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# Research of truck train aerodynamic indicators by using computer simulation

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The article describes the possibility of studying aerodynamic parameters of a freight train using computer simulation. This method of research can reduce the costs of designing new structures of road trains and determine the optimal design features of the car's modification with insignificant costs. In order to reduce the cost of cargo transportation, some manufacturing companies apply the method of reducing and improving aerodynamic performance and installing new economical engines. Improved aerodynamics by some of the manufacturers provides fuel savings of up to 3% for long-distance and regional transportation. In order to improve aerodynamic performance (reduction of air resistance) of a road train, its shape was analyzed, taking into account possible side winds affecting the car body

**Keywords:** aerodynamics; road train; tail bag, rear wing, wing skirt

# Дослідження аеродинамічних показників вантажного автопоїзда за допомогою комп'ютерного моделювання

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У статті описана можливість дослідження аеродинамічних показників вантажного автопоїзда за допомогою комп'ютерного моделювання. Даний спосіб дослідження може знизити затрати на проектування нових конструкцій автопоїздів та з незначними затратами визначити оптимальні конструктивні особливості доробки автомобіля. Деякі фірми виробники для зменшення вартості перевезення вантажів ідуть шляхом зменшення та покращені аеродинамічних показників та встановленням нових економічних двигунів. Економія в деяких виробників після вдосконалення аеродинаміки забезпечує економію пального до 3% для далеких і регіональних перевезень. Для покращення аеродинамічних показників (зниження опору повітрю) автопоїзда, що рухається, нами було проаналізовано його форму, враховано можливі бічні вітри, що впливають на кузов автомобіля. Дослідження проводилися для трьох типів компоновки автопоїзда Mercedes-Benz Actros 1851 LS і чотирьох швидкостей. Перша вдосконалена модель автопоїзда із розташованим позаду крилом – юбкою, друга модель – з обтікачем нижньої частини причепу та хвостом мішком Хеннинга Марксена та антикрилом. Розподіл тисків навколо машини, що рухається, відбивається на її русі по дорозі визначено, що при використанні класичної компоновки автопоїзда на високих швидкостях призводить до значного лобового опору, що призводить до що найбільшої витрата потужності. Провівши дослідження з вдосконаленими схемами автопоїзда було визначено, що найкраща схема з обтікачем нижньої частини причепу та хвостом мішком Хеннинга Марксена та антикрилом. При такій компоновці позаду автомобіля відсутня зона розрядження повітря, а отже і відсутнє зниження тиску що призводить до зменшення опору руху та витраті пального

**Ключові слова:** аеродинаміка; автопоїзд; хвостовий мішок, антикрило, крило-юбка

## Introduction

While reviewing the materials of scientific studies [1-6] it was defined that carrier companies spend up to a third of their expenses on fuel, which leads to increase in the cost of transportation.

In order to reduce the cost of goods transportation some manufacturing companies apply reducing and improving aerodynamic parameters and installing new economic engines. Improved provides fuel savings of up to 3% for long-distance and regional transportation.

Aerodynamic resistance of a car is caused by movement of the latter with a certain relative speed in the surrounding air environment. Among all the forces that resist the car movement, aerodynamic resistance is of the biggest interest due to the transport vehicles movement speeds. The fact is that it is at a speed of 50-60 km/h that aerodynamic resistance exceeds any other force of resistance to a car movement, and around 100-120 km/h it exceeds all of them combined.

## Defining the unsolved aspects of the problem

To date, there is no method of aerodynamic resistance force theoretical calculating, and therefore its value can only be determined experimentally. Thus, it would be useful to perform a quantitative assessment of the car's aerodynamics at the design stage and optimize it by changing the shape of the body parts in a certain way. Unfortunately, solving of this task proves to be uneasy. Various researchers and manufacturers tried to find the solution to the problem [4, 7, 8]. It was, in particular, by creating catalogs where the values of an object's aerodynamic resistance were set in accordance with the main parameters of its shape [9]. This approach is appropriate only in cases of application to relatively simple in aerodynamic sense bodies. The number of parameters describing the geometry of a passenger car is too large, with individual flow fields being in a very complex interaction with each other, so that in this case an attempt to tame aerodynamics failed.

## Problem statement

The purpose of the work is to review the ways of reducing aerodynamic resistance. We chose to conduct a study of aerodynamic indicators of a freight train using computer simulation. This method of research can reduce the costs of creating new designs of freight trains and determine the optimal design features of the car's modification with negligible costs.

## Basic material and results

The aerodynamic shape of the car body is a component of safety and driving comfort.

