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DESIGN OF AN AERODYNAMIC AID FOR THE UNDERBODY OF A TRAILER WITHIN A TRACTOR-TRAILER COMBINATION

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Introduction The heavy duty transport sector which uses trucks to transport cargo is a very large business area since it is still the most efficient transport solution within the European context. This fact manifests itself in an increasing amount of trucks on the road and an increased total fuel consumed, together with the related cost, for road transport. Due to the rising fuel prices it is crucial however, to find solutions for these high fuel cost in order to stay competitive in this aggressive and fast changing market.

Generally there are two ways to reduce the fuel consumption of a vehicle. One can improve the efficiency of the power delivered by the engine (available power) or one can lower the required power. The latter can be achieved by reducing the weight of the vehicle, reducing its aerodynamic drag and/or reducing the friction resistance of the tires.

The reduction of fuel consumption of trucks by aerodynamic means has become an accepted practice in the last decades by mounting add-on devices for the tractor and the trailer. Also modifications of the main shape of the vehicle improved the aerodynamic efficiency in a positive way. In this perspective several aerodynamic add-ons for the underbody of a trailer are designed and tested in the wind tunnel during the research presented here.

In the past several aerodynamic devices were developed for the front and top of the tractor, the back of the trailer and for the gap between the tractor and trailer, [1, 2, 3]. Only few solutions were tested for the underside of the trailer [1, 4, 5] while this area is characterized by highly turbulent and separated flows [6]. Besides drag measurements, the pressure coefficients are determined at the back of the vehicle to give an indication of the influence of drag decrease on the wake and thus the pressure at the back surface.

The design together with the mutual drag reduction differences of several aerodynamic devices for the underbody of a trailer in a tractor-trailer combination is presented in this paper.

Wind tunnel and model set-up The wind tunnel experiments were executed in the Low Turbulence Tunnel at the Delft University of Technology, The Netherlands. This closed circuit windtunnel has a octagonal test section with an cross sectional area of $2.07m^2$ (width of 1.8m; height of 1.25m) and a maximum speed of 120m/s. The used wind tunnel test section is calibrated with the aid of a pitot tube to measure the dynamic pressure.

The windtunnel does not have a moving belt which is desirable to investigate the ground effect of, for instance, race cars. Ground simulations and its study have been the subject of many research projects [7, 8, 9, 10, 11]. The most basic simulation approach used for passenger cars is the most direct and simple one: to test a vehicle on a fixed surface. The major issue is that the approaching floor boundary layer is too thick. According to Cooper [12, 13] one can conclude that a fixed-floor with a thinned boundary layer is sufficient for current automotive and commercial vehicle applications, particularly where the underbody clearances are large and the underbodies are rough.

To test the vehicle the model is suspended on a parallel floor which has an offset of 250mm with respect to the upper (horizontal) wind tunnel wall and has the same width as the test section. On the rounded front edge of the plate develops a new thinner boundary layer in comparison with the boundary layer on the wind tunnel wall. This solution together with the conclusion of Cooper [12] and the fact that one was interested in the drag changes between the several aerodynamic aid will satisfy for the experiments.
A $1/14^{th}$ scaled truck model (TAMIYA Mercedes Benz 1838LS truck 1/14 and TAMIYA Container-trailer) was purchased in a hobby shop to execute the experiments. The model is adapted in order to generate a nice boundary layer directly to the back-end of the trailer. The initial truck model had sharp corners which would result in flow separation at those front edges and therefore would make any aerodynamic improvement at the bottom and back of the trailer ineffective. A new cover, fig.1, with properly chosen round-off edges [14] has been made which prevent flow separation at the front cabin corners and initiates a turbulent boundary layer before it reaches the back edges of the tractor [12]. The model was not equipped with a cooling and fans system and is mounted up-side-down due to location of the balance system.

The Reynolds number for a full scale truck, based on the square root of the frontal area of $A = 10.34m^2$ and a driving velocity of 25m/s, becomes 5.4×10^6 [12]. The scaled wind tunnel model has a Reynolds number of 0.98×10^6 which is high enough for bluff bodies, [15]. After testing a certain Reynolds number range, no Reynolds effects were deducted. Also no wind tunnel corrections methods were applied on the dynamic pressure.

Measuring techniques The six-component mechanical balance system measures the resulting forces acting on the truck model. Only the drag coefficient C_T of the vehicle will be discussed. The pressure at the back surface of the trailer is measured to calculate a corresponding pressure coefficient C_p in order to investigate its relation to the change in drag coefficient C_T and its behavior towards different aerodynamic aids. The pressure measurements were executed with the aid of Esterline pressure scanners [16] which can measure 32 different pressure orifices.

