

Evaluation and Optimization of Aerodynamic and Aero-Acoustic Performance of a Heavy Truck using Digital Simulation

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ABSTRACT

The engineering process in the development of commercial vehicles is facing more and more stringent emission regulations while at the same time the market demands for better performance but with lower fuel consumption. The optimization of aerodynamic performance for reduced drag is a key element for achieving related performance targets. Closely related to aerodynamics are wind noise and cabin soiling and both of them are becoming more and more important as a quality criterion in many markets.

This paper describes the aerodynamic and aero-acoustic performance evaluation of a Dongfeng heavy truck using digital simulation based on a LBM approach. It includes a study for improving drag within the design of a facelift of the truck. A soiling analysis is performed for each aerodynamic result by calculating the accumulation of particles emitted from the wheels on the cabin.

One of the challenges in the development process of trucks is that different cabin types have to be designed. The aerodynamic performance study considers a high roof and a low roof version of the truck. For the high roof version, the existing model is compared to the initial facelift version. Design recommendations for guide vanes, sun visor, mirrors and roof fairing are derived from the flow analysis. The design changes are then applied by morphing the simulation

model and tested by simulating the modified geometry in a very short design cycle. While drag is improved by 7.4% the detailed analysis shows that not all changes are really effective and that in particular soiling is affected in an adverse way. For the low roof version of the truck the effectiveness of a roof fairing is evaluated by comparing to the low roof model without roof fairing and to the best high roof model.

The aero-acoustic evaluation considers two areas of interest. The first one is typical greenhouse wind noise where wall pressure fluctuations (WPF) on the glass panels are main contributors to the interior noise. Problem areas are identified through surface dB maps and design recommendations are derived from a detailed analysis of the flow structures. The second area considers problems that are related to appendages like a sun visor or the roof fairing. Such problems have occasionally been observed on trucks and a methodology to address such issues in the development process is shown.

INTRODUCTION

MOTIVATION AND BACKGROUND

Aerodynamic drag has become a key performance attribute of heavy trucks over the past years. Reduction of aerodynamic drag is directly translating into reduction of fuel consumption and thus operating cost of a truck [1]. Due to high fuel prices, fuel efficiency is one of the key drivers in today's commercial

vehicle market. Reducing fuel consumption does also help meeting the more and more stringent emission regulations that are being enforced everywhere in the world. At the same time, customers are demanding more performance and more comfort. Furthermore, a comfort attribute directly related to aerodynamics is wind noise that is transmitted into the interior.

The process for development of heavy trucks at Dongfeng has to account for the above mentioned requirements. State of the art technologies have to be introduced and implemented for the development of new trucks. While aerodynamic wind tunnels belong to the advanced technologies in the truck development, the availability of such facilities is very limited. No facilities are available for aeroacoustic testing. Computer simulation can be an alternative to testing if it can give accurate results for realistic vehicle models and if it can support the development process in a timely manner. The study described in this paper is the first step to introduce simulation for aerodynamics and aeroacoustics evaluation and optimization into the development process.

Exa's PowerFLOW software was selected for this work. PowerFLOW is based on the Lattice Boltzmann Method (LBM) which has been in use for over 15 years in prediction of flow over a wide range of geometries, from simplified representative geometries [2] to fully detailed passenger vehicles [3] and trucks [4]. The LB method is coupled with a turbulence model especially designed to allow for the resolution of the large-scale unsteady flow structures which are important in the accurate prediction of highly separated flows. The capabilities for simulation of wind noise aeroacoustics have been developed and validated over the past years [5], [6], [7], [8]. A brief description of the LB method is given in [9], more detailed descriptions of the LB method and respective approaches for turbulence modeling can be found in [10] - [15].

OUTLINE

The study was carried out for an existing truck which has different cabin versions, namely a low and a high roof cabin.

The high roof cabin is undergoing a facelift and therefore an aerodynamic performance evaluation of the baseline and the facelift together with a detailed analysis and comparison was needed. The analysis included an evaluation of the soiling of the cabin side caused by dirt and water ejected from the wheels. The analysis led to recommendations for improvement of aerodynamic performance and one iteration step was allocated for improving the drag of the facelift. As multiple design changes were combined into this single iteration step, a detailed analysis was done to assess which of the changes were effective.

The drag of the low roof cabin is extremely dependent on the design of the roof fairing if a high trailer is used. Therefore a comparison of aerodynamic performance between a model without roof fairing and a model with a newly designed roof fairing has been carried out. Both results were again complemented by a soiling analysis.

The aeroacoustic analysis considers the low roof model combined with the standard roof fairing. One of the common wind noise problems is caused by turbulent flow structures generating wall pressure fluctuations on the side glass. These wall pressure fluctuations (WPF) are effectively transmitted through the glass to the interior. It's therefore the objective of a standard wind noise analysis to assess the fluctuation levels on the glass, identify the cause for areas of high levels and derive design changes for reducing the fluctuation levels. Such analysis has been applied in a first step.

