IUTAM Symposium on Unsteady Separated Flows and their Control, June 18-22, 2007, Corfu, Greece

UNSTEADY FLOW AROUND IMPULSIVELY STOPPED BLUFF BODIES

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Introduction

The acceleration and deceleration of a body in a fluid is a process relevant to a wide range of applications ranging from vehicular aerodynamics, propulsion and ballistics to mixing and multi-phase fluid mechanics. Whereas the flow around impulsively started objects of simple geometry (circular cylinders, spheres) has previously been the object of a large number of studies, the problem of the flow generated by a sudden arrest of the motion of such bodies has received relatively little attention in the past. In this presentation, a series of recent experimental and numerical investigations of 'stopping flows' for cylinders and spheres will be reviewed, with particular attention to the effect of the proximity of a wall.

Configuration and methods

Figure 1 shows a schematic of the geometry and flow situations. A cylinder or sphere of diameter D is impulsively set into motion from rest, and it travels a distance L at constant speed U before impulsively stopping at a distance S from a solid wall, aligned perpendicular to the direction of motion. These flows were studied experimentally, using mainly dye visualizations in a water tank, where the bodies were held by thin threads attached to a computer-controlled motor allowing for a well-defined motion. Complementary information was obtained by performing spectral-element direct numerical simulations using the same flow configurations and parameter values. Technical details can be found in Thompson *et al.* (2007) and Sheard *et al.* (2007). Low to moderate Reynolds numbers Re (= UD/ν) were considered, ranging from 100 to 1000; and in most cases the running length was between 1 and 5 body diameters, which prevented development of vortex shedding before the end of the motion. (Some cases with much longer running distances were also included).

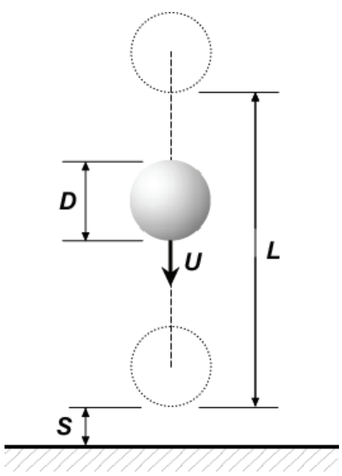

Fig. 1 Problem definition (example of a sphere).

Results

We focus here on two sets of results, one for which the body is stopped in mid-fluid (S/D » 1), and a second one where it is impacting a solid wall without rebound (S = 0). The structure of these unsteady flows is a function of the non-dimensional time $t^* = tU/D$, measured from the time of arrest. For running distances up to about 7 body diameters, the initial scenario is quite

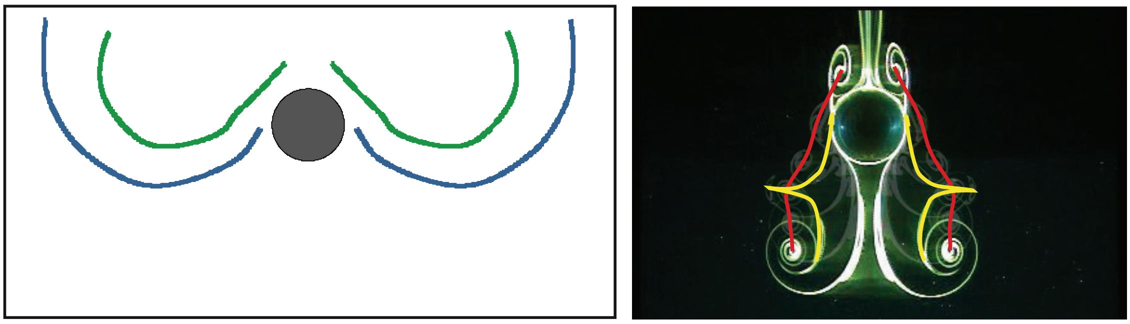

Fig. 2. Trajectories of primary (red, green) and secondary vortices for a circular cylinder (left, from DNS) and a sphere (right, from experiment) stopping in mid-fluid. $Re = 500$, $L/D = 5$, $0 < t^* < 24$, bodies were moving down.

similar in all cases: after the impulsive start, a symmetric vortex pair (for the cylinder) or axisymmetric vortex ring (for the sphere) develops in the wake of the body, and remains attached to it until the motion is stopped. The pair (ring) then continues its trajectory past the body, whereby vorticity of opposite sign is generated at the surface, which separates and rolls up into secondary vortices. These interact with the primary ones from the wake, changing their trajectories and possibly leading to three-dimensional instability.

For the case of stopping in mid-fluid, the difference between the 2D and the axisymmetric dynamics is quite striking (Figure 2). Whereas for the cylinder, the secondary vortices are strong enough to induce a pronounced outward, and even backward, motion of the newly formed pairs (Sheard *et al.* 2007), the secondary vortex ring of the sphere is too weak to prevent an overall forward motion of the system.

When the motion of the bluff bodies is stopped at a wall, the interaction with the image vortices leads to an outward spreading of the primary system after passing over the body (Thompson *et al.* 2006, Schouveiler *et al.* 2007). The additional secondary vorticity generated at the wall rapidly attenuates this effect, and it increases the tendency towards 3D instability, which occurs at lower *Re* than for bodies stopping in mid-fluid.

In the presentation, results will be shown for all the cases listed, highlighting the differences between 2D (cylinder) and axisymmetric (sphere) flows, and between free-fluid stopping and wall impact for the two geometries. Concerning the latter, a parallel will also be drawn between the flow generated by the impact of a body, and the case of a free vortex pair (Duponcheel *et al.* 2007) or vortex ring approaching a solid wall, with emphasis on the three-dimensional instabilities occurring in each flow (Leweke *et al.* 2006).

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