UNST Politehnica University of Bucharest

Faculty of Transport

Analysis of aerodynamic performance of trucks and methods for their improvement

~ Thesis summary ~

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Drd. Ing. Vieru Emanuel-Mihai

Key words

Aerodynamic performance of trucks

Aerodynamic optimization

Numerical simulations for improving the aerodynamics of trucks

Design solutions for trucks with aerodynamic profiles

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Introduction

The field of truck development in terms of dynamic, consumption and cargo transport performance is approached with great interest, especially taking into account current trends related to the efficient transport of goods and the reduction of polluting emissions. Trucks, although in terms of the percentage of use on public roads have a lower share than personal vehicles (small class), they, by construction, have the potential to consume and generate more, speaking here of fuel, power or polluting emissions. Therefore, there is a need to analyze and deepen potential solutions that could make cargo transport more efficient.

The field of aerodynamics in terms of trucks has a series of limitations resulting from compromises necessary for the smooth operation of freight transport.

The purpose of this paper is to analyze the various current constraints and propose different solutions to improve the aerodynamic performance of trucks. Therefore, the proposed objectives for the paper include:

- analysis of the constructive solutions of current trucks;

- attempt to optimize the current constructive solutions of trucks;

- proposal of new solutions to improve the aerodynamic performance of trucks.

Chapter 1. The evolution of trucks in road traffic

Among many other factors, a society needs goods to exist but also to develop continuously. In this case, goods, in a single word, include all the general necessities that humans need to exist: food, clothing, raw materials, pre-fabricated, finished products and others. These goods need to be transported, especially in the context of the current development of societies in which there is a global interconnection. This transport, in order to be efficient, has exploited all available branches: road, rail, naval and air. Without interpenetrating, the 4 branches have specific areas of operation, which divides this transport into 4 different sectors. Sectors that have been forced to bring innovative solutions for sustainable development and that have even competed, in some cases, to show their potential in the goods transport market.

This paper will focus on road freight transport, mainly carried out by trucks. Seeing the importance of this sector, this *forces* and favors work towards an evolution. At the same time, it is necessary to take into account the current constraints imposed, mainly for: reducing polluting emissions, implicitly reducing fuel consumption, but also for transporting a larger volume of goods.

Aerodynamics in the field of trucks did not have a very significant impact on performance when mass development of these types of vehicles began. However, given current conditions, there is a fairly high interest in this field and it is aligning new constraints in terms of their development [50].

Since ancient times, goods have been transported either for trade or for personal use. The first methods of transport were rudimentary and were carried out by using bags carried on the back or in specific carriages pulled by animals, but later, after massive industrialization, road, rail, naval and even air transport were emphasized. Mainly, for the best possible economic development, a large part of the goods were transported across the oceans, or seas, from one continent to another, or from one country to another. From the ports, the goods had to reach either different economic agents or different users. To carry out these transports, the main methods were either rail or road. Given that there was a recurrence in terms of this connection between the different branches of transport, the need to optimize them also arose.

Road transport, by trucks, has become a necessity and, in addition, has become indispensable for connecting localities both over short, medium and long distances. In addition, trucks allow the greatest coverage of land locations given the spread of rolling roads, in addition to rail transport which, although it allows the transport of a larger volume of goods in a single transport, does not have such a large land spread or even geographically the terrain does not allow it. In addition to the fairly large land coverage, through the road network, trucks have the advantage of mixed transport of goods. This refers on the one hand to the delivery of reduced volume goods between two locations or on the other hand it targets several consecutive locations with a single transport.

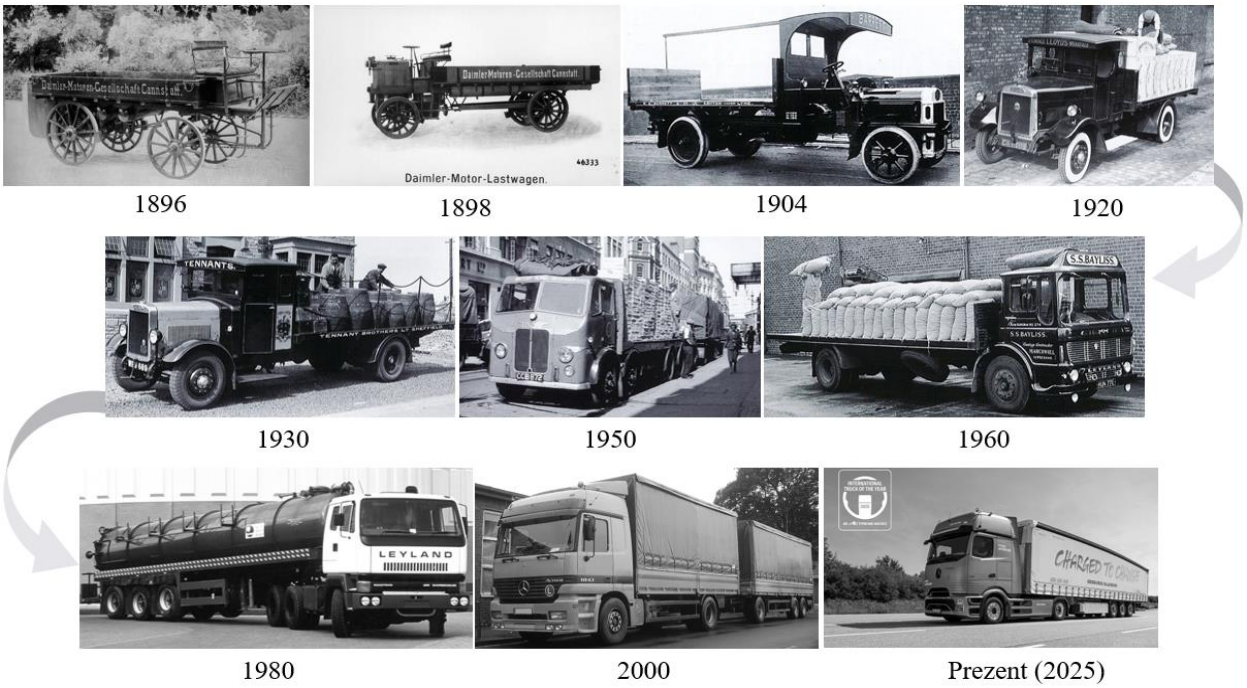


Figure 1. The evolution of trucks over the years, represented. [22], [23], [24], [25], [26].

In addition, the easy maneuverability of this type of vehicle is suitable for transporting goods in the vicinity of cities, on the outskirts, in warehouses where rail transport is not a suitable option.

Taking into account a multitude of constraints and regulations, trucks have developed and evolved in a relatively clear direction in terms of shape. In figure 1, this evolution of trucks can be observed.

As can be seen in Figure 1, starting from approximately 1900, the design of trucks began to have a common shape. In general, all manufacturers adopted the same constructive solution, i.e. a dump truck. Moving forward chronologically to 1920, taking into account the needs for the wide variety of goods, a multitude of constructive solutions were adopted. Around 1950, a new design for trucks was introduced, especially for their cabin [26]. The changes were major mainly in terms of dimensions and loading capacities; in addition, internal combustion engines also evolved. Towards 1980, trucks adopted various constructive solutions and began to be built with more emphasis on the driver, thus making trucks more comfortable, safer and more ergonomic [26]. The 2000s brought new safety constraints to truck design and put the emphasis on reducing pollutant emissions and reducing fuel consumption, which further emphasized the interest in aerodynamic performance. Currently, trucks, with a very wide variety of constructive solutions, are subject to very strict regulatory norms related to the safety of both the driver, the cargo and the other road users. And this again imposes a series of constraints in terms of design.

