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Study on the Influence of the Convoy Rolling over Aerodynamic Resistance

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Abstract. The aim of the study is to investigate how the aerodynamic resistance is influenced by the convoy rolling and to see how much this is possible by varying the distance between trucks. Then to see how the gains correlate with the position occupied by the truck in the convoy. The study starts from current research on the premises of running in convoy. Aerodynamic analysis was performed using software finite element of Computational Fluid Dynamics (CFD) type, where it was modeled the convoy rolling of a variable number of trucks. The number of trucks and the distance between them was varied in the model in order to acquire an understanding of the flow field around the trucks and how the distance between them can improve the aerodynamic parameters. The results are presented in the form of streamlines of the air, which indicates the air volume travel speed and direction and of the pressure distribution on the surface of the body. The most significant drop in pressure on the front surface was obtained for the second truck of the convoy, whereas for the following ones the reduction was less important. The participation in a convoy of more than two trucks is justified by the reduction of the whirls that appear and by the uniform air flow. The main advantage of running in convoy mode is to decrease aerodynamic resistance, with beneficial consequences on economic and ecological parameters. Continuing work from here on, it could be analyzed the impact of changing the distance between trucks on the aerodynamic coefficient. The results of CFD simulations need to be verified with experimental data, such as wind-tunnel test, to ensure reliability of the results.

1. Introduction

Transport is a vital part of each industry sector and our daily life. According to recent E.U. statistics, more than half of transport of goods is made by road (50.6%) [1], thus having a significant impact on the economy and environment. To reduce emissions footprint of heavy trucks, extensive research is necessary on all systems, in order to reduce energy consumption. This paper proposes to study the aerodynamic drag which is an important part of the total force that has to be exceeded by a moving vehicle [2].

To improve the aerodynamic performance of a vehicle body, studies are performed on air flow around the vehicle body and engine compartment in order to minimize the energy lost by vortices [3]. Studies performed at highway speed showed that aerodynamic losses can raise up to 55% [4]. Due to large projected area and massive shape, engineers are highly challenged to find ways of reducing aerodynamic drag. Thus, every solution can bring an important gain. Engineers started to conduct aerodynamic studies once the highway speed exceeded 80 km/h. Nowadays, studies are performed by research facilities all around the world. The result is a new design that is with approx. 40% aerodynamically improved as compared to models from mid-20th century.

2. Convoy concept

To keep reducing the aerodynamic drag, researchers are now focusing on the particular way of movement of trucks on the high-speed roads, one behind another. The term of "convoy" is now seen as a good way of improving the movement efficiency of goods by road. Experiments performed with CFD tools showed that reducing the distance between 2 or more moving trucks, can bring a significant reduction of drag for the vehicles included in the platoon, thus leading to energy save [5].

As seen in figure 1, the c_d value (drag coefficient -parameter that shows the aerodynamic performance) reduction for the second vehicle in the convoy depends on the distance between trucks. The c_d value for the third truck is even smaller, however, the c_d value difference between the second and the third truck is significantly smaller than the first and the second truck. This leads to the conclusion that by moving in a convoy, the total energy consumption is reduced and transport performance is increased.

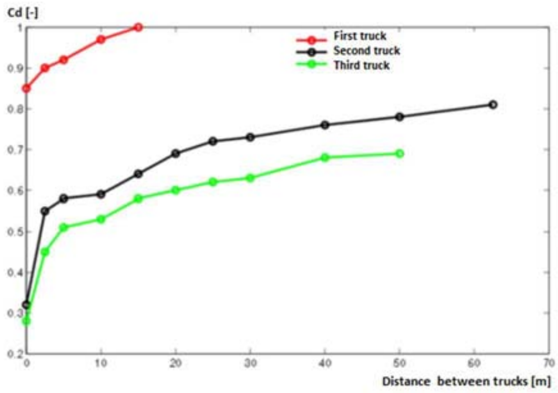

Figure 1. Influence of distance between vehicles on c_d, when moving in convoy [5]

The main constraint in reducing the distance between vehicles is technologic capacity of assuring safe travel condition – allowing all vehicles to stop at every moment, if necessary. Due to human factor, the minimum distance between vehicles to assure safe stop is not small enough to reduce the c_d value, at highway speed. To compensate this, introduction of autonomous functions are imperative. In a controlled environment, trucks equipped with all the necessary sensors and special trained drivers, managed to roll with a distance of just 3m between them (figure 2) [6]. Even if the test was not performed in heavy traffic conditions, this first step may be the down of autonomous driving trucks, where moving in convoy can become the general way of rolling on highways.

