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Aerodynamic optimization of a next-generation freight-train wagon

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Abstract

The research presented focuses on reducing the aerodynamic drag of standard freight wagons by optimizing their geometry to improve energy-efficient operation and reduce the overall carbon footprint. Within the scope of this work, a variety of aerodynamic measures for an improved underbody geometry of conventional freight wagons have been investigated in a wind-tunnel experiment to provide a detailed overview of their effectiveness in drag reduction. The experiments were performed at a Reynolds number of 5.0×10^5 in the Crosswind Simulation Facility at DLR Göttingen with an optimized moving-ground condition simulated by a moving belt. The pivoted mounting system of the model enabled crosswind investigations with yaw angles of the model up to 10°, which corresponds to typical crosswind flow conditions during operation. The simplified geometry of a Lgs580 freight wagon was used as a generic baseline model in a scale of 1:10, to which aerodynamic improvements were added and compared. The aerodynamic drag was evaluated in terms of the aerodynamic forces on the full freight wagon model with container, which were measured with a 6-component strain-gauge balance between the mounting sting and the base plate of the freight wagon model. More than 50 different configurations were measured and further combinations are considered for future measurements in view of the benefits of single measures. Five selected measures are presented here based on the feasibility and the significant effect on the aerodynamic drag. The results have shown that simple, feasible measures like covering of roughness in the base frame design provide a significant decrease in the aerodynamic drag by 8-24%. A full fairing on the underbody was identified as the best aerodynamic measure with a decrease of 31%. The full

parametric geometry investigation of the shape and size of aerodynamic fairings and side skirts offers train manufacturers recommendations for optimized wagon design for improvements in energy efficiency of next-generation freight trains.

Keywords: railway aerodynamics, freight-train wagon, aerodynamic drag, underbody geometry, wind-tunnel measurement, crosswind simulation facility.

1 Introduction

In contrast to the extensively studied and subsequently aerodynamically optimized high-speed passenger trains, there exists great scope for aerodynamic optimization of freight trains, particularly the basic wagon geometry, loading configuration and geometry of the superstructures. The increasing density of the railroad network and the optimization of cargo transport management provide a sustainable alternative to road transport. The total cost and emissions of international cargo transport depends strongly on the energy efficiency of the freight train. One major issue is identifying how to decrease the energy consumption by reducing the aerodynamic drag of the train. At current operational speeds of 80-110km/h, with plans of up to 160km/h [1], the aerodynamic drag of freight trains contributes significantly (~40%) to the total driving resistance [2]. The conventional design of freight trains provides great potential for aerodynamic optimization such as optimized loading configurations, filled inter-car gaps and covering loads with fairings [3,4]. Previous studies have shown that single measures in a specific configuration such as side skirts on tank wagons [3] and fairings on the under-body of auto-carrying or passenger wagons [5] lead to a significant decrease in the aerodynamic drag. The research presented focuses on reducing the aerodynamic drag of standard freight wagons by optimizing their geometry to improve energy-efficient operation and reduce the overall carbon footprint.

Within the scope of this work, a variety of aerodynamic measures for an improved underbody geometry of conventional freight wagons have been investigated in a wind-tunnel experiment to provide a detailed overview of their effectiveness in drag reduction. The parametric geometry investigation of the shape and size of aerodynamic fairings and side skirts offers train manufacturers recommendations for optimized wagon design for improvements in energy efficiency of next-generation freight trains. The presentation of all tested measures goes beyond the scope of the short paper. A selection of five different measures are presented here to show the significant effect of simple changes in the underbody geometry on the aerodynamic drag of a freight-train wagon.

2 Methods

The experiments were performed at a Reynolds number of 5.0×10^5 in the Crosswind Simulation Facility (SWG, Figure 1) at DLR Göttingen. The SWG is a closed-circuit wind tunnel with a test-section of 2.4m×1.6m×9m. An optimized moving-ground condition is simulated by a moving belt of 4m length and 1m width suitable for wind-tunnel train models with a high length to width ratio. The flow speed within the test section was set to 30m/s according to the maximum velocity of the moving belt. A newly developed sting was used, which connects the model with the ceiling of the

SWG to provide a model above the moving belt without physical contact. The pivoted mounting system of the sting in the ceiling also enables crosswind investigations with yaw angles of the model up to 10°, which corresponds to typical crosswind flow conditions during operation.