In the context of this paper, the analysis regarding the history of truck development focuses more on their profile and does not focus much attention on different performances, such as their power.

In addition to the design of the cab, another point of a truck that has changed a lot over the years is the loading area (more precisely the area where goods are transported). Over the years, especially on the European continent, the type of road assembly for trucks, i.e. trucks with semi-trailers, has developed a lot, as can be seen in figure 1.

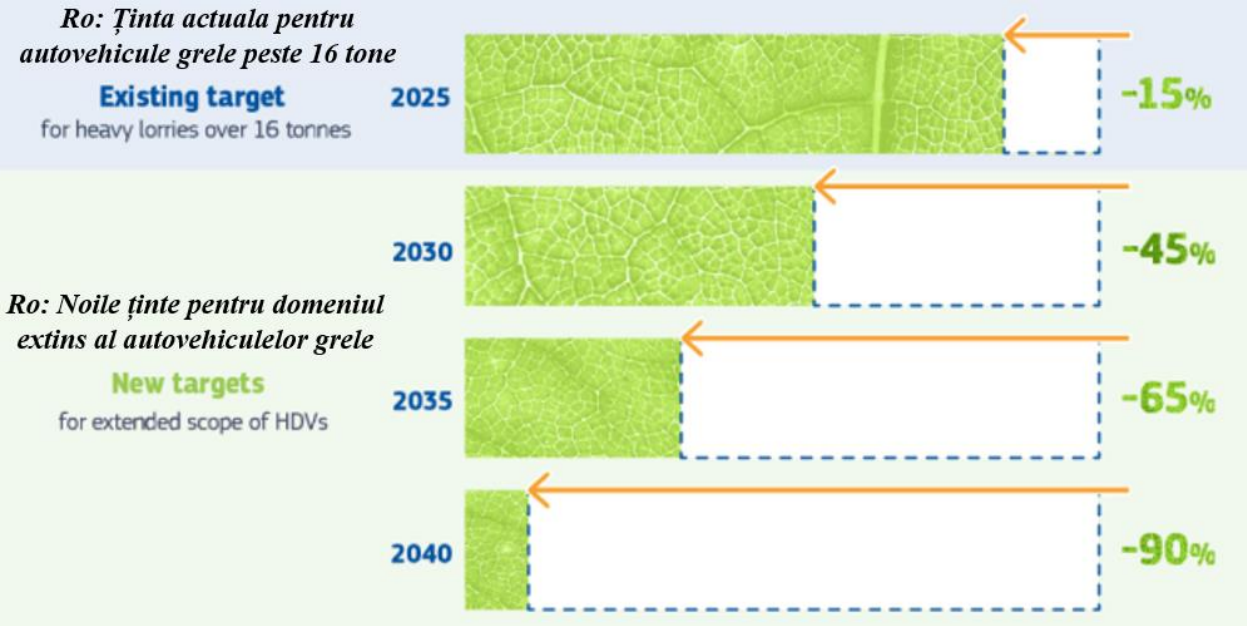


Figure 2. Targets, by year, for reducing pollutant emissions specific to heavy vehicles, at European level [50].

Transport can be considered efficient when: it is carried out in a short time, it is economically profitable (for both parties: the carrier and the beneficiary) and it is carried out safely. Carrying out transport in a short time is important to ensure a continuous flow of goods that will

be used/marketed. From an economic point of view, the transport of goods has two components: the transport must ensure increased profitability taking into account fuel consumption, truck maintenance and others, and for the beneficiary of the delivered goods to be profitable later, in order to market or use the goods. Mainly, good aerodynamic performance of the vehicle leads to reduced fuel consumption (and therefore reduced pollutant emissions), good directional stability, reduced aerodynamic noise, and more efficient engine and brake cooling [1].

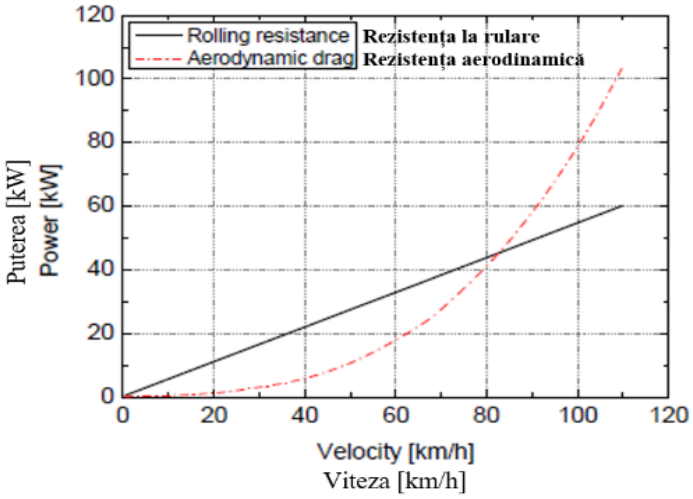


Figure 3. Relationship between the power required to overcome rolling resistance and aerodynamic resistance [21].

Aerodynamic performance can be obtained by measuring the aerodynamic coefficient c_D, which is dimensionless. It can also be calculated using formula 1.1 taking into account the parameters listed below such as: aerodynamic force, air density, etc.

$$c_D = \frac{F}{\frac{1}{2}\cdot\rho\cdot v^2\cdot A} \tag{1.1}$$

F is the aerodynamic force;

ρ is the air density;

v is the speed of travel;

A is the cross-sectional area [1].

The aerodynamic coefficient can be calculated on the 3 axes: x, y, z and has a corresponding aerodynamic (air) force on each of these: Fx, Fy, Fx. The largest weight for estimating the aerodynamic performance of a vehicle is on the x axis [1].

The aerodynamic resistance of a vehicle is directly proportional to the speed of travel. From figure 3 it can be seen that the aerodynamic resistance (Aerodynamic drag) appears starting with a speed of 20 km/h but compared to the power required to overcome this resistance (Power), it can be considered negligible [21]. Starting with speed values of approximately 80 km/h it is observed that the power required to overcome air resistance also increases significantly.

Another factor that makes it difficult for vehicles to move is rolling resistance, which increases linearly with speed. Therefore, the vehicle must develop a sufficiently high power to overcome these two resistances. The values in figure 3 correspond to a 40-ton truck with a cD of 0.5.

A simple equation describes the fact that high fuel consumption also generates high consumption of polluting emissions. In the current context, it is necessary for these pollutants to be reduced as much as possible and why not, even eliminated. In addition to the technical solutions applied to internal combustion engines, the reduction of internal friction of various components and the use of alternative fuels, there are still areas that have the potential to reduce emissions [19]. As observed in figure 3, forward resistance also includes air resistance and rolling resistance. As the latter can be improved, for example, by developing better performing tires, air resistance can also be reduced by reducing the aerodynamic coefficient. This can be done mainly by designing a profile that is as fluid as possible, thus allowing the air to flow smoothly, without disturbances. In figure 4 we have two types of trucks: A – truck with a high aerodynamic coefficient (low aerodynamic performance) and B – truck with a low aerodynamic coefficient (high aerodynamic performance).

