Safety to crosswind of railway vehicles passing by a windbreak gap: numerical-experimental methodology

Carlos Esteban Araya Reyes[1], Elia Brambilla[1], Paolo Schito[1], Gisella Tomasini[1]

[1]Politecnico di Milano, Milan, Italy.

Abstract

One of the main countermeasures to the problem of crosswind in railway vehicles is the introduction of windbreaks in the windiest points of a railway line. However, in some cases due to the morphology of the terrain or because operational reasons, gaps can be found in the stretch of windbreaks with a consequently reduction of efficiency. The goal of this work is to develop a methodology for the evaluation of the effects on the safety to crosswind of high-speed trains running in a track where a gap is present in barriers. An innovative numerical-experimental procedure has been developed based on experimental full-scale tests, wind tunnel tests, CFD with moving mesh and multi-body simulations. An "amplification function", defined as a non-dimensional function which represents the amplification effect due to the gap was evaluated for different scenarios. This amplification function is then combined with the force, obtained with the stochastic methodology for the evaluation of the aerodynamic force in presence of turbulent wind. The new forces accounting for the gap presence in the windbreak barriers, are the input of the multi-body model used for the evaluation of the train stability by computing the CWC, it means, the critical wind speeds that leads the vehicle to overcome the overturning safety limit threshold. The results for a high-speed train and porous windbreaks with gap of different dimensions have shown a reduction in CWC values.

Keywords: Train aerodynamics, crosswind, CWC, CFD.

1 Introduction

As trains are inherently exposed to wind, and as a measure to reduce the risk of overturning in particularly windy sections of the railway line, windbreaks are commonly used [1]. However, the introduction of barriers is affected by the morphology of the terrain and the presence of interruptions or discontinuities cannot be avoided. The effects on the dynamics of a discontinuity in a windbreak barrier have been studied using experimental tests and numerical methods, showing detrimental effects on train stability [2], [3], [4].

To evaluate the overturning risk for a train running in open air, the standard method is the estimation of characteristic wind speed, defined as the limit wind speed causing the vehicle to exceed a characteristic limit for wheel unloading. A set of characteristic wind speeds, evaluated for different train speeds and wind angles, is referred as characteristic wind curve (CWC) [5].

While the methodology for the evaluation of the CWC is well described in the European Standard [5] and TSI [6], no major reference is given in the European standards to analyse the effects of windbreak infrastructure in the stability of rolling stock. Therefore, a methodology is proposed here to evaluate the stability to crosswind when a gap is present in windbreak barriers.

The innovative numerical-experimental procedure has been developed based on wind tunnel and on-line tests, plus Computational Fluid Dynamics (CFD) and time-dependent multi-body simulations. The data obtained from the experimental tests is used to validate the moving mesh CFD model that is then used to determine the time history of aerodynamic forces and moments, that are introduced into the multi-body model to estimate the CWC for different gap lengths.

2 Methods

In this work a numerical-experimental methodology is developed to evaluate the stability to crosswind of a train running in a line where a gap is present in porous windbreak barriers. The procedure is based on experimental tests (full-scale and wind tunnel) and numerical simulations (CFD and multi-body).

As a first step of the procedure, a CFD model is developed and validated in a two-step process:

1. Validation by comparison of aerodynamic coefficients (forces and moments) with wind tunnel measured coefficients for a still vehicle model, in presence of porous windbreaks with and without gaps of different lengths.
2. Validation by comparing the simulated pressure time history on a barrier (solid) from CFD with moving mesh with data obtained from full-scale test on high-speed railway line in Italy.

A more detailed description of this first part can be found in [7].

Then, the CFD model is used to determine the time history of aerodynamic coefficients of a high-speed train passing through the wind gust generated by the windbreak gap. Diverse gaps dimensions are simulated for evaluating the "amplification function", representing the ratio between the force acting on the vehicle in presence of the gap, and the steady value obtained for the vehicle running behind barriers without the gap, as function of time.

By combining this function with the force, numerically obtained, with the stochastic method for the evaluation of the aerodynamic force in presence of continuous barriers, it is possible to obtain the new input to multi-body simulations for evaluating the critical wind speed that leads the vehicle to overcome the overturning safety limit threshold. The methodology can be summarized in the flow-chart displayed in Figure 1.