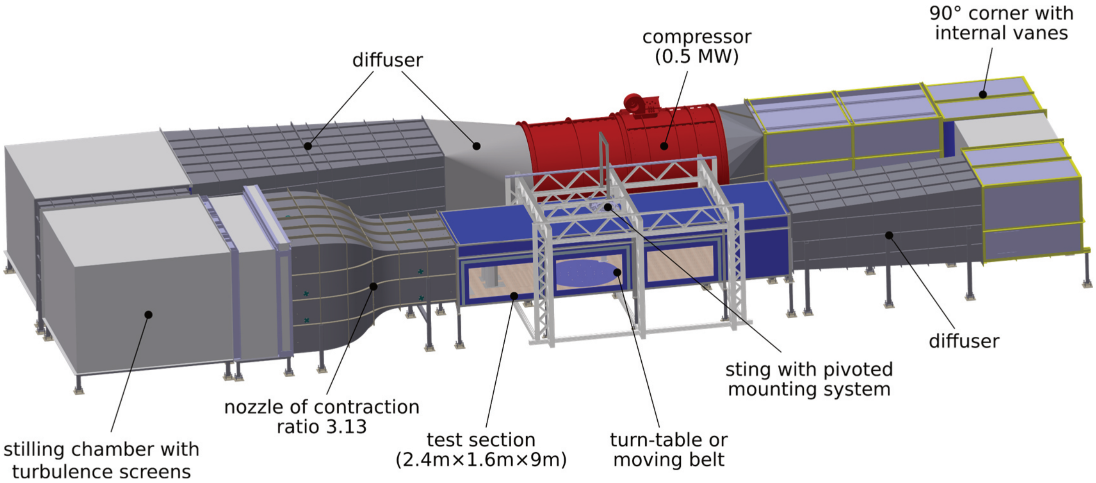

Figure 1: Crosswind Simulation Facility (SWG) at DLR, Göttingen.

The geometry of the freight train was designed for experimental investigations in the SWG with a focus on the aerodynamic measures for drag reduction on a basic freight wagon in a scale of 1:10. The simplified geometry of a Lgs580 freight wagon was used as a generic baseline model, to which aerodynamic improvements were added and compared. Figure 2 shows the freight train model over the moving belt on a sting attached to the ceiling of the SWG. The freight wagon model with a single-stacked container was positioned between a decoupled up- and downstream body to provide similar flow conditions as in full-scale. The aerodynamic measures on the freight wagon were designed in a modular system of components for the front, rear, side and centre sections and for three different heights in the underbody area. The design of the front and rear part differ in the curvature of the frontal edges between circular, ellipsoid and spline. Furthermore, side skirts were used in different shapes and sizes on the side edge of the underbody. More than 50 different configurations were measured and further combinations are considered for future measurements in view of the benefits of single measures. Selected configurations have been tested under crosswind in a yawed model setup with ψ=5° and ψ=10°. The aerodynamic drag was evaluated in terms of the aerodynamic forces on the full freight wagon model with container, which were measured with a 6-component strain-gauge balance between the mounting sting and the base plate of the freight wagon model.

