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NON-UNIFORM BLOWING AND ITS APPLICATION FOR AERODYNAMIC EFFICIENCY IMPROVEMENT OF HIGH-SPEED TRAINS

Introduction

Turbulent Flow Control (TFC) is one of the most perspective directions of modern Fluid Dynamics. Its **practical actuality** can be demonstrated by the fact that due to typical sizes and speeds of modern vehicles (aircrafts, ships, trains, cars) the most of their surface is streamlined by turbulent flow mode. Turbulence, as one of the most complicated physical phenomena, holds a unique challenge place in the field of fundamental theoretical problems of classical fluid mechanics. Due to the well-known fact that turbulence causes the additional generating of a wide range spectra of vortical structures and initiates the process of strong energetic interaction between them, turbulent flow mode is characterized by substantial increment of energy loss and, as a result, additional friction. It is practically impossible to avoid the turbulent mode of streamline, but the efforts, directed to a purposeful modification of turbulent exchange mechanism can effectively reduce the friction drag of vehicles and, therefore, minimize the fuel consumption and harmful pollution into atmosphere. These factors became very actual in the world during last 45 years because of continuous growing the importance of energy efficiency, ecological safety and, accordingly, the search and implementation of various energy-saving technologies in different spheres of human activity and, primarily in the power engineering and transport sectors. So, investigations of possibility to control of turbulent mechanism development are actual not only from the point of view of classical fluid mechanics, but as a potential direction of further effective development and optimization of different engineering devices. In particular, this field of study is immediately applicable to wide range of modern high-speed vehicles.

1. Microblowing as a basis of proposed drag reduction methodology

One of the most perspective and currently intensively investigated methods of flow control with the aim of friction drag reduction is based on the technology of microblowing of fluid through the penetrable streamlined surface into the turbulent boundary layer, developing over it. Term “micro” means that the velocity of blowing, normal to streamlined surface, is negligibly small (traditionally not greater than 0.3% of free stream velocity). The principal idea of flow control by means mass of transfer through a streamlined surface is not new.

Technologies of suction and blowing began to be studied intensively since the 60s of the last century and many promising results have been obtained. Fig. 1 illustrates several aircrafts, whose wings were modified by porous sections. But at that time these technologies could not be practically implemented in volume production and use because of technological problems of making cheap samples of penetrable surfaces.

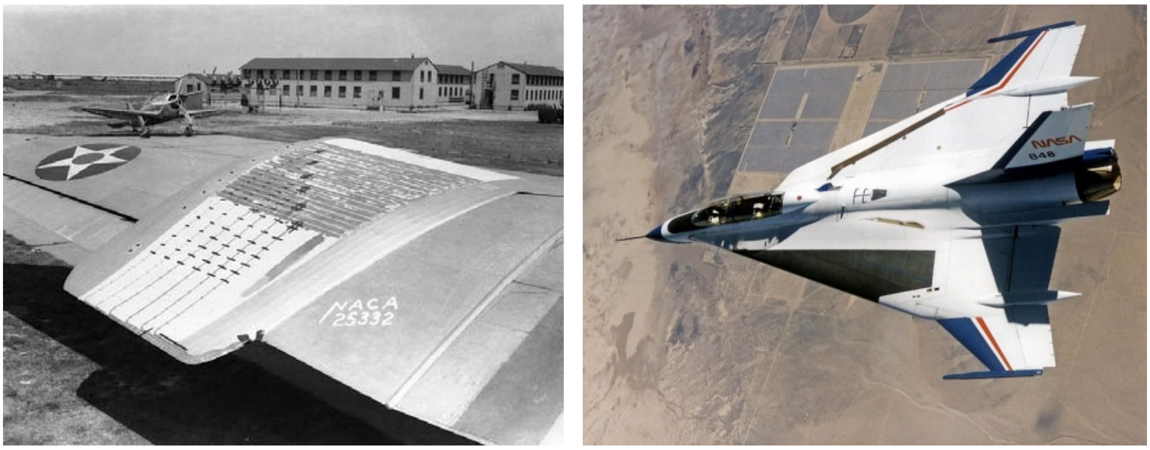

Fig. 1. Suction through the porous section of wings of experimental aircrafts:
Douglas B-18 (1941) (left) and F-16XL #2 (1996) (right)

