УДК 532.526

Shkvar Ye.O., Kryzhanovskyi A.S., Jian-Cheng Cai

PERSPECTIVE METHODS OF TURBULENT FLOW CONTROL WITH COMBINED SUPPRESSION OF NEAR-WALL VORTICITY AND DRAG

Introduction

Modern high-speed transportation and wind power generation is a rapidly developing area in the modern energetic system to effectively minimize the consumption of natural non-renewable energy sources. Many countries of the world focus their special attention on developing these promising directions. During last decade China became the world leader on wind power generation and today it is ahead of the USA for the production of wind energy by 75%, of Germany almost in 3 times and of Spain in 5 times. So, this problem has all the world importance and is perspective for further elaborating on the base of new technological decisions. Nowadays, traditional bladed wind wheels with a horizontal axis of rotation have found the widest application in the world. But they are quite expensive and unsafe for the environment. That is why it is currently important to develop alternative solutions, based on not only improvement of performance of traditional wind wheel generators, but also working out the new design wind power generators. In this way one of perspective directions is usage of self-oscillatory principle for energy transformation. Regardless of kind of wind power generators the further improvement of their efficiency can be obtained by generating the regular longitudinal vortical systems around active aerodynamic surfaces. But successful realization of the last idea supposes the deep investigation of very complicated mechanism of interaction between artificially created vortical systems and natural energy exchange of turbulent different scales vortical structures. The proposed research is dedicated to consideration of different aspects of this problem.

1. Engineering and natural basis of the formulated research direction

One of the most natural methods of generating the regular longitudinal vortical structure is modification of geometry of leading edge of active aerodynamic surfaces and regular profiling of these surfaces by the system of microgrooves. This method is not new and there are several effective engineering realizations of this idea. In particular, the technology of artificial vortex generation is regularly used in aviation. For example, a single vortex generators can be mounted on engine nacelles (Fig. 1), as well as a system of small vortex generators is installed on the wing upper surface of an airplane Boing 737. Very effective leading edge induced practical realization has been developed and applied in the design of the wing of the Soviet Union aircraft Ilyushin – 62 (Fig. 2) and confirmed its performance by long-term operation despite of the fact that the single vortex generator was applied at the leading edge of this airplane.

Fig. 1. Vortex generators mounted on engine nacelles

Fig. 2. Aircraft Ilyushin – 62 with single vortex generator on the wings

It is known that there were successful attempts of realization of leading edge vortex generator systems both in aviation (Fig. 3) and wind power generators (Fig. 4).

These modifications are expected to be the most effective in case of unstable streamline and there is the natural implementation of this fact as the fins of humpback whales (Fig. 5). One more bright example of natural usage of artificial suppression of near-wall turbulence energy dissipation is regular shark skin structure (Fig. 6). The mentioned above natural and engineering examples demonstrate the great potential ability of longitudinal regular vortex systems to improve characteristics of streamlined surfaces. But the most important problem in their technical implementation requires finding the optimal parameters of these systems and it can be effectively solved theoretically only on the base of modern high-resolution numerical methods.

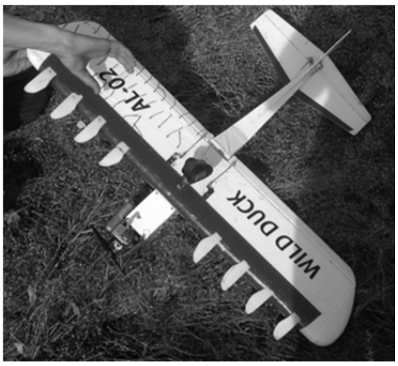

Fig. 3. Vortex generators on the lifting surfaces of aircraft

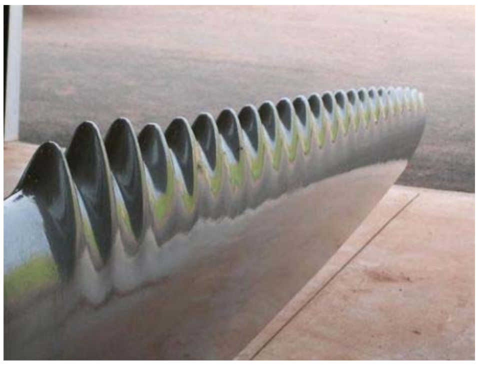

Fig. 4. Vortex generators on the lifting surfaces of aircraft

Fig. 5. Fins of humpback whale

Fig. 6. Shark skin structure

2. Numerical modeling the turbulent flow around the modified surfaces

During researches the most advanced mathematical modeling technologies based on the numerical solution of differential equations describing the nonstationary dynamics of a viscous continuous medium (RANS – Reynolds Averaged Navier-Stokes Equations, LES – Large Eddies Simulation) were used. To model the peculiarities of the formation of the turbulent flow mode the approach of constructing the hybrid algebraic-differential models of turbulence, developed by one of the authors, Prof. Shkvar E, was applied [1]. This approach allows to reflect the physical features of the vortex generation both in the inner and outer areas of the boundary layer, mutual interaction between small and large scales of vortical structures and their cumulative resulting influence on the mean flow parameters and, in particular, on its stability to separation and drag coefficient. As an example the results of modeling the complicated effect of influence of ribbed by triangular grooves surface, simulating the shark skin relief, on the turbulent wall jet parameters are illustrated by Fig. 7.

