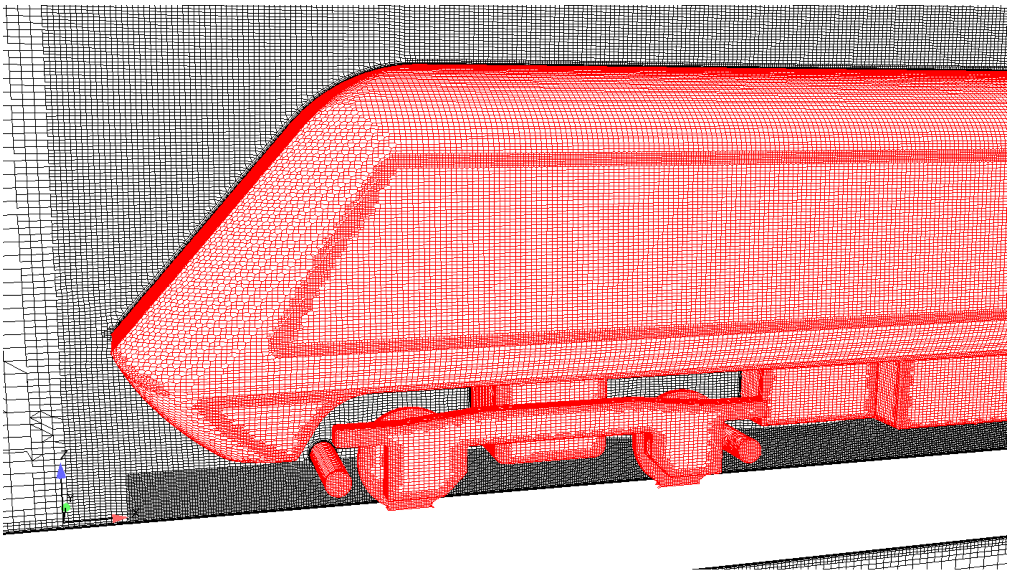

Figure 5: Close up of Fine mesh, showing engine and first bogie (red) and a central slice through the mesh (black)

Figure 5 shows a close up of the fine mesh, along the central slice it can be seen how the mesh density is varied depending upon its location, the mesh near the train is reduced in size in comparison to the larger cells that can be seen on the left side. Due to the importance of underbody detail on the flow field around a train as described in Baker (2010) and Jönsson (2010) the mesh is further refined between to ballast shoulder top and the mid axel height.

4 Results

Pressure taps fitted to the wind tunnel model are grouped in lines (clips) around the train on all three axis, The location of the chossen clip lines for study can be seen in **Error! Reference source not found.**6.

