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CONTROL OF THE NEAR WAKE OF A CIRCULAR CYLINDER IN BLOWING OUT OF LOW-HEAD JETS

V. L. Zhdanov,[a] S. A. Isaev,[b] and H.-J. Niemann[c]

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Nonstationary flow past a cylinder with organized blowing out of jets in the bottom part with the aim of reducing an alternating load on the body is investigated numerically.

1. As is well known, in the case of flow of a wind current past tall buildings of the type of towers or sky-scrapers, nonstationary vortex trails (streets) occur behind them; these streets induce alternating power loads on the objects which lead to their swinging. It turns out to be possible to decrease aerodynamic loads on the bodies under consideration by affecting the flow in the near wake. For this purpose, one proposes to use low-intensity blowing out of air jets through windows in the bottom part of the bodies.

This range of problems belongs to the fundamental scientific direction in aerodynamics which is related to a search for rational methods of control of flow past bodies with the aim of improving their aerodynamic characteristics. One has investigated in detail for several decades methods of organization of large-scale vortex structures in the vicinity of bluff bodies and within them (see, for example, [1, 2]) that lead to a substantial reduction in the drag and to stability improvement in motion of the objects. Vortex generators in the form of thin obstacles (disks or shields) installed in front of a body and behind it and vortex cells built into the casing of a body are used as a means for producing a controlling action on the flow [3]. It is shown in [4] that low-intensity blowing out of jets in the bottom part of bluff bodies also leads to marked changes in the vortex structure of the wake and a reduction in the bottom resistance.

We selected the methods of numerical modeling as basis ones. For analysis of the physical mechanism of the action of blown-out jets on the flow in the near wake we employ a specially developed calculational method which is based on the use of multiblock different-scale grids.

2. The existing mathematical models based on solution of a system of Reynolds equations for the turbulent regime of flow are used for analysis of two-dimensional nonstationary flows in the vicinity of a cylindrical body in the presence of blown out jets in its bottom part.

Discretization of the initial equations is carried out within the framework of the concept of splitting by physical processes using the implicit finite-volume method, which is applied to equations written in increments in dependent variables in the so-called *E*-factor formulation. In order to provide high accuracy of the calculations of shear flows for high Reynolds numbers, we use the counterflow scheme with quadratic interpolation for approximation of convective terms on the explicit side of the equations; the scheme was proposed by Leonard and makes it possible to prevent the distorting action of the effects of numerical diffusion on the solution. At the same time, an improvement in the calculational stability of the process and damping of possible nonphysical oscillations on the implicit side of the equations are attained using the counterflow-difference equations of first order in combination with the introduction of additional artificial diffusion. The

[a]Academic Scientific Complex "A. V. Luikov Heat and Mass Transfer Institute," National Academy of Sciences of Belarus, Minsk, Belarus; [b]Academy of Civil Aviation, St. Petersburg, Russia: email: isaev@SI3612.spb.edu; [c]Ruhr University, Bochum (Ruhr-Universität, Bochum), Germany. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 74, No. 5, pp. 36–38, September–October, 2001. Original article submitted May 14, 2001.

