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AERODYNAMICS OF ARTICULATED MULTILINK TRUCKS

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Abstract

Development of new generations of supersize heavy-duty highway trucks for cargoes transportation on long and super long distances between Europe, Asia and Far East is actual now. New trucks shall reduce amount of transport on roads and quantity of drivers, involved in the transportation, will raise economic efficiency and safety of transportations and reduce fuel consumption, CO_2, and harmful emissions. Multilink trucks (number of trailed links is three and more and the total truck length is above 40 m) are to achieve designated purposes and thus are under the scope in the article. The advantages of multilink trucks are formed mainly by reducing the cost of power to overcome the aerodynamic resistance of each co-trailer unit in comparison with the head element. However, the airflow in every trailer-trailer gap has been not studied for articulated vehicles such as multilink highway trucks. This zone of the truck is characterized by a rather large length and height, and the condition of the air mass is influenced by airflow from the roof, side panels and area under the bottom of a truck links. A study of this task will help us to analyse aerodynamic losses mechanics in the trailer-trailer gap and to come to new effective and substantiated decision allowing power loss and thus fuel consumption reduction. The study lists the general calculation method evaluating the aerodynamic characteristics of the multilink truck on the base of numerical simulation of fluid dynamics using Flow Vision software. During calculation, there were determined speed distribution and power lines along the truck, the distribution of pressure on the truck surface, power and full drag coefficient. The results obtained allowed numerically evaluate the effect of the distance between the links on fuel consumption for multilink trucks and define the desired changes in their design.

Keywords: *truck, aerodynamic resistance, articulated truck, trailer-trailer gap, modelling*

1. Introduction

One of the perspective strategies of increase of fuel economy and improvement of ecological characteristics of heavy-load vehicles realized in world automotive industry is improvement of their aerodynamic characteristics. It consists in creation of a continuous flow of air, which is reached by change of a form of the vehicle, use of hinged elements, fairing, spoilers, etc. [1]. It is quite explainable as one of the essential factors having impact on fuel consumption of cars at the movement at big speeds is aerodynamic resistance [2]. Results of researches [2, 3] show that at increase in speed of the movement from 60 to 100 km/h fuel consumption for overcoming of aerodynamic resistance of the truck increases to 100 km/h in 2.5 … 3 times.

For more detailed research of aerodynamic processes carry out full-scale tests of vehicles, and also testing in wind tunnels of models of trucks in the reduced scale. The approximate assessment in engineering practice is carried out on the basis of known empirical formula and semi-empirical-formula dependences [2]. Thanks to development of numerical methods and computing opportunities of the computer, equipment aerodynamic investigations on the basis of computer modelling of tests (virtual tests) are widely adopted. In comparison with full-scale tests computer modelling allows to implement a wide variation the studied parameters, to provide repeatability of conditions of computing experiment and more operational receiving result, and also significantly smaller cost of carrying out experiment.

Data of researches [5-7] show that application of opportunities of a modern computing gas dynamics on the basis of finite volume method for the solution of problems of an external flow of vehicle air environment gives the chance of creation of a picture of a flow, research of distributions of speed, pressure on a truck surface, and also forces operating on separate elements of a design of vehicle.

The flow of air in trailer-trailer gap is a little studied question for articulated vehicles such as trailer-trailer trucks. This zone of trailer-trailer truck is characterized by rather big length and height, and the condition of air mass in it is subject to influence of oncoming flows of air from a roof, sidewalls, and a sub bottom zone of a link of the articulated multilink truck. Research of this question will allow to analyse mechanics of aerodynamic losses in trailer-trailer gap and to define the effective and reasonable solutions allowing lowering a loss of power and by that fuel consumption.

