

Aerodynamic Investigation of Gap Treatment- and Chassis Skirts Strategies for a Novel Long-Haul Vehicle Combination

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ABSTRACT

Constantly lowering emissions legislation and the fact that fuel prices have increased tremendously over recent years, have forced vehicle manufacturers to develop more and more energy-efficient vehicles. The aerodynamic drag is responsible for a substantial part of the total driving resistance for a vehicle, especially at higher velocities; thus it is important to reduce this factor as much as possible for vehicles commonly operating in these conditions. In an attempt to improve transport efficiency, longer vehicle combinations are becoming more common. By replacing some of the shorter vehicle combinations with longer combinations, the same amount of cargo can be transported with fewer vehicles; hence there is large potential for fuel savings. The knowledge of the aerodynamic properties of such vehicles is somewhat limited, and therefore interesting to study.

This paper deals with the aerodynamic properties of a novel vehicle combination, which has a total length of almost 32m, and consists of a tractor unit in combination with two semi-trailers, supported by a dolly in-between the trailers. This vehicle combination was evaluated in terms of aerodynamic properties, by the use of numerical simulations in the form of Computational Fluid Dynamics [CFD]. Both the gap between the cargo-units and the irregular chassis of the trailers are known areas of substantial energy losses; it has also been shown in previous studies that a lot of the drag reduction that is created in the cab region is lost downstream. Hence it was of interest to investigate possibilities for improving these two areas. Two approaches to improve the flow in the gap region were evaluated: coverage of the gap and elimination of the gap. For the chassis treatment, chassis skirts were added along the entire vehicle combination. Eventually, these two strategies were added to investigate their combined effect. In addition, a more practical solution of the gap treatment was tested; a so-called gap-fairing system, which was applied to both semi-trailer units.

The results from the simulations showed that there is great potential for the two drag-reducing strategies used. The combined gap treatment and chassis skirts were especially successful; the total drag coefficient was reduced significantly. It was seen that the chassis skirts were far more efficient compared to gap treatment; as a consequence of blocking the main part of the airflow at chassis level in yawed-wind conditions. The practical solution with a gap fairing was shown to be efficient, if used for both semi-trailer units.

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INTRODUCTION

The strive towards more and more energy-efficient vehicles is gaining more importance, due to the fact that both fuel prices have increased and at the same time the permissible emission levels have decreased. Vehicle

manufacturers today therefore, focus much of their attention on reducing the fuel consumption and emission levels for their vehicles. The aerodynamic drag is one factor, which, together with other parameters, determines the total driving resistance for a vehicle. At higher vehicle speeds, in the range

of 80km/h and above, the aerodynamic drag is the dominant resistance. This is due to the aerodynamic drag increasing with the square of the velocity [1].

Aerodynamics of heavy trucks has increased in importance in recent years and a substantial amount of research has been performed to optimize the aerodynamics of trucks [2,3,4,5,6,7]. Focus has been on shorter vehicle combinations, such as tractor-semi-trailer combinations. However, replacing tractor-semi-trailer combinations with longer vehicle combinations would be one way of improving the transport efficiency. In the European Union (EU), a system called the European Modular System [EMS] has been in use since the late 1990's. The EMS is a standardized system for truck-trailer combinations, allowing some countries (e.g. Sweden and Finland) to use vehicle combinations up to 25.25m by using modules building up the vehicle combination [8]. Several studies have shown that fuel consumption and emission levels [8,9], as well as the logistics system [10,11], would benefit from such transport concepts. However, the research on the aerodynamic properties of longer vehicle concepts is still somewhat limited.

There have been previous studies examining the aerodynamics of different truck-trailer combinations and their problem areas have been highlighted. Martini, Bergqvist, Hjelm and Löfdahl [12] found that both the gap between two cargo-units and the bare under-body of the trailers were large sources of energy losses for longer vehicle combinations; especially in yawed-wind conditions. It was seen that the vehicle combinations with a larger gap between two cargo-units showed larger drag values.

In another investigation carried out by Martini, Bergqvist, Hjelm and Löfdahl [13] the efficiency of two common drag-reducing devices; the roof deflector and cab side-extendors; were investigated for different vehicle combinations. It was found that, even though the devices reduced drag significantly for all vehicle combinations, a large portion of the drag reduction was lost downstream. The reason for this behaviour was mainly that the trailers were not aerodynamically considered and hence disturbed the flow to a larger extent when having an improved flow-field upstream.

A study carried out by Hjelm and Bergqvist [14] states that the truck operation can differ significantly and it is possible to distinguish between two distinct modes. The first operation mode is when driving slowly or standing still, for example when loading or unloading, driving on and off ferries, etc. For this driving condition it is important to ensure sufficient ground clearance, and also to be able to manoeuvre the vehicle in confined places. The second operation mode can be seen as high-speed driving, typically highway driving. In these conditions only a small amount of manoeuvrability is needed and at the same time less ground-clearance is required. In order to take advantage of this driving condition one could use altering designs of the entire vehicle combination; for example via adjustable gap-size between the cargo-units. An adjustable gap between the cargo-units could

be a satisfactory solution if it is not possible to make a permanent solution by covering the gap.