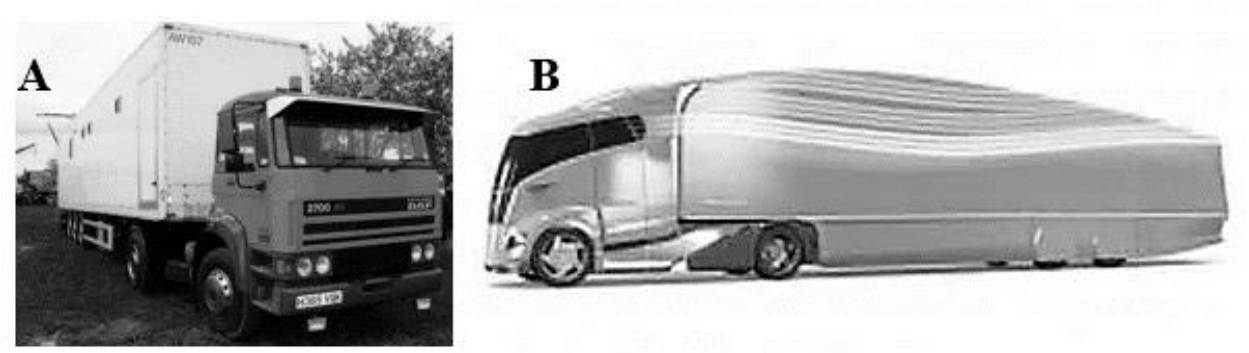


Figure 4. Types of trucks with different aerodynamic performance: A - increased c_D, B - decreased c_D, [33], [24].

The difference between the two vehicles is noticeable, in the case of truck A there are no areas that indicate good performance. On the other hand, model B has a continuous shape, rounded edges and corners and describes an overall good aerodynamic shape, which is close to a drop of water.

The areas with the greatest potential for improving the aerodynamic performance of trucks are:

- Cab: front, roof and side areas;

- Side areas between the truck or tractor axles;

- Semi-trailer or upholstery, in the case of single trucks;

- Wheel areas;

- Side areas of semi-trailers;

- Area between the cab and semi-trailer or upholstery.

Figure 5 shows the areas listed above, on a road vehicle of the same size as a tractor unit with a semi-trailer and which does not have elements to improve aerodynamic performance.

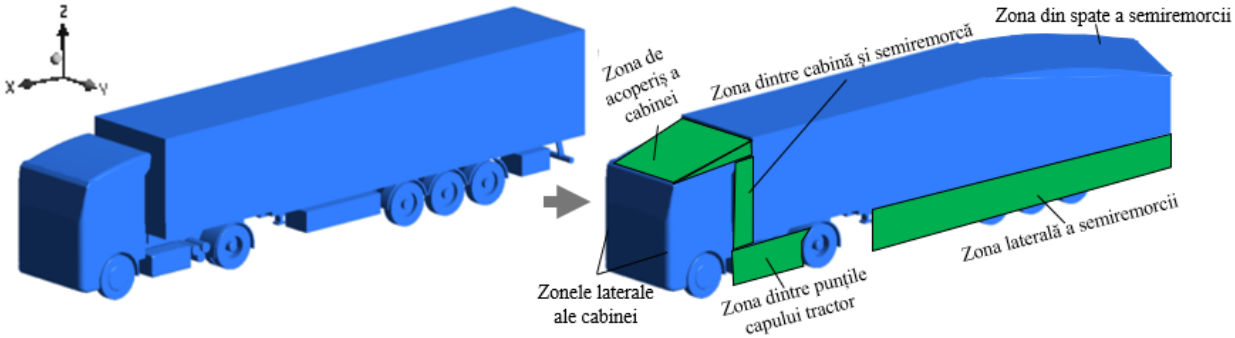


Figure 5. Areas with potential for improving the aerodynamic performance of a road assembly [4].

Chapter 2. Study of the aerodynamic performance of trucks

Based on the above, it can be considered that aerodynamic performance is given by several factors, among which the most important would be: the general shape and the auxiliary elements added to it. Although commercial vehicles have evolved in terms of aerodynamics in recent years, there are still solutions for improving them. Starting from figure 5, the presented elements will be detailed, both from a constructive and performance point of view. In addition, various constraints related to the delivery of goods, safety or comfort will also be taken into account. The study will not focus on a specific constructive solution, such as a road assembly consisting of a tractor head and semi-trailer, but will analyze all the solutions adopted on the commercial vehicle market. Mainly, whether we are talking about an articulated truck or a short truck with a van, the principle of improving aerodynamic performance remains the same: eliminating or reducing high pressure areas which leads to an increase in the c_D coefficient. Figure 6 shows the high pressure areas, i.e. those that generate drag from an aerodynamic point of view [19]. It can be seen from this that the areas with very high pressure (marked with "+") for the section at the center of the vehicle are: the front area of the cabin and the van above the cabin, in the area of its roof. The areas marked with "-" are represented by reduced or negative pressure; the pressure can only be zero or positive, but the statement of a negative pressure is given by pressure values below the atmospheric value.

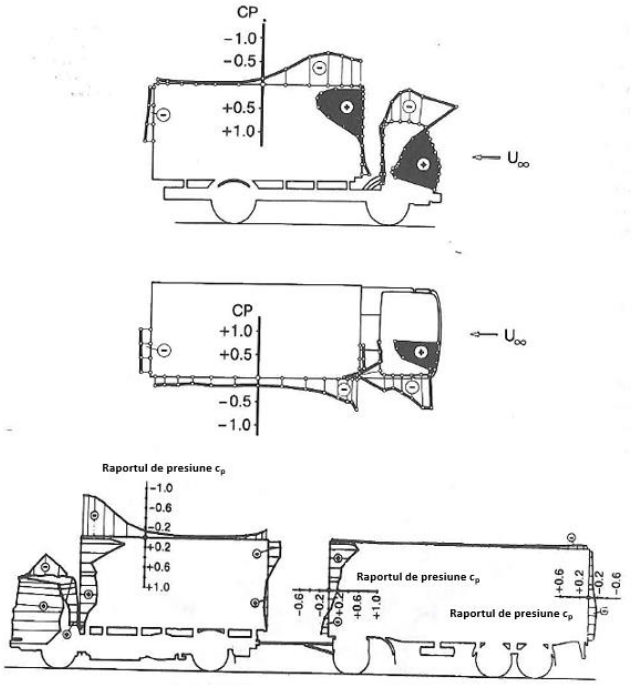


Figure 6. Pressure coefficient cP, on the body of a truck, section at the center of the vehicle, top view; road assembly consisting of truck and trailer [19].

As exemplified in Figure 6, the truck cab is an important area that generates high

pressure, and therefore creates a high resistance to forward movement. The truck cab as a set of areas can be divided into: the roof, the front and its side areas. In addition, it must ensure: good ergonomics for the driver, allow good visibility to the outside and the surroundings of the truck and be safe in the event of an impact. In addition, from a technical point of view it must allow a series of openings, hereinafter referred to as air inlets, in the front, mainly to facilitate the cooling of the internal combustion engine through radiators [18], [22].

Taking into account these constraints, manufacturers must combine current technologies with current regulations in order to design a profile that is as aerodynamic as possible [1], [11], [13].

The roof of a conventional truck cab is straight in the x-axis and if behind it is the transport area (van, upholstery) which is offset in the z-axis, this generates the pressure variations previously announced.

Another notable point regarding the potential for improving the aerodynamic performance of the cab is its lateral areas, mainly the corners. These can be considered as: the side mirrors, the junction between the front and side surfaces below the windshield, in the z-axis, and the lateral terminations in the vicinity of the van.

Internal combustion engines are still the main means of propulsion for commercial vehicles. As they require the development of increased power to be able to move such a road assembly, they obviously also need efficient cooling. This can be done through well-sized air inlets positioned on the surface of the radiators to allow air to reach them efficiently. From an aerodynamic point of view, voluntarily allowing the deflection of external air towards the radiators generates an aerodynamic brake by introducing increased forward resistance.

The lower area of the cabin is another important point for good air flow, especially for the area under the vehicle. The theoretical principle of optimization is to have well-defined areas without disturbing factors of the air flow.