2. Multilink truck with active (tractive) links

For the countries of the Customs Union creation and application of multi-link trucks allow to reveal the transit potential of Russia, Belarus and Kazakhstan on a new level. Therefore, studies to enhance their safety remain in the spotlight. The project, implemented by Joint Institute of Mechanical Engineering and Minsk Automobile Plant (MAZ), with the support of the Ministry of Industry of the Republic of Belarus, involves the creation of an experimental truck with active links (Fig. 1).

Fig. 1. Experimental multilink truck MAZ-2010

Carrying out rated impact assessment The calculation of the influence of trailer-trailer gap on aerodynamic and fuel and economic characteristics was carried out using the example of articulated multilink truck for high-speed transportations of large volumes of loads on long distance, international and transcontinental routes [4]. The considered multilink truck contains two gaps between links (Fig. 2). Their availability leads to emergence of essential vortex formations at the movement at a high speed. Moving along a roof and sidewalls, the airflow reaches a gap and breaks in it, forming the volume of strongly condensed and swirled air, which interacts with the basic flow, which is flowing round the truck and increases its aerodynamic resistance.

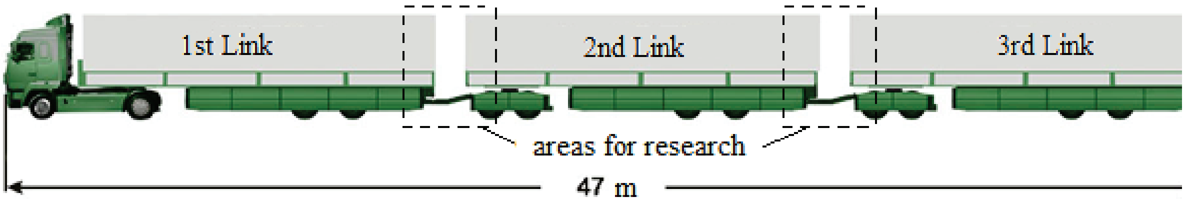

Fig. 2. The articulated multilink truck

3. Method of calculation

The main stages of the calculation method for estimating the aerodynamic characteristics of a multilink truck on the basis of numerical modelling of gas dynamics processes: creation of CAD-model, preparation of calculation CAD-model, creation and the description of grids, the description of initial and boundary conditions of modelling, calculation and processing of results. Let us consider the implementation of the calculation methodology for the research object – articulated multilink truck, using the Siemens PLM NX and Flow Vision software complexes.

For carrying out computational researches used the modelling software Siemens PLM NX. The 3D model of the object is a multilink truck. A computational model is a closed volume with a multitude of surfaces including the object and the area imitating the environment, in which the air masses move relative to the object.

At the stage “Preparation of the computational CAD-model”, the 3D model of the articulated multilink truck was adapted. For this purpose, a procedure was performed to remove duplicate surfaces, lines, and nodes, merge surfaces, group surfaces depending on the type of boundary conditions specified on them. As a result, the number of faces is reduced and the geometry of the model of the road train is adjusted so that it becomes suitable for constructing a calculation mesh.

The calculation area is a parallelepiped with dimensions of 100×15×12 m. The external boundaries of the computational domain are chosen relative to the size of the object located inside the object from the point of view of sufficiency for realization of the movement of the truck in unlimited space (Fig. 3).

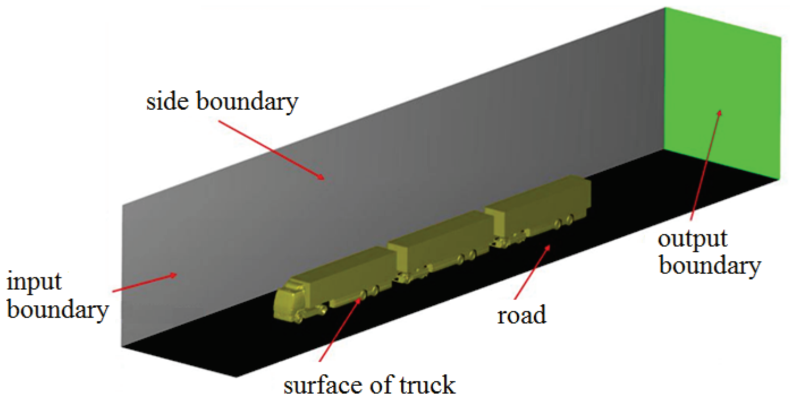

Fig. 3. The calculation area with model of the multilink truck

The calculated mesh is constructed in software complex FlowVision (Fig. 4 and 5).