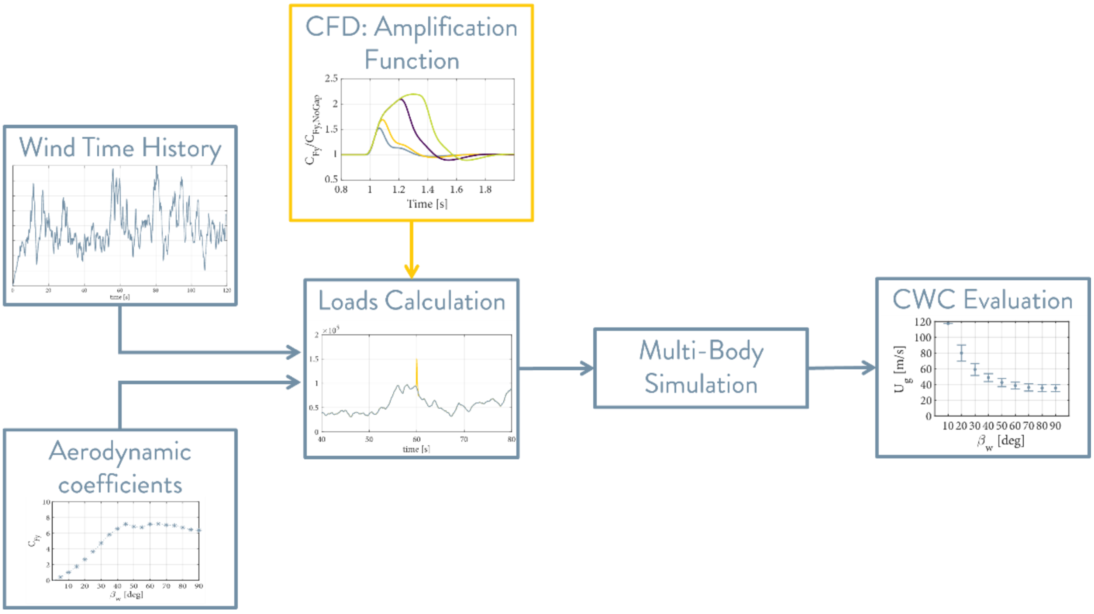

Figure 1: Flow-chart of the procedure for crosswind stability of railway vehicles.

For the evaluation of the CWC, the stochastic methodology developed by POLIMI [8], included in TSI [6], has been applied. Time histories of forces and moments for the continuous stretch of barriers are generated using the aerodynamic coefficients measured in wind tunnel in presence of the barriers and the wind speed profile considering turbulent wind.

Characteristic wind curves were computed with multi-body simulations using the multi-body code A.D.Tre.S developed by the Mechanical Department of Politecnico di Milano. From the results of MBS, the wheel unloading criteria is evaluated and compared to an average limit for wheel unloading of 90% to determine the CWC.

3 Results

Relative wind yaw angles of 10°, 20° and 30° were simulated for the porous windbreak. Train speed was fixed at 300 km/h, wind was set perpendicular to train, while wind speed was varied to obtain the correct yaw angle.

In Figure 2, the results for a gap 30 m long are shown. The increment in yaw angle generates an increment in the complete time history of lateral force, roll moment and lift. As can be observed, increasing wind yaw angle, forces acting on the train increase both: in the gap section and behind the windbreak.

