Parallel CFD computations of cross-wind stability on an ICE2 train

Hassan Hemida and Siniša Krajnović

Chalmers University of Technology, SE-412 96 Göteborg, Sweden,
`hemida@chalmers.se`,
WWW home page:
`http://www.tfd.chalmers.se/~lada/projects/sidewind/proright.html`

Abstract. Many rail way accidents have been reported in the last two decades due to strong side winds. Thus, a suitable design for the new generation of the high speed trains should take into account the resistance to the strong side winds. To help engineers to achieve optimum design, both the time-averaged and the instantaneous flow structures around the train should be understood. The flow around high speed ICE2 train subjected to a 30^o side wind yaw angle is solved using large eddy simulation (LES). The Reynolds number used in the simulation is 2×10^5 based on the freestream velocity and the height of the train. Both the time-averaged and the instantaneous flow are investigated. The simulation gives a full picture of the wake behavior and its impact on the train aerodynamics.

1 Background and numerical simulation

The development of trains production in last century produces high speed trains that are characterized with light weight. When such trains cruise in strong side winds, they experience strong aerodynamic forces and moments that tend to derail or overturn them (in extreme situations). The freestream flow impacts the streamwise face of the train causing stagnation region with high pressure. Since the flow should follow the surface of the train, part of the wind moves toward the top-side face while part moves toward the belly of the train. The combined speed of the train and side wind determines if the flow remains attached to the surface or if it separates on the top-side face. At enough high speed, the flow separates from the top-side face at the trailing edge making the wake flow (flow downstream of the train). The pressure of the separated wake flow is much smaller than the stagnation pressure in the streamwise face. The difference between the pressure on the streamwise face and the pressure on the lee-side face produces side force which tends to push the train from the side. On the other hand, the flow on the top-side face is completely different from the flow on the bottom-side face and consequently the pressure. The difference between the pressure on the bottom-side face and the pressure on the top-side face is the lift force which rise the train from the rail. Since the flow is unsteady (i.e. changing in time), these forces are unsteady and depends very much on the train speed and side wind direction. It is worth mentioning that the only force that works against the side and the lift forces to stabilize the train is the weight of the train. Since the high speed trains have light weight, they are in a high risk of accident occurring when cruising in a strong side wind. This phenomena has ensured that the cross wind stability of trains is an area of research which has recently undergone a revival. To avoid the unwanted influences of the side wind, the flow structures around the train should be understood in both the time-averaged and instantaneous flow. Experimental investigation of the flow around trains are difficult to make. Most of the previous experimental studies like that in [1–3] have focused on measuring some integral parameters but not much on understanding the flow. Although numerical studies like that in [4, 5] are very powerful tools to understand the flow, they are rare and most of them are based on the Reynolds averaged Navier Stokes (RANS) equations that gives only the time-averaged information. In this paper, we used large eddy simulation (LES) to solve the side wind flow around the ICE2 train subjected to 30^o side wind yaw angle. Beside the high accuracy of the time-averaged results, the method gives the instantaneous information about the flow since it solve the instantaneous governing equations. Ten years ago, LES was not a feasible method to solve the flow around bluff bodies in general owing to its highly computational cast. Nowadays due to the existence of high efficient Linux clusters and supercomputers, LES has became feasible and it is spreading fast to be the method that accurately solve the flow in many applications. The main problem of LES is that we can not afford to use it for high Reynolds number since the computational time would be very long or instead we need many CPUs in parallel to reduce the computational time. The Reynolds number in the present paper is 2×10^5, based on the free stream velocity and height of the train. The ICE2 model and the computational domain is shown in figure 1.

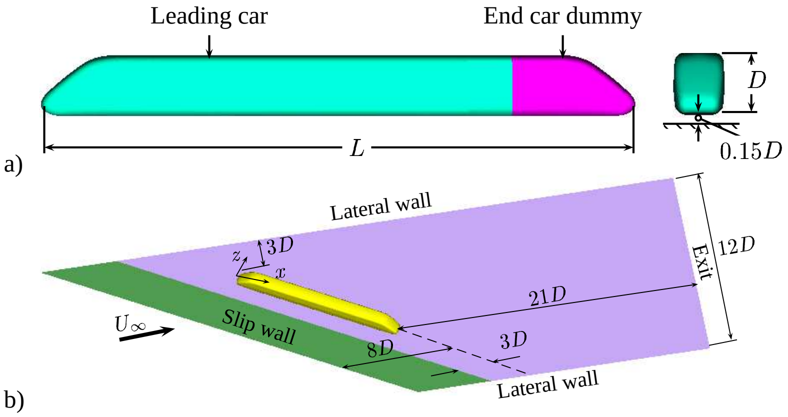

Fig. 1. (a) ICE2 train model. (b) Computational domain.

