CFD Analysis Of Dutch Rail Network (NS) Trains And Its Improvement Into A Sustainable Design

Pablo Druetta[1], Arno Oosterhof[1]

[1]University of Groningen, Groningen, the Netherlands

Abstract

In today's industry, there exists a rising concern about becoming more environmentally friendly. Large
CO2 emissions have a significant effect on global warming, and together with the problem of the depletion of natural resources, this has directed companies and governments in a greener direction. One of
the sectors with a strong tendency to become more sustainable is transportation. The demand for high-speed travel has surged and has led to the development of large travel networks and the adoption of faster transportation modes. Most effort for the speed-up of transportation methods has been paid to the improvement of the efficiency of the (electrical) motors in these vehicles rather than understanding flow physics around their shapes. This research delves into the aerodynamic performance of NS intercity trains through a comprehensive approach encompassing Computational Fluid Dynamics (CFD) simulations and flow tank experiments. This includes mainly the analysis of the complexity of the fluid dynamics impacting aerodynamic drag on trains. Factors such as aerodynamic drag, lift, cross-winds, vortices, and pressure variations in tunnels are identified as crucial components. The study focuses on two intercity train models from the Nederlandse Spoorwegen (NS): the NS DDZ (Dubbeldekker Zonering) and the NS VIRM (Verlengd InterRegio Materieel), utilizing COMSOL Multiphysics to analyze flow characteristics and identify areas for shape improvement. The trains were initially modelled from scratch in a 3D environment, integrating customized meshing strategies and the k-ε turbulence model to accurately capture flow physics. The average drag coefficients across varying inlet velocities, found from the CFD analysis, for the DDZ and the VIRM trains, are found to be 0.84 and 0.72, respectively. Critical pressure force areas are identified prompting iterative shape adjustments targeting on the frontal and rear, roof configuration and inter-carriage gaps of the intercity trains. Significant drag reductions are achieved for both trains through shape enhancements in the CFD model. For the DDZ, frontal and rear adjustment result in a remarkable 10.2% reduction. In combination with adjustment in the roof configuration, the drag coefficient was even further improved to a reduction of 10.9%. The VIRM sees a 4% reduction from frontal and rear adjustments and a reduction of 3.9% resulting from the roof configuration enhancement. For the VIRM, a combination of these enhancements result in a total drag coefficient reduction of 6.7%. Flow tank experiments serve as a critical validation tool for the CFD simulation results, albeit with minor discrepancies. Furthermore, the experiments provide valuable insights into flow dynamics, particularly in the visualization of the streamlines and confirming the efficacy of the shape adjustments. The economic analysis reveals a significant Return on Investment (ROI) associated with the proposed shape enhancements. The frontal and rear adjustments yield an ROI of 305% for the DDZ and 189% for the VIRM within one year. Break-even points for the drag coefficient reductions are identified, providing insights into the cost implications of the implementation of the enhancements.

Reference

[1] B. Abdessalem, D. Hargreaves et al. CFD simulations of crosswind impinging on a high speed train model. Tech. rep. (2012). URL: https://www.researchgate.net/publication/319059444.
[2} G. Bouladon. Technological forecasting applied to transport. In: Futures 2.1 (1970), pp. 15–23. ISSN: 00163287. Doi: 10.1016/0016-3287(70)90004-2.
[3] N. Brockie and C. Baker. The aerodynamic drag of high speed trains. Tech. rep. (1990).
[4] F. Cheli et al. Aerodynamic behaviour investigation of the new EMUV250 train to cross wind. In: Journal of Wind Engineering and Industrial Aerodynamics 98.4-5 (2010), pp. 189–201. ISSN: 01676105. Doi: 10.1016/j.jweia.2009.10.015.
[5] T. Dong et al. The effect of ground clearance on the aerodynamics of a generic high-speed train. In: Journal of Fluids and Structures 95 (2020). ISSN: 10958622. Doi:10.1016/j.jfluidstructs.2020.102990.
[6] X. Fang and E.J. Stamhuis. Bio-Model Selection, Processing and Results for Bio-Inspired Truck Streamlining. In: Biomimetics 8.2 (2023). ISSN: 23137673. DOI:10.3390/biomimetics8020175.
[7] Z. Guo et al. Numerical simulation of the aerodynamic characteristics of double unit train. In: Engineering Applications of Computational Fluid Mechanics 14.1 (2020), pp. 910–922. ISSN: 1997003X. Doi: 10.1080/19942060.2020.1784798.
[8] H. Hemida and S. Krajnović. LES study of the influence of the nose shape and yaw angles on flow structures around trains. In: Journal of Wind Engineering and Industrial Aerodynamics 98.1 (2010), pp. 34–46. ISSN: 01676105. Doi: 10.1016/j.jweia.2009.08.012.
[9] T. Li, D. Qin, et al. Effect of RANS Turbulence Model on Aerodynamic Behavior of Trains in Crosswind. In: Chinese Journal of Mechanical Engineering (English Edition) 32.1 (2019). ISSN: 21928258. Doi: 10.1186/s10033-019-0402-2.
[10] D. Wang et al. The effect of Reynolds number on the unsteady wake of a high-speed train. In: Journal of Wind Engineering and Industrial Aerodynamics 204 (2020). ISSN: 01676105. DOI: 10.1016/j.jweia.2020.104223.
[11] S. Bao Yao et al. Numerical study on wake characteristics of high-speed trains. In: Acta Mechanica Sinica 29.6 (2013), pp. 811–822. ISSN: 05677718. Doi:10.1007/s10409-013-0077-3.
[12] J. Zhang et al. Impact of ground and wheel boundary conditions on numerical simulation of the high-speed train aerodynamic performance. In: Journal of Fluids and Structures 61 (2016), pp. 249–261. ISSN: 10958622. Doi: 10.1016/j.jfluidstructs.2015.10.006.