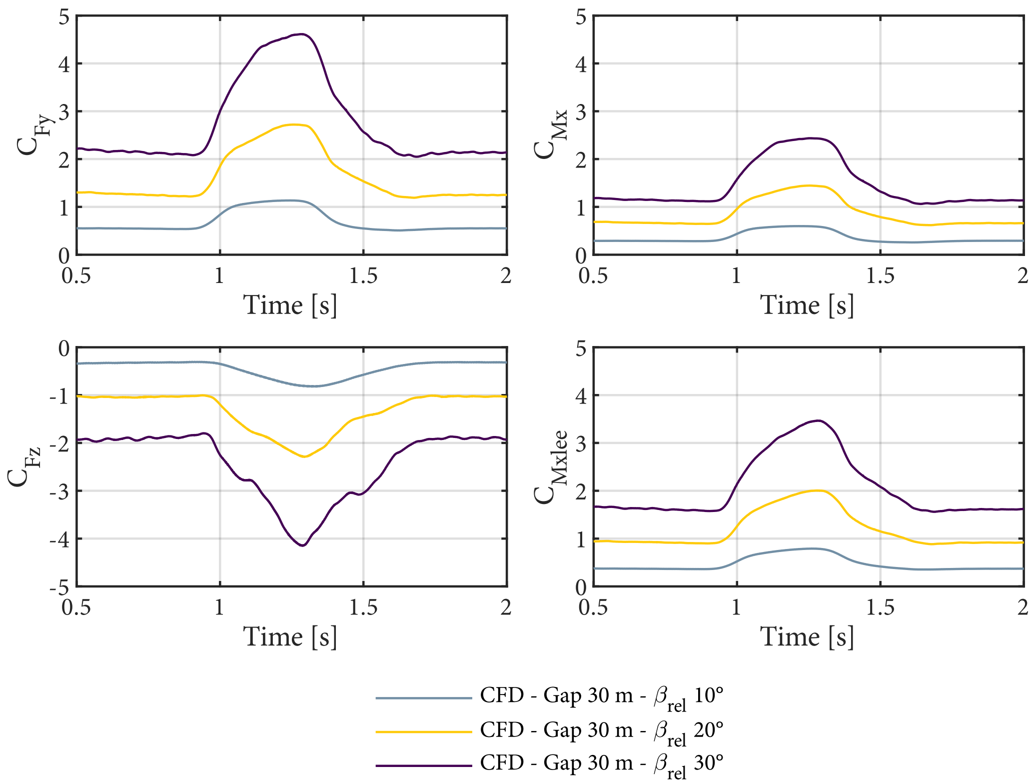

Figure 2: V=300km/h, β_{rel}={10°, 20°, 30°}, Porosity=40%, Gap=30m. Time history of aerodynamic coefficients.

It can be observed that the shape of the time response does not change considerably with the increment in relative yaw angle, but it seems to be scaled up. In fact, the ratio between the actual force and the value before the start of the gap section, that was previously defined as the "amplification function", does not change considerably with relative yaw angle, as can be seen from Figure 3.

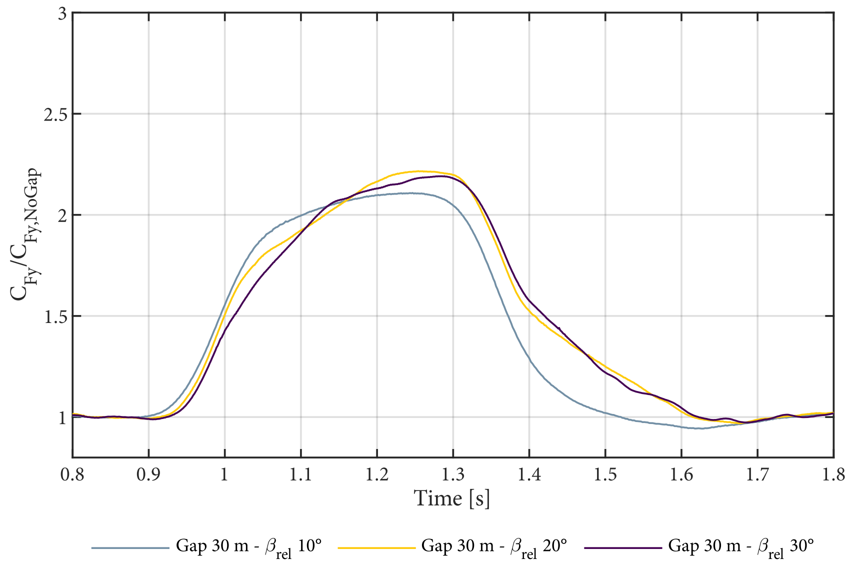

Figure 3: Amplification function of lateral force from numerical simulations. V=300km/h, β_{rel}={10°, 20°, 30°}, Porosity=40%, Gap=30m.

The effect of gap length was studied comparing the time history of coefficients obtained from CFD simulations for gap dimensions of 3, 6, 18 and 30m. Increasing the gap length, the shape of time response changes, as can be seen from Figure 4. Due to the increment of surface area exposed to the wind gust when gap size increases, the peak value reached by force coefficients also increases.