It is known that when driving two trucks one after the other, there is reduction of resistance to movement of not only the second vehicle moving in an airbag, but also the front one's resistance, according to measurements in the wind tunnel, decreases by 27%-32%.

As for automotive engineering, aerodynamic resistance can be defined as the sum of its several components.

These include:

– form resistance;
– outer surface frictional resistance;
– resistance caused by protruding parts of the car;
– internal resistance.

As known, form resistance is also called pressure resistance or frontal resistance.

Form resistance is the main component of the air resistance perceived by the frontal part of the car, it reaches up to 60% of a car total resistance.

The reason for occurrence of resistance of this type is compression of the air flow that hits the front part of a car during the movement of the vehicle in the surrounding air environment. As a result, an area of increased pressure is created in front of the frontal part, which increases with increasing speed. Under the influence of increased pressure, air flows are directed to the rear part of a car; sliding over its surface, they flow around the contour of the vehicle in some places along the length of a car body, and phenomenon of elementary flows separation from the surface around which they flow and appearance of vortices in these places begins to appear.

As it is defined by leading researchers [3, 6], in the rear part of a truck the air flow breaks off from the body of the vehicle, which negatively contributes to formation of a reduced pressure area, where air is constantly sucked in from the surrounding air space.

A classic example can be often observed in the pressure reduction area, namely the presence of dust and dirt settling on the structural elements of the rear of the vehicle.

Considering the difference in wind pressure in front and in the back of the car, the force of resistance is created.

The further behind the body, the disruption of the air flow from the streamlined surface, the smaller accordingly, the area of reduced pressure, the smaller the force of frontal resistance will be.

This happens as a result of partial filling of the area of reduced pressure and reduction of the discharge behind it. It is known from the above that the shape of the vehicle body in this case has a significant role.

The body of the car must be made in such a way that the process of air movement from the front area of the car to the back takes place with the least amount of energy, and the latter is determined mainly by the nature of vortices.

The less local vortices are formed, which interfere with the normal flow of air flows under the influence of pressure differences, the less the force of frontal resistance will be.

Frictional resistance is due to ‘adhesion’ of moving layers of air to the surface of the vehicle body, as a result of which the air flow loses its speed. In this case, the value of frictional resistance depends on the properties of the body surface treatment material, as well as its condition. The fact is that any surface has a different surface energy that can affect the environment to varying degrees. The greater the value of the surface energy of the car covering material, the stronger its surface interacts at the molecular level with the surrounding air environment, and the more energy must be spent on the destruction of Van-der-Waals forces (the forces of molecules mutual attraction), that prevent mutual movement of the touching substances volumes. This type of loss accounts for about 10-20% of all aerodynamic losses.

The lowest values of frictional resistance refer to cars with new, well-polished coatings, as opposed to cars with poorly painted bodies or coatings that have lost most of their consumer properties over time.

The main objective of the work is to develop a construction model of a semi-trailer-container train and determine the engine power for different types of road trains.

To create a model and reduce time and costs during the designing, we recommend using the SolidWorks 2020 program, in which a model of a road train can be easily created and the parameters to study are set.

The Mercedes-Benz Actros 1851 LS car was chosen as a tractor (Figure 1)

**Figure 1 – Mercedes-Benz Actros 1851 LS car**

The created model of the tractor, which is shown in Figure 2, copies all the details of the car and enables studying aerodynamics at different speeds.

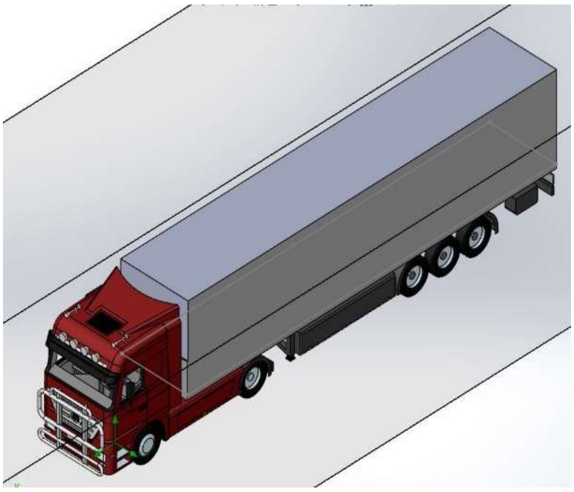

**Figure 2 –Mercedes-Benz Actros car model**

At the initial stage, aerodynamic performance of the model was studied on example of a standard road train at different speeds of 36, 60, 80, 100 km/h.

The results of the research can be seen in Figures 3-6.