The airflow around the vehicle during its motion occurs in a turbulent mode (the Reynolds number is Re > 10^6). In this case, the solution of applied problems of modelling the process of turbulent flow around is carried out by solving the system of Navier-Stokes equations [8]:

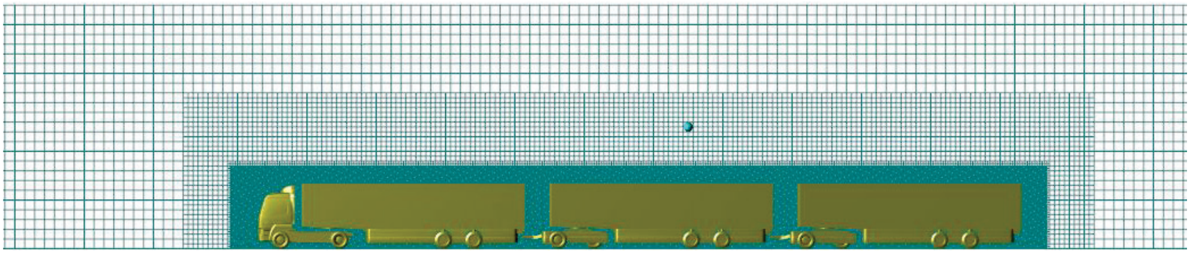

Fig. 4. The calculation mesh in median plane of the multilink truck

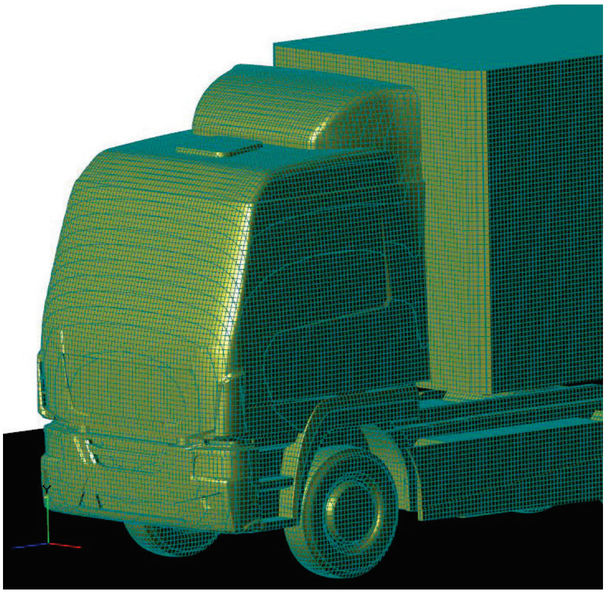

Fig. 5. The calculation mesh on the multilink truck surface

$$\frac{\partial \overline{u_i}}{\partial \overline{x_i}} = 0,$$
$$\frac{\partial \overline{u_i}}{\partial t} + \frac{\partial \overline{u_j u_i}}{\partial x_j} = -\frac{1}{\rho} \cdot \frac{\partial \overline{p}}{\partial x_i} + \frac{1}{\rho} \cdot \frac{\partial}{\partial x_i}\left[\mu\left(\frac{\partial \overline{u_i}}{\partial x_j} + \frac{\partial \overline{u_j}}{\partial x_i}\right) - \overline{u_i' u_j'}\right], \tag{1}$$

x_i, x_j – the directions of the Cartesian coordinate system,
u_i, u_j – the velocity components in the direction of the corresponding axes,
p – pressure,
t – time,
ρ – gas density,
μ – coefficient of dynamic viscosity [8].