Another class of problems could be caused by appendages creating coherent flow structures which lead to tonal noise. This can in particular appear on trucks where side mirrors, sun visor or roof fairing could cause such problems. It is therefore a good practice to analyze any result for the possible presence of coherent flow structures. Because Dongfeng had a particular interest in analyzing the roof fairing and the surrounding area for such potential problems, another aeroacoustic simulation focusing on this area was done.

All the above simulations used a fully detailed model of the tractor with open grille and complete underhood geometry. The trailer geometry was however simplified and therefore obtained drag numbers are not fully realistic. The comparison between the different cases is fully valid though. The modular approach for building the simulation geometry helped to keep the effort for preparing the different models low. The chassis is identical for all models and was combined with three different cabins for assembling high roof baseline, high roof facelift and low roof cabin. These cabins are then furnished with different aero devices (roof fairing/deflector, side extenders).

SIMULATION MODEL DETAILS

GEOMETRY

As a first step of the simulation process, a geometric representation of the different truck models has to be developed. For the tractor, all the details including full underhood and underbody geometry are represented while the trailer is replaced by a simple box and doesn't contain any of the underbody geometry or rear wheels. The tractor chassis as well as the trailer of all models are identical and this geometry as shown in [Figure 1](#) is thus built only once and shared between the models.

The two high roof models shown in [Figure 2](#) are very similar because only minor changes have been made for deriving the facelift from the original model. In particular, changes have been made to front grilles, corner vanes, sun visor, location of the horns and to the shape of roof deflector and side extenders. The latter have been extended in the axial direction with the intent to better guide the air over the tractor trailer gap and improve aerodynamic performance.

[Figure 3](#) shows that the most drastic difference can be found between the two low roof models. One of them doesn't have any typical aerodynamic devices like roof fairing or side extenders while the modified version is equipped with such aerodynamic devices giving a significant visual impact. The third low roof model shown in [Figure 4](#) has a more standard roof fairing and no side extenders. This model has been used for aeroacoustic analysis only and no comparisons to the other two models regarding aerodynamics are made.

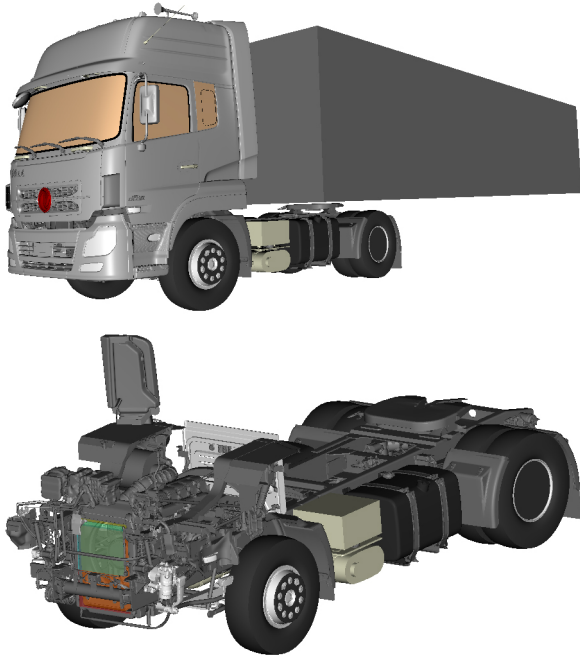


Figure 1. Complete truck geometry with simplified trailer (top) and common chassis geometry (bottom).

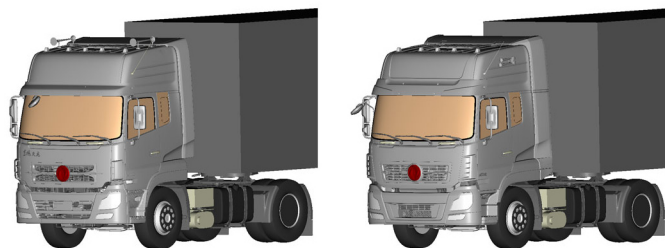


Figure 2. Geometry of high roof baseline (left) and facelift (right) cabin.

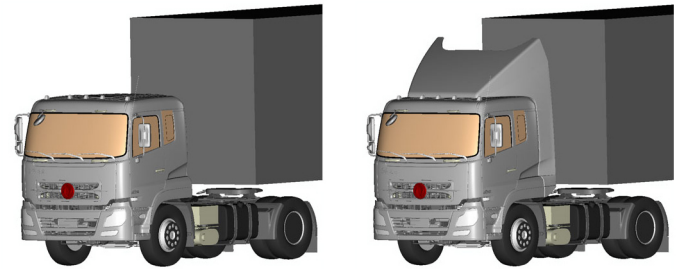


Figure 3. Geometry of low roof cabin without and with roof fairing.



Figure 4. Geometry of low roof cabin with standard roof fairing.