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Figure 2. Trucks rolling in convoy, in controlled environment [6]

3. CFD analysis

The aerodynamic drag of trucks moving in convoy is studied in this paper by using finite element method and ANSYS software. The first step consists in defining the geometry of the 3D model (figure 3) - a rigid frame truck model with aerodynamic kit applied was chosen. The applied aerodynamic elements mimic the recent truck models and were validated in previous work.

The simulated air speed is 25 m/s. This value was chosen based on general speed limitation on EU roads, for this type of vehicles. Solutions that bring a gain at this speed will be amplified if the speed is increased.

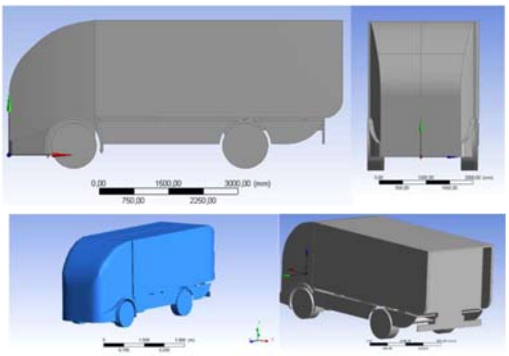

Figure 3. 3D model

The simulation consists in studying the air flow and the aerodynamic drag for a convoy of four identical trucks that follow each other at a three meters distance. This total number of trucks was chosen as a start point for the general picture of the air flow. The three meters distance between trucks was set as such because physical tests confirmed that present technology can sustain travelling in safe conditions at this distance.

This is a 3-parameters analysis: (i) vector analysis, (ii) air flow streamline and streamlines plotted on surface analysis and (iii) pressure plotted on surface analysis.

3.1. Vector analysis

In figure 4, vectors plotted on Y=0 plane show how the efforts are distributed near each truck of the convoy. It can be observed that the first truck encounters a higher resistance than the following ones (that travel in its wake).This may lead to the conclusion that the first truck will have a higher fuel consumption (similar to a truck that travels alone). The following trucks should have a reduced fuel consumption. Therefore, an improved average fuel consumption

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should be obtained leading also to a lower emission footprint - both environmental and financial advantages.

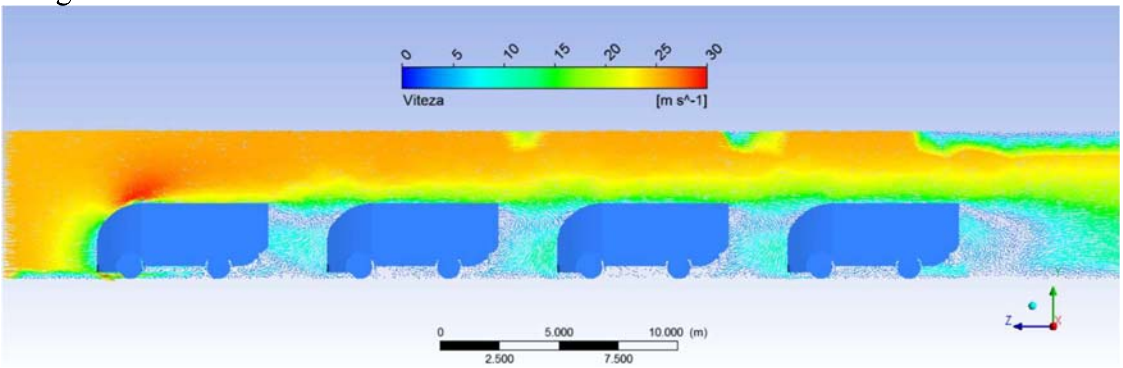

Figure 4. Air speed by vector at Y=0 for a 4 truck convoy, inlet air speed =25m/s

The wake between the trucks has similar shape, except the wake between first two trucks which does not follow yet the formed pattern between the other vehicles. This shows that the second truck has a significant advantage if part of the convoy. In going further, the aerodynamic resistance of the third and fourth trucks are very similar. Also, the picture shows how a stream of air with higher speed envelopes the convoy, thus reducing the aerodynamic drag.

