INFLUENCE OF APPROXIMATION VISCOSITY ON THE ANALYSIS OF TURBULENT FLOWS WITH CIRCULATION ZONES

S. A. Isaev

UDC 532.517.4

The influence of approximation viscosity is investigated by comparing the results of physical and numerical modeling of axisymmetric turbulent flow over two disks.

In constructing difference algorithms for analyzing turbulent separated flows it is necesary to deal with the problem of estimating the effect on the solution of the approximation viscosity due to errors in the discretization of the basic system of differential equations. The approximation viscosity functions are sometimes difficult to take into account in the calculations. Thus, in connection with the now widely used "hybrid" difference scheme [1], which in order to represent the convective terms of the transport equations combines one-sided "counterflow" differences with central differences, it is assumed that the approximation viscosity, on the one hand, ensures the stability of the calculation procedure and, on the other, significantly distorts the real flow pattern owing to the possibility of the corresponding artificial diffusion exceeding the molecular diffusion (by several orders). Obviously, in "hybrid" scheme calculations the artificial diffusion can be reduced by refining the grid, but in practice this method is generally unsuitable owing to the extremely large amounts of machine time and storage capacity required. The undesirable effects of approximation viscosity can also be counteracted by using schemes with a more accurate representation of the convective terms, in particular the Leonard scheme with quadratic "counterflow" differences [2, 3]. Our use of this scheme has made it possible to estimate the effect of approximation viscosity in analyzing turbulent separated flows. The investigation is based on the example of the uniform flow of an incompressible fluid with velocity U_∞ and density ρ_∞ past two disks of radius r and R mounted in line a distance L apart. Developed turbulence at a Reynolds number Re = 10^5 is assumed. As the characteristic quantities we have taken the radius of the downstream disk and the velocity and density of the undisturbed flow. The results of the calculations are compared with the experimental data published in [4, 5].

The basic system of equations describing the turbulent flow comprises the system of Reynolds equations in natural variables, written in canonical form in cylindrical coordinates, supplemented by the differential equations for the turbulent fluctuation energy k and its dissipation rate ε, together with the algebraic expression for the turbulent viscosity coefficient. The calculations employ the fixed set of standard constants entering into the semi-empirical k–ε turbulence model (see, for example, [1]). In constructing the algorithm we will employ a pressure correction scheme; in this case the convective terms in the momentum equations will be represented in accordance with both the "hybrid" scheme [1] and the Leonard scheme [2], the other terms of the equations being approximated by means of central differences. Following [2], where it was shown that the solutions for the turbulence characteristics k and ε are on the whole insensitive to the discretization method, especially in the regions of intense shear at the edge of the circulation flow, the difference analogs of the differential equations for k and ε are represented in accordance with the "hybrid" scheme. The difference equations obtained are solved by the linear scanning method [1].

The boundary conditions are assigned in the usual way [6]: at the inlet boundary we specify the parameters of the undisturbed flow, at the upper and outlet boundaries "mild" boundary conditions, and on the axis of symmetry the symmetry conditions. As distinct from [6], at the inlet boundary for the turbulence characteristics we select "mild" boundary conditions, and thus the turbulence is generated as a result of the flow past the disks. The parameters in the neighborhood of the disks are determined from the calculations for the cells adjacent to the walls on the assumption of a negligibly small diffusion flow from the wall as

---

Leningrad Mechanical Institute. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 48, No. 6, pp. 918-921, June, 1985. Original article submitted June 25, 1984.

0022-0841/85/4806-0662$09.50

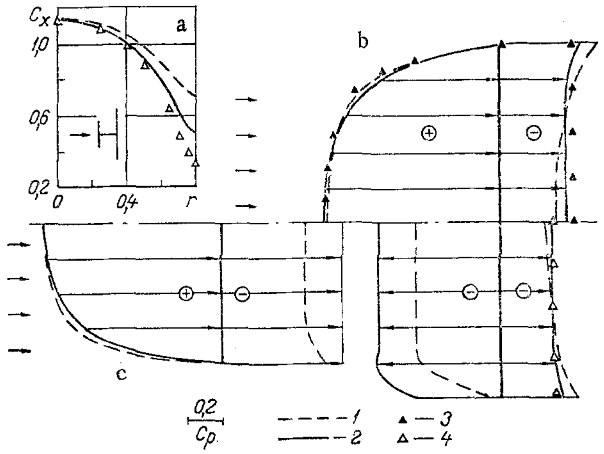

Fig. 1. Drag coefficient C_x of the two disks as a function of the radius of the forward disk r (a); vector diagrams of the distribution of the pressure coefficient C_p for a single disk (b) and for two disks at r = 0.8 (c): 1) calculated in accordance with the "hybrid" scheme; 2) using the Leonard scheme; 3) experimental data of [4]; 4) data of [5]. A plus sign corresponds to a region where $C_p > 0$, a minus sign to a region where $C_p < 0$; the solid vertical lines are the disks.

compared with the other flows through the faces of the cells. As shown in [6], this approach is justified in analyzing flows with flow separation and a pressure gradient.

Calculations were carried out on the interval of variation of the relative radius of the forward disk r from 0 to 0.8 at a relative distance between the disks L = 0.5. The "boomerang" type grid [1] with grid lines parallel to the coordinate directions contained 60 × 30 grid points with increased density in the neighborhood of the disks and their edges (minimum step 0.02). At the forward disk there were 9 grid points, at the rear disk from 12 to 14, and between the disks 12 grid points. The distances from the disks to the left, right, and upper boundaries were determined in numerical experiments and taken equal to 12, 24, and 18, respectively. The solution of the problem for fixed r and L takes on average 1500–2000 iteration steps; in this case the convergence of the solution is determined from the stabilization of the turbulence characteristics in the calculation field.

