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RESEARCH ARTICLE

Effect of Inner Air Flow on the Aero-dynamics of the Car

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Abstract

The increase of frontal aerodynamic drag of the car, connected with the move of the air flow through the engine bay depends on various factors. Among them there's an interference of inner and outer air flow, which leads to the alteration of pressure on the surface of the car body in the front part of the car. The nature of this phenomenon, associated with the move of the air flow through the engine bay, is connected with the increase of pressure around inlet openings and with the increase of rarefaction on the surface of the car body, situated at an angle to the oncoming airflow. As a result of investigations, it was found that the degree of influence internal air flow on aerodynamic drag depends on the design and shape of the car body, but mainly by the air consumption through the engine bay.

Keywords

aerodynamic resistance of the car, air flow through the engine bay, pressure distribution, interference, computational modeling

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As it's known, the airflow passing through the engine bay leads to an increase in the coefficient of aerodynamic drag. In spite of the fact that this effect was discovered long ago, its mechanism has not been studied to the end yet. There are several explanations for this. For example, the most widely-spread theory, explaining this regularity is based on law of impulse conservation (Schütz, 2013; Williams, 2003). There is an opinion that aerodynamic drag of the car depends on location of the air outlet from the engine bay (D′Hondt et al., 2010). Sometimes the effect of inner air flow on the aerodynamics of the car is connected with the drag of the inner passage through which the air moves (Schütz, 2013; Williams, 2003; D′Hondt et al., 2010; Marion, 2010; Katz, 1995). While the main thing is the air consumption through the channel. In another case the alteration of aerodynamic drag of the car is connected with the interference of air flow, coming out of the engine bay, but at the same time the mecha-nism of this phenomenon is not revealed (Schütz, 2013; Baeder et al., 2012; Baeder et al., 2013; El-Sharkawy et al., 2011; Tesch et al., 2010).

Force of frontal drag of cooling system may be evaluated using the equation of conservation of impulse:

$$F_{cs} = m \cdot \left(V_\infty - V_e \cdot \cos\gamma\right), \quad (1)$$

where m – mass air consumption through the motor bay, V_∞ and V_e – the speed of air coming in and out of the engine bay, γ – the angle of the air flow coming out of the engine bay.

Let's examine model M90L, having through passage with uniform section (Fig. 1). If to suppose that air doesn't undergo any drag inside the passage and the speed of air, coming into and out of the passage is equal, then force $F_{cs} = 0$. In this case, it turns out that air movement inside the model should lead to the decrease of its aerodynamic drag by the amount of pressure force, acting on the plate of the locking channel, when there is no inner flow. Let's examine the second variant, when model M90P has an air outlet at a right angle to the oncoming flow (Fig. 2). If the speed of air, coming into and out is equal (when the square of its flow area section is equal), and cosγ = 0. In this case $F_{cs} = m \cdot V_\infty$, that is the force of aerodynamic drag will be proportional to the air consumption through the internal space of the model. Formula (1) is often used in some theories but is not proved experimentally.