SETUP AND BOUNDARY CONDITIONS

The geometry of the different truck models are placed in the low blockage digital wind tunnel of PowerFLOW where the wind speed is specified as inlet boundary condition. For the aerodynamic simulations a moving floor in combination with rotating wheels are used to account for a realistic on-road driving condition. For the aeroacoustic case the wind tunnel floor and the truck wheels are set to static condition. [Table 1](#) gives a brief summary of important setup parameters.

The heat exchangers present in the underhood are modeled as porous media using a Darcy law and the coefficients are derived from test bench measurements of the cooling air side pressure loss provided by the supplier of the heat exchangers.

Table 1. Summary of setup parameters.

	Aerodynamics	Aeroacoustics
Wind speed	100 km/h	100 km/h
Yaw angle	0°	0°
Floor condition	Slip wall	Standard wall
Wheel condition	Rotating wall	Standard wall
Finest cell	2.5 mm	1.5 mm

AERODYNAMIC RESULTS

PERFORMANCE EVALUATION

The calculated aerodynamic drag of all 4 models is normalized by the drag of the high roof original model and the results are listed in Table 2. The drag of the two high roof models is almost identical with the performance of the facelift being slightly worse. As to be expected the drag of the low roof model without roof fairing is by far the worst. Taking the model with the highest drag as a reference, the fuel consumption at highway speed of the two high roof models would be lower by ~16% according to [1]. The addition of the aerodynamic devices gives a significant improvement and at a first glance it seems surprising that the drag is in fact even below the tow high roof models. The detailed flow analysis given in the following sub-sections will show that this is very feasible though. The improvement would result in a reduction of fuel consumption of ~21% at highway speed.

Table 2. Summary of aerodynamic drag for the 4 baseline models. Normalized numbers are given.

Model	Version	Normalized Drag
High Roof	Original	1.00
	Facelift	1.01
Low Roof	Without Roof Fairing	1.49
	With Roof Fairing	0.86

Detailed Analysis of High Roof Models

The comparison of the drag forces has already shown very little difference between the original and facelift version of the high roof model. This is confirmed by looking at detailed flow structures. As an example it can be seen from velocity field and streamlines in the center plane slice shown in Figure 5 that the overall flow field is very similar. Both models do in particular show a stagnation of the flow underneath the top corner of the trailer front face. This results in a significant amount of flow from the top into the tractor trailer gap. This does already indicate that the extension of roof deflector and side extender does not have the expected effect.

This observation is further confirmed by the surface pressure distributions in Figure 6. They do also show similar patterns for high pressure areas on the cabin front and again on the front face of the trailer in particular. From the surface

velocity distribution in Figure 7 it can be seen that there are some subtle differences in flow structures in some local areas. The surface streamlines indicate some separation of the flow over the sun visor of the facelift model. The separation is not present for the original model though the velocity magnitude is very low in this case as well.

A more pronounced difference can be observed for the flow past the corner vanes which doesn't stay fully attached for the facelift model indicated by less acceleration and a very low flow velocity at the trailing edge of the vane. This is shown in more detail in Figure 8. As a result, the area of attached flow along the door surface is smaller with the magnitude of surface velocity being lower compared to the original model.

As the main intent of the corner vanes is to prevent soiling of the door and in particular door handle from the wheels by creating an area with attached high momentum flow over the cabin side, a soiling calculation is included in this analysis. Figure 9 shows that the reduction in attached flow does not result in a worse soiling behavior. The facelift model does in fact show less accumulation of particles around the door handle and the upper areas of the door. It should be noted that the attached flow has an upward directed velocity. It does thus seem that the stronger attached flow does actually carry more particles to the upper areas of the door. In addition to generating attached flow, a second target for designing the corner vanes should be to generate at least a horizontal flow direction or better yet a downward pointing direction. Such a flow pattern can be expected to be much more effective in preventing the soiling of the cabin door.

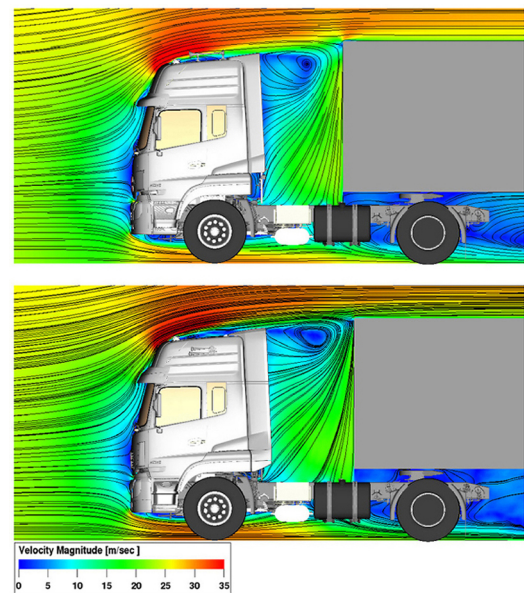


Figure 5. Velocity magnitude with streamlines in the center plane slice for high roof original (top) and facelift (bottom) cabin.