Figure 1 shows some of the integral and local characteristics of the turbulent flow past the disks. The results of the calculations using the "hybrid" scheme and the Leonard scheme are compared with the experimental data of [4, 5]. As in [6], numerical modeling using the "hybrid" scheme leads to a length of the circulation zone that is smaller than the experimental value (about 4.6 as compared with about 5.2) and to considerable nonuniformity in the pressure distribution over the rear face of the disk (Fig. 1b). As the order of approximation of the difference scheme increases, we observe not only a near-uniform distribution of pressure behind the disk but also coincidence of the experimental and calculated values of the length of the circulation zone in the wake.

As shown in [5], the flow past two disks is characterized by a more complex structure, the most important element of which is the shear layer that develops at the edge of the forward circulation zone between the disks. At small forward-disk radii (r not greater than 0.4), when the forward circulation zone is isolated from the flow in the wake behind the disks, the effect of the approximation viscosity on the drag coefficient C_x of the system is not very great (see Fig. 1a). However, as r increases, the errors of modeling the shear layer in accordance with the "hybrid" scheme lead to a considerable (up to 75%) discrepancy between the calculated and experimental values of C_x. As a result of the calculations using the Leonard scheme, owing to the superior reproduction of the shear layer, a higher (up to 1.5 times) level of negative pressure is obtained in the forward circulation zone and hence a much smaller value of the total drag of the disks. It should be noted that increasing the order of approximation of the difference scheme has practically no effect on the base drag of the two disks (see Fig. 1c).

Thus, reducing the artificial diffusion leads to results in qualitative and quantitative agreement with the experimental data, i.e., to an improvement in the quality of the difference modeling.

NOTATION

ρ_∞, density (density of undisturbed flow); U_∞, velocity of undisturbed flow; p, pressure in excess of undisturbed flow pressure; Δp, pressure drop at forward and bottom disk surfaces; μ, dynamic viscosity; r and R, radii of forward and rear disks, respectively; L, distance between disks; y, radial coordinate; k, turbulent fluctuation energy; ε, turbulence dissipation rate; Re, Reynolds number; $Re = \rho_\infty U_\infty R/\mu$; C_x, drag coefficient of the disks; $C_x = 4\left(\int_0^r \Delta p y dy + \int_0^R \Delta p y dy\right) / (\rho_\infty U_\infty^2 R^2$; C_p, pressure coefficient, $C_p = 2p/(\rho_\infty U^2_\infty)$.

LITERATURE CITED

1. A. D. Gosman, E. E. Khalil, and J. H. Whitelaw, "Calculation of two-dimensional turbulent recirculating flows," in: Turbulent Shear Flows, 1 [Russian translation], Mashinostroenie, Moscow (1982), pp. 247-269.
2. M. A. Leshtsiner and W. Rodi, "Calculation of annular and paired parallel jets by means of various finite-difference schemes and turbulence models," Trans. ASME. J. Basic Eng., 103, No. 2, 299-308 (1981).
3. H. R. Baum, M. Giment, R. W. Davis, and E. F. Moore, "Numerical solutions for a moving shear layer in swirling axisymmetric flow," in: Proc. 7th Int. Conf. on Numerical Methods in Fluid Dynamics, W. C. Reynolds and R. W. MacCormack (eds.), Lect. Notes Phys., 141, 74-79 (1981).
4. T. Carmody, "Development of the wake behind a disk," Trans. ASME, J. Basic Eng., 86, No. 4, 281-296 (1964).
5. T. Morel and M. Bon, "Flow past two circular disks in line," Trans. ASME. J. Basic Eng., 102, No. 1, 225-234 (1980).
6. I. A. Belov and N. A. Kudryavtsev, "Assigning boundary conditions in the numerical calculation of the flow past a disk of a turbulent incompressible fluid," Pis'ma Zh. Tekh. Fiz., 7, No. 14, 887-890 (1981).

EFFECT OF VARIATION OF THE PHYSICAL PROPERTIES OF THE GAS ON THE STABILITY OF LAMINAR NONISOTHERMAL FLOW IN A CHANNEL WITH PERMEABLE WALLS

V. M. Eroshenko, L. I. Zaichik, and V. B. Rabovskii

UDC 536.24

An investigation is made into the stability relative to small perturbations of a quasideveloped gas flow with variable physical properties in a plane channel in the presence of heating or cooling.

In [1] the flow of a gas with variable physical properties was investigated in the entry region of a plane channel with permeable walls. The flow stability in a channel with permeable walls has been investigated only for isothermal flow of a constant-property fluid, e.g., [2, 3]. We have now analyzed the effect of varying the physical properties of the gas on the quasideveloped flow and its stability in the presence of heating and cooling.

For two-dimensional plane flow the system of equations describing the mass, momentum, and heat transfer has the form

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u_x}{\partial x} + \frac{\partial \rho u_y}{\partial y} = 0, \tag{1}$$

$$\rho\left(\frac{\partial u_x}{\partial t} + u_x \frac{\partial u_x}{\partial x} + u_y \frac{\partial u_x}{\partial y}\right) = -\frac{\partial p}{\partial x} + \frac{\partial}{\partial x}\left\{\mu\left[2\frac{\partial u_x}{\partial x} - \frac{2}{3}\left(\frac{\partial u_x}{\partial x} + \frac{\partial u_y}{\partial y}\right)\right]\right\} + \frac{\partial}{\partial y}\left[\mu\left(\frac{\partial u_x}{\partial y} + \frac{\partial u_y}{\partial x}\right)\right], \tag{2}$$

G. M. Krzhizhanovskii State Scientific-Research Power-Engineering Institute. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 48, No. 6, pp. 921-925, June, 1985. Original article submitted May 21, 1984.

0022-0841/85/4806-0664$09.50