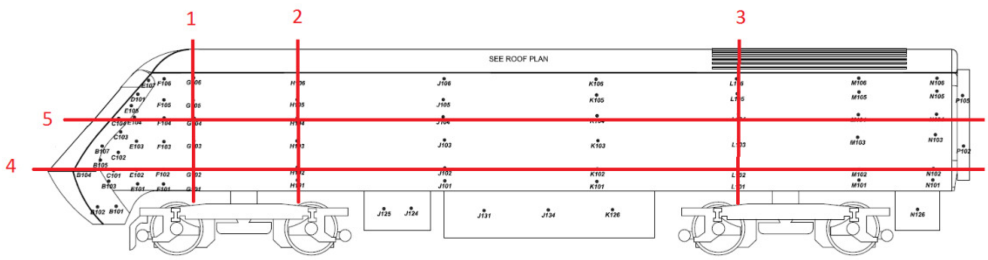

Figure 6: Clip locations on train

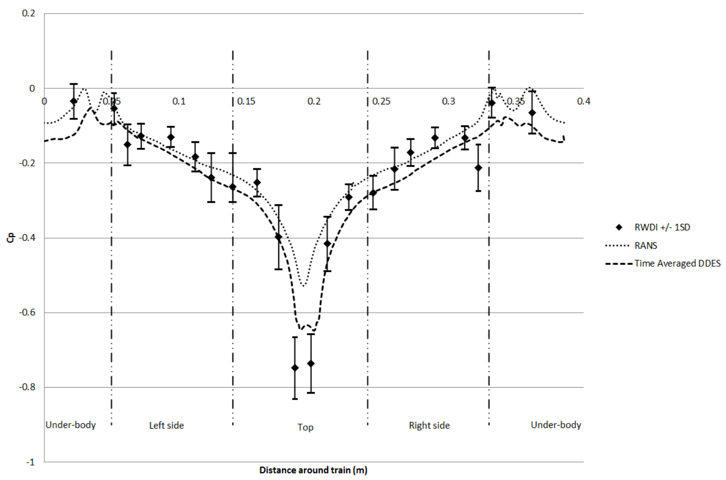

Figure 7: Cp at clip location 1

Error! Reference source not found.7 shows surface pressure coefficient around clip location 1, it can be seen that both the RANS and the DDES approach have similar profiles with the DDES results predicting lower pressure coefficients at all locations. Around the train sides and the undercarriage the two approaches are within or close to the margin of error for the wind tunnel results. Over the roof the RANS method significantly under predicts the pressure coefficient in comparison to the wind tunnel measurements. The DDES method better predicts this, though the calculated value is still below the measured value and its margin of error. It is worth noting that neither the RANS nor DDES approach predicted the pressure drops recorded near the lower sides to the train.

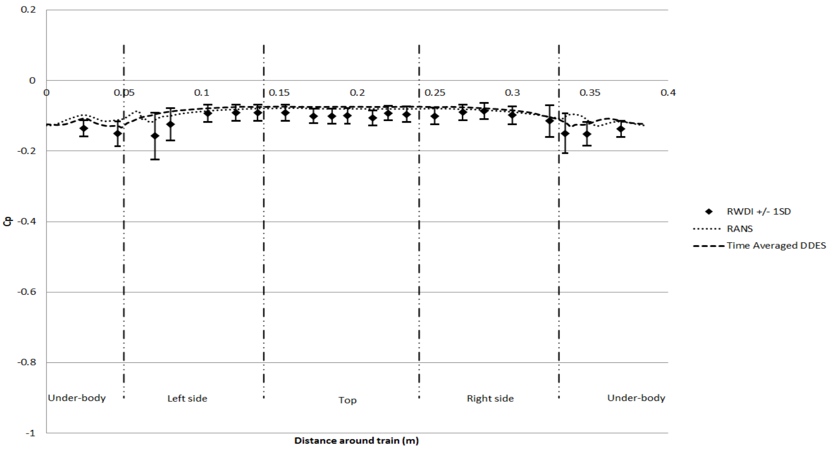

Figure 8: Cp at clip location 2

Error! Reference source not found.8 shows the surface pressure coefficients at clip location 2, at this location both CFD methods predicted similar pressure coefficients to each other over the trains side and roof but differ slightly within the under-body region. Both approaches predict higher pressure coefficients than recorded however both are nearly entirely within the margin of error for the wind tunnel data. Around the lower right side and under carriage the DDES approach proves to be more accurate by correctly predicting the drop in pressure whereas the RANS approach predicted a rise in the surface pressure coefficient.

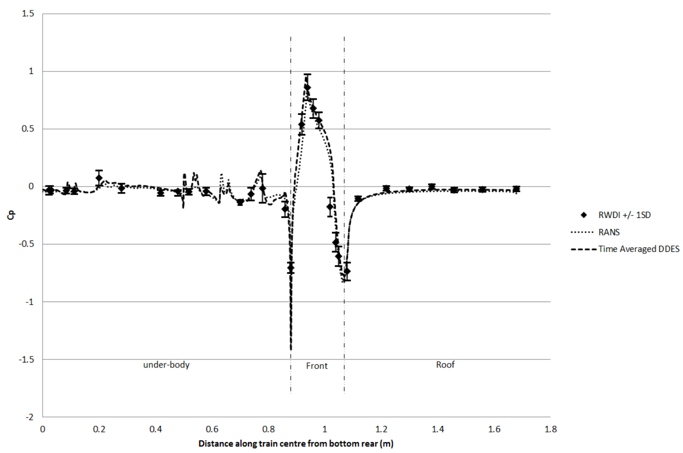

Figure 9: Cp along train centre line

Figure 11 shows a clip along the trains centre line, at this locations the surface pressure coefficients over the trains roof were calculated as an average of pressure taps that are located in close proxiemty each side of the centre line. Along the centre line of the train both approaches predict the surface pressure coefficients generaly stay within the margin of error for the wind tunnel results. The RANS and DDES results also predict simular surface pressure variations within the under-body region, however a lack of pressure tap points within this location in comparison to the geometric complexity adds uncertainty to any conclusions that could be made.