In the formulation of the problem under consideration, the required functions are the velocity of the airflow of the surface of the truck and the pressure on it. To solve the Navier-Stokes equations, a κ-ε turbulence model is chosen [8, 9].

4. Simulation and results

Modelling is performed for the case of motion truck with a constant speed V = 85 km/h. The longitudinal component of the velocity was equal to the speed of the incoming flow (the speed of the truck). During the development of computer models, it is assumed that the flow is by airflow at normal atmospheric pressure ($p_0 = 10^5$ Pa) and a constant temperature of 20ºC. Soft boundary conditions are set at the output boundary of the calculation area (Fig. 4), when, in addition to leakage, it is possible for air to flow through this surface. On the upper and lateral surfaces of the computational domain, the conditions of the wall (solid body) are established, but with zero friction (the condition of flow slip at the wall), which made it possible to simulate the real conditions of an unlimited region in a limited space of the computational domain. To ensure the correctness of the simulation, the movement of the roadway with the speed of the truck is taken into account.

Based on the calculation results, the following were obtained: the distribution of velocity and current lines along the truck, the distribution of pressures on the surface of the truck, the values of the force and the coefficient of total aerodynamic resistance.

Figure 6 shows the distribution of speed and current lines along the articulated multilink truck.

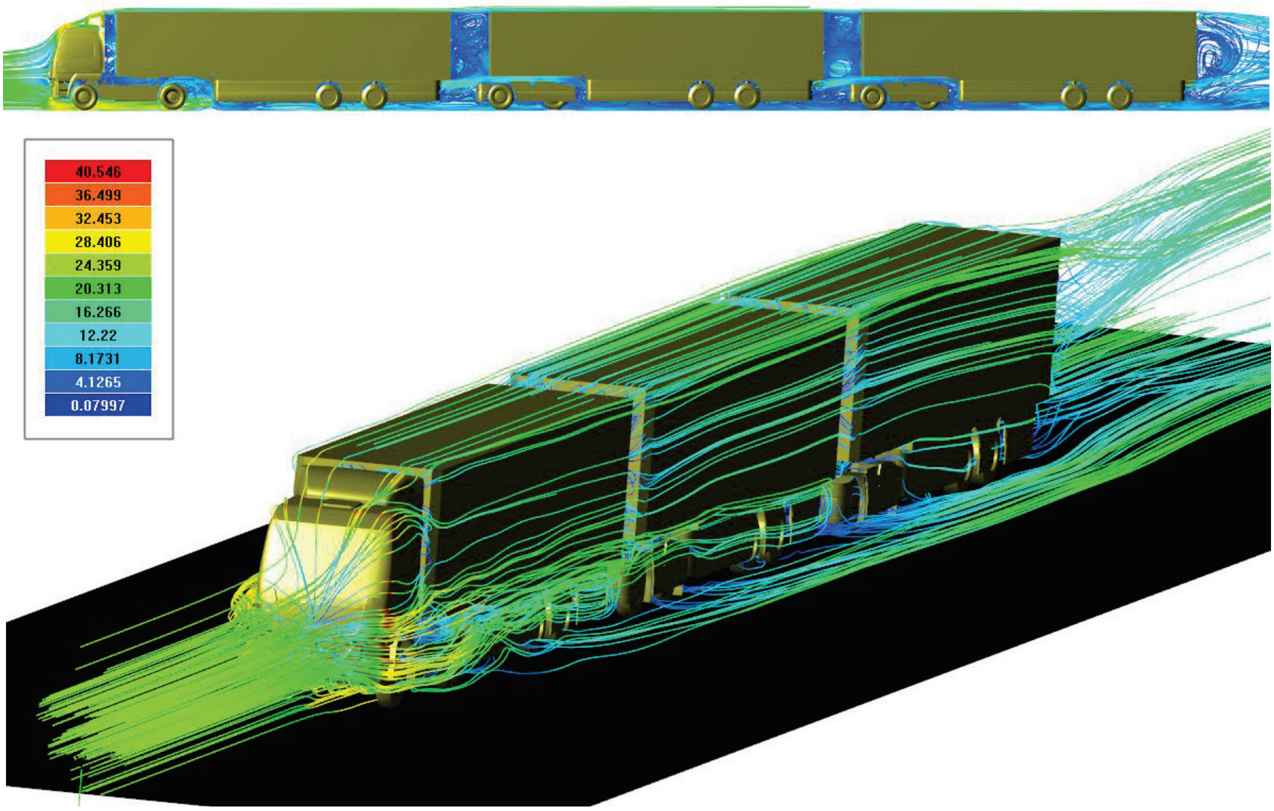

Fig. 6. The distribution of speed and flow lines along the articulated multilink truck