Using the principle stated in the previous chapter, good aerodynamic performance is described by a continuous and undisturbed airflow, which generates a balanced wake. Therefore, it is important that on the lateral surfaces of trucks, whether we are talking about a road unit consisting of a tractor and semi-trailer or a simple truck with and without a trailer, there are no large areas that disrupt the airflow. Mainly, for commercial vehicles that have the cargo loading area covered with a tarpaulin, padding or even a container, and the profile is rectangular from the front of the truck, the improvements stated in the previous lines are respected and it can be considered that the airflow is undisturbed or has very small influences [4], [7], [12]. However, one area that involves such degradations of the airflow is the one between the vehicle axles [9]. Most often these are covered by technical elements such as: the fuel tank, brake system air cylinders, storage boxes and other auxiliary equipment.

The cargo transport area must allow both a useful loading surface and an appropriate volume that allows easy arrangement and loading of goods. For the present study, the emphasis will be on the rectangular transport areas used on trucks and which are covered with tarpaulin or

of the refrigerated or container type. These, by construction, have well-established maximum dimensions and given the regulations in force.

In order for most vehicles to travel on public roads, wheels are indispensable for their operation. Given their necessity, it is important to pay increased attention to them, especially if they have an impact on aerodynamic performance [7]. Given the potential for generating turbulence and, therefore, disrupting the overall air flow, wheels are considered elements with an impact on aerodynamics [14], [15].

Chapter 3. Aerodynamic performance verification study

Aerodynamic performance can be assessed by c_D, a parameter that can be measured or calculated with formula 1.1, taking into account the aerodynamic force, on the axis of interest. In the case of verifying this performance by measurement, there are, as in many other fields, two test methods: the virtual environment (CFD – Computational Fluid Dynamics) and the physical environment (wind tunnel). Each test case comes with its advantages and disadvantages. However, for a good development of motor vehicles, and not only, the combination of the two test methods is vital to obtain the most conclusive results [5]. The purpose of these tests is to verify the exact performance of the designed shapes, on the one hand from a theoretical point of view but also from the experiences accumulated over time. Thus, through tests of this type, existing solutions can be optimized and even new ones can be researched. Verifications in CFD and physics are done in parallel and mainly take into account the same input parameters but also dimensional ones.

Intensive work is done to design an aerodynamic profile that is as efficient as possible. In addition to theoretical proposals, tests in the physical environment are absolutely necessary. Until a profile is finalized, it goes through several stages of development: the appearance of a model on a reduced scale and then on a 1:1 scale. The work for these is done in the wind tunnel and the models are prepared from different materials: clay, fiberglass, polystyrene, etc. [19]. After the model is created (either reduced scale or normal scale) in a specialized design studio, it is tested in a wind tunnel itself. These tunnels are, in operation, of two types:

- - Göttingen type closed return wind tunnel;
- - Eiffel type open return wind tunnel [19].

Figure 7 depicts these two types of wind tunnels, the top image is the Göttingen type and the bottom is the Eiffel type.

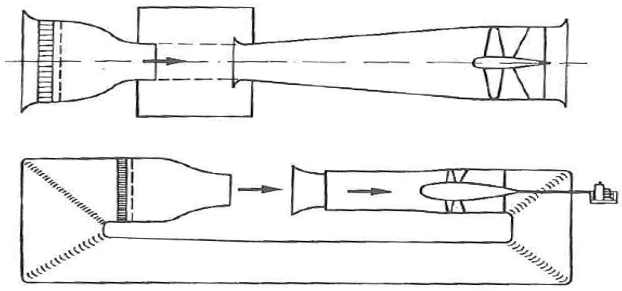


Figure 7. Types of wind tunnel [19].

For the closed return method the air flow is recirculated in the wind tunnel while the open return method describes a fresh air flow each time. For the Göttingen type the advantage is given by the fact that it requires a reduced power to set the air in motion in terms of operating cost. Therefore, financially this type of wind tunnel is a winner

compared to the Eiffel model. However, a disadvantage of this tunnel is its very large dimensions, especially for 1:1 scale models [19].

The open-return model is very dependent on the external environment, so this type of tunnel is suitable for areas with moderate climates due to the continuous need for a fresh air flow. In addition to the ability of this tunnel to be operated outdoors, it has many operational constraints: wind conditions do not allow for proper testing, leaves, tree branches or other impurities can enter the fan. Figure 3.2 shows the fan of a closed-return wind tunnel for testing 1:1 scale models and can be seen by comparing its diameter with a person of normal height.

As for trucks, the testing methods are slightly different even though the wind tunnel principle is retained.

Due to the large size and mass of these types of vehicles, a different approach is needed to verify the aerodynamic performance in the wind tunnel. Therefore, different conditions are considered for testing commercial vehicles such as, for example, the moving ground is neglected and the wheels are positioned on a series of fixings (marked with arrows in) which can be viewed in figure 8 [20]. In the same figure, a wind tunnel (LLF – Large Low Speed), for trucks, DNW in the Netherlands, is described, which has a test section of 9.5m x 9.5m.



Figure 8. DNW wind tunnel, Netherlands (left image). Truck positioning in DNW wind tunnel (right image) [20], [63].

As previously mentioned, the verifications in the virtual environment are done using Computational Fluid Dynamics. This type of test is based on a calculation software that directly measures the aerodynamic performance. The interest adopted for this method arose as a result of the relatively long processes of vehicle development and the need to shorten them. CFD is not only used in aerodynamics, its applicability exists in a wide variety of fields. This testing method has numerous advantages as follows: reduction of test time for model preparation, possibility of testing several configurations in parallel. Most often, CFD is used to predict the trend of how the air flow will be modified by adding different elements. In the virtual environment there are a multitude of situations for visualizing the air flow: pressures, streamlines, vectors and others [19]. However, in order to have a good visualization of these situations listed above, it is necessary that the calculation program be given a series of input data to process some results. Therefore, discussing

air directly, in the present work, it can be considered that the flow generated in relation to the body/profile/vehicle creates different pressure fields that are the result of the aerodynamic forces experienced by it [19].

In order to perform a CFD simulation of a profile, several steps must be followed as follows:

1. Discretization of the shape and/or test domain and the model;

2. The actual calculation;

3. Post-processing to obtain the results [19].

So, both in the physical and virtual environment there are situations that present advantages and disadvantages. However, working in parallel between the two methods is absolutely necessary. And this mix is given by the fact that for a project, any, at a stage of development it is necessary to verify different methods of improving aerodynamic performance. If we were to rely on testing them only in the physical environment, a fairly large amount of time would be required for testing and preparing the models, energy consumed for putting the wind tunnel into operation and a relatively large volume of work in terms of personnel. If we refer to the same stage of development and the tests are only in the virtual environment, we can say that we can simultaneously test all the proposed solutions. However, it should be noted that the CFD simulation must be prepared and has a specific working time. Therefore, we cannot describe a perfect recipe for when to use either the physical or virtual testing methods. For different projects, a combination is made, as mentioned above, between the two methods to obtain the best and most accurate results: the virtual environment allows easy visualization of the air flow at different speeds, but due to various constraints, the numerical values may have small errors and thus do not reflect reality; the physical environment does not allow such an easy visualization of the air flow, however, given the latest generation measurement methods, they can generate robust numerical values that can be taken into account.

Chapter 4. Analysis of aerodynamic performance of trucks

For the analysis of the aerodynamic performance of trucks, road assemblies that include semi-trailers were mainly chosen, as these are the most common in the use of freight transport, especially on highways and high-speed roads. Several truck models were chosen, either commonly found on public roads or solutions that only have aerodynamic potential in terms of shape.

