Formation of Vortex Structures in a Viscous Incompressible Flow Past an Airfoil

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The airfoil aerodynamics problems represent a diversity of examples of separated flows and the vortex structure formation. The important practical significance and numerous experiments make this direction of the separated flow investigations attractive for investigators.

At present, the fundamental challenges concerning the problem statement of a viscous incompressible flow around an airfoil remain valid. The problems of constructing the wake asymptotics and a local solution in the vicinity of the trailing edge can be singled out. The papers [1,2,3,4,5] can be mentioned where other basic investigations in this field are presented. It should be stressed here that these problems are associated directly with the investigation of separated flows and the vortex structures formation. The dependence of separated and vortex structures formation for the flow around an airfoil on the asymptotics at the external boundary of the calculation domain, namely on the values of the dipole and circulation terms in the asymptotics for velocity is shown in [6, 7].

Having no possibility to carefully describe in a short article the problem statement and the numerical solution method being used we refer to the published papers [6,8,9] where these problems are discussed in detail. Here only the basic features of the numerical method are given briefly, namely, the full nonstationary Navier - Stokes equations are solved; stream function - vorticity variables are used; the Poisson equation is solved by the direct method while the vorticity transport equation by the alternate direction method; the procedure of a separate successive solution of the equations for a system with internal iterations at each time step is used.

As an example, for a flow around a 12 percent Joukowsky airfoil it is shown in paper[6] that when the circulation term is specified at the external boundary at the computational domain there exists a range of values of circulation where such a criterion is fulfilled so that the airfoil pressure unambiguity is realized. It is also noted that taking into account of the dipole terms at changes the flow topology in the vicinity of the trailing edge which results in a formation of an isolated vortex.

Assuming that the flow outside the wake is potential (for the main term of the asymptotics ) the influence of the dipole terms on must be significant, i.e. the fulfilment of
the integral law of conservation of momentum (the Blaziiš-Chaplygin formulae) depends on the dipole intensities at a given circulation \( \Gamma \). However, the exact quantitative estimate of the dipole term contributions to the above law which is obtained for a potential ideal fluids flow is not valid for a viscous incompressible fluid as shown in [6]. It is associated with a variation of the flow structure, i.e., with an increase of the separation region dimensions. E.g., Fig. 1 presents the flow topology around a 12 percent Joukowsky airfoil (with a finite angle of the trailing edge) at the Reynolds number \( Re = 10^4 \) and an angle of attack \( \alpha = 7.25^0 \); here a,c) are the streamlines, b,d) are the equal vorticity lines. In the first case the flow with a weak nonstationarity of the internal region of the near wake is realized (Fig.1a,b), while in the second case -- a developed separated flow (Fig.1c,d).

![Fig.1. Flow around 12% Joukowsky airfoil, Re = 10^4, \alpha = 7.25^0](image)

In the case shown in Fig.1a,b the boundary conditions of an uniform flow are used while in Fig.1c,d the uniform flow asymptotics on \( x_\infty \) involving dipole and circulation terms is specified.

Of some interest is also the nonstationary flow in the vicinity of the airfoil trailing edge where low-strength vortices are formed and shed into the wake. Fig.2 presents the streamlines in the vicinity of the trailing edge (1/4 airfoil chord with non-dimensional time interval of 0.6 is shown); a vortex above the upper surface is clearly seen as well as the formation of low-strength vortices and their shedding into the wake. In this case a large vortex oscillating with the Struhal number of about 4

![Fig.2 Streamlines around a trailing edge, \alpha = 7.25^0](image)