3.2 Streamline analysis

The plotted streamlines (figure 5) show how the wake tends to have the same pattern. Therefore, the drag can be controlled easier by developing new aerodynamic parts for this rolling conditions. This picture also confirms the higher resistance encountered by the first truck.

The streamlines plotted on the surface of the trucks show how the 2nd and 3rd vehicle have very similar contour maps implying a similar air flow. It also can be seen that the second truck encounters a slightly higher turbulence than the following ones.

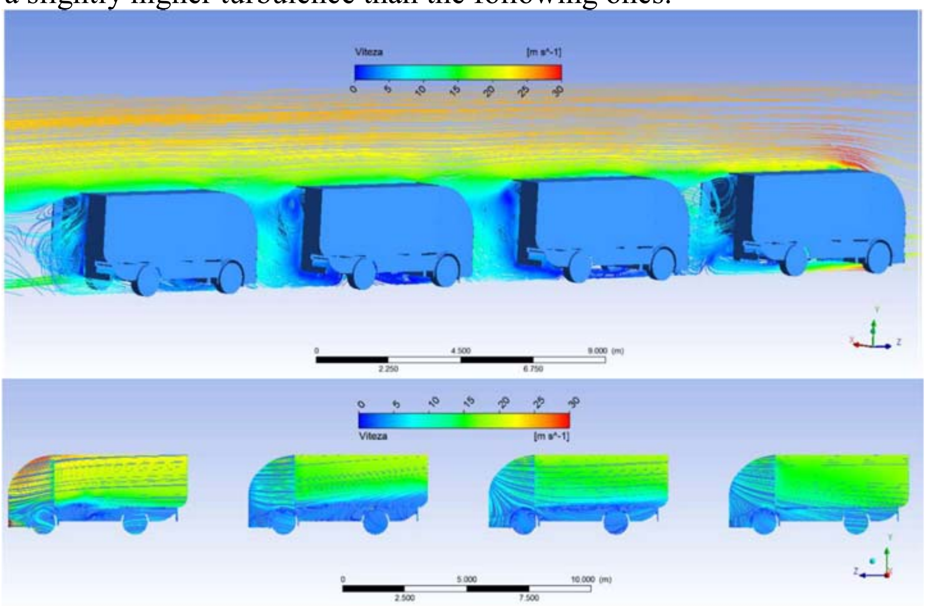

Figure 5. Air speed by streamline, isometric and Y=0 view for a 4 truck convoy, inlet air speed =25m/s

3.3 Pressure map

The air flow image (figure 6) is completed by plotting the pressure on the surface of each vehicle. By identifying the areas with different pressure values, two conclusions may be drawn in relation to: (1) the pressure distribution and (2) the area where the air detaches from the body, leading to vortex' birth. From the picture, it can be easily seen that the three trucks in the convoy have similar pressure patterns. By analyzing the pressure borders, we can identify areas of the body that may be improved in order to reduce energy losses – front part of cab, rear cab area.

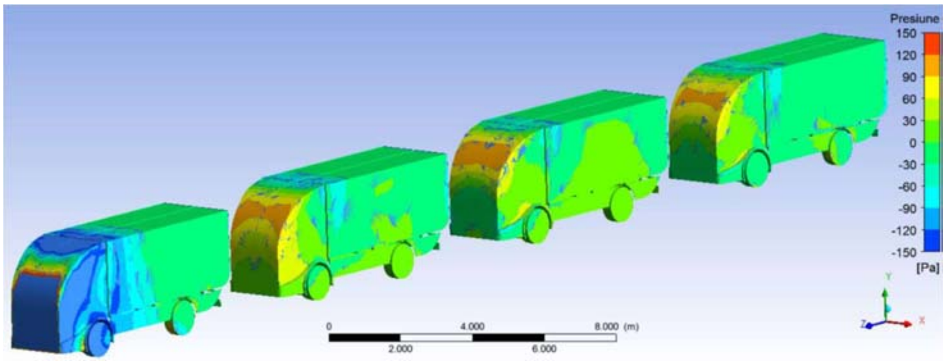

Figure 6. Pressure map on truck body for a 4 truck convoy, inlet air speed =25m/s