These solutions were modeled in 3D in order to be subsequently tested in the virtual environment and have a scale of 1:35. Moreover, they are relatively simplistic models, especially in the architecture under the vehicle. This simplistic modeling was chosen to avoid the long calculation times of the numerical simulations. At the same time, the models are complete solids, so the wheel rotation criterion is excluded, this factor not being taken into account in terms of aerodynamic performance, which is verified only from the point of view of the shape of the trucks.

The models analyzed will be presented in Figure 9 and we will start with a conventional truck. Although this is not current and there are already solutions to improve aerodynamic performance applied to it, it is necessary to present a basic model, a comparative model with which

different solutions can be compared and thus the evolution in terms of improving or degrading aerodynamic performance through the proposed solutions can be more easily observed.

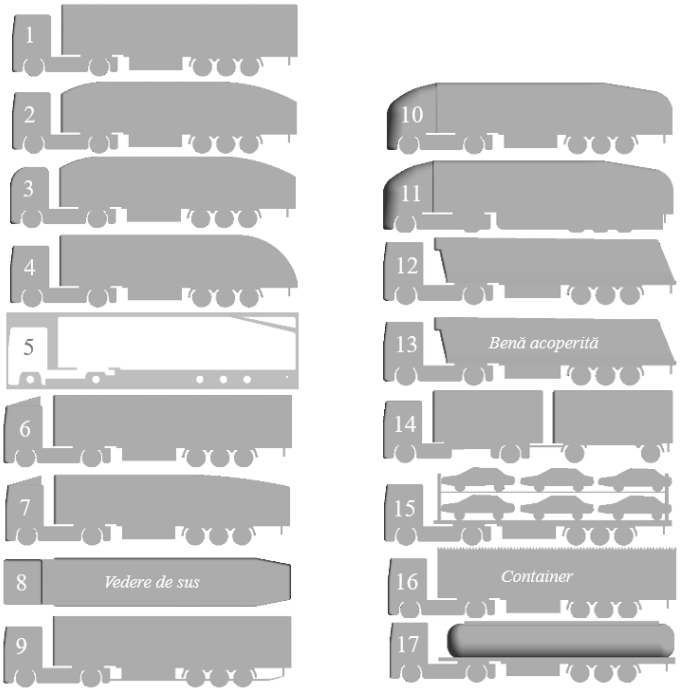


Figure 9. Truck solutions analyzed.

To verify the constructive solutions of the trucks, together with the conventional truck, it will be done by observing the air flow around the geometry but also the force measurements on the x-axis, the possibility related to the improvement of the various constructive solutions will be concluded.

Regarding the virtual testing of the models presented above, a brief presentation of the test configuration will be made. In terms of the test area, only one test chamber will be used, the dimensions of which can be seen in figure 10. This is described by two views (side and front) and is presented in the test configuration for the conventional truck. On the same occasion, in the following figure, the overall dimensions of the truck at a scale of 1:35 can be seen; dimensions that are the same for the other configurations.

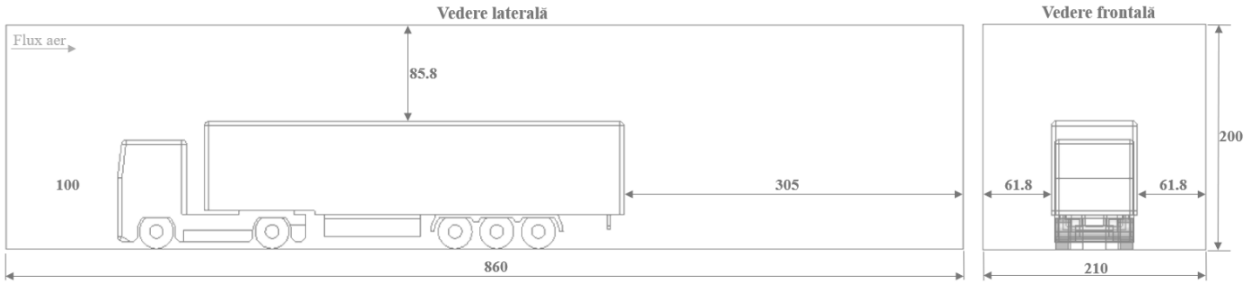


Figure 10. Virtual environment test chamber with conventional truck at 1:35 scale. Values expressed in mm.

For a good observation of the air flow, as mentioned in the previous chapters, the discretization is a very important factor. Thus, the size of the discretization elements was chosen to have a value of 3 mm. Figure 11 shows the discretization of the model.

In terms of input data for numerical simulations, it was chosen to adopt a value of 25 m/s (90 km/h) as the air flow velocity in the test chamber and the condition of non-slip walls was set for the walls of the test chamber. In terms of computing power, it had the following characteristics: Intel® Core™ i5-7200U processor @ 2.5 GHz, 12 GB RAM, integrated Intel® HD Graphics 620 video card.

The aerodynamic study was based on the analysis of the airflow on each of the solutions presented in Figure 9. Moreover, Table 4.1 describes, comparatively, the force on the x-axis between the conventional truck and the other configurations.

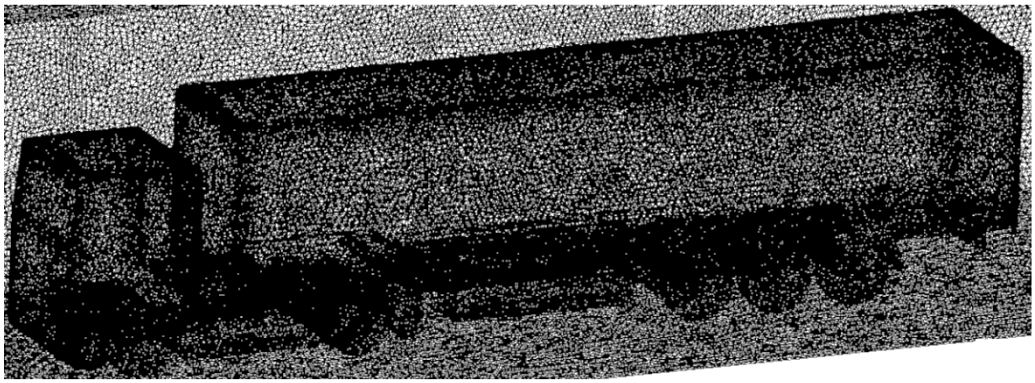


Figure 11. Meshing of the model and test chamber.

Table 4.1. The value of the force on the x-axis for the 17 truck models.

	Image	Fx	Δ % compared to 3,296 N
Model 1		3,296 N *(base)*	0.00%
Model 2		3,040 N	-7,76%
Model 3		3,314 N	+0,55%
Model 4		4,787 N	+45,26%
Model 5		3,566 N	+8,20%
Model 6		2,993 N	-9,20%
Model 7		2,845 N	-13,69%
Model 8		3,406 N	+3,34%

Model 9		3,296 N	0,00%
Model 10		2,350 N	-28,70%
Model 11		2,235 N	-32,20%
Model 12		4,005 N	+21,52%
Model 13		3,496 N	+6,07%
Model 14		3,785 N	+14,85%
Model 15		4,002 N	+21.43%
Model 16		5,033 N	+52,69%
Model 17		2,205 N	-33,13%

Based on the centralization of the values obtained in the table above, it can be seen that there is a fairly large variation in them. The best aerodynamic performance is described by Model 17 which is followed by Model 11 and describes improvements in aerodynamic performance by over 30% compared to the conventional truck. At the opposite pole, with a very degrading aerodynamic performance are Model 16 and Model 4 which generate aerodynamic degradation by over 45%, even up to 50%.

