

# FUEL COST REDUCTION BY IMPROVING AERODYNAMICS OF A SEMI TRAILER

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## Abstract

Semi trailer manufacturer H.W. van der Peet & Zn aims for low total cost of ownership for its end users. By improving the aerodynamics of a truck with a semi trailer, the fuel costs are reduced. The aim of this research is how to reduce the aerodynamic drag of the “Kolibri” semi trailer (a belt unloader), without compromising production costs and load capacity, and with the new design still satisfying legal demands.

Using computational fluid dynamics, the aerodynamic drag of the semi trailer has been examined and a new design has been developed with reduced drag. Coast down tests have been carried out to validate the CFD investigation. Rounding of the front end of the semi trailer and tapering of the rear end resulted in the biggest improvement. Side skirts added to drag reduction as well. Fuel consumption tests were carried out, using the final production version of the semi trailer. With an empty vehicle, the fuel consumption was reduced by 6.5%.

**Keywords:** semi trailer aerodynamics, CFD (computational fluid dynamics), coast down tests, fuel consumption reduction

## 1. Introduction

Semi trailer manufacturer H.W. van der Peet & Zn aims for an optimal productivity in terms of fuel costs in relation to loading capacity. One of their vehicles, and subject of this study is the “Kolibri” semi trailer, see figure 1. This trailer is used for carrying potatoes and other bulk goods.



**Figure 1 – The standard Kolibri semi trailer loading (left) and unloading (right)**

Goal of this research was to investigate aerodynamic drag reduction without raising production costs significantly and without compromising load capacity. Legislation also had to be taken into account.

The main motivation for improving the aerodynamics of the Kolibri semi trailer was reducing the running costs in transportation, applying this vehicle.

Nowadays, the reduction in CO<sub>2</sub> emissions and therefore reduction in fuel consumption is important. A reduction of CO<sub>2</sub> emissions can be achieved by reduction of the trailer weight and by aerodynamic improvements. Both steps have been taken. The first improvement, reducing weight, was achieved by using a unibody structure and sandwich panels. The second step is to look for reduction of the aerodynamic resistance, reported in this paper.

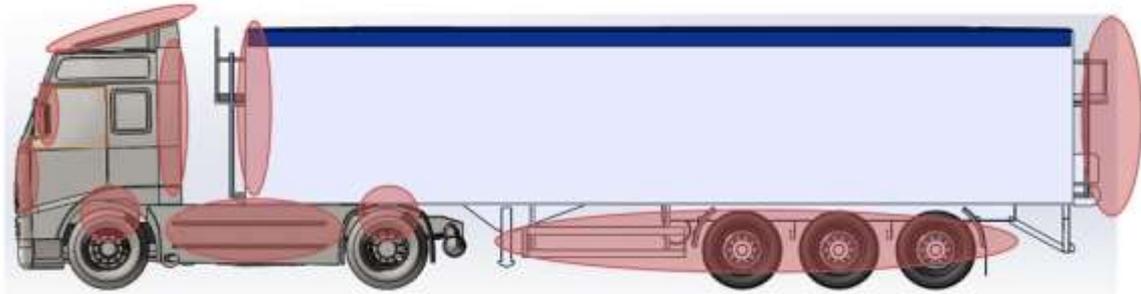
In this paper the research/design method is presented in chapter 2. In chapter 3 the results of the final design are shown. Conclusions are listed in chapter 4.

## 2. Research/Design Method

As a first step in the research, the aerodynamic basics for larger vehicles have been studied as well as existing methods and practices of reducing the aerodynamic drag for semi trailers. For aerodynamic drag reduction it is important that:

- the airflow stays attached to the surface of the cabin and semi trailer
- the wake behind the trailer is as small as possible
- vortices should be kept to a minimum

In figure 2, the major areas are highlighted where aerodynamic improvement of a truck-semi trailer is possible. See also the standard work on aerodynamics by W-H. Hugo (2008) [1], and the treatment of aerodynamics for commercial vehicles by Van Tooren in (2009) [3] (in Dutch).

