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Microblowing as an effective tool of drag reduction of modern high-speed vehicles

The advantages of high-speed train as an object of micro-blowing drag reduction application are introduced. Predictions of the turbulent boundary layer over permeable surface with different modes of micro-blowing have been presented and analyzed. The dependence between drag reduction effect and length of train body with realized micro-blowing and its intensity is established.

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 area is streamlined by the turbulent flow mode. One of the perspective and intensively investigating methods of TFC for friction drag reduction is based on the technology of microblowing the small amount of fluid (traditionally injecting velocity doesn’t exceed 0.3% of the free stream velocity) through the penetrable streamlined surface into the turbulent boundary layer (TBL). We propose to apply this method for the external surface of high-speed trains (HST), because the most actual (up to 85%) source of their drag is aerodynamic interaction [1]. The principal idea of the flow control by means of transfer mass 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. But at that time these technologies could not be practically implemented in mass production and use because of technological problems of making cheap samples of penetrable surfaces. Moreover, the microblowing looks like the most effective, reasonable and practically applicable method among the rest of known TFC technologies in case of its application to HST due to the following advantages:

1) it doesn’t influence on motion stability and can’t lead to flow separation;
2) it effectively acts, first of all, on friction drag (reduce it up to 90%) that is the most actual for very long bodies like train;
3) effects like shock waves, typical for aircraft’s cruising flight, aren’t actual and don’t need to be accounted for train as negative factors.

The goal of this research is to study the efficiency of microblowing, realized on the HST surface (Fig. 1).

Methodology

Hwang (USA) [2], Kornilov (Russia) [3] provided wide-scale experimental studies of the microblowing, realized by one or several penetrable sections of flat plate with different air blowing intensity. These experiments demonstrated the great potential of this TFC technique. But experimental study of very delicate effects of injecting air and TBL interaction is very limited in possibilities to investigate a wide variety of different ways to produce penetrable surface with different porosity and roughness. Moreover, in case of HST application any small model would not be able to simulate all real aspects of microblowing physics and, in addition, the moving ground effect is a typical problem that can't be adequately solved by experiments. So, the experimental study of microblowing through the train surface is not effective method for this problem solving and therefore we have built our methodology on the base of mathematical modelling.

But even for mathematical description the physical problem statement is complicated due to actuality to get the aerodynamic characteristics of a long (200-400 m) high-speed (about 100-125 m/s and more) train and take into account a small value of blowing velocity (about 0.1-0.3 m/s), locally injected through a huge array of small holes (diameters about 0.1-0.25 mm). Under these circumstances it is very difficult to ensure the practically required computational resolution level. In this case any unified approach will require very detailed mesh and be too ineffective in sense of required computational and time resources. Moreover, interest to optimize the microblowing parameters distribution makes any unified strategy absolutely unpromising. That's why the methodology, realized in this research, is based on decomposition of the problem for determining the HST aerodynamic characteristics into two sequential parts: 1) modelling of 3D flow around HST ignoring the microblowing effect in a big domain, covering the whole train body; 2) independent modelling the TBL in small enough domain, located in the vicinity of HST surface.

A slightly simplified (by excluding bogies) geometry of typical 8 carriage of 200m length HST "CRH3-380a", moving at speed 100 m/s was chosen as the object of modelling. Each of the mentioned above parts of the problem in the current study was formalized in frames of the Reynolds Averaged approach (RANS) with the 2-nd accuracy level of approximation. The first part of the problem was solved on the base of the full 3D system of Reynolds equations and Spalart-Allmaras turbulence model and formalized in ANSYS-17.1. As a result, the distributions of pressure, velocity, shear stresses and total drag coefficient without microblowing effect influence have been determined. The second part of TBL modelling was realized on a very detailed orthogonal nonuniform mesh (500000 nodes in total, 200000 of them are inside viscous sublayer) on the base of 2D system of turbulent boundary layer equations with the use of the modified Cebeci-Smith model of turbulence. The algebraic level of turbulence description in frames of TBL modelling was chosen as the most reliable approach for modelling the near-wall effects of flow control. The microblowing effect was taken into account both as the boundary condition and with the use of proposed modification of parameter A+ in the inner part of turbulence model. The 2D approach is applicable for this case due to approximate uniformity of pressure distribution along the train surface (excluding head and tail cabins). It was formalized in frames of our own C++ program code. It allows to simplify as much as possible considering complicated problem and improve the accuracy of modelling.