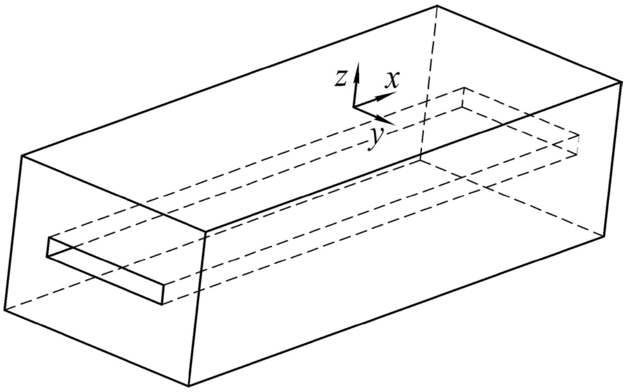

Fig. 1 Model of parallelepiped with internal through channel

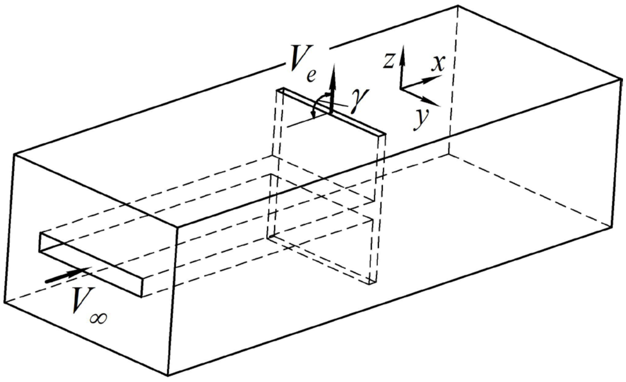

Fig. 2 Model of parallelepiped with internal channel, exiting at an angle γ=90º M90P

Given hypothesis, built on law of impulse conservation, has been tested. Investigations have been carried out by numerical methods (CFD). For this they used simple geometrical figures, which had width, height and length corresponding to the size of a car of middle class. The models had the square of flow area section of inlet openings equal to the square of an inlet opening of the car.

Model M90L had an internal through channel (Fig. 1). The effect of the inner flow was estimated as compared with the model with a closed inlet opening. The aerodynamic drag of the model, through which air flow passed, turned out to be by 1.5% more than the model without an inner channel had. This is significantly different from the calculations according to formula (1), why does it happen? Formula (1) doesn't consider the drag of the surface friction inside the channel, but this is not the main thing. In Fig. 3 we show the pressure distribution in horizontal and vertical plane of the model, appearing on the front panel. Line 1 corresponds to the model with a closed inner channel, line 2 corresponds to the model, through which the air flow passes. Zone I is situated against an inlet opening, which is indicated by lines 3. In this zone in consequence of air flow inside the model the pressure decreases, because of it the force of aerodynamic drag decreases. This process is described by formula (1). The air flow inside the model leads to a very different pressure distribution on the front panel. In zone III the pressure also decreases, but the front square of this zone is not big, and in contrast to zone II, on which the pressure, on the contrary, increases. That's why the result of this difficult process doesn't coincide with formula (1).

Frontal aerodynamic drag of the second model M90P, air flow in which turns by 90º, turned 6 % more than that of the model with a closed inlet opening. With the same air consumption aerodynamic drag of the model car increases much more significantly. To check this discrepancy models, which front part has chamfered corners, were examined.

Eight models with chamfered edges at angles α=60, 45, 30 and 20 degrees were considered. Four models didn't have air channel: M60, M45, M30 and M20 and four models with inner channel: M60P, M45P, M30P and M20P (Fig. 4).

In Fig. 5 the results of the investigation are represented. The force of the aerodynamic drag of the models with chamfered edges $F_{x\alpha}$ is given in regard to the force of the aerodynamic drag F_{x90} of model M90P Fig. 5a, where $F_{x\alpha}$ – force frontal aerodynamic drag of models MP90P, M60P, M45P, M30P and M20P. As expected, the models with chamfered edges have less aerodynamic drag, but at the same time, the proportion of the inner flow in a general aerodynamics of the models