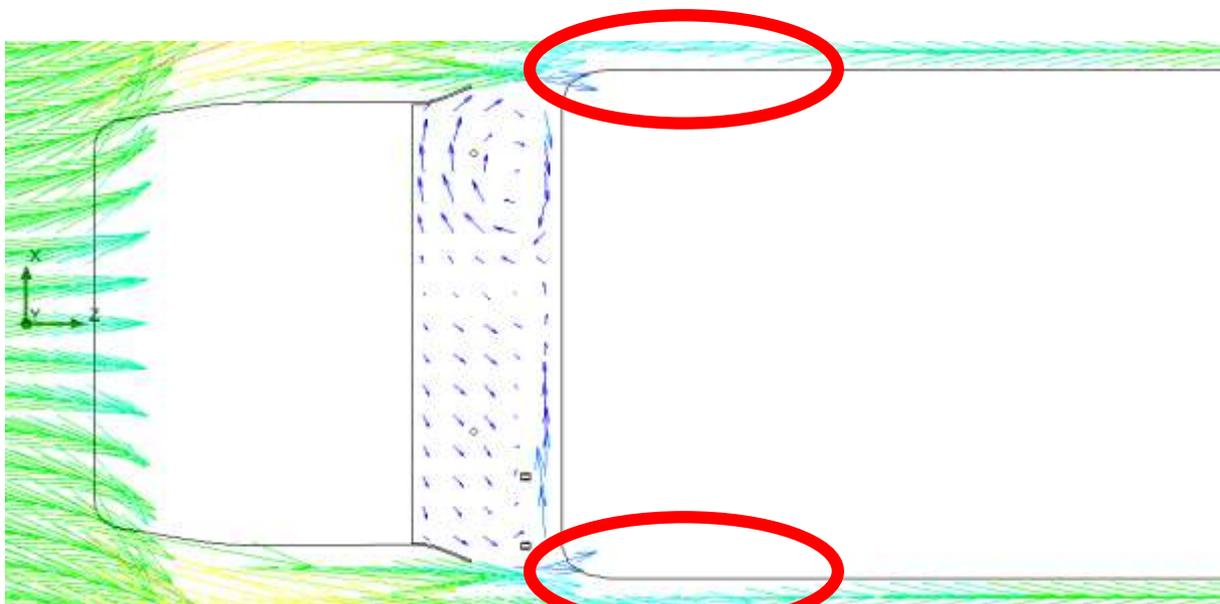


**Figure 2 – Possible areas for improving aerodynamics of a truck with semi trailer**

As a trailer manufacturer, the possible areas of improvement for the Kolibri semitrailer are the front, the rear, and the side skirts of the semi trailer. For the truck itself, only the preferred cabin could be taken into account.

### 2.1 Rounded Front Edges

There is a significant distance between the cabin of a truck and the front of a semi trailer, limiting the aerodynamic design. Because of this distance, there is a risk of flow separation just behind the leading edge of the semi trailer. The air cannot follow the side walls and the air drag is higher. In figure 3 where the flow field of the air around a moving truck is shown, this effect is shown at a top view of the truck. Although the leading edges of the trailer are somewhat rounded, it can be seen that the flow cannot follow the surface (“separation”). There is a “gap” between the arrows and the sidewall of the trailer. This can be seen in the region marked within the red ovals.



**Figure 3 –Top view of the flow field of the air around a moving truck with a semi trailer. Some separation can be seen just behind the leading edges of the semi trailer.**

To overcome the risk of separation at the front edge (leading edge) of the semi trailer, the leading edge should be sufficiently rounded. According to Hugo (2008) [1] a certain minimum radius of the leading edge is needed to avoid flow separation at the leading edge. Using CFD (computational fluid dynamics) a minimum radius for this situation was found. The leading edge was given a certain radius and the drag was calculated. The radius was gradually increased until the calculated drag did not reduce anymore. In Figure 4 a picture of the standard trailer is shown which was equipped with a leading edge radius to test the effect in practice.



**Figure 4 – a rounded leading edge on the test vehicle**

## **2.2 Boat Tail**

Tapering of the rear of a vehicle is called “boat tailing”. The boat tail is used to reduce the size of the wake behind the vehicle. The wake is the low pressure zone behind a vehicle. This low pressure zone “sucks” the vehicle back and thus causes a high air drag. Reducing the size of the wake reduces the air drag. The boat tail can be seen in figure 5.