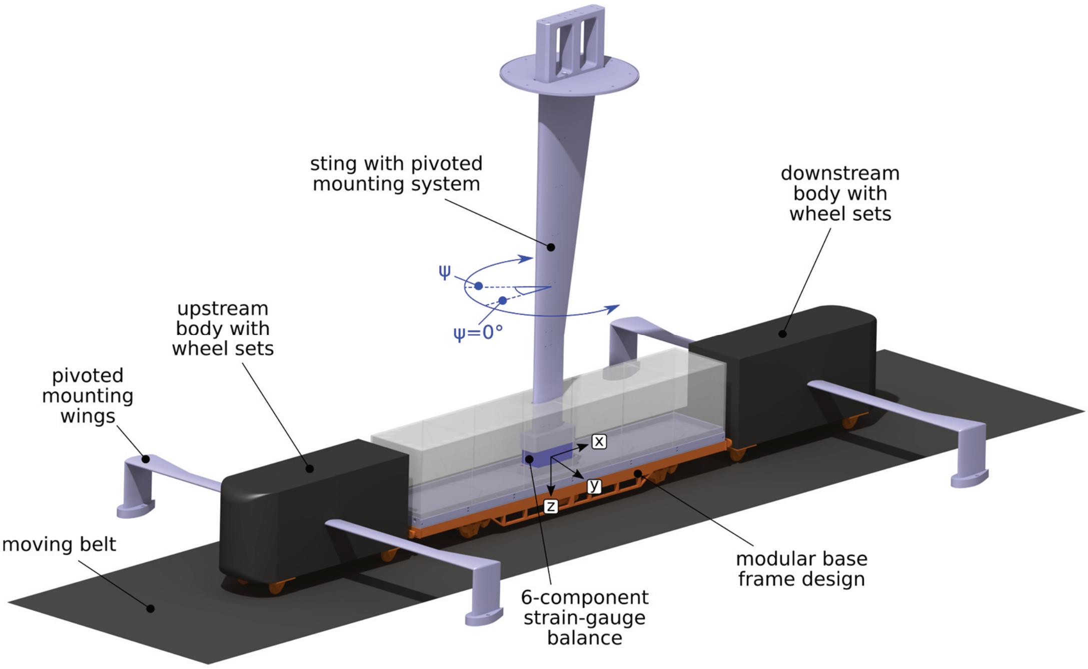

Figure 2: Wind tunnel model of the freight wagon attached to a pivoted sting above a moving belt.

3 Results

The reference configuration REF-0 of the freight wagon model is shown in Figure 3a. It was assumed that the open base framework, buffer plates, skirts, fluid tanks and the wheels sets have a major effect on the aerodynamic drag. The average drag coefficient $c_{w,x}(\psi)$ of the reference configuration is $c_{w,x}(0°)=0.198$ and respectively $c_{w,x}(5°)=0.253$ and $c_{w,x}(10°)=0.316$. To estimate the range for drag optimization, a minimum drag configuration REF-CLN-C without any parts attached to the base frame and with a plate covering the framework was measured. It was assumed that the best aerodynamic measures would be between REF-0 and REF-CLN-C. Five selected measures are presented in Figure 3b-f based on the feasibility and the significant effect on the aerodynamic drag. The results for the difference in the drag coefficient $\Delta c_{w,x}$ for $\psi=0°$, 5° and 10° are summarized in Table 1.