By computing the pressure on frontal panels we can obtain an overview of the resistance of each truck in the convoy and its advantage depending on its place in the convoy (figure 7). The image shows that the second truck encounters a pressure with almost 75% smaller than the convoy leader. For the following trucks, the pressure is still decreasing but with far less. It can be easily concluded that by reducing the aerodynamic resistance with convoy formation, the average fuel consumption is reduced. Considering the advantages brought by this solution it would be worth implementing the convoy formation in practice.

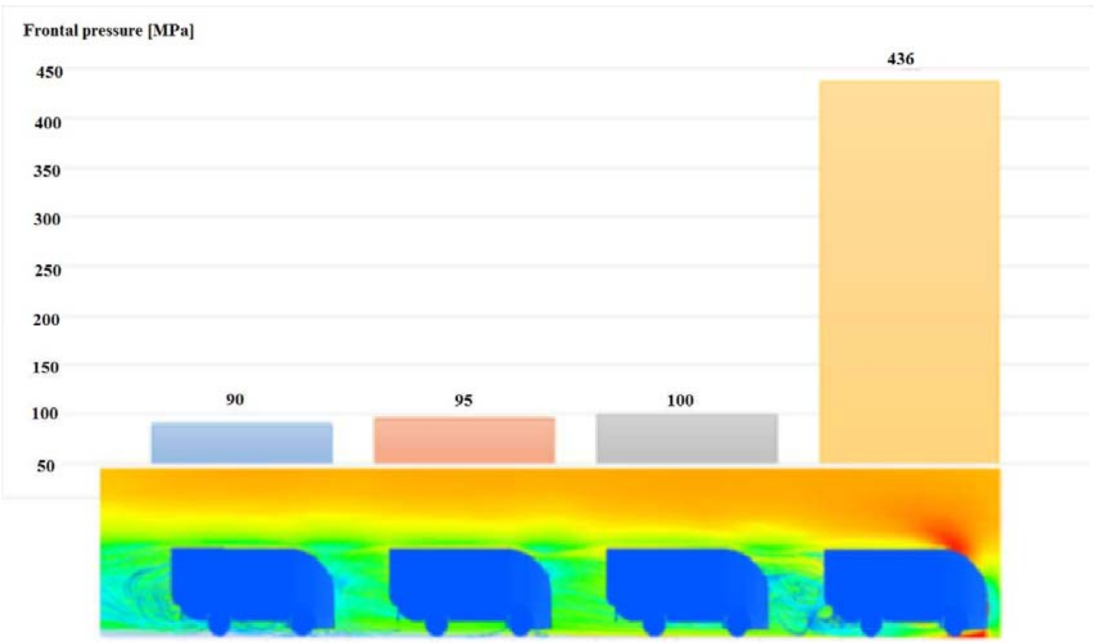

Figure 7. Value of frontal pressure for each truck of convoy

4. Conclusions

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The perspective of new legislation on emission footprint (quite restrictive) and the competitive environment of business, drive engineers to come up with ideas that may seem eccentric. However, these are necessary if new regulatory framework should be met.

The convoy concept that was first inspired by nature wild life may bring a big advantage in fuel consumption by reducing the aerodynamic drag for those vehicles following the leader. The advantage is directly dependent on the distance between the vehicles. A distance of three meters between vehicles can reduce by 75% the aerodynamic resistance for the vehicles included in convoy.

A further study may focus on varying the distance between trucks in order to define a dependence equation between c_d and distance.

A direct consequence of traveling in a convoy is that, the trucks in the convoy (except the leader) may benefit from a reduction of engine cooling capacity. Due to reduced resistance, the engine can run at a lower rpm, which implies lower cooling requirements. Therefore, an optimization of cooling system should be performed. On the other hand, the lack of direct air on heat exchangers may lead to a higher energy consumption for cooling module. Most likely, the increased electric energy requirement will not cover all the aerodynamic advantage from convoy formation, so the balance should be still positive.

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