Path instabilities of axisymmetric bodies falling or rising under the action of gravity and hydrodynamic forces in a Newtonian fluid

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The understanding of the motion of a single body driven by gravity and buoyancy in a quiescent fluid is fundamental for all problems involving a free motion of particles in laminar and turbulent flows. Intuitively, a sphere or a flat axisymmetric body (disc, flat cylinder or an oblate spheroid) is expected to fall vertically with its axis oriented vertically. To predict its terminal velocity the knowledge of the drag is sufficient.

This simple picture considerably changes with the onset of instabilities in the solid-fluid system in which the 6 degrees of motion of the solid body interact with the surrounding fluid [4]. As soon as instabilities set in, many counter-intuitive phenomena appear concerning not only a single particle in quiescent fluid but also affecting the particle interaction with turbulent flow and multi-particle systems.

In these two lectures, we shall focus on the fact that, contrarily to intuitive expectations, spheres and flat axisymmetric bodies do not fall (or rise) vertically. The flow past a vertically falling or rising body being axisymmetric the non vertical motion can be associated, from the viewpoint of the bifurcation theory, to the problem of axisymmetry breaking. The first lecture focuses on axisymmetry breaking in wakes of fixed bodies. The second one takes up the problem of the trajectography of free bodies.

Lecture 1: Axisymmetry breaking in the wakes of axisymmetric bodies

Experiments [12], linear analysis [11] and numerical simulations [9, 7] allowed to set a very accurate limit to the stability of the axisymmetric flow past a fixed sphere. It is now widely accepted that the critical Reynolds number at which the axisymmetric flow loses its stability lies at 212. Beyond this value, the flow remains steady but it's asymmetry yields a non zero lift. The way how axisymmetry breaks can very easily be understood on the basis of a very simple weakly non-linear model [7]. At higher Reynolds numbers, the flow becomes unsteady (at a Reynolds number of 273) ([9, 7]). Further investigation [1] showed that at Reynolds numbers exceeding about 350 the flow becomes chaotic via a stage of quasi-periodic transition. A remarkable feature of transition to chaos in the wake of a sphere is the planar symmetry persisting until the onset of chaos. Wakes of flat non spherical bodies do not preserve the symmetry plane [5, 10] and a quite rich variety of transitional states has been evidenced in a parametric study of wakes of oblate spheroids going from a thin disc to the sphere [2]. Though mainly numerical and theoretical, the lecture is concluded by a discussion of experimental validations. Some theoretically predicted features are virtually impossible to evidence experimentally and detailed numerical simulations can explain why.

Lecture 2: Path instabilities of axisymmetric bodies

It has become common to refer to the instabilities arising in systems in which a free body interacts with its wake as path instabilities. The sphere was, again, the first body for which the path instabilities have been investigated [8]. It appears that the addition of degrees of freedom of the solid body does not only change the latter stages of transition but that even the threshold of axisymmetry breaking is modified. For the sphere, the solid body degrees of freedom have a destabilizing effect. The full transition scenario is shown to vary significantly depending on the solid to fluid density ratio. The difference between spheres and flat axisymmetric bodies is tremendous [6, 3] if they are let fall freely. The solid body degrees of freedom have sometimes destabilizing and sometimes stabilizing effects. Experimental validations are made difficult by the existence of states that are impossible to distinguish from experimental noise. The lecture will be concluded by discussing the impact of path instabilities on the sedimentation of many particles.

References

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