Chassis skirts for trailers have been investigated previously, but most focus has been on conventional tractor-trailer combinations. Landman, Wood, Seay and Bledsoe [15] performed a comprehensive study of the practical limits of heavy truck drag-reduction, where different approaches of reducing drag for the entire vehicle were investigated. Different types of chassis skirts were evaluated, with different levels of practicability, and the results for wind-averaged conditions showed that ideally, chassis skirts might reduce drag by up to 20%.

Schoon and Pan [16] performed a study where several drag-reducing devices were investigated for a tractor-semi-trailer combination. For example, different types of chassis skirts were evaluated. The results from the study showed that straight skirts along the trailer reduced drag by 8-11%. A similar study by Schoon [17], where fuel consumption tests were performed, showed that a trailer with side skirts along the entire trailer unit (except for the wheels) together with a boat-tailing device, showed a reduction of up to 11.5% in fuel consumption for highway conditions.

As mentioned previously, the gap between two cargo-units is a known source of aerodynamic resistance for a truck-trailer combination. Though, to design the technical solution that entirely closes the gap between the cargo-units is not an easy task, and hence other solutions may be more suitable. Among them is the so-called gap fairing, which is a device that is mounted on the front face of the cargo-unit. The purpose of the device is to obtain a better re-attachment of the flow on the top and side surfaces of the cargo-unit, and to prevent the areas of high pressure on the top and side edges of the front face of the cargo-unit. The use of a gap fairing was investigated by Hakansson and Lenngren [18], and it was found that this kind of fairing could reduce the drag coefficient by 0.02 in 5° yaw and by 0.015 in a wind-weighted condition for a tractor-semi-trailer combination. Similar devices have also been evaluated by Schoon and Pan [16] who found that a 2-3% drag reduction could be obtained with a trailer fore-body device.

The aim of this study was to investigate the possibilities for drag reductions by improving the flow at chassis level for the trailer units, and in the gap between the trailers. Chassis skirts were added to the trailer units and either gap coverage or gap elimination was conducted. Since both the chassis area and the gap are known sources of drag [12], and also that a large portion of the drag reductions that are obtained in the cab region are lost downstream [13]; interest has focused on improving these areas of the vehicle combination. Understanding the flow-field behaviour when performing the design changes was also a part of the aim with this study. Since both gap coverage and gap elimination was evaluated, it was desirable to analyse the difference between these two approaches and to see which method proved most suitable from a drag-reducing perspective.

Also, the aim was to investigate a more practical solution of the gap treatment: a so-called gap fairing system was investigated for both trailer units.

CASE DEFINITIONS

The vehicle combination that was the basis for this investigation was a combination that consisted of a tractor with two semitrailers in tandem, supported by a dolly between the trailers. The total length of the vehicle combination was 31.59m and the Gross Combination Weight [GCW] was 80tonnes. The tractive unit was a Cab Over Engine [COE] type Volvo FH of “Globetrotter” design; equipped with a full aerodynamic package including roof deflector, cab side-extendors and chassis skirts. The gap sizes between the cab and 1st semi-trailer and between the 1st and 2nd semi-trailer was 0.650m and 1.485m, respectively. The reference frontal area of the vehicles, used to calculate the drag coefficients was 10.2m², including the rear-view mirrors.

The reference vehicle combination that was used in the investigations is a novel vehicle combination, included in DUO² project [19]. Its purpose is to improve the transport efficiency by doubling the amount of transported cargo per vehicle, compared to a standard tractor-semi-trailer combination, and hence decrease the number of vehicles on the roads. At time of writing, the DUO² combination was tested on a trial basis between Gothenburg and Malmo in Sweden. The expected result from the study was a considerable reduction in carbon dioxide [CO₂] emissions, calculated per amount of transported goods.

Theoretically Ideal Solutions of Chassis Skirts and Gap Treatment

Since both the gap between two trailer units and the bare, exposed chassis of the trailers are two large sources of the total drag of the vehicle combination, strategies for reducing their impact have been investigated. The different vehicle configurations evaluated in this investigation are presented below: [Figure 1](#) shows Case 1A; the unmodified reference vehicle geometry.



Figure 1. Case 1A: Reference vehicle geometry. Tractor, semi-trailer, dolly and semi-trailer.

The reference vehicle geometry was modified in the gap region between the semi-trailer units and along chassis level. Two different strategies for the gap treatment were investigated: a covered gap and an eliminated gap, where the two semi-trailer units were simply pulled together. [Figure 2](#) shows Case 1B, the configuration with a covered gap between the trailers.



Figure 2. Case 1B: Covered gap between the semi-trailer units.

