Immersed Boundary Method for Flow Simulation

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ABSTRACT

The ability to handle complex geometries has been one of the main issues in computational fluid dynamics because most engineering problems have complex geometries. So far, two different approaches to simulating complex flows have been taken: the unstructured grid method and the immersed-boundary method. In the latter method, a body in the flow field is considered a kind of momentum forcing in the Navier-Stokes equations rather than a real body, and therefore flow over a complex geometry can be easily handled with orthogonal (Cartesian or cylindrical) grids which generally do not coincide with the body surface. The main advantages of the immersed-boundary method are memory and CPU savings and easy grid generation over the unstructured grid method. Even moving-boundary problems can be handled with the immersed-boundary method without regenerating grids in time, unlike the unstructured grid method.

An immersed-boundary method using momentum forcing was originally presented by Peskin [1], who simulated the blood flow in heart valves. Recently, Mohd-Yusof [2] suggested a method to evaluating directly the forcing from Navier-Stoke equations as an alternative for feedback forcing, and his method does not require a smaller computational time step, which is an important advantage of this method over previous methods. Fadlun *et al.* [3] applied the approach of Mohd-Yusof [2] to a finite-difference method on a staggered grid. In their method, the velocity at the first grid point external to the body is obtained by linearly interpolating the velocity at the second grid point (which is obtained by directly solving the Navier-Stokes equations) and the velocity at the body surface, which conceptually corresponds to applying the momentum forcing inside the flow field.

In the present talk, we explain our method that introduces the momentum forcing and mass source/sink on the body surface or inside the body to satisfy the no-slip condition and mass conservation for the cell containing the immersed boundary, respectively [4]. Moreover, the immersed boundary method that is applied to flow over an arbitrary moving complex body [5] is presented.

As examples of applying the present numerical methods, we present the results of the following problems: flows over a (finite) circular cylinder, a sphere and a two-dimensional model vehicle, inline (or transverse) oscillation of circular cylinder, vortex-induced vibration of a circular cylinder, freely-falling sphere under gravity, and an insect flight. Figure 1 shows the vortical structure behind a sphere at Re=10,000 [6], together with experimental flow visualization [7]. Figure 2 show the vortical structures behind two-dimensional flapping wings.

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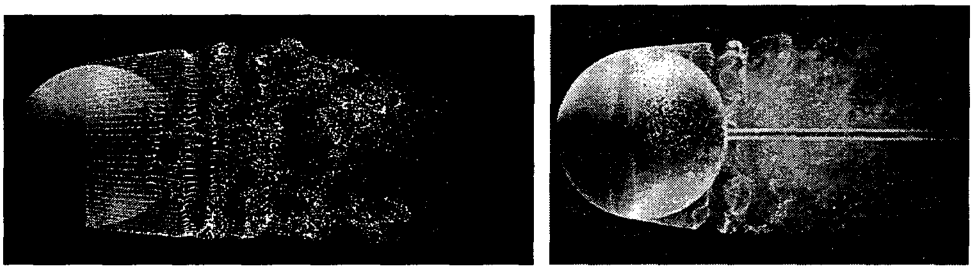

(a) (b)

Figure 1. Flow structures in the near wake: (a) Re=10^4 (present, [6]); (b) Re=1.5 x 10^4 (experiment, [7]).

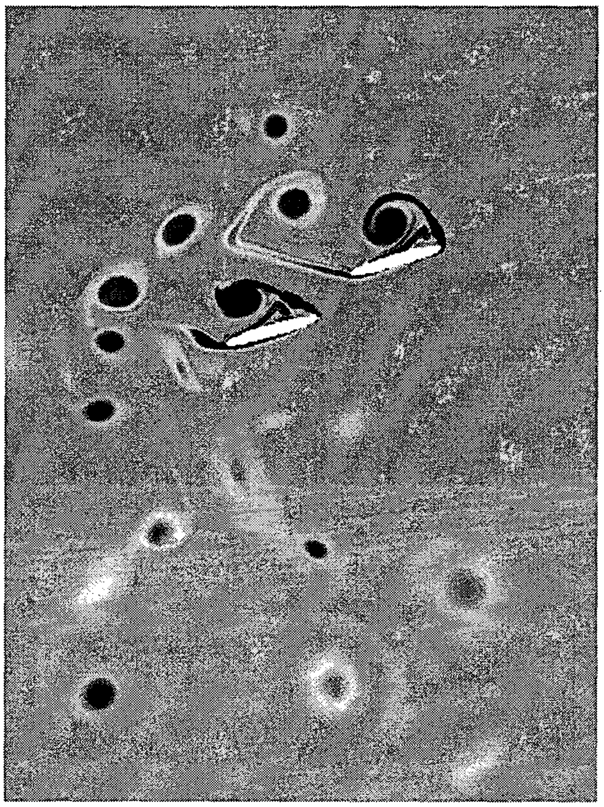

Figure 2. Flow structures behind two-dimensional flapping wings.