In the space between the links, there is a zone of low pressure. Therefore, airflows, that move along the surface of the truck move into this zone and form two vortex structures with the opposite direction of air rotation (Fig. 7). The upper vortex is formed by a stream that is torn from the roof, and the lower vortex is formed by a stream ejected from the bottom zone.

The simulation results showed that the main contribution to the aerodynamic resistance of the articulated multilink truck is made by the 1st link (Tab. 1). In addition, the data obtained make it possible to assert that each subsequent link has less aerodynamic resistance (Tab. 1). This explains the decrease in vortex formation in the gap between the links (Fig. 7).

Tab. 1. Values of forces and coefficients of aerodynamic resistance of the articulated multilink truck

	Pressure force F_p, N	Friction force F_f, N	Full aerodynamic force F_X, N	Pressure coefficient C_p	Friction coefficient C_f	Coefficient of total aerodynamic resistance C_X
1st link	1789.3	105	1894.3	0.484	0.028	0.512
2nd link	461.1	89.6	550.7	0.125	0.024	0.149
3rd link	431.1	68.9	500	0.117	0.019	0.135

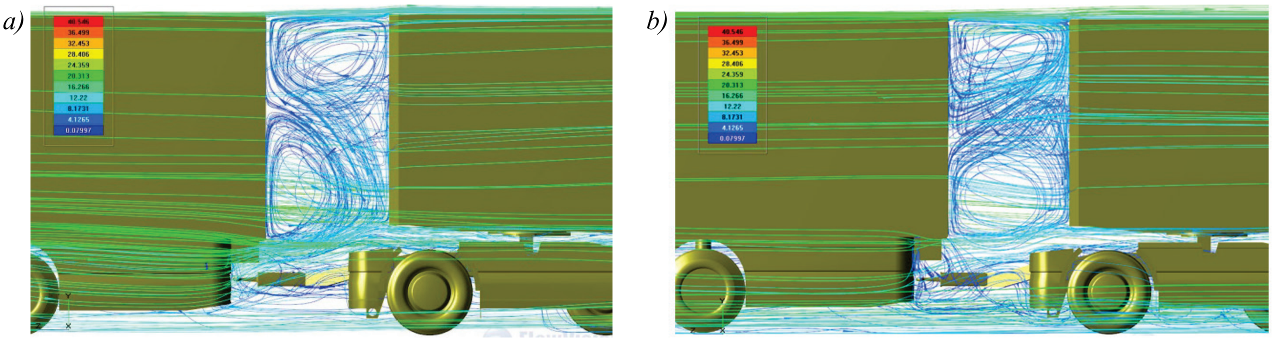

Fig. 7. The distribution of speed (m/s) and flow lines along the articulated multilink truck: a) gap between 1st u 2nd links, b) gap between 2nd u 3rd links

Based on the obtained data, the dependence of the coefficient of aerodynamic resistance C_X on the distance between the links was determined by calculation (Fig. 8). Approximating these data, an equation is obtained showing the dependence $C_X = f$ (L):

$$C_X = 0.0927L^2 - 0.0249L + 0.6879. \tag{2}$$

The correlation coefficient of the resulting mathematical dependence $R^2 = 0.98$.