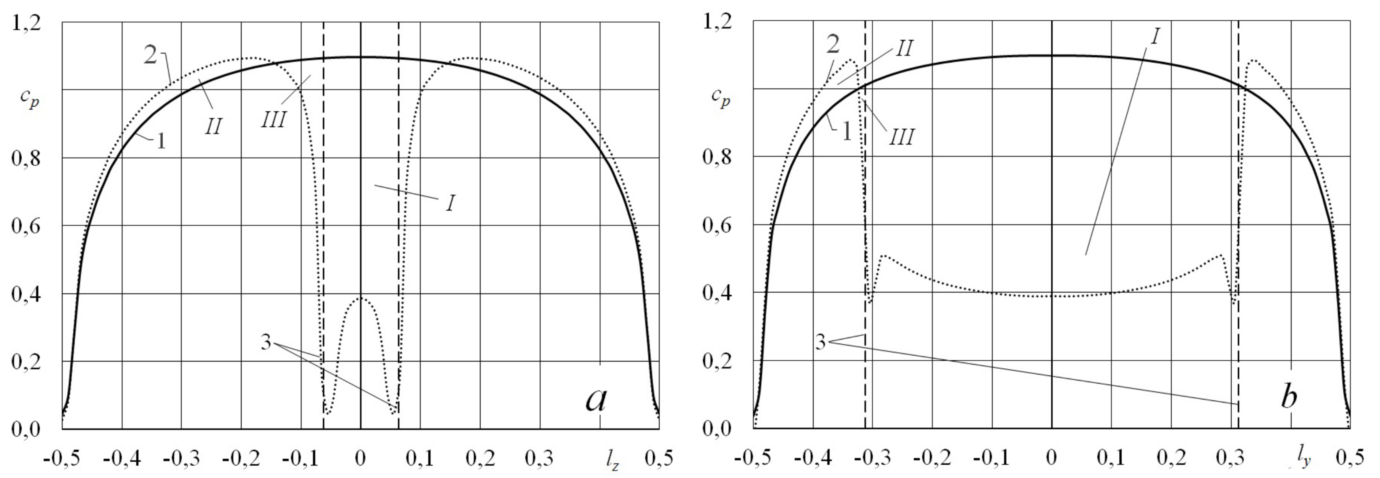

Fig. 3 Pressure distribution in horizontal *a* and vertical *b* plane of the model depending on the place of axes

increased much compared to the model with sharp edges. In Fig. 5b the relative force F_{xc}/F_{xo} is represented, associated with the passage of the air flow inside the model, where F_{xc} - force air drag of models (M90P, M60P, M45P, M30P and M20P) with an internal channel, Fxo - force air drag of models (M90, M60, M45, M30 and M20) without an internal channel. So, for example, aerodynamic drag of the models with chamfered edges α=30 increases by 16% when the air flow passes through. This doesn't correspond to formula (1). The comparison of mechanism of flow around of the models without inner passage M30 and models with air flow inside M30P will help uderstand why this is happening.

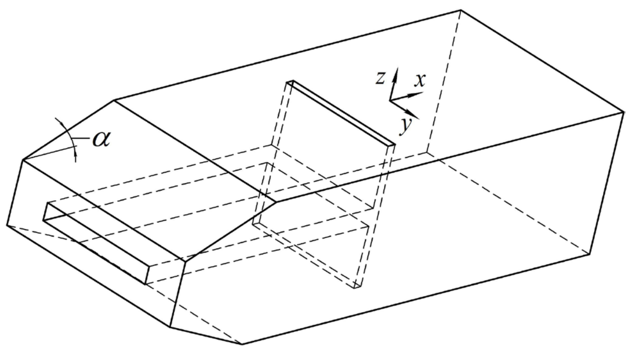

Fig. 4 Model of parallelepiped M30P with inner channel and chamfered edges

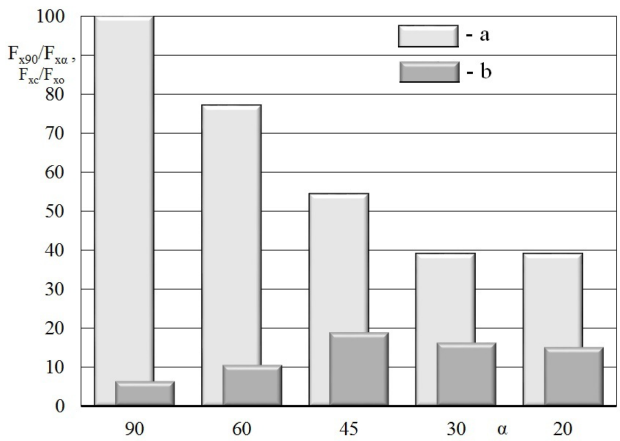

Fig. 5 The relative force of the aerodynamic drag models:
a – force of aerodynamic drag M90P, M60P, M45P, M30P and M20P compared to model M90P; b – relative force F_{xc}/F_{x0} of aerodynamic drag of models with opened and closed inner channel