2 Results

A computational grid that has been made around the model consists of 14 million hexahedral cells. This mesh is used to compute the flow. The simulation has been carried out at the Opteron cluster Sarek at HPC2N where 38 CPUs were used for the computations during three months. The turbulence governing equations are discretized and solved using in-house finite volume code that uses domain decomposition and MPI. The flow field is computed at each time step which requires about 30 seconds for convergence. The time step was 1.0×10^{-4} sec. 10 seconds were needed to compute the time-averaged flow. Figure 2 shows the time-averaged flow structures around the train by means of flow streamlines generated from the vortex cores and pressure minimum criteria. The flow separates from the top-side face forming recirculation region on the wake flow with a vortex core Vc_1. This vortex is stretching along most of the leading car length keeping attached flow to the surface. Its core has a fixed position in space while its size is increasing in the direction of the length of the train. The vortex sheet from the under body flow shed vortex cones in the wake flow at successive points on the bottom-side face with vortex cores, Vc_2, Vc_3, Vc_4 and Vc_5. These vortices are weak and they do not have fixed position for their cores.

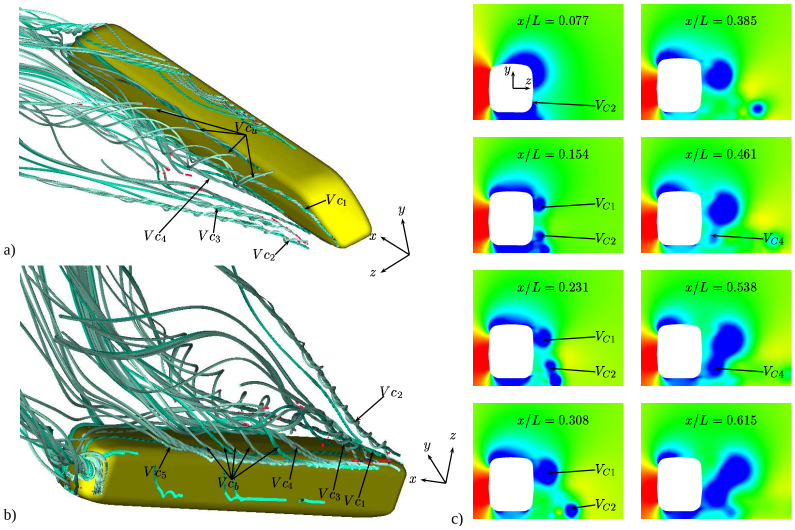

Fig. 2. Streamlines generated from the vortex cores: (a) view from above, (b) view from below the train. (c) Cross section colored by pressure showing development of the wake vortices.

Instantaneous pictures of the wake flow (not shown here) similar to that in figure 2 show that the lower wake vortices attach and detach from the train surface while the upper vortex, Vc_1, remains attached to most of the surface of the leading car. It detaches from the surface at $x/D \approx 0.6$ and another vortex is born. Weak vortex shedding is found in the flow from the lower recirculation vortices. These processes of attachment and detachment with the vortex shedding leave disturbances on the train pressure and hence the aerodynamic coefficients. Figure 3 shows the time histories of the aerodynamic side and lift force coefficients, C_s and C_l together with the corresponding autopower spectra. The dominating frequencies in the spectral plots are the frequencies of the movement of the wake vortices. There are also a number of high frequencies which are corresponding to the shear-layer instability frequency. The later is responsible for the shedding of the small vortices from the recirculation region.

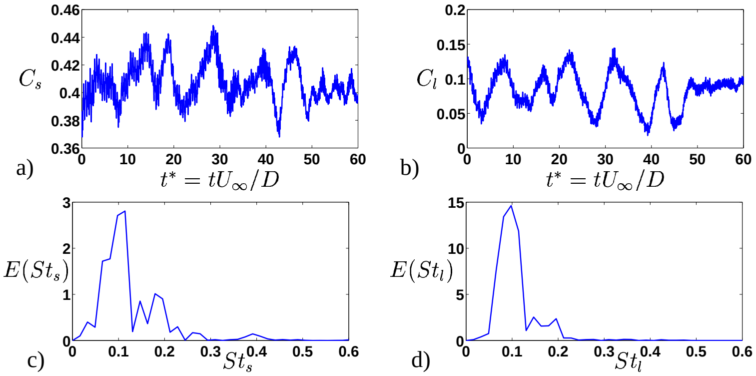

Fig. 3. (a) and (b) are the time history of the side and lift force coefficients, respectively. (c) and (d) are the corresponding autopower spectra.

References

1. C.J. Baker. Some complex applications of the wind loading chain. *Journal of Wind Engineering and Industrial Aerodynamics*, 91:1791–1811, 2003.
2. M. Suzuki, K. Tanemoto, and T. Maeda. Aerodynamic characteristics of train/vehicles under cross winds. *Journal of Wind Engineering and Industrial Aerodynamics*, 91:209–218, 2003.
3. J. M. Copley. The three-dimensional flow around railway trains. *Journal of Wind Engineering and Industrial Aerodynamics*, 26:21–52, 1987.
4. B. Diedrichs. On CFD modeling of crosswind effects for high-speed rolling stock. 2002. Accepted for publication in *Journal of Rail and Rapid Transit.*
5. H. Hemida, S. Krajnović, and L. Davidson. Large-eddy simulations of the flow around a simplified high speed train under the influence of a cross-wind. In *17th AIAA Computational Fluid Dynamics Conference*, Toronto, Ontario, CANADA 6-9 Jun, 2005.