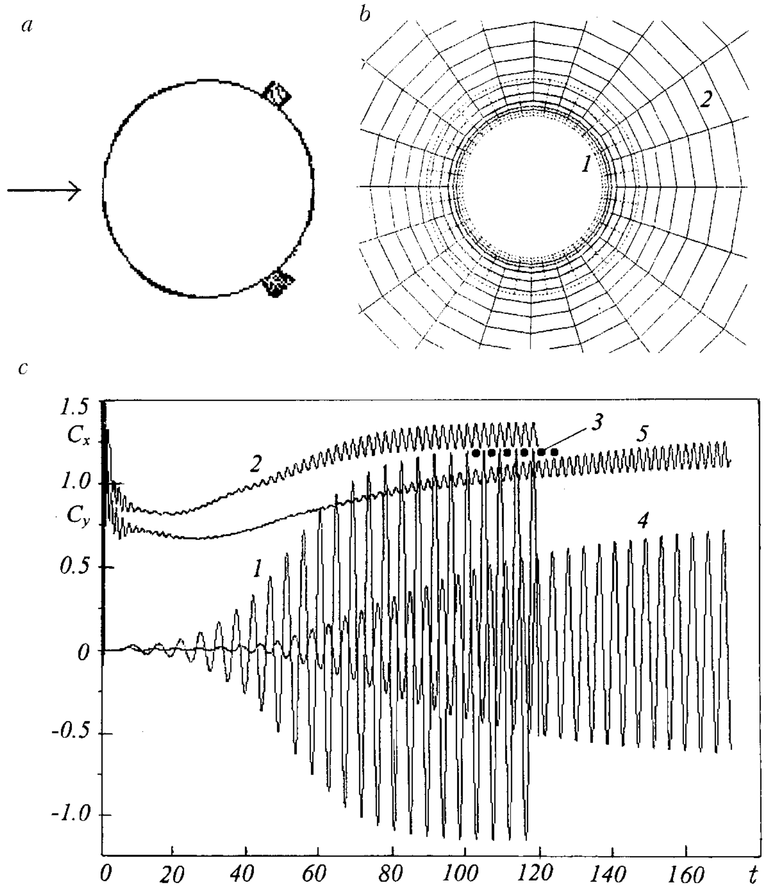

Fig. 1. Scheme of the object in question (a), fragment of the calculational grid (b) generated near the cylinder [1) external grid; 2) wall grid], and comparison of the coefficients of drag and transverse force acting on the circular cylinder in the presence of blown-out jets and in the absence of them (c): 1, 3, and 4) C_x; 2 and 5) C_y; 1, 2, 4, and 5) calculation results; 3) experimental data of A. Roshko [6].

high efficiency of the calculational procedure is provided by employment of the method of incomplete matrix factorization for solution of the system of difference equations. In the pressure-correction unit, we use the matched SIMPLEC procedure for the same purpose. The implicit scheme of first order of approximation is used for time integration. The time derivative of the dependent variable is transferred to the explicit side of the equations and thus the algorithm of solution of the nonstationary problem is a generalization of the solution of its stationary analog, i.e., its solution is obtained in the course of global iterations.

It is significant that an essential feature of the algorithm developed is its multiblock nature, which is related to the use of multilevel different-scale grids. A special procedure for interpolation of parameters from grid to grid in the region of their intersection is developed (Fig. 1). Such an approach makes it possible to reproduce with a sufficient degree of accuracy different-scale elements of the flow structure, such as boundary layers, shear layers, and large-scale vortices in a wake of a body.

For description of turbulent effects, the zonal two-parameter k–ω model of Menter [5] is used.

3. The calculational complex is tested on the problem of nonstationary turbulent flow of an incompressible viscous fluid past a circular cylinder for the Reynolds number Re = $1.5 \cdot 10^4$. The cylinder diameter D is selected as the characteristic dimension and the velocity of the incoming flow U as the velocity scale.