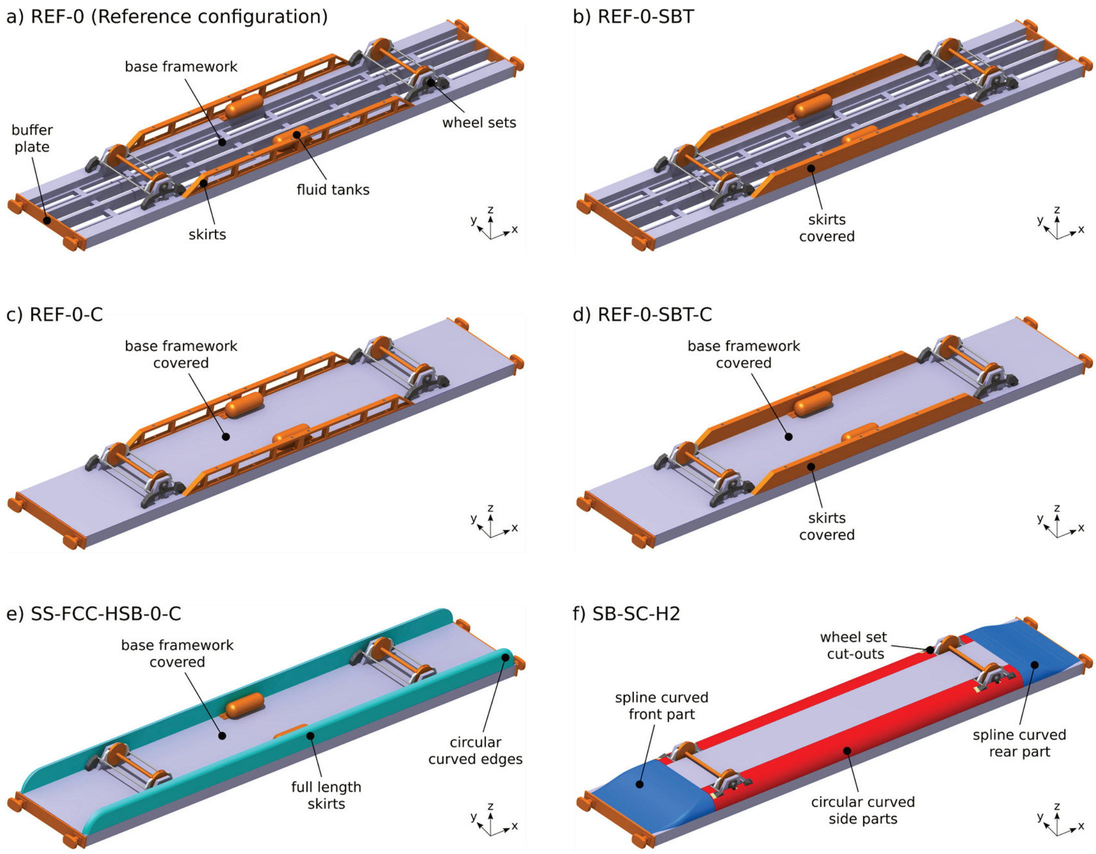

Figure 3: Reference configuration (a) and five selected aerodynamic measures for the base frame design (b-f).

Configuration	$\Delta c_{w,x}(0°)$	[%]	$\Delta c_{w,x}(5°)$	[%]	$\Delta c_{w,x}(10°)$	[%]
REF-CLN-C	-0.115	-58%	-0.182	-72%	-0.216	-68%
REF-0-SBT	-0.015	-8%	-0.040	-16%	-0.056	-18%
REF-0-C	-0.033	-17%	-0.033	-13%	-0.066	-21%
REF-0-SBT-C	-0.048	-24%	-0.067	-26%	-0.118	-37%
SS-FCC-HSB-0-C	-0.038	-19%	-0.042	-17%	-0.076	-24%
SB-SC-H2	-0.062	-31%	-0.089	-35%	-0.129	-41%

Table 1: Effect of different measures on the aerodynamic drag.

Table 1 shows that simple measures like covering the roughness of skirts (REF-0-SBT, Figure 3b) or a cover plate on the base framework (REF-0-C, Figure 3c) lead to a significant decrease of the aerodynamic drag by 8% and respectively 17% in the case of ψ=0°. Both measures were used in the configuration REF-0-SBT-C (Figure 3d) with an approximately cumulative, reducing effect of 24% on the drag coefficient. $\Delta c_{w,x}$ is even higher under 5° and 10° crosswind with a similar trend for the different measures. Further investigations are necessary to explain the increased drag coefficient with a full-length side skirt (SS-FCC-HSB-0-C, Figure 3e) compared to the original length (REF-0-SBT-C, Figure 3d). The configuration SB-SC-H2 (Figure 3f) with a full cover fairing on the underbody framework with spline curved front and rear parts, circular curved side parts and a height of H_2=38.125mm was identified as the best aerodynamic measure with a decrease of $\Delta c_{w,x}$ by 31% for ψ=0° and respectively 35% and 41% for ψ=5° and ψ=10°.

4 Conclusions and Contributions

The experimental capability developed for this research has demonstrated its suitability for performing large scale and high Reynolds number assessment of detailed, realistic geometries. The results of this research provide recommendations for aerodynamic measures that optimize the freight train wagon geometry for reduced aerodynamic drag and improved energy efficiency. The modular design and variety of different aerodynamic configurations provides an overview of potential design optimizations combined with the comparison of the effectiveness depending on the size and shape. The results of five selected configurations presented here have shown that simple, feasible measures like covering of roughness in the base frame design provide a significant decrease in the aerodynamic drag by 8-24%. A full fairing on the underbody was identified as the best aerodynamic measure with a decrease of 31%. Compared to other measures the practicability of full-length fairings depends on the need for accessibility, ventilation or maintenance of covered parts like the fluid tanks or parts of the wheel sets as the braking system. In collaboration with the stakeholders, the outcome of this work provides significant ideas for future freight train designs to strengthen the position in European freight transport.

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