Within the same work, it was also chosen to build a small-scale experimental wind tunnel in order to evaluate the aerodynamic performance of different constructive solutions in the physical environment. It was chosen to build an open return tunnel.

Given the subject of this work, verifying this performance in the physical environment is vital in obtaining the most complete picture of the subject addressed. The open return wind tunnel solution was chosen due to the ease of construction but also given the fact that it is suitable from the point of view of experimental tests. Its dimensions were chosen specifically to combine the correctness and visualization of the results with the time and workload for design and construction. The design method was chosen to be simplistic and is based on 3 modules of interest: the contraction zone, the test zone and the diffusion (collection) zone. The actual design started from the test zone: being a small tunnel, an area was created for visualization of the airflow. Therefore, the test area was designed with larger dimensions, especially in length, compared to the dimensions of the tested geometries. It is known that the proximity of the test chamber

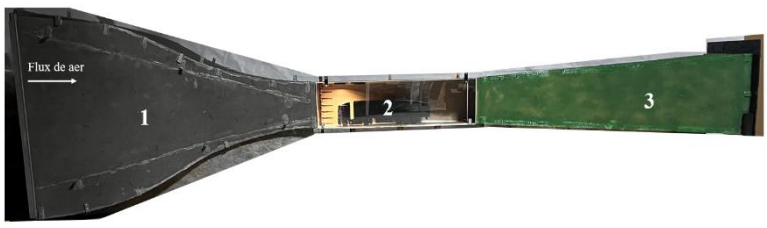


Figure 12. The experimental model and the 3 modules: 1 – contraction area, 2 - test area, 3 - collection area.

walls to the test model leads to a negative influence on the results obtained [5]. However, its dimensions were limiting given the need for subsequent maneuverability of the wind tunnel. Figure 12 shows the constructed experimental model and the notation of the main areas described previously. From the figure, the 3 distinct, standard modules of the experimental wind tunnel can be observed; in addition, the experimental model was also equipped with a smoke system for visualization of the air flow.

Before trying a series of scale models (1:35), it was chosen to test two simplistic geometries to verify the airflow in the experimental model. These flows can be observed in figure 13. It was observed that the two flows of the simplistic models have a theoretical characteristic, therefore the experiment through which the qualitative estimation of the aerodynamic performances will be made with the constructed wind tunnel will describe tangible and sufficiently robust results.



Figure 13. Simplistic quadrilateral model (left), simplistic circular model (right).

Using the previously designed and presented wind tunnel, it was chosen to verify the aerodynamic performance of the conventional truck in the physical environment. Mainly, the analysis of the aerodynamic performance will be based on the airflow around the geometry and its observation from the side view; thus being able to compare it with the test in the virtual environment. Figure 14 shows the 1:35 scale model of a 3D printed conventional truck that will be used in the test. Therefore, it was positioned in the test chamber and the fan was turned on at a low speed to help visualize the airflow as best as possible. Figure 4.58 shows the airflow on the front of the truck, at the cabin but also at the rear of the semi-trailer where the wake is created.



Figure 14. Conventional truck at 1:35 scale. 3D printed geometry.

From figure 15, the air flow for the conventional truck can be observed. For the cabin, the swirling air flow on the roof area is distinguished and which remains turbulent further towards the ceiling of the semi-trailer. Regarding the air flow for the rear area of the semi-trailer, the area of its

detachment is quite clearly observed, but the incipient shape of the wake can also be observed. For the semi-trailer, it is observed that after detachment, the air continues to flow towards the rear of the truck and generates, practically, a theoretical flow.



Figure 15. Airflow on a conventional truck for the cabin area and the rear area of the semi-trailer – experimental wind tunnel test.

It can be said that verification in the physical environment with the experimental wind tunnel generates a much more truthful idea in terms of observing airflow.

It was chosen to test in the physical environment, in the experimental wind tunnel, a truck model with good aerodynamic performance that was verified in the virtual environment and it was observed that it has a decrease in force on the x-axis compared to the conventional truck. Therefore, in figure 16 such a truck is presented and the analysis will be based on the observation of the air flow.



Figure 16. 3D printed aerodynamic truck at 1:35 scale.

It can be seen in Figure 16 that there is a significant difference in the airflow both in the cabin area and in the rear of the semi-trailer and the flows are similar to those observed in the numerical simulations.

Comparing the test in the physical environment with that in the virtual environment, it can be said that there are similarities between the two in terms of airflow on the geometry, but verification in the experimental wind tunnel has the potential to allow a much more realistic

visualization of the airflow due to the fact that the type of airflow (laminar or turbulent) is given, in itself, by the architectural methods used.

The paper also proposed, using existing solutions, adapting them to optimize the aerodynamic performance of trucks, especially those with semi-trailers.

It was chosen to start from a conventional truck and by modifying the chassis length and the rear height of the transport area, they can describe a very good aerodynamic performance. Thus, in figure 17, the evolution from the conventional truck to the concept truck with the best aerodynamic performance can be observed.

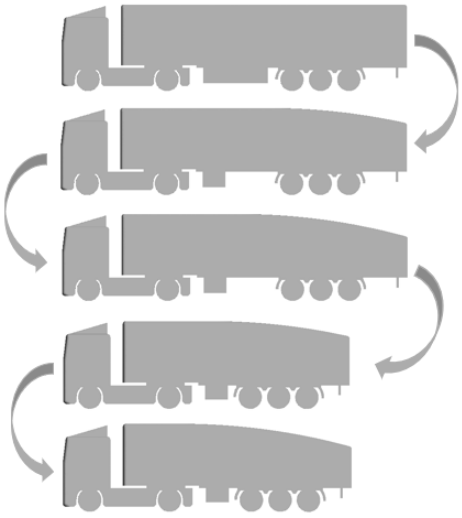


Figure 17.

The evolution of the concept

Chapter 5. Artificial Intelligence in Aerodynamics

In recent years, since the writing of this paper, there has been an increasing interest in artificial intelligence (AI) in various fields. These algorithms have the ability to analyze in a very short time different solutions and find the most feasible and applicable for a given requirement [58]. Among the vast areas of possible application of AI is engineering, in this case the field of aerodynamics. Numerous attempts and analyses have been made to present and at the same time, if feasible, to exploit this tool for a better convergence of different profiles with an increased aerodynamic performance [59], [60].

AI works directly, at least at this point, on a series of data/requirements/indications specified by a human user, and then, through algorithms, generates conclusive results.

For this work, an experiment will be conducted to analyze the solutions proposed by AI in the field of aerodynamics. Therefore, the experiment will look like this: the human user will build a simplistic geometric profile, without taking into account its aerodynamic performance. This pilot profile will be presented to both the human user and an artificial intelligence program and will be asked,

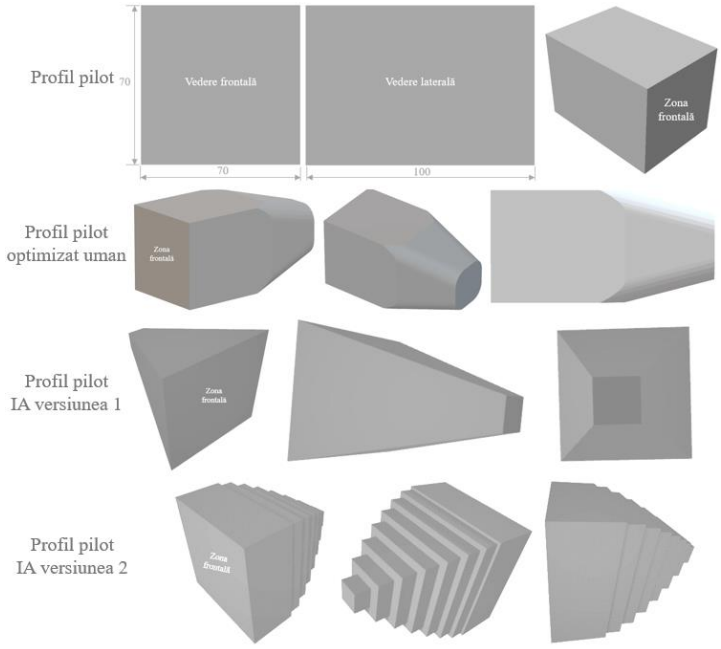


Figure 18. Pilot profile and its optimizations.

in both situations, to optimize this profile from an aerodynamic point of view. Figure 18 presents the pilot profile and the optimization solutions of the human user and those made by the artificial intelligence program. Based on these 4 geometries, a verification was made in the virtual environment and it was observed that based on this experiment it can be described that the potential use of this tool in the development phase of trucks can become a necessity for better global development.