Case 1C is shown in [Figure 3](#) and was the configuration with chassis skirts along the semi-trailers. The chassis skirts covered a large part of the otherwise bare under-body of the trailers. The chassis skirts for the 1st trailer also covered the already existing chassis skirts for the tractor: to obtain a smooth shape along the sides. Also the wheel housings of the trailers and the rear wheels of the tractor were covered, to eliminate the main part of the turbulent structures originating from the wheels. The ground clearance between the chassis skirts and ground was 220mm, the same clearance as for the regular chassis skirts for the tractor.



Figure 3. Case 1C: Chassis skirts along semi-trailer units.

Case 1D was a combination of Case 1B and 1C, where both gap coverage and chassis skirts were employed on the vehicle combination. See [Figure 4](#).



Figure 4. Case 1D: Covered gap and chassis skirts for semi-trailer units.

Case 1E was a configuration where the gap between the trailer units had been eliminated. See [Figure 5](#). As a consequence of pulling the trailer units together, this vehicle combination was shorter than the reference case. The total length was 30.1m.



Figure 5. Case 1E: Eliminated gap between semi-trailer units.

[Figure 6](#) shows the case with combined eliminated gap and chassis skirts, denoted as Case 1F. As for Case 1E, the total length was reduced to 30.1m.



Figure 6. Case 1F: Eliminated gap and chassis skirts for semi-trailer units.

In the analysis performed for the ideal design changes, adjustments of the geometries were only made for the trailer units and the gap region between the trailers. The cab was left unmodified and also the gap between the cab and the first trailer unit. All modifications here were rather ideal; practical technical solutions for solving the gap coverage or chassis skirts have not been investigated at this stage. The intention was to investigate the potential for aerodynamic reductions by working with the gap and chassis region.

Practical Gap Fairing Device

The coverage, or elimination of the gap between the trailers are ideal solutions of the gap treatment. In order to achieve an understanding of the performance of a more realistic solution of this problem, a so-called gap fairing system was investigated. It is a device that had smooth, rounded edges, which was mounted on the front face of the trailer and its purpose was to reduce the high-pressure area at the edges of the trailer, and instead guide the flow onto the trailer roof and sides and hence improve re-attachment of the flow. The gap fairing also reduced the gap size where it operated. A picture of the gap fairing device mounted on the trailer front face can be seen in [Figure 7](#).

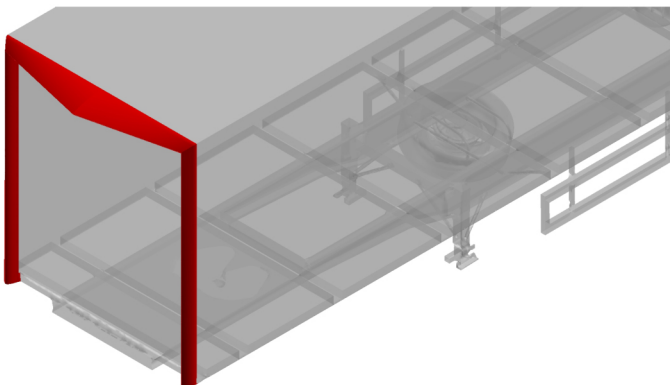


Figure 7. Gap fairing mounted on the trailer front face.

Three additional cases with different combinations of gap fairings were evaluated. These are shown in the following figures. Case 1G was a combination where a gap fairing was added to the 1st semi-trailer unit and the rest of the vehicle combination was left unmodified. See [Figure 8](#), with the gap fairing shown in red.



Figure 8. Case 1G: Gap fairing on the 1st semi-trailer unit.

Case 1H was a combination where a gap fairing was added to both 1st and 2nd semi-trailers, leaving the rest of the vehicle combination unmodified. See [Figure 9](#), the gap fairings shown in red.



Figure 9. Case 1H: Gap fairing on the 1st and 2nd semi-trailer units.

Case 1J was a combination with gap fairing mounted on the 2nd semi-trailer only. Shown in [Figure 10](#), where the gap fairing is marked in red.



Figure 10. Case 1J: Gap fairing on the 2nd semi-trailer unit.

NUMERICAL SET-UP

The method used in this investigation was Computational Fluid Dynamics [CFD]. CAD cleaning and initial surface meshing was performed in the software ANSA by Beta CAE Systems, while the models were wrapped, re-meshed, volume meshed and run in STAR-CCM+ by CD-adapco.

Mesh

Open-road conditions were used for the computational domain, i.e. the wind tunnel domain was very large in order not to affect the simulation results. The extension of the calculation domain was 2.5 times the combination length upstream of the vehicle and 5 times the combination length downstream of the vehicle, in the longitudinal direction. In the lateral direction, the domain was 12 times the vehicle width in total, and in vertical direction 5 times the vehicle height. The longest vehicle combination was used for dimensioning the size of calculation domain, and its extension was based on recommendations from CD-adapco.

The mesh was hexahedral dominant, by using the STAR-CCM+ trimmer model [20]. The resulting number of volume cells was in the range of 75millions throughout the cases. Closest to the vehicle surface, prism layers were created to capture the viscous effects of the flow near the wall. For surfaces where mainly attached flow was predicted, 3 layers