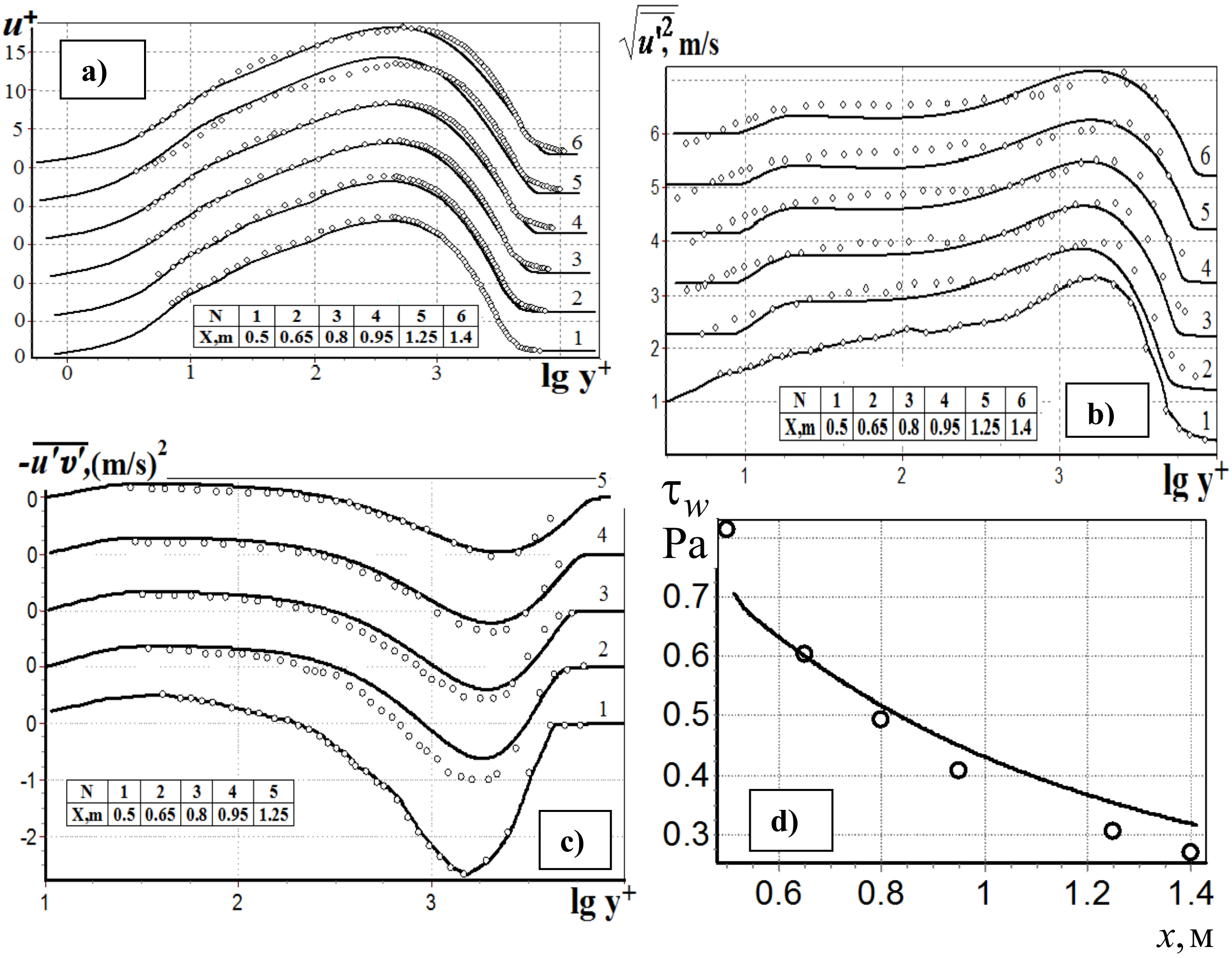

Fig. 7. Comparison of predicted (lines) and experimental [2] (circles) distributions of mean velocity **(a)**, longitudinal pulsating velocity $\sqrt{u'^2}$ **(b)**, shear stresses $-\overline{u'v'}$ **(c)** and wall shear stresses $\tau_w(x)$ **(d)** along flow development direction over the ribbed surface

Conclusion

The described methodology of numerical predictions of turbulent flows with modified geometry of the streamlined surface allows to get the substantial economic benefits in a wide range of practically important areas of its potential application.

References

1. Kulik M.S., Movchan V.T., Shkvar E.O. "Mathematical modeling of near-wall turbulence", Monograph. – K.: NAU, 2012. – 356 p.

2. Yamashita S. An Experimental Study on the Wall Jet over a Riblet Surface (Measurement of Mean and Fluctuating Velocities and Estimation of Drag Reduction) / S. Yamashita, H. Hayashimoto, Y.Inoue, Y.Iwakami // Transactions of the Japan Society of Mechanical Engineers: B 60 (572), 1994-04-25. – 1994. – P. 1145–1151.