Experimental results During the experimental measurements more than 93 different aerodynamic devices were built and tested on different vehicle configurations. Only a short selection of the most promising solutions is being discused below. All the drag coefficients C_T in longitudinal direction of the vehicle with the different aerodynamic devices will be compared with

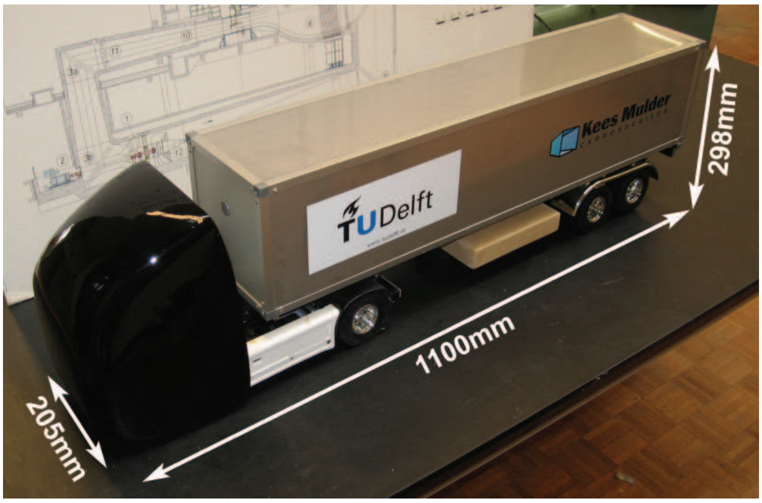

Figure 1: Wind tunnel model dimensions

the standard tractor-trailer combination with rounded trailer corners ($C_T = 0.443$ at zero yaw angle, blue line, fig.2) resulting in a difference in terms of percentage. The clean configuration is not equipped with rounded trailer corners (red line, fig.2), this results immediately in a drag increase especially with increasing yaw angles. Removing the mud flaps (green line, fig.2) results in a general drag decrease of 5%. Blocking the underbody (black line, fog.2) flow by mouting a vertical plate between the underside of the trailer and floor has disastrous effects on the total drag. Meaning that the underbody flow is crucial for the drag built up of a truck.
Fig.3 presents an overview drag reductions of a selection of two types of aerodynamic aids: full

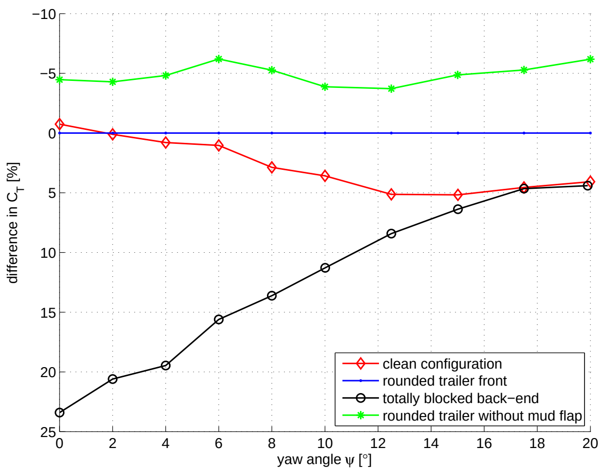

Figure 2: Drag coefficient difference results

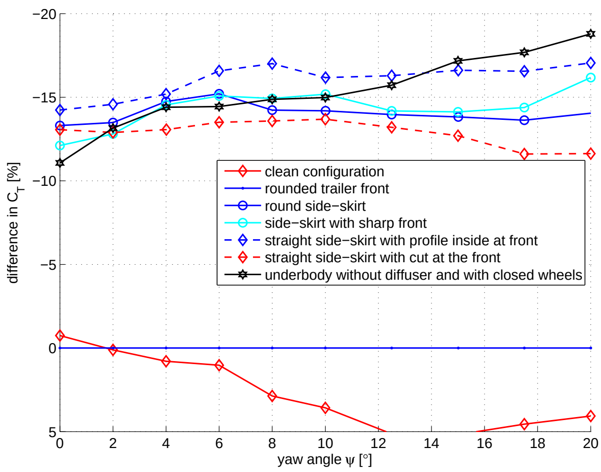

Figure 3: Overview drag coefficient difference results

underbody and side-skirts. It turned out during the tests that covering the wheels is always beneficial for the drag coefficient and that a full underbody that covers the support legs, pallet box and the axles of the wheels is not performing as well as the straight side-skirts which comprises two single panels along the lower side of the trailer in longitudinal direction. Modifications to these side-skirts improved the drag reductions even further up to 14% which corresponds with a ΔC_T of 0.062.