Figures used in the abstract

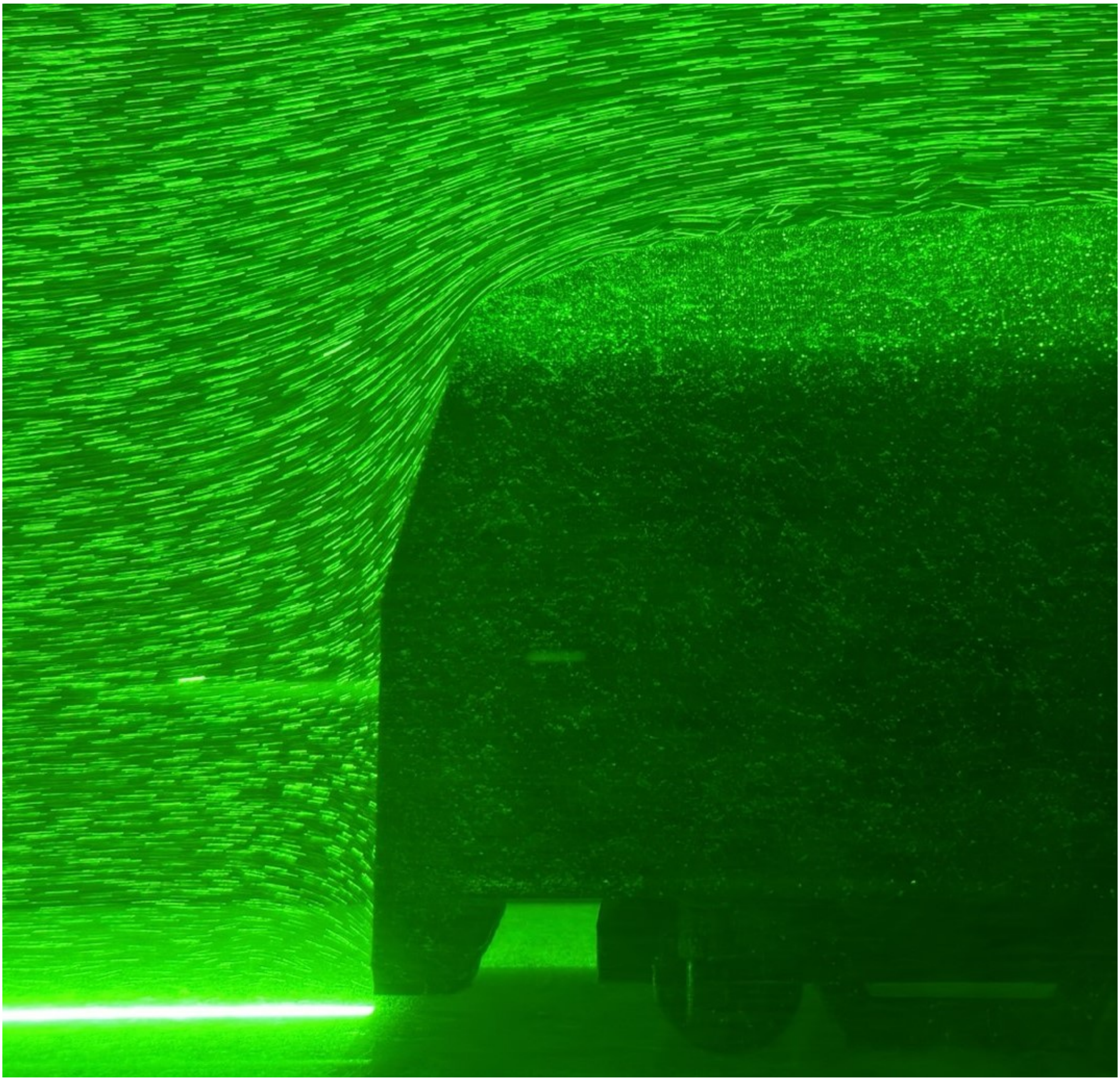

Figure 1 : Water tank experiments

Figure 2 : DDZ meshing domain

