

A New Approach for the Reduction of Aerodynamic Drag of Long-Distance Transportation Vehicles

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ABSTRACT

The optimization of aerodynamic drag represents an important research area for the fuel consumption reduction of heavy duty commercial vehicles. Today's design of tractor-trailers is significantly influenced by legal conditions regarding the vehicle dimensions and the provision of a maximum transportation volume. These boundary conditions lead to brick-shaped trailer outer geometries, especially at the rear ends. That is the reason why the investigations of aerodynamic optimization of commercial vehicle trailers are predominantly restricted to detail measures up to now. The present publication treats the aerodynamic characteristics of general modifications on the outer contour of long-distance haulage trailers in regard of reducing the drag resistance and, thus, potentially also the fuel consumption in highway traffic. A new approach for the realization of a variable outer contour of trailers provides the possibility to adjust the rear end to an aerodynamically optimized shape. The variable adjustment of the sidewalls and the top of the trailer's rear end can take the actual space requirements of the transportation load into account; by this an optimal transportation efficiency is guaranteed. The research work is based on a generic, virtual 3D-CAD semi-trailer truck, which displays the characteristics of commercial vehicles and serves as a basis for several modifications. All geometrical modifications at the virtual reference vehicle are investigated and assessed by 3D-computational fluid dynamics simulations. The achieved reduction of drag leads to a decrease of fuel consumption, which encloses both, optimized operating costs for carriers as well as reduced CO₂ emissions which support the intentions of environmentally friendly road transport.

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INTRODUCTION

Road transportation is a main pollution emitter of carbon dioxide. About one third of the CO₂ emissions from road traffic is caused by commercial vehicles, especially from the widely-used semi-trailer truck class. This type of vehicle combination is currently predominant in long-distance transportation on road. Reducing the fuel consumption of such commercial vehicles would contribute to a decrease of exhaust emissions from road traffic. Due to the harsh economic competition between the carriers, it's a requirement to transport goods as cost efficiently as possible. Transport efficiency is, thus, top priority for commercial vehicles in order to survive in the carrier business. Depending on the economic region, between a third (U.S.) and up to a half (Europe) of the entire annual operation costs of long-distance haulage semi-trailer trucks are caused by fuel expenditures. This leads to conclude, that a reduction of fuel consumption

could be one factor to improve the transport efficiency, [1, 10, 12].

An important contribution to increase the transport efficiency can be accomplished by improvements of the aerodynamic characteristics of vehicle combinations. Today's design of long-distance trailers is significantly influenced by legal conditions regarding the overall vehicle dimensions. These constraints in combination with the requirements of high transport volumes lead to brick-shaped vehicle bodies which cause high aerodynamic drags. As an example, a 40 tons semitrailer truck needs 40 percent of the provided driving performance for the aerodynamic resistance at a constant speed of about 50 miles per hour on a horizontal highway (Figure 1). Due to the limitation of trailer dimensions on account of legal regulations, the investigations of aerodynamic optimization for commercial vehicles have been restricted to detail measures [1, 2, 3].

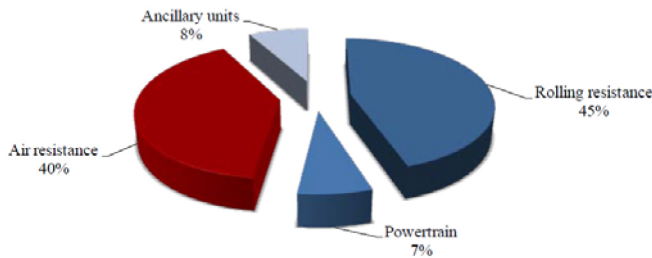


Figure 1. Resistance distribution of a 40 tons semi-trailer truck at about 50 miles per hour [2]