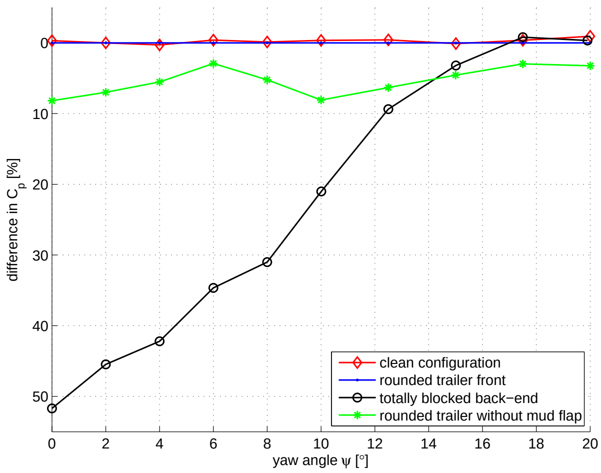

Figure 4: Pressure coefficient difference results

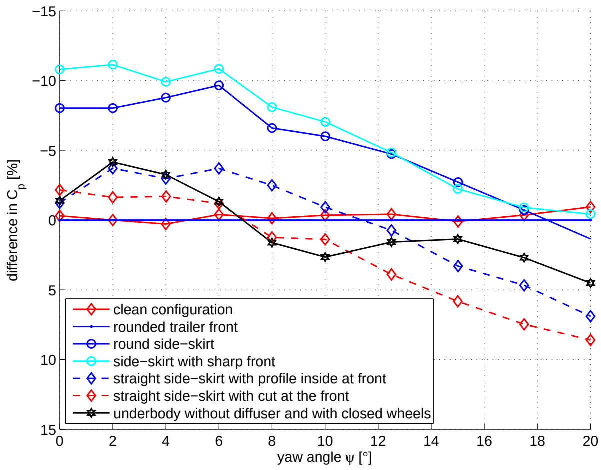

Figure 5: Pressure drag coefficient difference results

Fig.4 as well as fig.5 shows that changes in drag coefficient are not immediately translated in the same change of pressure coefficient at the back surface of the trailer. The behavior of the changes is different with respect to increasing yawing angles. Only the totally blocked back-end configuration demonstrate a corresponding behavior, but the difference in terms of percentage of the pressure coefficient decrement is double compared to the drag increase. Removing the mud flaps around the wheels results in a drag decrease of the vehicle but results in a more negative underpressure at the back surface.

All the aerodynamic devices in fig.5 are showing rather the same behavior: at zero yaw angles there is a certain benefit, a less negative C_p, only the amount of this benefit in terms of percentage is dependent of the corresponding aid. This benefit is constant and slightly increases over the range $2° - 4°$ and then decreases with yaw angles above the $4°$. It is not easy to understand why the benefit in terms of percentage is decreasing with increasing yaw angles without proper flow investigation techniques to determine the flow behavior. Literature also does not provide an explanation for this mechanism, apparently the relation of the change of pressure coefficients with the yaw angle has not been investigated yet.

Discussion and conclusion With the aid of wind tunnel tests an aerodynamic aid for the lower region of the trailer was developed which reduces the drag coefficient significantly. The model bought for the wind tunnel test is modified at the front of the cabin and around the trailer box. The sharp edges of the cabin are successfully rounded to prevent separation of flow around the cabin. The suspension of the model in the wind tunnel test section is such that the thickness of the boundary layer of the ground plane is reduced to a minimum. The measuring velocity in the wind tunnel is set at 60m/s due to the low sensitivity of Reynolds effects of the model and the high aerodynamic forces at higher wind tunnel speeds. The testing Reynolds number is within the margin defined by the SAE and the drag coefficient stays constant with increasing speed. Both facts underline that the chosen measuring velocity is sufficient to perform the tests.

Two different types of aerodynamic aids are initially selected and made: the side-skirt and the underbody principle. The drag force of the total vehicle and the pressure at the back of the vehicle are measurement to investigate the influence of the different aerodynamic aids. In total more than 90 different configurations are tested in the wind tunnel. The configurations with the straight side-skirts and profiles generated the highest drag reductions: up to 14%. The reasons that this new aerodynamic aid reduces the drag can be found in the fact that the locally applied modifications prevent separation of the same flow, in the first instance, at the sharp vertical edge of the side-skirt. Numerical analysis of the truck model with the new aerodynamic aid should clarify the total drag decrease of the vehicle and make it possible to optimize and increase the efficiency of the device.

Besides drag measurements also pressure measurements are performed at the back of the trailer for all the different configurations in order to gather more information and to get insight in the pressure field at the back of the trailer. Just like the drag coefficient, the pressure coefficient stays constant with increasing Reynolds: no Reynolds effects are occurring. The comparison of the pressure coefficients between the different trailer configurations revealed other results with respect to the corresponding values and behavior of the drag coefficient differences. A reason for these differences is that the corresponding aerodynamic aid reduces the drag locally and that this is not always translated into a pressure coefficient benefit at the back of the vehicle. Flow visualization and other measuring techniques should help with gathering a more fundamental insight in the flow mechanisms in the wake of bluff bodies.

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