2. Technical implementation aspects and perspectives

In addition, that is very actual in this connection, their long-term exploitation due to contamination has been hampered. Here it is important to note, that the problem of providing the long-term reliable exploitation of drag reduction methods without their properties degrading in time is common for all different techniques and it must be analyzed as very actual together with the rest of the considered method properties. But in this context the microblowing technique looks much better in comparison with suction due to possibility to blow the previously cleaned air.

Nowadays this method can be effectively technically realized on the base of new kinds of polymeric materials, having penetrable structure and negligibly small (in hydraulic sense) surface roughness, which open a wide range of perspectives in the future, in particular due to possibility to produce cheap enough porous elements of streamlined surface. In comparison with the other passive and active drag reduction methods the microblowing technique is much more effective. According to the results of detailed experimental researches, made by Hwang [1] and then by Prof. Kornilov [2], microblowing allows to substantially reduce local friction drag till 90%. This experimental fact is in a good agreement with results of numerical modeling, realized by Prof. Shkvar and his follower Danevskyi [3] for turbulent boundary layer, developing over a flat plate with local porous section (Fig. 2). Here it is very important to note the fact that microblowing acts only locally in the vicinity of streamlined surface, so it can't influence on the rest of aerodynamic characteristics like lift force and aerodynamic moment. There is one principal disadvantage of blowing – in case of its application for aircrafts blowing decreases the interval of angles of attack for streamline without separation. But in case of microblowing this tendency is not so actual due to negligibly small blowing velocity. On the other side, this technique is actual (and must be applied) just on the cruising flight mode of aircrafts, where due to great speed the angles of attack are small enough and, therefore, their reserve to critical value is big.

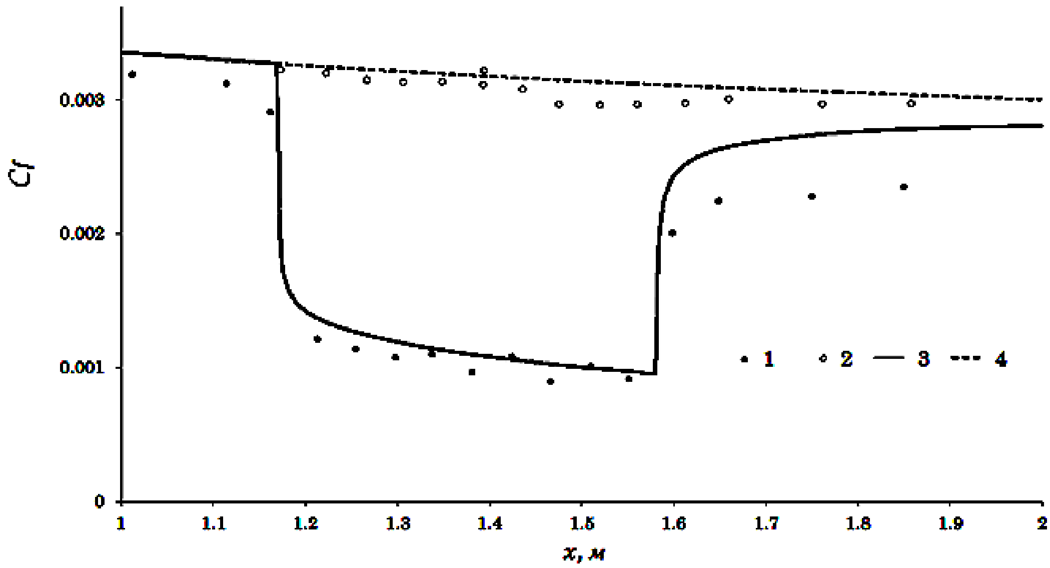

Fig. 2. Skin friction coefficient C_f distribution along direction of flow development x along flat plate with (1, 3) and without (2, 4) microblowing: 1, 2 – Kornilov's experiments [2], 3, 4 – Shkvar, Danevskiy numerical predictions [3]