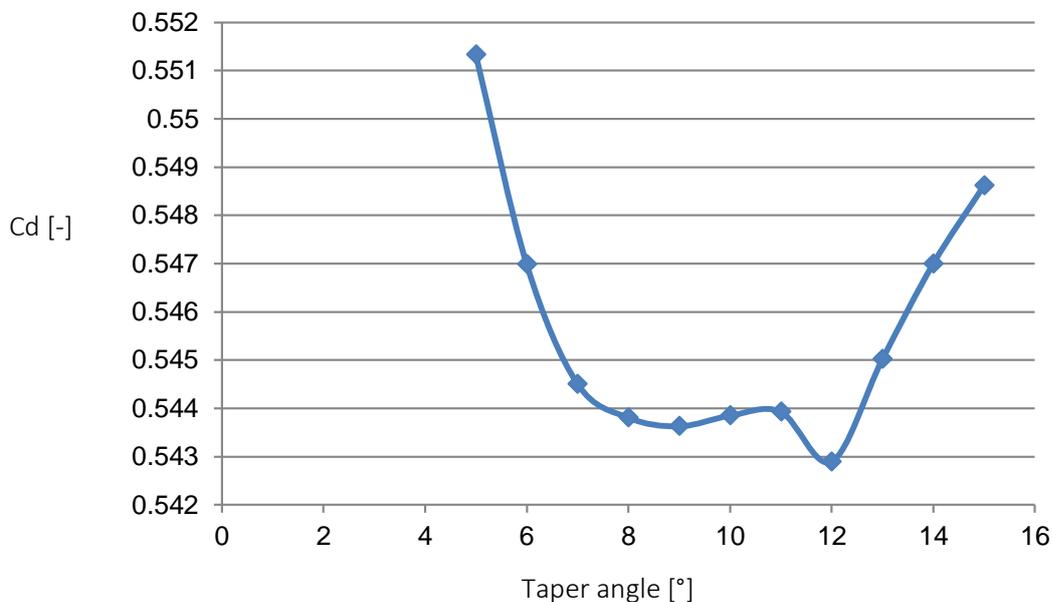


**Figure 5 – Drawing of a streamlined semi trailer, the boat tail can be seen at the rear of the semi trailer**

In rear view, the wake is very roughly the size of the flat rear side of the trailer. The wake can be made smaller by means of:

2. Longer boat tail. When the boat tail is longer using the same taper angle and starting point of the boat tail, the size of the wake reduces. But due to legislation, the length of the trailer is restricted.
3. Starting the boat tail earlier upstream the trailer, but this would result in reduced transport capacity.
4. A steeper taper angle. But if the taper angle of the boat tail is too steep, the air drag increases.

The length of the boat tail have been chosen so that it still gives the wanted transport volume. The angle at the connection between boat tail and trailer had to be determined such that the drag coefficient is minimal. These investigations have been performed using CFD with the results shown in figure 6. Figure 6 shows that 12° results in the lowest drag.



**Figure 6 - Drag coefficient as a function of boat tail taper. Taper is measured of one sidewall with respect to the longitudinal axis of the vehicle.**

### 2.3 Tests with the Converted Existing Semi Trailer

Coast down tests [4] were done with the converted standard trailer to assess the aerodynamic benefit. The tests were carried out on a horizontal flat road with an empty vehicle to be able to see the effects of the aerodynamic more clearly (the rolling resistance is more with a fully laden vehicle. If the absolute number of the aerodynamic improvement is the same, the part of the aerodynamic drag is more in case of an empty vehicle and therefore easier measurable). Due to planning issues the tests were unfortunately carried out on a windy day. Therefore the drag forces cannot be taken as absolute numbers. By measuring the deceleration at 80 km/h and also at 10 km/h for different setups, the rolling resistance and air resistance could be

calculated (table 1). With speeds as low as 10 km/h the air resistance is very small compared to the rolling resistance. Therefore the deceleration at 10 km/h gives an order of magnitude for the rolling resistance. At higher speeds the deceleration is due to rolling resistance and air resistance. When the rolling resistance is derived from the lower speeds, the air resistance can be calculated.