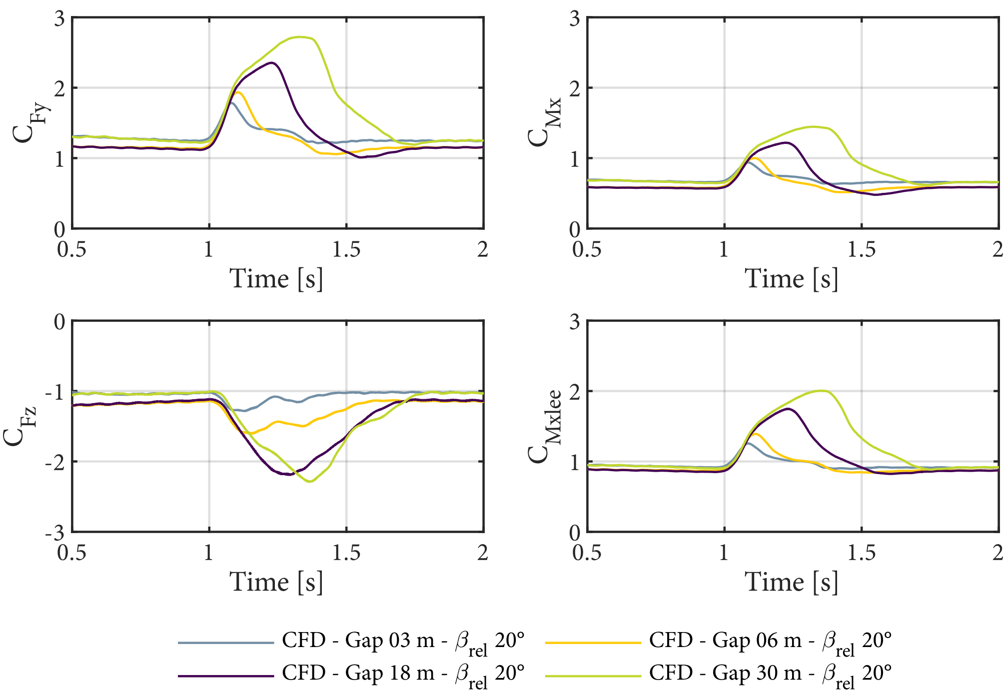

Figure 4: Time history of aerodynamic coefficients. V=300km/h, β_{rel}=10°, Porosity=40%, Gap={3, 6, 18, 30}[m].

The general setup for cases including a gap was the following:

- TSI standard wind characteristics: turbulent intensity=24.5% and integral length scale= 96m.
- V_{train}=300km/h.
- β_w=10°-90°.
- Aerodynamic coefficients from wind tunnel for ETR1000 train on double ballast track and rails with barriers (40% porosity, 2 m height).
- Gaps lengths: 3, 6, 18, 30m.

Finally, the CWC are shown in Figure 5. The CWCs are contained between the two limit cases: continuous windbreak and without windbreaks. Increasing wind angle and gap size, the values of characteristic wind speed obtained are closer to those obtained in the case without windbreaks (open air).