In addition to traditional aviation sphere of this technology application we propose to apply it for high-speed trains (Fig. 3) and expect to get a significant benefit in this new and perspective field, having the following advantages: 1) microblowing in this case doesn't influence on motion stability and can't lead to separation streamline regime; 2) air for blowing can be taken from the nasal part of locomotive coach and then be redistributed with the help of compressor over the porous streamline surface. This approach will allow to reduce overpressure in the vicinity of forward stagnation point and, therefore, will promote to pressure drag reduction; 3) the blowing technology is very applicable to high-speed trains because it effectively acts, first of all, on friction drag and, according to previous item, can reduce pressure drag. These two components are the most actual for high-speed trains, because for this kind of vehicles the skin-friction coefficient is dominant (more than in two times greater) in comparison with a regional train (Fig. 4, [4]); 4) even for the highest trains speed 603 km/h=167.5 m/s

(M=0.506) flow can be considered as slightly compressible, so effects like shock waves and their strong interaction with boundary layer aren't actual and don't need to be accounted as factors that can influence negatively on the blowing efficiency.

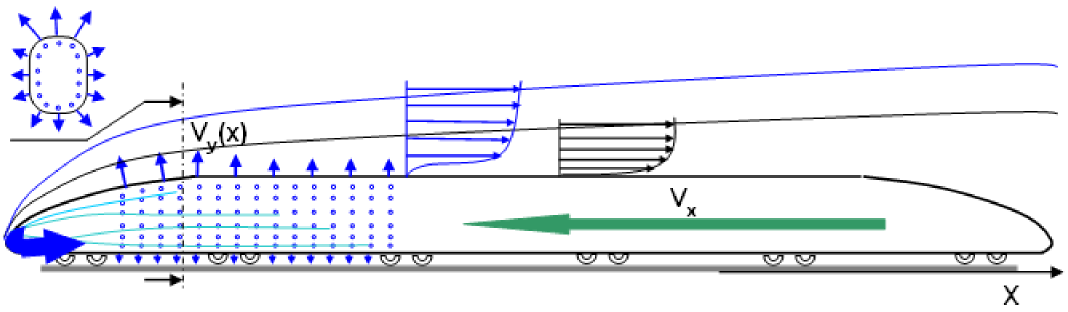

Fig. 3. The principal idea: to realize blowing through the part of streamline surface of high-speed train