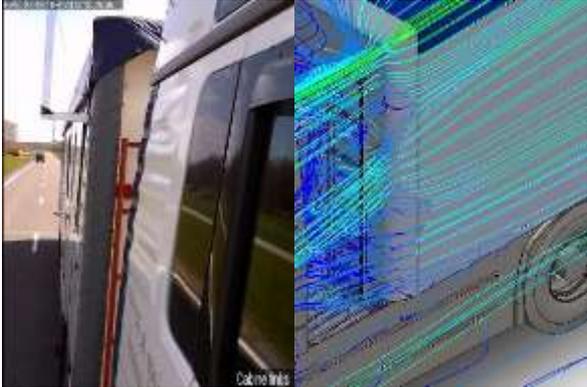
**Table 1 - Drag numbers for the standard trailer with different aerodynamic attachments according to the coast down tests.**

<b>Configuration</b>	<b>Fdrag [kN] measured</b>	<b>Cd [-] measured</b>	<b>Cd [-] calculated CFD</b>
Standard trailer open top	7.6	0.95	0.96
Standard trailer closed top	4.8	0.60	0.69
Standard closed top+boat tail	3.6	0.45	0.67
Standard closed top+boat tail +rounded leading edges	3.5	0.44	0.65

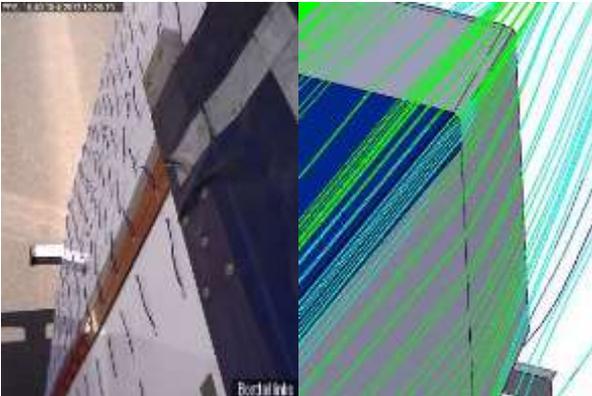
The rounding of the leading edges of the semi trailer did show some effect, but this was in the order of the measurement uncertainty. Apparently the cabin of the truck made the flow to attach on the sidewalls of the semi trailer quite easy, even without the rounding of the leading edges of the semi trailer.

The enormous drag penalty with the top of the semi trailer open was an eye-opener. The rear wall of the semi trailer is thought to cause this high drag. This makes it clear that improving aerodynamics is of little use when the end user drives the unladed semi trailer with the top open.

With a boat tail attached, the drag was clearly reduced with respect to the standard non boat tail trailer. Wool strings, so called tufts, were used to visualize the airflow. Tuft tests showed no separation behind the leading edge (figure 7). Also at the boat tail there were no signs of separation of the airflow (figure 8)



**Figure 7 - Tuft test on the leading edge of the semi trailer and the CFD analysis.**



**Figure 8 - Tuft tests at the boat tail and the CFD analysis.**

The absolute drag numbers of the CFD calculation differ from the measured values. But the trend is clear. Reasons for the difference was not extensively researched. Reasons for the differences could be:

- Mesh size in CFD calculations
- influence of the turning wheels (in the CFD the wheels were not turning)
- different Reynolds number than the CFD analysis due to the strong headwind in the coast down tests (transition laminar to turbulent boundary layer). Of course the different relative wind speeds were taken into account calculating Cd.
- Less details in the CFD model
- Unaccurate wind speed measurement on the test day
- Differences in windspeed during a coast down test

## 2.4 The Production Version

After the promising results of especially the coast down tests, the production version was designed. For the profiles of the leading edge an aluminum extrusion profile was designed. This made it possible to give the profile an ellipsoid curvature which performed better than a circular curvature.

Instead of a separate boat tail, the boat tailing was integrated in the sidewalls and part of the top. Wabco/Ephicas side skirts added extra aerodynamic drag reduction (figure 9).