The situation of flow around of models differs from each other greatly (Fig. 6 a part of the model is shows). On model *a*, which has no air channel, it is possible to single out two zones. They are central part *1*, which is situated perpendicularly to the air flow, here the air undergoes braking thanks to which there's maximum pressure. At point 2 air flow separates from the surface of the model as a result there's rarefaction on this surface. The flow around of model *b*, having inner channel, is more complicated. Model *b* has flow separation at point 3, one air flow around of model outside and the other goes through it. As a result of trajectory contortion in zone *4* added pressure increase is observed. This zone is situated along the whole perimeter of inlet opening. At point 5 air flow also separates from the chamfered surface of the model, but here there's a difference from the first model too. As the part of air goes through inner channel, the quantity of air, going outside the model, decreases. At point 5 flow separation less, as a result rarefaction decreases.

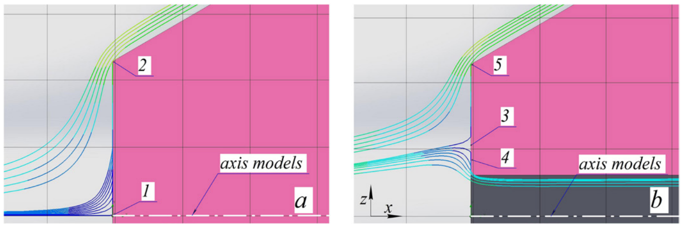

Fig. 6 Trajectories of air flow movement in longitudinal plane:
a – model M30; *b* – model M30P

Air flow inside the model is connected with multidirectional factors, influencing the front part of the model, on the one hand, pressure around inlet opening decreases, which leads to decreasing of force on the front panel (Fig. 7). On the other hand, pressure along the perimeter of inlet opening increases and this leads to increase of force of aerodynamic drag. Decrease of rarefaction on chamfered edges leads to decrease of force, influencing these panels, as this force is directed forward, that's why frontal force of aerodynamic drag increases.

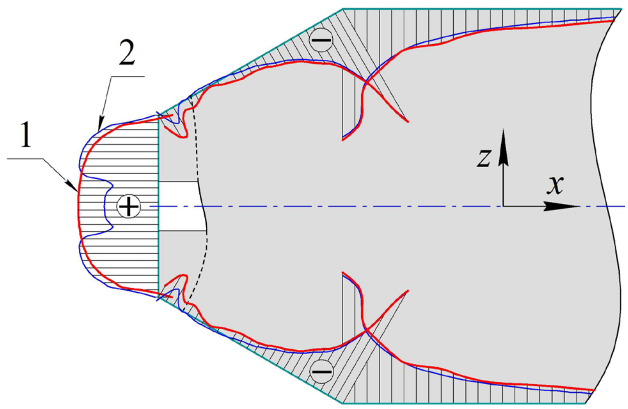

Fig. 7 Pressure distribution in longitudinal section of the model

The influence of the rarefaction, appearing on the chamfered edges of the models, can be seen at Fig. 8. At the picture, there are results, showing what part in the whole aerodynamics of the model belong to the forces, influencing the front planes. For model M90P there is one surface, for other models there are three surfaces, one – central and two – chamfered. Besides, in the picture it is shown what part in the whole aerodynamics of the model belong to just chamfered planes. They are of a great interest. Model M90P hasn't chamfered surfaces Air flow of this model separates at the extreme points and rarefaction appears on the side surfaces and doesn't influence for frontal aerodynamic drag at all. The process of flow around of model M60P differs little from model M90P, air flow separates only on the side surfaces. As for models M45P, M30P and M20P air flow separates on the chamfered panels, and air flow movement inside the model leads to the change of rarefaction on these panels. The result can be assessed if to compare models inside which the air passes *b* and models inside which the air doesn't pass *c*.