**Figure 3 – Diagram of air speed distribution around the road train at a speed of 100 km/h**

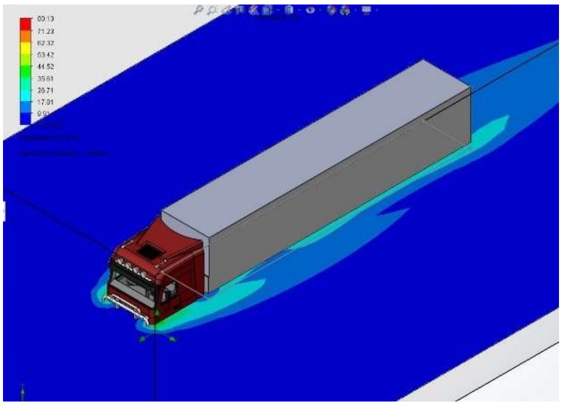

**Figure 4 – Diagram of air vorticity distribution around the road train at a speed of 100 km/h**

**Figure 5 – Diagram of air pressure distribution around the road train at a speed of 100 km/h**

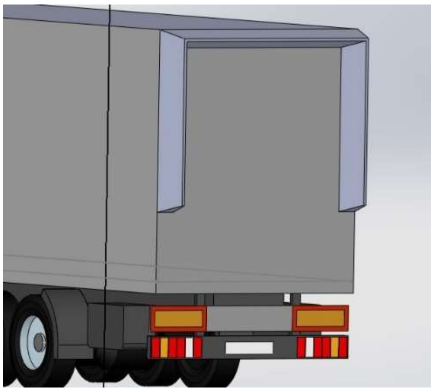

**Figure 6 – Model of the Mercedes-Benz Actros car with a rear wing-skirt**

Then the models were created according to the recommendations described in the works [3, 4, 6]: - with a located behind wing - a skirt (Figure 5), - with a fairing of the lower part of the trailer and a tail with Henning-Marxen's bag (Figure 7), and an anti-wing (Figure 8).

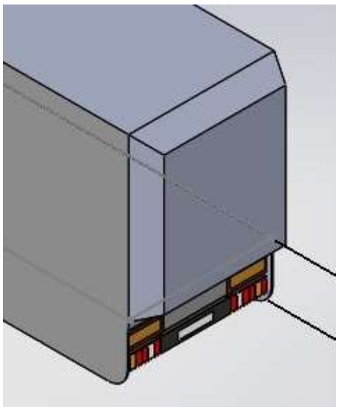

**Figure 7 – Mercedes-Benz Actros car model with trailer underbody fairing and Henning-Marxen bag tail**

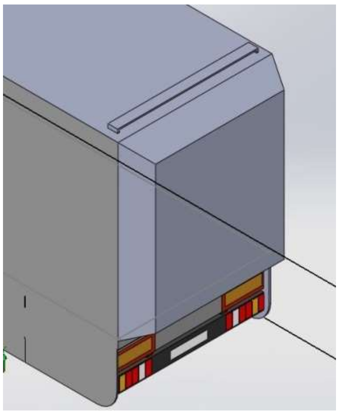

**Figure 8 – Mercedes-Benz Actros car model with trailer underbody fairing and Henning-Marxen tail bag and rear wing**

After conducting a study, the aerodynamics of the road train was analyzed in different layouts (Figure 9-13), and it was found that layout of the road train with the fairing of the lower part of the trailer and the tail of the Henning Marxen bag and anti-wing proves to be the best.

Having analyzing figures 3 and 9-11, the conclusion can be made that the greatest power consumption will be with the classic scheme of the auto-top train layout, and the best scheme is with fairing of the trailer lower part coupled with the tail with a Henning Marxen bag and an anti-wing. With such a layout, there is no air discharge zone behind the car, and therefore there is no pressure drop, which leads to a decrease in movement resistance.

It was decided to make a verification calculation of the effect of attachment on the engine power in various driving conditions.

Calculations were made for the following layouts:
1 – a standard road train with a Actros car;
2 – road train with Actros located behind the wingskirt;
3 – a car train with a fairing of the lower part of the trailer and a tail with a Henning Marxen bag and an rear wing.