Modeling results

The realized approach was successfully verified by comparison of the numerical results with the Kornilov's experimental data (Fig. 2) and then applied in wide range of parametric computational experiments. In particular, the distributions of the local skin friction coefficient vs. blowing intensity (Fig. 3) and length of penetrable section (Fig. 4) demonstrate the significant effect of microblowing realization on the HST streamline surface.

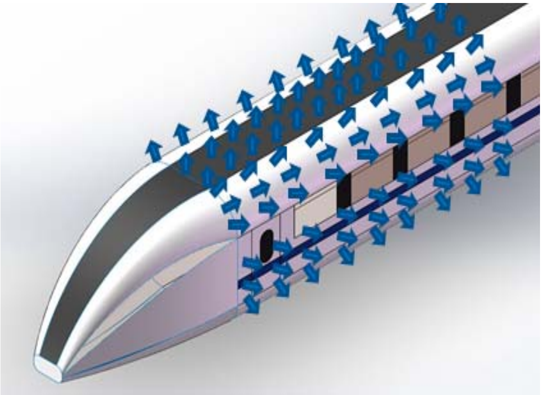

Fig. 1. The principal scheme of microblowing application to HST

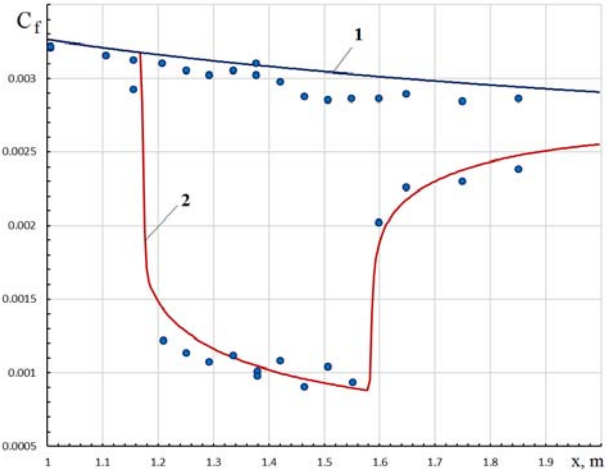

Fig. 2. Local skin friction coefficient $\mathbf{C_f}$ distribution along longitudinal coordinate **x** of flow development around flat plate without (1) and with (2) microblowing: circles – Kornilov's experiments [3]; lines – Shkvar's numerical predictions

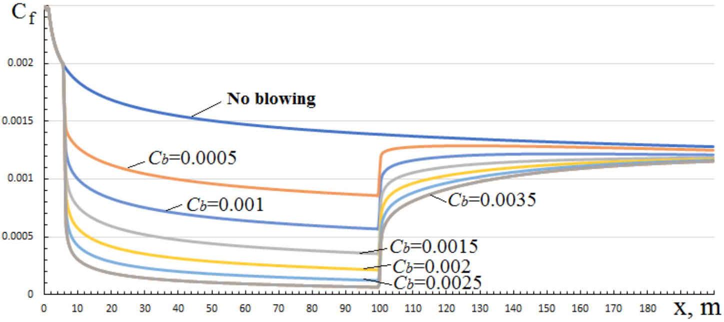

Fig. 3. Local skin friction coefficient $\mathbf{C_f}$ distribution as a function of the blowing intensity $\mathbf{Cb=Vy/V_\infty}$ for the **L**=100m length porous section