AERODYNAMICS SIMULATION OF DIFFERENT TRAILER REAR END SHAPES

The aerodynamic studies of the present research work were based on generic virtual semi-trailer truck models according to the European legislation. Because the investigations focused on the rear end of the trailers, the findings are applicable to the aerodynamic characteristics of trailers in different markets, e.g. the United States. The first step of the research work entailed the derivation of a generic virtual reference vehicle, which had been created as 3D-CAD model. Therefore, several cab-over-engine semi-trailer tractors for long-distance haulage of six different European truck manufacturers were evaluated and compared. From this investigation the configuration and the dimensions for an average tractor were determined. The same procedure had been performed to collect information of typical semi-trailers with curtainsider configuration for long-distance transport.

Aerodynamic Investigations

The aerodynamic semi-trailer truck optimization was carried out according to the following investigation procedure, see [Figure 2](#). This investigation process was split up in two main parts, a coarse geometrical concept study by use of a simplified vehicle model and a detailed study based on a high-resolution reference truck model.

The coarse concept study was based on a simplified reference model, which was designed in shape of a single-volume model. During this study, principal geometrical modifications were performed at the outer contour of the semi-trailer. Following that, the air drag of each simplified model variant was assessed by application of 3D-CFD simulations by use of a commercial software [4]. In the next step, two characteristic model variants with specific aspects were selected out of the coarse study. The subsequent detailed study was based on the detailed reference truck model. The geometries of the two selected simplified models were used as drafts to design two detailed truck models in a high resolution, which were influenced by the outer shape of the two selected single-volume-models. After finishing the design phase, the aerodynamic drag coefficient in driving direction C_D of the detailed reference truck and the two

detailed optimized trucks were evaluated by detailed Reynolds Averaged Navier-Stokes 3D-CFD simulations. Finally the results of the optimized truck models were compared and assessed in relation to the characteristics of the generic reference truck model.

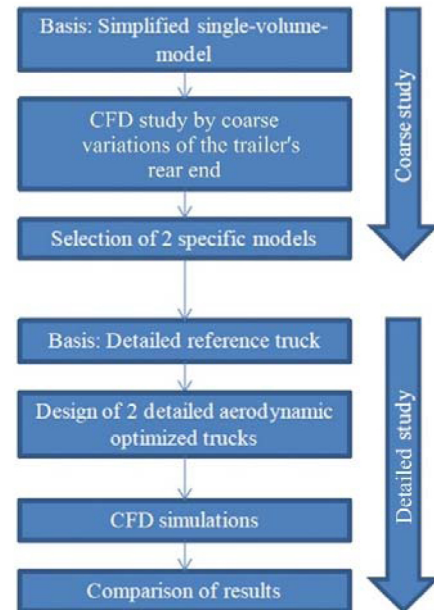


Figure 2. Investigation process

3D-CFD simulation

The CAD-models of the vehicle configurations were imported to the CFD environment using faceted geometry representation (STL). This low qualitative surface geometry was re-meshed to achieve a high quality, triangulated mesh as adequate input for subsequently performed volume meshing. A trimmed cell meshing software was used for volume meshing, which initially was based upon hexahedral cells and successively cuts edges to polyhedral cells near the geometrical boundaries. One important aspect of the present research work focused on the elaboration of an efficient simulation mesh as a pre-condition for short computation cycles. In particular, the goal of using a minimum number of volume cells was reached in an iterative way. Starting from a highly resolving mesh, the amount of cells was reduced since the number of mesh elements did not influence the simulation results within predefined boundaries. The boundary surface sizes of the volume mesh is shown in [Table 1](#).

To define the surface size of geometrical boundaries, local mesh refinements were applied ([Figure 3](#)), which allowed a significant reduction of the number of volume cells. Due to the comparatively small impact of the cooling flow on the air drag, especially considering principal, comparative investigations of the present contribution, the initial analyses of the research work were performed using closed grill geometry. The application of wall treatment functions near walls allowed the definition of a coarse mesh to compute the