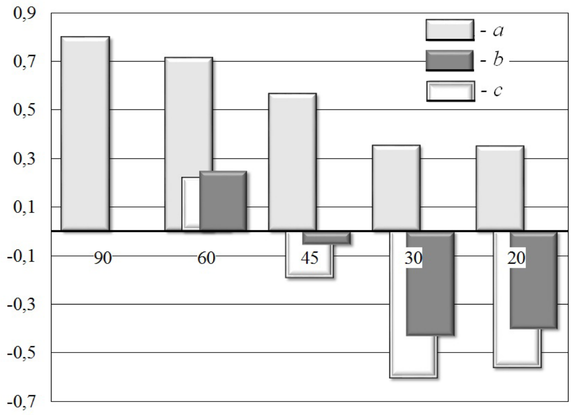

Fig. 8 Share of forces aerodynamic drag compared to the totaldrag of models: *a* – part of summary force, influencing the front panels (air passes through the models), *b* – the part of force, influencing the chamfered panels (air passes through the models), *c* – part of force, influencing chamfered panels of models without inner channel

In spite of the fact that the models had simple geometry, they show at a full extent what processes arise at the flow around of a real car. The car body has a more difficult construction that's why the process of interaction of air flow with its surface has not a clear character. In Fig. 9 pressure distribution is shown in longitudinal plane of the car. Interference of airflow with protruding parts of the car body and asymmetrical flow of the air through the inlet openings, influence of the road surface make it difficult to point out main factors of inner flow effect on the aerodynamics of the car. At the same time it's necessary to mention typical signs of flow around of the car body, which were noticed with the help of flow around of simple models. In the picture these zones are shown. The flow of air into inlet openings (zones 1) is few expressed, because it's neutralized by a flow, interacting with a bumper. Influence of zones 2 is apparent. On the contrary inlet openings decrease of pressure is seen (zones 3). In the zones of chamfered surface of the car body (zones 4) we can also see characteristic decrease of rarefaction of air, especially it's obvious on the lowest edge of the hood. On the top surface of the hood the change of rarefaction is not so evident as a little quantity of air flows through the upper opening. By increasing flow capacity of the upper opening, the effect will be greater.

Conclusions

1. Moving of the cooling air flow through engine bay of the car, as a rule, leads to the increase of its frontal aerodynamic drag and it is accompanied by quite complicated processes of interaction of outer and inner flows appearing on the car body surface of the car, especially in its front part.

2. Change of frontal aerodynamic drag under the influence of inside air flow is connected with interference of air flow, flow around the car outside and air flow, passing through the car.

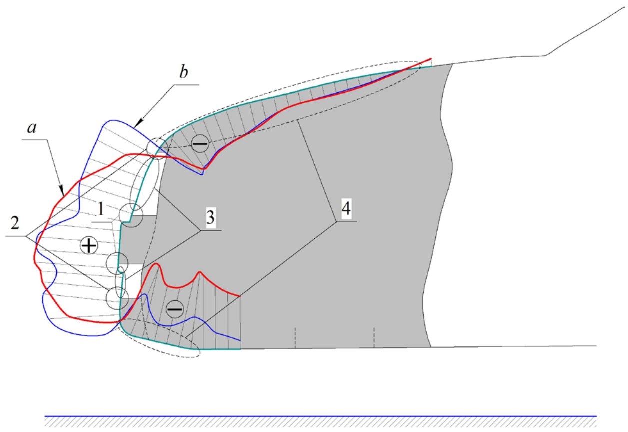

Fig. 9 Pressure distribution in longitudinal section of the car and typical zones of pressure change with air flowing through engine bay: *a* – air doesn't flow through engine bay; *b* – air flows through engine bay

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