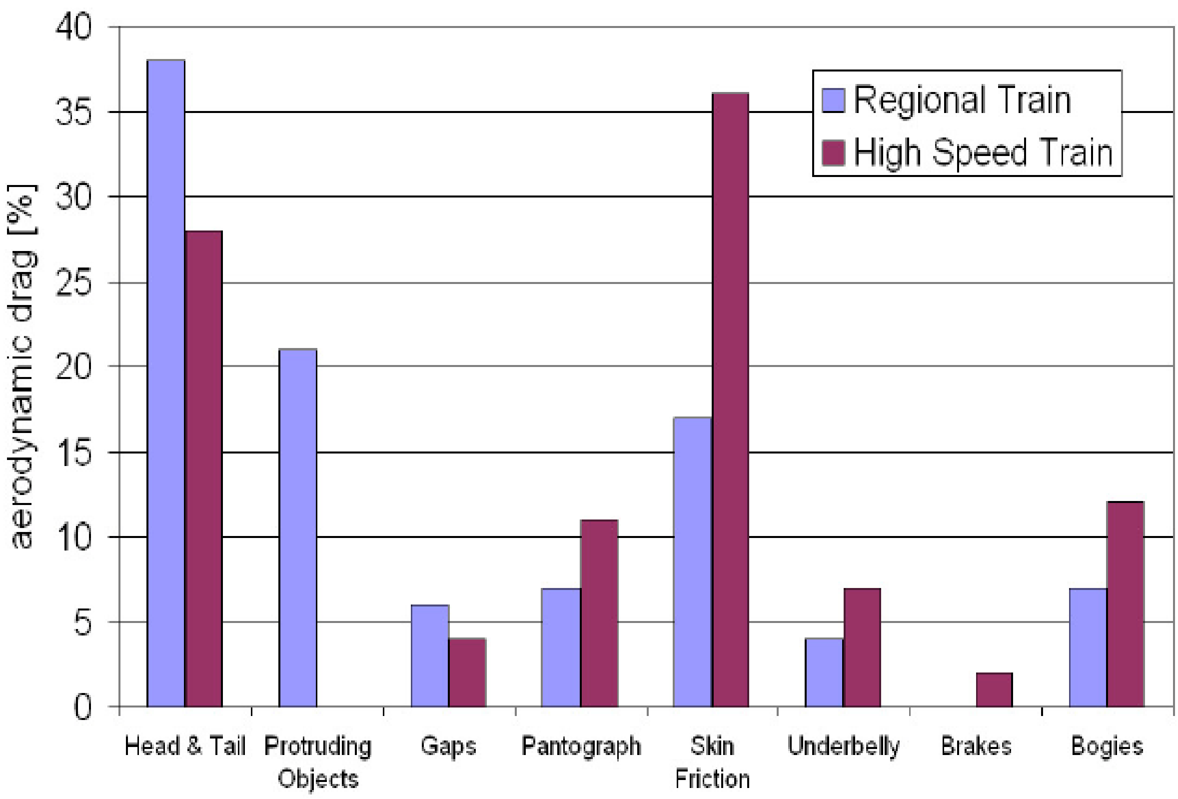

Fig. 4. Aerodynamic drag components for regional and high-speed trains [4]

Thus, the blowing technology is very perspective for high-speed vehicles, but until now its theoretical and experimental analysis was limited predominantly by cases of the simplest streamlined shapes (flat plate, airfoil) and uniform blowing with constant (both in space and time) parameters. We started to develop principally new strategy, based on application of non-uniform blowing, that will allow to: 1) decrease an air consumption, required for blowing realization; 2) generate the artificial anisotropy of the mean flow in the form of additional near-wall regular vortical systems, that will 3) realize effective interaction with the turbulence energy exchange process and 4) decrease for some favorable modes the dissipative mechanism of the disturbed turbulent motion and, as a result of this complex interaction, 5) expect the feedback in the form of skin friction coefficient reduction (Fig. 5).

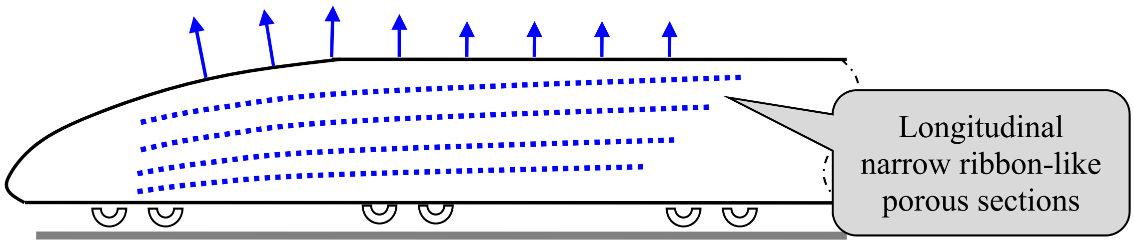

Fig. 5. One of possible realizations of non-uniform blowing

Conclusion

The proposed concept of non-uniform blowing through the streamlined surface of high-speed vehicles have been analyzed and discussed in various aspects. Its complete realization allows to get the substantial economic benefits in a wide range of practically important areas, associated with transportation and other industrial applications.

References

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