Chapter 6. Conclusions

Aerodynamics has been and is a strong indicator of the energy performance of vehicles, whether we are talking about small, medium, large cars or even trucks. It is one of the factors that directly contributes to reducing rolling resistance and, adjacently, has benefits related to stability and reducing rolling noise.

Based on the current work, an analysis was made of the aerodynamic performance of trucks. Performance that has been studied with great interest and integrated by all manufacturers in the development part of each model. However, an ideal aerodynamic modeling at this time is not feasible due to technology that cannot yet encompass all concept ideas. Therefore, manufacturers must adapt each idea or ideas to current technical constraints, those given by the transport of goods but also regulations. Moreover, the field of aerodynamics requires testing, either physically or virtually and this, for trucks in particular, describes a large volume of resources: whether we are talking about financial, computational or even space. The analysis of aerodynamic performance in the current work was made in the direction of observing potential areas that can still be optimized before moving on to new technologies and, why not, maybe other architectural configurations of trucks.

It has been observed that the current versions of trucks in operation have a high degree of auxiliary elements that reduce the aerodynamic coefficient or that even through their design bring a positive note in terms of this performance. Therefore, the starting point to follow this trend is to optimize existing solutions or use pre-existing ones to develop new ones.

Specifically, based on the analysis in this paper, it was observed that the most important area for aerodynamic performance is the rear area of the trucks, therefore the area of wake creation but which is correlated with everything that happens before it. From the point of view of the analyses performed, these were done on 1:35 scale trucks in order to reduce the simulation times, but this choice could also have negative effects because it describes the possibility of inducing erroneous results. However, the global test orientation also on scale trucks remains valid and effective for approximating the various impacts on aerodynamic performance.

It was observed that for the two aerodynamically shaped trucks verified in the virtual environment, they described good performance and from an architectural point of view they would have a fairly high potential for applicability.

Considering the analysis made in this paper, several solutions can be proposed to improve aerodynamic performance for different constructive solutions. These, although not at the same level as aerodynamically efficient trucks, will still improve the aerodynamic coefficient.

In order to put into practice a series of solutions for improving performance, it will be directed that for future research an expansion of the tests in the virtual environment will be made for the full exploitation of the technical solutions that can generate a gain in aerodynamic performance by integrating all the constraints and current regulations but also aligning with new technologies. The emphasis will also be placed on refining the results obtained in the small-scale wind tunnel.

Bibliography

[1] Mihail-Daniel Iozsa, Caroserii pentru autovehicule rutiere, Editura Politehnica Press, București, 2016;

[2] Aurel P. Stoicescu, Proiectarea performanțelor de tracțiune și de consum ale automobilelor, Editura Tehnica, București, 2007;

[3] Constantin Ghiulai, Mecanica Automobilului, Editura Tehnică, București, 1965

[4] **E M Vieru**, C Stan, I Laurențiu, Analysis of the aerodynamic performance of truck semitrailers, Economicity, Safety and Reliability for Motor Vehicles Congress (and SIAR International Automotive and Transport Engineering Congress), Bucharest, 2023, doi:10.1088/1757-899X/1303/1/012044

[5] **E M Vieru,** D M Iozsa, A M Manea and L Ilea, Analysis of different dimensions of a virtual wind tunnel and different wall conditions, Economicity, Safety and Reliability for Motor Vehicles Congress (and SIAR International Automotive and Transport Engineering Congress), Bucharest, 2023, doi:10.1088/1757-899X/1303/1/012043

[6] **E M Vieru**, M D Iozsa, L Ilea and G Frățilă, The influence of warning lights on the truck cabins on aerodynamic performance, The 32nd International Congress of SIAR of Automotive and Transport, Timisoara, 2023**,** doi:10.1088/1757-899X/1311/1/012017

[7] Navid Balazadeh Meresht, Sina Moghadasi, Sandeep Munshi, Mahdi Shahbakhti, Gordon McTaggart-Cowan, Advances in Vehicle and Powertrain Efficiency of Long-Haul Commercial Vehicles: A Review, 2023

[8] **E M Vieru**, D Iozsa, L Ilea and G Frățilă, Influence of air flow in the lateral areas of a tractor unit on its, aerodynamic performance, The 10th International Conference on Advanced Concepts in Mechanical Engineering (ACME 2022), Iasi, 2022, doi:10.1088/1757-899X/1262/1/012075

[9] Wei Gao, Yuping He, Deng Zhaowen, A Comparative Study of Tail Air-Deflector Designs on Aerodynamic Drag Reduction of Medium-Duty Trucks, 2022

[10] L Scurtu, M I Gheres, Numerical evaluation of vehicles aerodynamics in platoon using CFD simulation, The XXXI-st SIAR International Congress of Automotive and Transport Engineering "Automotive and Integrated Transport Systems" (AITS 2021), Chisinau, 2021, doi:10.1088/1757-899X/1220/1/012024

[11] A A Markina, A D Lukashuk, S N Chepkasov, A V Starovoytenko, Improving aerodynamic characteristics for drag reduction of heavy truck, Mechanical and Automation Engineering for Industry, 2020, DOI 10.1088/1757-899X/862/3/032032

[12] Yifan Gan, Linghao Li, Optimization of Aerodynamic Profile of Ground Vehicle, 2023 2nd International Conference on Aerospace, Aerodynamics and Mechatronics Engineering (AAME 2023), Beijing, 2023, DOI 10.1088/1742-6596/2569/1/012068

[13] J Liu, C Zhuang, S Liu and H M Zhou, Numerical simulation of heavy truck's aerodynamic noise, 2nd International Conference on Numerical Modelling in Engineering 19–22 August 2019, Beijing, 2019, doi:10.1088/1757-899X/657/1/012070

[14] L Ilea, D Iozsa, Wheels aerodynamics and impact on passenger vehicles drag coefficient, 2018, DOI 10.1088/1757-899X/444/7/072005

[15] SeongJin Cho, SangWook LEE, Aerodynamic Performance Analysis on Various Wheel Configurations of Commercial Vehicle, https://doi.org/10.21203/rs.3.rs-3826917/v1

[16] Ausilio Bauen, Inmaculada Gomez, Dave OudeNijeweme, Maria Paraschiv, Alternative Fuels Expert group report, ISBN 978-92-79-71857-1

[17] L 235/59 JURNALUL OFICIAL AL COMUNITĂȚILOR EUROPENE 17.9.1996. DIRECTIVA 96/53/CE A CONSILIULUI din 25 iulie 1996 de stabilire, pentru anumite vehicule rutiere care circulă în interiorul Comunității, a dimensiunilor maxime autorizate în traficul național și internațional și a greutății maxime autorizate în traficul international