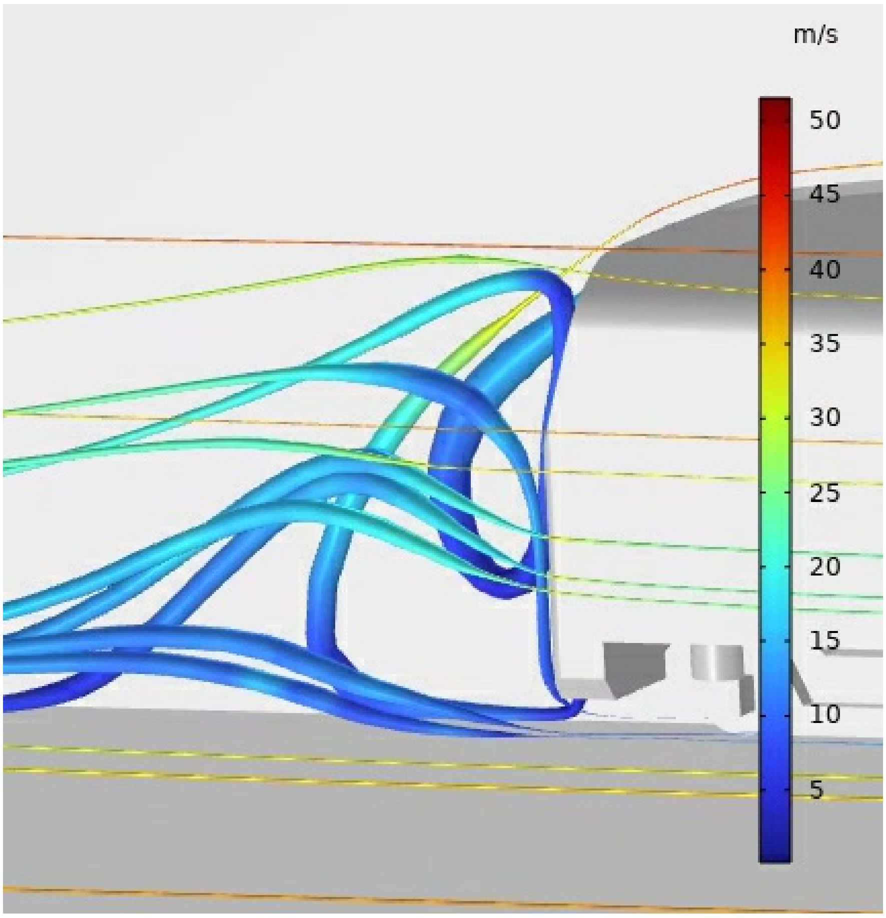

Figure 3 : DDZ velocity streamlines

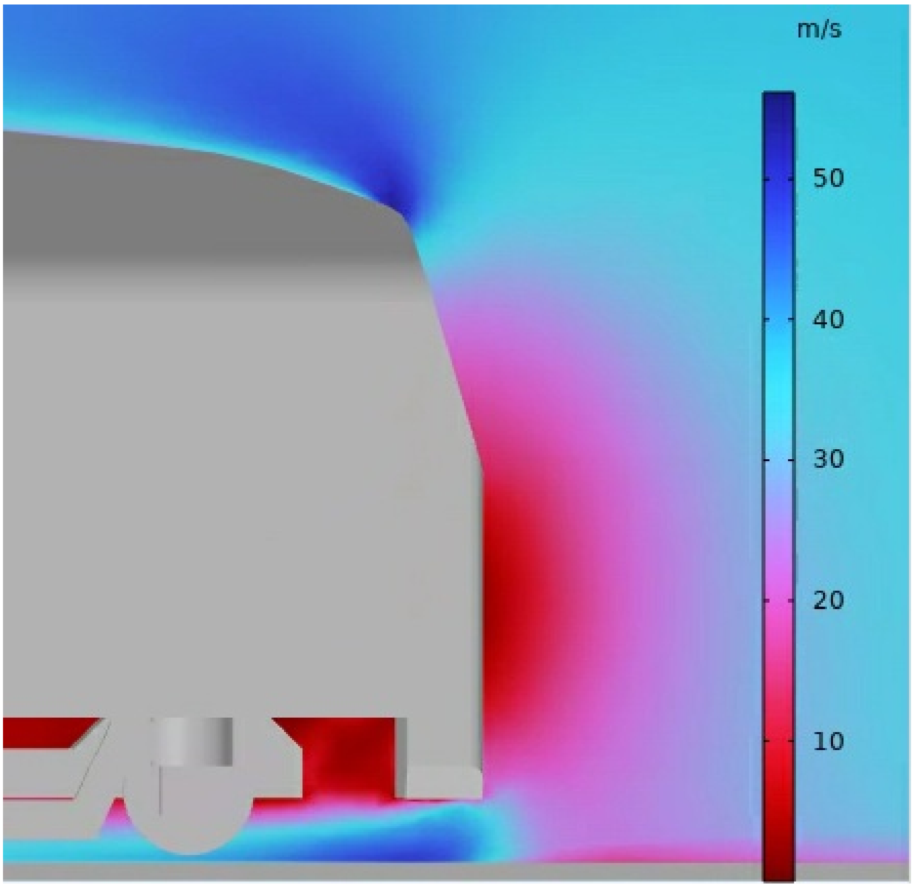

Figure 4 : DDZ front velocity field