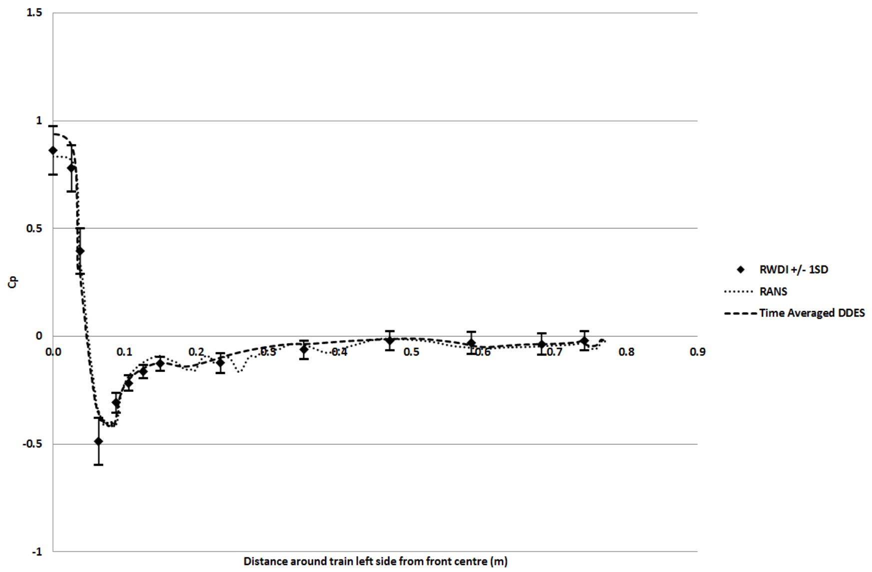

Figure 10: Cp at clip location 4

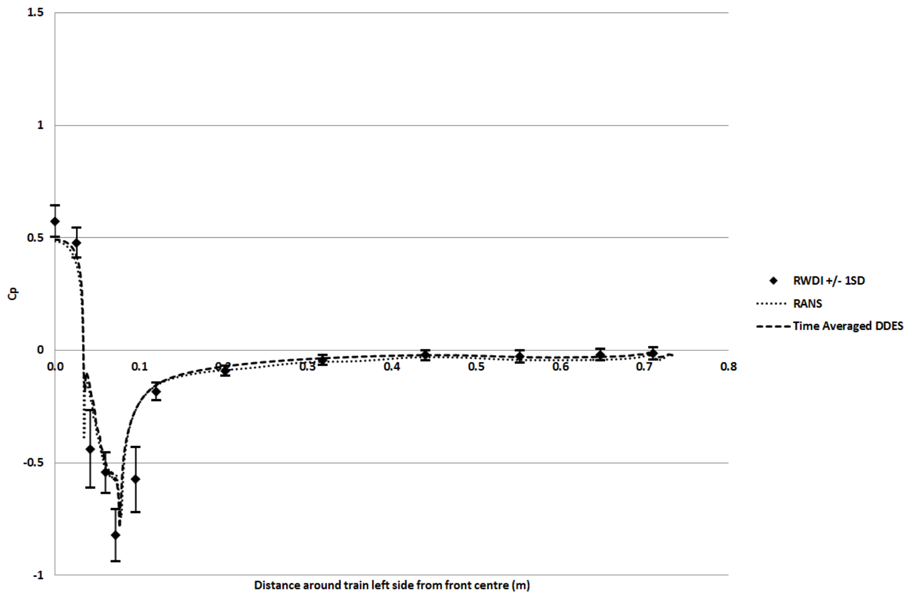

Figure 11: Cp at clip location 5

Error! Reference source not found.10 and 11 shows surface pressure coefficients around the left side of the train starting at the front centre. Both CFD methods show good correlation with results obtained from the wind tunnel tests by remaining within the margins of error for a large majority of the results. In **Error! Reference source not found.**10 it can be seen that the DDES results over predict the head peak pressure coefficient, the difference between the DDES and RANS results at this point are due to differences in predictions of seperation over the ballast shoulders step. In Figure 11 both approaches under predict the head peak pressure and the surface presures around the corners of the train, this is caused by the removal of the windscreen detail which is normaly recessed causing disturbance to the flow around its edges.

5 Conclusion

Both methods accurately replicated the surface pressure coefficients over the train, generally the DDES approach better predicted peak pressures in comparison to the RANS results. The simularity of results was to be expected due to the relative simplicity of calculating surface pressures and due to both approaches relying upon a RANS approach in the near wall regions. A larger difference in the approaches could be seen when the drag coefficients were compared to the wind tunnel data, the wind tunnel model had a drag coefficient of 0.12 whilst the DDES results calculate the drag coefficient to be 0.095, This was considerably more accurate than the RANS results that calculate the drag coefficient to be 0.074. The large difference between the two approaches was due to the difference in wake predictions and the underpredictions of the train head pressure by the RANS approach. The results showed that the overall increase in accuracy and flow information obtainable from the DDES simulation out weighed its increased computational expense when compared to the RANS approach.

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