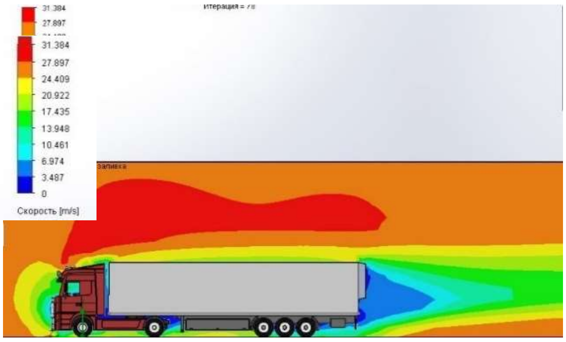


**Figure 9 – Diagram of air speed distribution around the road train at a speed of 100 km/h with a wing-skirt located behind**

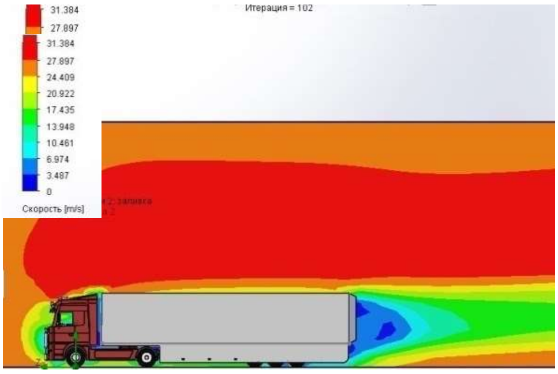


**Figure 10 – Diagram of the air velocity distribution around the road train at a speed of 100 km/h with the fairing of the lower part of the trailer and the tail of the Henning-Marxen bag**

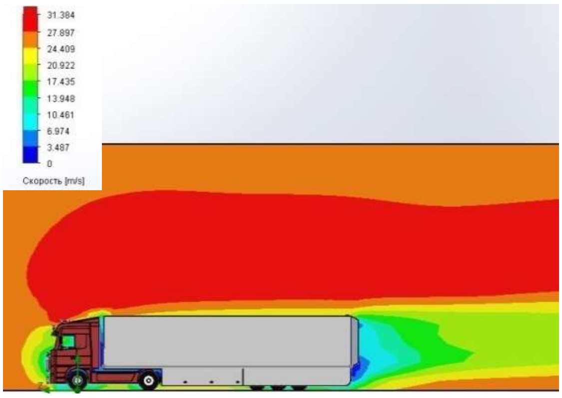


**Figure 11 – Diagram of wind speed distribution around a road train at a speed of 100 km/h with a fairing of the lower part of the trailer and a Henning-Marxen bag tail and an rear wing**

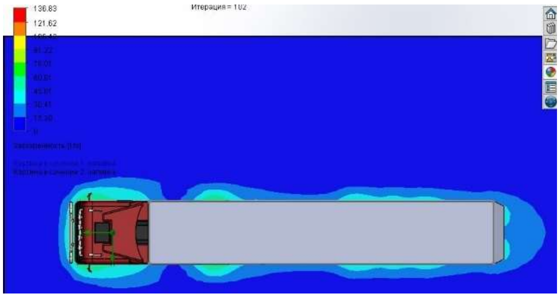

**Figure 12 – Diagram of air vorticity distribution around a road train at a speed of 100 km/h with a fairing of the lower part of the trailer and a Henning-Marxen bag tail**

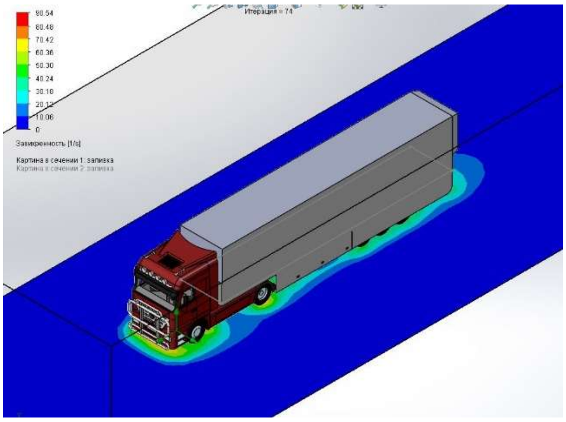

**Figure 13 – Diagram of air vorticity distribution around a road train at a speed of 100 km/h with the fairing of the lower part of the trailer and the tail with a Henning Marxen bag and an rear wing**

Also, according to the diagrams of air flows distribution, it can be said that the phenomena described in the first section are confirmed, namely the strengthening of discharge zone behind the car, which will create additional movement resistance.

*Calculation of the air resistance factor*

The air resistance factor $W$, (N·s$^2$/m$^2$) is equal to:

$$W = k_b F_a \qquad (1)$$

$$W = 0.7\ 8.64 = 6.048$$

where $k_b$ is coefficient of a car flow; for the first version of the layout $k_b = 0.95$, for the second version $k_b = 0.85$, the third version is $k_b = 0.70$;

$F_a$ − frontal area − the area of a car projection in a section perpendicular to its lateral longitudinal axis, m.