[18] D Iozsa, C Stan, L Ilea, Study on the Influence of the Convoy Rolling over Aerodynamic Resistance, CAR2017 International Congress of Automotive and Transport Engineering - Mobility Engineering and Environment 8–10 November 2017, Pitesti, 2017, doi:10.1088/1757-899X/252/1/012035

[19] Wolf-Heinrich Hucho, Syed R. Ahmed, AERODYNAMICS OF ROAD VEHICLES, Society of Automotive Engineers, 1998, ISBN 0768000297, 9780768000290

[20] Eddy Willemsen, Kurt Pengel, Herman Holthusen and Albert Kupper (2011), Automotive Testing in in the German-Dutch Wind Tunnels, New Trends and Developments in Automotive Industry, Prof. MarcelloChiaberge (Ed.), ISBN: 978-953-307-998-8, InTech

[21] Odenir de Almeida, Rodrigo Mendes Alves, Validation of Experimental and Numerical Techniques for Flow Analysis over an Ahmed Body, International Journal of Engineering Research and Applications, 2017, DOI: 10.9790/9622-0704036371

[22] *** https://www.worktruckonline.com/10140905/history-of-the-first-truck-1896, accesat la 03.11.2024

[23] *** https://www.ontheroadtrends.com/history-and-development-of-the-truck/?lang=en, accesat la 06.01.2025

[24] *** https://en.wikipedia.org/wiki/Mercedes-Benz_Actros, accesat la 06.01.2025

[25] *** https://www.daimlertruck.com/en/newsroom/pressrelease/mercedes-benz-eactros-600-is-international-truck-of-the-year-2025-52835440?modal=asset-modal-uid-30903, accesat la 09.01.2025

[26] *** https://www.leylandtrucksltd.co.uk/en-gb/about-leyland-trucks/leyland-history, accesat la 11.01.2025

[27] *** https://www.mercedes-benz-trucks.com/ro/ro/trucks/eactros-600.html, accesat la 11.01.2025

[28] *** https://en.wikipedia.org/wiki/Semi-trailer_truck, accesat la 11.01.2025

[29] *** https://en.wikipedia.org/wiki/Chassis_configuration, accesat la 12.12.2024

[30] *** https://www.euload.com/info.php?catID=26, accesat la 22.02.2025

[31] *** https://op.europa.eu/webpub/eca/special-reports/intermodal-freight-transport-08-2023/ro/, accesat la 15.03.2025

[32] *** https://www.audi.ro/stories/aerodinamica-lupta-pentru-fiecare-miime, accesat la 12.11.2024

[33] *** 15 https://www.scdigest.com/ASSETS/NEWSVIEWS/12-09-27-1.php?cid=6252, accesat la 02.11.2024

[34] *** https://www.truckanddriver.co.uk/latest-stories/thinking-about-the-rare-daf-3200-ati-an-obscure-and-interesting-truck-from-the-early-90s/, accesat la 06.02.2025

[35] *** https://en.wikipedia.org/wiki/Wake_turbulence, accesat la 03.11.2024

[36] *** https://www.inverse.com/innovation/tesla-semi-price-specs, accesat la 09.01.2025

[37]***https://transporteprofesional.es/noticias-fabricantes/marcas-camion/mercedes-benz/nuevas-versiones-del-actros-y-arocs-de-mercedes, accesat la 06.01.2025

[38]***https://www.daimlertruck.com/en/newsroom/pressrelease/second-generation-of-mirrorcam-mercedes-benz-trucks-is-evolving-some-important-details-of-the-mirror-camera-system-51930556, accesat la 06.01.2025

[39] *** https://www.daimlertruck.com/en/newsroom/pressrelease/economy-from-goodaerodynamics-the-new-actros-is-trimmed-for-efficiency-45659918, accesat la 06.01.2025

[40] *** https://www.greencarcongress.com/2012/09/mbaero-2010918.html, accesat la 02.03.2025

[41] *** https://www.volvotrucks.ro/ro-ro/news/press-releases/2024/jan/new-more-powerful-engine-for-volvo-fh16-gives-maximized-productivity.html, accesat la 06.01.2025

[42]***https://www.daf.com/en/news-and-media/news-articles/global/2023/12-05-2023-new-generation-daf-xf-450-crowned-green-truck-2023, accesat la 06.01.2025

[43] *** https://www.autotrader.co.za/commercial/news-and-advice/transportation-news/uncovered-why-the-fh-is-one-of-the-most-aerodynamic-trucks-around/10376, accesat la 06.01.2025

[44] *** https://www.carbodydesign.com/2011/11/mercedes-benz-aero-trailer-concept/, accesat la 09.02.2025

[45] *** https://www.cargobull.com/ro/presa/2021/ecogeneration, accesat la 09.02.2025

[46]***https://www.fleetequipmentmag.com/saving-fuel-improved-truck-trailer-aerodynamic/, accesat la 09.02.2025

[47] *** https://www.fleetequipmentmag.com/aerodynamic-heavy-duty-truck-wheel-covers/, accesat la 09.02.2025

[48] *** https://www.volvotrucks.ro/ro-ro/trucks/electric.html, accesat la 09.02.2025

[49] Miguel A. González Hernández, Ana I. Moreno López, Artur A. Jarzabek, José M. Perales Perales, Yuliang Wu and Sun Xiaoxiao, Design Methodology for a Quick and Low-Cost Wind Tunnel, 2013, DOI: 10.5772/54169

[50] *** https://climate.ec.europa.eu/eu-action/transport-decarbonisation/road-transport/heavy-duty-vehicles_en, accesat la 20.04.2025

[51] *** https://www.tesla.com/semi, accesat la 09.02.2025

[52]***https://road-safety.transport.ec.europa.eu/eu-road-safety-policy/priorities/safe-vehicles/archive/safety-design-needs/heavy-goods-vehicles_en, accesat la 09.02.2025

[53] *** https://www.volvotrucks.com/en-en/news-stories/press-releases/2022/dec/volvo-trucks-cuts-fuel-use-in-road-test.html, accesat la 10.02.2025

[54] *** https://www.daimlertruckshuntingwood.com.au/blog-posts/fuel-efficiency-fore-new-actros-13-litre-delivers-fuel-cuts-four-cent, accesat la 10.02.2025

[55] *** https://en.wikipedia.org/wiki/Volvo_FH, accesat la 10.02.2025

[56] *** https://www.horiba.com/aut/mobility/products/wind-tunnel-balance/, accesat la 10.02.2025

[57] Cihan Bayındırlı, Yahya Akansu, M. Sahir Salman, The Determination Of Aerodynamic Drag Coefficient Of Truck and Trailer Model By Wind Tunnel Tests, 2016, International Journal of Automotive Engineering and Technologies 5(2):53, DOI:10.18245/ijaet.11754

[58] *** https://ro.wikipedia.org/wiki/Inteligen%C8%9B%C4%83_artificial%C4%83, accesat la 04.04.2025

[59] Jiaqing Kou, Tianbai Xiao, Artificial intelligence and machine learning in aerodynamics, 2024, DOI:10.3934/mina.2024009

[60] *** https://www.navasto.de/resources/blog/artificial-intelligence-in-engineering/, accesat la 04.04.2024

[61] *** https://chatgpt.com/, accesat la 04.04.2025

[62] *** https://www.youtube.com/watch?v=1tjJmArxVBM, accesat la 10.02.2025

[63]***https://www.studocu.com/ro/document/universitatea-politehnica-din-bucuresti/dinamica-autovehiculelor/cap-3-rezistente-la-inaintare/10089286, accesat la 15.12.2024

[64]***https://blogs.vahak.in/what-are-the-different-categories-of-trucks-in-india/, accesat la 06.01.2025