**Figure 9 – The production version of the aerodynamic semi trailer, the Kolibri Streamer.**

**3.Results**

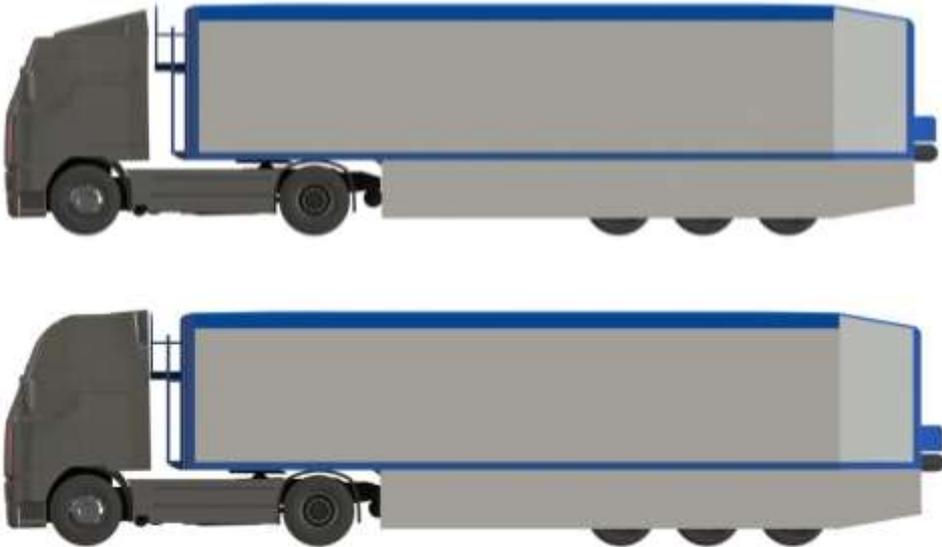
The CFD calculations for the production version were done with a finer mesh size than the rather coarse calculations before. This resulted in different Cd numbers than previous calculation of the standard Kolibri semi trailer.

**3.1 The Reduction of Cd**

The Kolibri Streamer shows an aerodynamic drag reduction of about 10% (table 2). The Drag coefficients below are calculated with a low cabin with a roof spoiler and a space cabin (figure 10).

**Table 2 – coefficient of drag of the Kolibri Streamer compared with the standard Kolibri**

	Cd [-] (CFD results) low cabin with roof spoiler	Cd [-] (CFD results) Space cabin
Kolibri standard	0.51	0.506
Kolibri Streamer	0.47	0.47
Kolibri streamer with sidewings	0.45	0.45



**Figure 10- CFD model of the Kolibri Streamer with two different cabins. A low cabin (top) and a space cabin (below)**

A space cab showed the (almost) the same numbers with the Steamer but with the standard Kolibri a space cab gave a lower coefficient of drag.

**3.2 Calculated Reduction in Fuel Consumption**

The calculated fuel consumption reduction is less than the reduction in air drag because the rolling resistance has to be taken into account. With the assumption that the specific fuel

consumption remains the same (which is theoretically not the case), the calculated reduction of fuel consumption is in the order of 7 to 8% (the last number for the version with side wings) with an unladen vehicle at a constant 90 km/h with a 5 km/h headwind. The reduction with a fully laden vehicle is lower as the rolling resistance is a bigger part in the total resistance. The calculated reduction is in the order of 4 to 5% at 90 km/h with a 5 km/h headwind for a fully laden vehicle.

### **3.3 Breakeven Point**

The Kolibri Streamer is more expensive to produce. Therefore the purchase costs of the Kolibri Streamer are higher than the standard Kolibri semi trailer. The breakeven point depends on the fuel consumption of the truck, fuel prize, driving conditions (average speed) and of course the extra costs of the Streamer. For a Dutch transport firm driving longer distances on the highway (when average speeds are lower, aerodynamic improvements are less effective) the breakeven point is about 300,000 km.

### **3.3 Validation of the Reduction in Fuel Consumption**

Independent tests have been done by Wabco on the RDW (Dutch road authorities) test track. The unladen Kolibri Streamer with side skirts showed a 6.5% lower fuel consumption at 90 km/h than the standard Kolibri.

## **4. Conclusions**

For semi bulk trailers like these (without the need for full width doors in the back side and its cargo capacity limited by weight and not by volume), an improvement in aerodynamic drag can be made without compromising load capacity and hardly compromising production costs. This is done by “boat tailing”, rounding the leading edges and Wabco/Ephicas side skirts. By these relatively simple means, the aerodynamic drag can be reduced for a measurable improvement in fuel consumption and thus CO<sub>2</sub> emissions.

## **References**

- [1]. Wolf-Heinrich Hugo: *Aerodynamik des Automobils*. Fifth edition, Vieweg+Teubner 2008, Wiesbaden.
- [2]. R.H. Barnard: *Road Vehicle aerodynamic Design*. Third edition, MechAero Publishing 2009, St Albans.
- [3]. Van Tooren: *Aerodynamica van vrachtauto's*. TU Delft and CINTEC 2009.
- [4]. Verdaas and Oosting: *Aerodynamische bandlosser*. Graduation report HAN University of Applied Sciences, automotive department, 2013.
- [5]. *H.W. van der Peet & Zn*, information about the Kolibri streamer <http://www.vanderpeet.nl/bedrijfsinformatie/nieuws/kolibri-streamer>