The frontal area is determined by the drawing of the general view of the car $F_a = 8.64$ (m$^2$).

The required effective power of the engine, $Nv$, kW, of the designed car is determined according to the $v_{max}$, $\psi_v$ values specified in the assignment for the course project, from the balance power equation when the car is moving at maximum speed – $v_{max}$ :

$$Nv = \frac{\psi_v \cdot Ga \cdot v_{\max} + W \cdot v_{\max}{}^2}{1000 \cdot \eta} \qquad (2)$$

$$Nv = \frac{0.026 \cdot 131516 \cdot 27.7 + 6.047 \cdot 27.7^2}{1000 \cdot 0.88} = 177{,}53$$

where $\psi_v$ is coefficient of road resistance at the maximum speed of the car;

$Ga$ − gravitational force from the total weight of the car, N;

$v_{max}$ − is maximum speed of the car, m/s;

$W$ − is the air resistance factor, (N·s$^2$/m$^2$);

$\eta$– is mechanical transmission efficiency

Speed characteristics of engines show the change in power, torque, fuel consumption and a number of other parameters. Depending on the position of the body controlling the fuel supply, external and partial speed characteristics are distinguished.

As a result of calculation the data were obtained (table 1, figure 13), which testify to the effectiveness of use of overhead elements on the container and trailer when transporting the cargo, the data are presented in table 1 and a graph is constructed (figure 14).

It is estimated that effectiveness of the proposed solutions is 17%.

**Table 1 – Dependence of engine power for different types of execution of road trains**

| Road train type | Speed of movement km/h | Air resistance factor $W$, (N·s$^2$/m$^2$) | Effective engine power $Nv$, kW |
|---|---|---|---|
| 1 layout | 36 | 8,208 | 48,184 |
| 2 layout | 36 | 7,344 | 47,20 |
| 3 layout | 36 | 6,048 | 45,72 |
| 1 layout | 60 | 8,208 | 107,16 |
| 2 layout | 60 | 7,344 | 102,67 |
| 3 layout | 60 | 6,048 | 95,93 |
| 1 layout | 80 | 8,208 | 188,31 |
| 2 layout | 80 | 7,344 | 177,56 |
| 3 layout | 80 | 6,048 | 161,45 |
| 1 layout | 100 | 8,208 | 305,86 |
| 2 layout | 100 | 7,344 | 284,62 |
| 3 layout | 100 | 6,048 | 253,69 |

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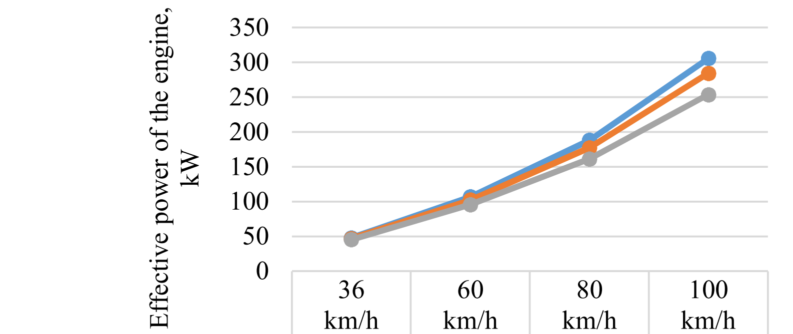


| | 36 km/h | 60 km/h | 80 km/h | 100 km/h |
|---|---|---|---|---|
| 1 road train type | 48,18 | 107,16 | 188,31 | 305,86 |
| 2 road train type | 47,2 | 102,67 | 177,56 | 284,62 |
| 3 road train type | 45,72 | 95,93 | 161,45 | 253,69 |

**Figure 14 – Dependence of engine power for different types of road trains makings**

**Conclusions**

The work considered and analyzed the current state of theoretical and experimental work on the problem of researching the external and internal aerodynamics of road transport, which determines the need for further scientific development of research that will be able to consider the issue of external and internal aerodynamics, based on the current state of methods of computer modeling and research.

The main directions for improving the aerodynamic characteristics of the elements of the top-of-the-road train are proposed.

A computer model of a road train and a method of its calculation are proposed, which allows to adequately determine the aerodynamic characteristics with high probability.

The dependence of the engine power for different types of road trains at different speeds is determined.

The presence of vortex areas was revealed during the study and a solution to their elimination was proposed.

The data obtained as a result of calculation, indicate the efficiency of overhead elements use on the container and trailer when transporting cargo is 17%.

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