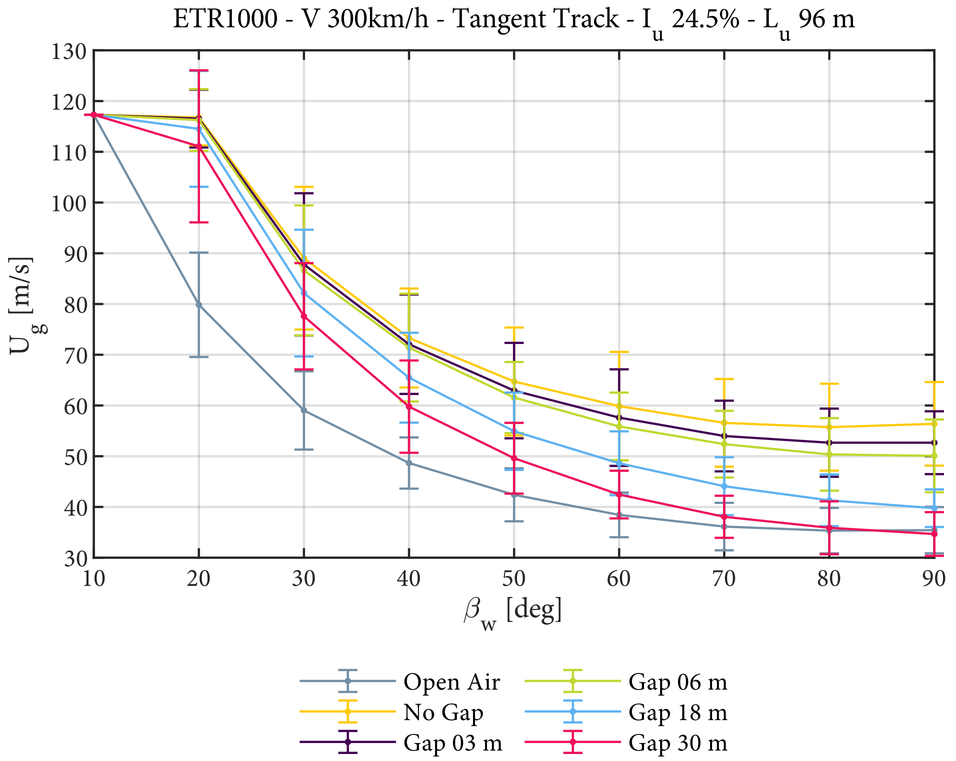

Figure 5: CWC comparison for different cases: open air, continuous barrier, and gaps of diverse lengths. Tangent track, I_u=24.5% and ^xL_u=96m.

4 Conclusions and Contributions

In this work a new methodology based on the stochastic method for estimation of the probability distribution of the characteristic wind speed was developed and applied to evaluate the increment of overturning risk of a high-speed train in presence of a gap in windbreak barriers.

An amplification function can be defined as the ratio between the actual value of the coefficient and the coefficient obtained for a continuous stretch of barrier. This function has been adopted to modify the standard forces to account for the presence of the gap.

In the range of β_{rel} studied, between 10° and 30° which is typical for high-speed trains, the amplification function for lateral force and roll moment seems to depend only on gap length.

The characteristic wind speed curve obtained in presence of a gap are contained between two limit cases: the CWC for the case with a continuous barrier and the CWC for the case without windbreaks (open air).

Increasing the length of the gap, the values of characteristic wind speed approached those of the train in open air. In fact, when the gap is longer than the head vehicle, for example for a gap of 30 m, the two conditions are almost coincident at bigger wind angles, because the complete vehicle get exposed to wind.

References

[1] G. Tomasini, S. Giappino, F. Cheli, P. Schito, Windbreaks for railway lines: Wind tunnel experimental tests. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit. 2016.

[2] D. Wang, D. Chen, M. Li, and G. Liu, "Research on aerodynamic characteristic for emu passing by windbreak wall gap under crosswind," vol. 113, Jan. 2017, pp. 19–26. doi: 10.2991/ifmca-16.2017.3.

[3] Z. Sun, H. Dai, H. Gao, T. Li, C. Song, "Dynamic performance of high-speed train passing windbreak breach under unsteady crosswind", Vehicle System Dynamics, vol. 57, pp. 408–424, May 2018. doi: 10.1080/00423114.2018. 1469777.

[4] Z. Sun, H. Dai, H. Hemida, T. Li, C. Huang, "Safety of high-speed train passing by windbreak breach with different sizes", Vehicle System Dynamics, 2019.

[5] EN14067-6:2018, "Railway applications - aerodynamics, part 6: Requirements and test procedures for cross wind assessment." CEN, Standard, 2018.

[6] European Rail Agency, "Technical specification for interoperability relating to the rolling stock locomotives and passenger rolling stock subsystem of the rail system in the European Union". Standard, 2014/1302/CE.

[7] E. Brambilla, C. Araya, P. Schito, G. Tomasini. Procedure for evaluating crosswind safety of a train running in presence of windbreaks with gap, Part 1: Determination of the Aerodynamic Loads Fourth International Conference in Numerical and Experimental Aerodynamics of Road Vehicles and Trains (Aerovehicles 4). 2021.

[8] F. Cheli, R. Corradi, and G. Tomasini, "Crosswind action on rail vehicles: A methodology for the estimation of the characteristic wind curves," Journal of Wind Engineering and Industrial Aerodynamics, vol. s 104–106, pp. 248–255, May 2012. doi: 10.1016/j.jweia.2012.04.006.