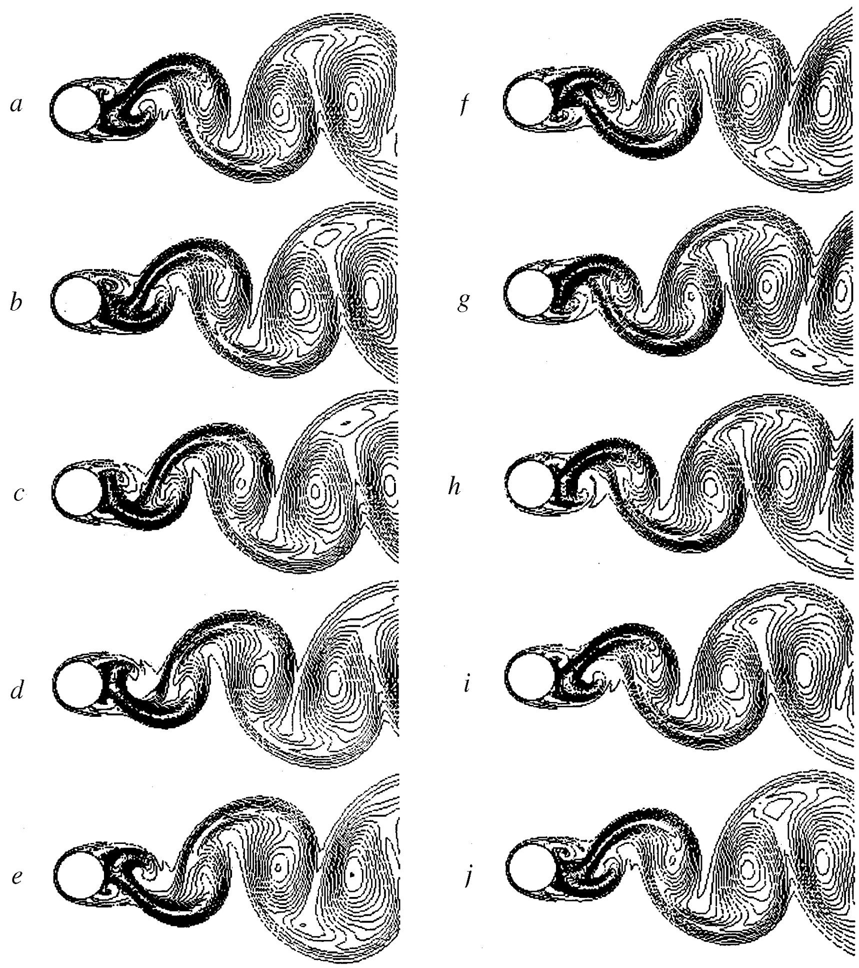

Fig. 2. Von Kármán vortex street in the wake of a cylinder in the presence of jets blown out in the bottom region: a) t = 63; b) 63.5; c) 64; d) 64.5; e) 65; f) 65.5; g) 66; h) 66.5; i) 67; j) 67.5.

The calculation was carried out on a two-level grid. On the contour of the cylinder, 401 nodes were located. The wall region of thickness 0.1 was subdivided into 15 layers with bunching toward the cylinder surface. The size of the wall step was prescribed to be equal to 0.002. The calculational grid of the external stage with the number of nodes 201×401 extended to a distance of $20D$.

The calculated data on the drag coefficient of the cylinder were compared to the data of A. Roshko's physical experiment [6], whose conditions were modeled in the numerical experiment.

Satisfactory agreement of the data of Fig. 1c makes it possible to judge the adequacy of the developed calculational complex and to use it for analysis of the influence of jets blown out through slot windows on the vortex dynamics and aerodynamic loads on the cylinder.

Figure 1a shows the sites of location of two blown-out jets in the bottom part of the cylinder. The width of the slot jets is $0.1D$, and the velocity on the cut of the slot is $0.65U$. The parameters of turbulence on the cut were prescribed to be equal to the parameters in the incoming flow.

Figure 2 shows periodic changes in the fields of the isolines of the transverse component of the velocity in the vicinity of a circular cylinder with blown-out jets. The self-oscillating regime of change in the coefficients of drag and transverse force (see Fig. 1c) is characterized by a developed von Kármán vortex street. It is of interest to note that the vortex pattern in the near wake and the far wake of the cylinder depends weakly on the presence of blown-out jets. This is reflected in a slight decrease in the drag coefficient of the cylinder.

The structure of the flow just near the body is modified to a much greater extent. Recording of the sites of separation of the flow on the body for the considered location of the slot jets enabled us to decrease the transverse vibrations of the flow near the body and to reduce significantly (by more than a factor of 1.5) the alternating load on it and consequently decrease substantially the transverse vibrations of the cylinder.

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NOTATION

t, time; U, velocity of the incoming flow; D, cylinder diameter; k, energy of turbulent pulsations; ω, specific rate of dissipation of turbulence; Re, Reynolds number; C_x and C_y, coefficients of drag and transverse force.

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