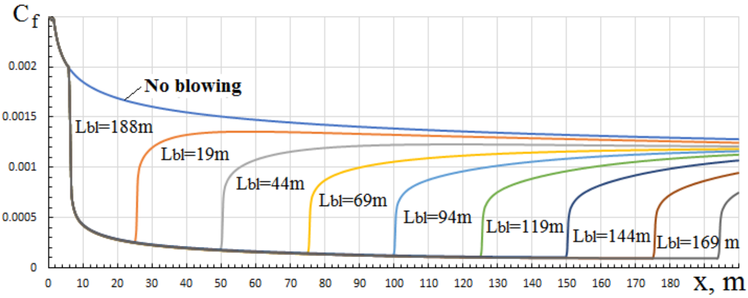

Fig. 4. Local skin friction coefficient $\mathbf{C_f}$ distribution as a function of the length **L** of penetrable section for $\mathbf{C_b}$=0.0025

Conclusions and Perspective Research Directions

1. The concept of microblowing, realized through the streamlined surface of HST has been proposed, analyzed and discussed in various aspects.
2. The corresponding RANS mathematical model of aerodynamic characteristics of HST taking into account the microblowing effect through its streamline surface is developed and verified.
3. The dependence of change of the friction component of drag coefficient C_F vs. blowing intensity C_b (Fig. 5) demonstrates that for HST like “CRH3-380a”, moving at V_∞=100 m/s the interval of values Vy=[0.15-0.3] m/s is close to optimal.
4. The realization of microblowing on 70% of the streamline surface area of any carriage at V_y=0.25 m/s and V_∞=100 m/s reduces the total HST drag coefficient C_D approximately by 5.25% of its value without microblowing (Fig. 6) and about 42% for the whole HST.
5. The further development of this methodology can be connected with the nonuniform microblowing development and study that will allow to: 1) decrease an air consumption, required for microblowing realization; 2) generate the artificial anisotropy of the mean flow in the form of additional near-wall regular vortical

systems; 3) realize effective interaction with the turbulence energy exchange process; 4) decrease the dissipative mechanism of the disturbed turbulent motion for some favorable modes.

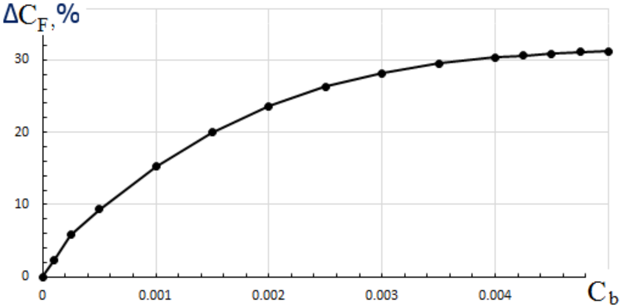

Fig. 5. Reduction of the skin friction coefficient $\mathbf{C_F}$ vs. blowing intensity **Cb** for the length of porous section **L**=100m at $\mathbf{V}_\infty$=100 m/s

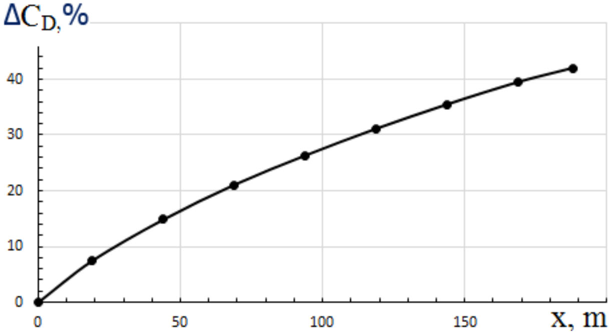

Fig. 6. Numerical prediction of the total coefficient $\mathbf{C_D}$ reduction vs. the length **L** of porous section with realized microblowing at $\mathbf{C_b}$=0.0025 m/s and $\mathbf{V}_\infty$=100 m/s

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