From the graph (Fig. 8), it can be seen that the presence of distance (clearance) between the links increases by 16% the total aerodynamic drag of the multilink truck. Dependence $C_X = f$ (L) shows that with increasing distance L between the links of the road train, additional resistance increases, and accordingly the value of the total coefficient of aerodynamic resistance of the truck. Therefore, increasing the distance between links by more than 1 m causes a significant nonlinear increase in aerodynamic resistance.

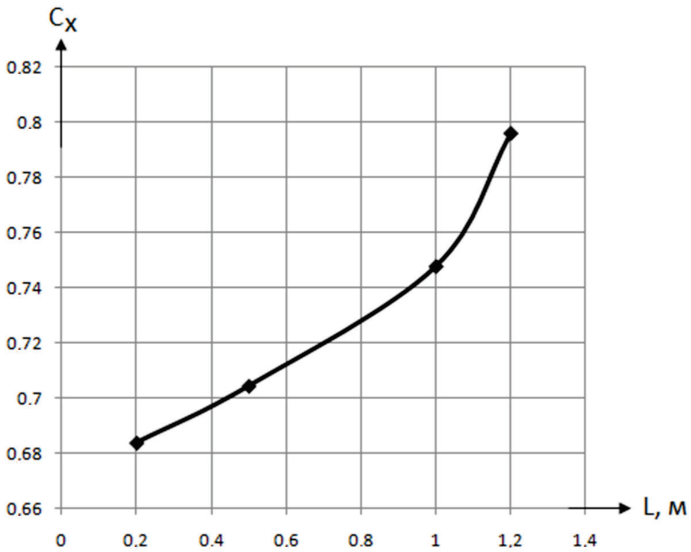

Fig. 8. Dependence of coefficient of aerodynamic resistance of the articulated multilink truck on distance between links

In life, an important indicator of the fuel economy of a car is fuel consumption, expressed in litres per 100 km of travelled. To calculate the fuel consumption Q_s used the dependence [10]:

$$Q_s = \frac{100 g_e N_e}{\rho_T V}, \tag{3}$$

where:

g_e – the specific fuel consumption determined by the multi-parameter characteristic of the engine under steady-state motion,

N_e – the power required to overcome the resistance to movement,
ρ_T – fuel density 820 kg/m^3,
V – speed of the truck.

Dependences $Q_s = f(V)$ (Fig. 9) show that the fuel loss of the multilink truck with a gap between links increases with increasing speed. At speed of 90 km/h, fuel losses amount to 3.5 l/100 km, which is 6% of the multilink truck fuel consumption. Reducing such fuel losses with an average annual mileage of 100 thousand km, [11] will save the owner of vehicle to 3,500 litres of fuel.

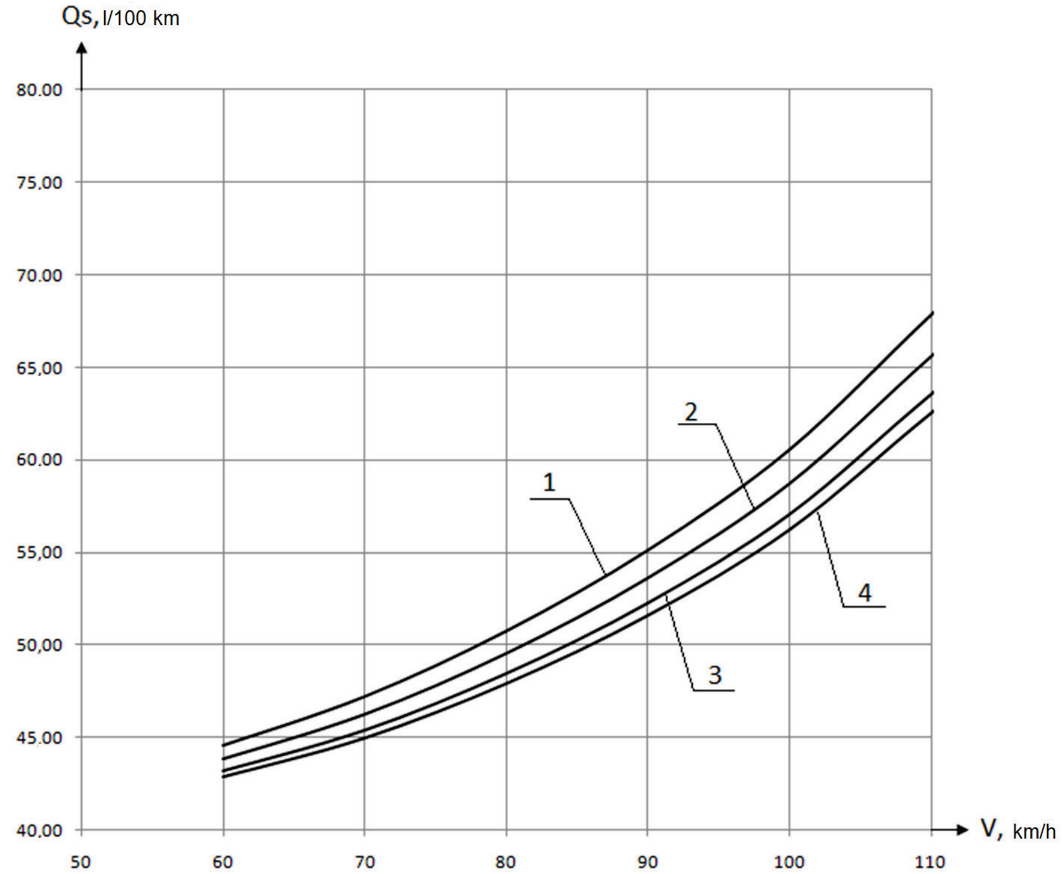

Fig. 9. The fuel characteristic of the established movement on the highest gear stage of the multilink truck: 1 – fuel consumption in the presence of 2 gaps of 1.2 m between the links, 2 – fuel consumption in the presence of 2 gaps in 1 m, 3 – fuel consumption in the presence of 2 gaps in 0.5 m, 4 – fuel consumption in the presence of 2 gaps in 0.2 m

5. Conclusion

The main provisions of the calculation methodology for estimating the aerodynamic characteristics of the multilink truck on the basis of numerical modelling of gas dynamics with the use of the software package Flow Vision are presented. As a result of the calculation, the distributions of velocity and current lines along the multilink truck, the distribution of pressures on the surface of the multilink truck, the values of the force and the coefficient of total aerodynamic resistance were obtained.

The influence of the distance between links on the coefficient of aerodynamic drag is analysed on the basis of computer simulation of the process of flow around the multilink truck by an airflow. The obtained results made it possible to numerically estimate the effect of the distance between links on fuel consumption of the multilink truck.

Based on the calculated data, the dependence of the coefficient of aerodynamic drag of the truck on the distance between the links is obtained.

To reduce fuel consumption, it is advisable to reduce the distances between the links of the multilink truck or to exclude them due to special devices or structural elements. Calculations indicate (Fig. 8) that in order to reduce losses, it is necessary to improve the processes of moving airflows in the gap space and the sub bottom area of the truck. From this point of view, it is reasonable to use an adjustable coupling device: at low speeds, the long coupling provides the necessary manoeuvrability, while at a large speed it reduces the aerodynamic losses.

In order to minimize aerodynamic losses, the effective value of the distance between the links can be taken from the range 0.4 ... 0.5 m, which will allow reducing the fuel consumption to 5% and eliminating the contact of the link elements during the movement of the road train.

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