FLOW AROUND A TETHERED NEUTRALLY-BUOYANT SPHERE

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Summary The sphere is the generic geometry for three-dimensional bluff body flows. Here, the flow-induced vibrations of a tethered sphere is investigated for the special case of neutral buoyancy. A high order spectral element method is employed to predict the wake structures and oscillations of a sphere over a range of Reynolds numbers. The predicted transitions in the wake are related to those observed for the fixed sphere case. Experimental validation and the effect of slight buoyancy will also be presented at the conference.

Flow-induced vibration of structures is of practical interest to many fields of engineering; for example, it can cause vibrations of heat exchanger tubes, and it influences the dynamics of offshore risers. It is important to the design of civil engineering structures such as bridges and chimney stacks, as well as to the design of marine and land vehicles, and it can cause large amplitude vibrations of tethered structures in the ocean. In the area of biological flows, biconcave and spherical cells such as platelets [1] and leukocytes [2] undergo tethering to vessel walls leading to adhesion. The practical significance of flow-induced vibrations has led to a large number of fundamental studies, many of which are discussed in the comprehensive reviews of Sarpkaya [3], Griffin & Ramberg [4] and Williamson & Govardhan [5]. The body oscillations and wakes of a tethered sphere for the case of neutral buoyancy are the subject of the present study.

A high-order, three-step, time-splitting scheme is employed to evolve the velocity and pressure field in time. For the spatial discretisation, a spectral-element method is used, with a global Fourier spectral discretisation in the third dimension, which is the azimuthal direction in the present study. This approach has been employed previously for the case of the flow past a circular cylinder by Karniadakis & Triantafyllou [6] and Ryan, Thompson & Hourigan [7].

As the sphere is tethered in a uniform stream, the body moves under the influence of fluid forcing. Tracking the body motion is achieved by solving the equations of motion for the sphere, using the total pressure and viscous force acting on it, simultaneously with the flow field integration. A non-inertial frame is used in which the body was stationary.

It is found that as the Reynolds number, Re, based on the mean flow velocity and sphere diameter, D, is increased, the wake of the tethered sphere experiences six different flow regimes, which have some similarity to those of the fixed sphere (see figures 1 and 2). The regimes here are defined mainly by the amplitude, A, and the Strouhal number, St, of the body oscillation. Regime I, over Re = 6 - 205, is characterised by a steady axisymmetric flow structure without body movement. The second regime (Regime II) is also steady but with a loss of axisymmetry (the double-threaded wake appears), observed within the range Re = 210-250. In Regime II, the sphere is steady (but with a radial off-set that increases with Re). As the Reynolds number is increased further, the sphere starts to vibrate from Re = 270, initiating Regime III. Regime IV begins at Re = 300, showing a decreased body oscillation amplitude (and a steep decrease of the radial offset). The time-mean position of the sphere in Regime V is on the streamwise axis, the Strouhal number being approximately 0.11. In Regime VI, the vibrations become chaotic and the sphere undertakes chaotic wandering, having no restoring buoyant forces.

The streamwise vorticity in the wakes of each regime is shown in figure 3 (except for Regime I for which the wake is axisymmetric). In Regime II, the sphere is off-centred from the axis of symmetry although the flow is steady. This is due to the asymmetry of the double-threaded vortex loops. In Regime III, the vortices start to shed periodically; however, the hairpin-shaped vortex loops do not appear until Regime IV, where they are found to maintain their planar-symmetry. These loops begin to lose their planar symmetry within Regime V. In Regime VI, the wake shows irregular behaviour, coupled with chaotic sphere wandering. Related studies on slightly buoyant spheres, as well as experiments being carried out in a water tunnel to validate the predictions, will be reported at the conference.

References

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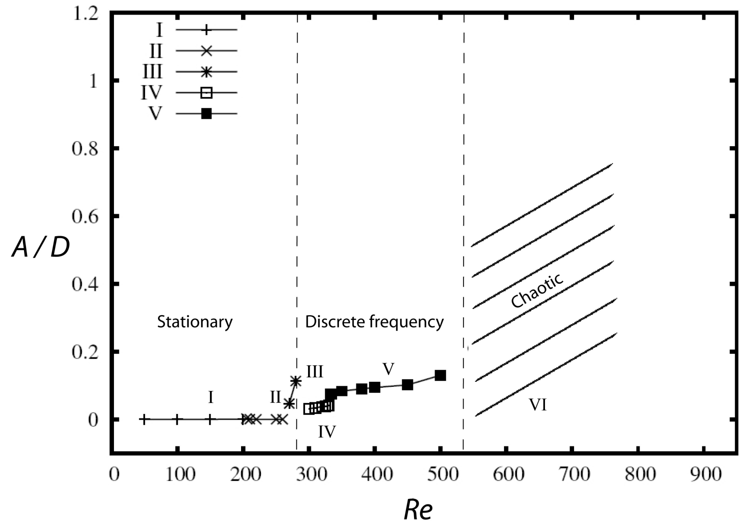

Figure 1. Amplitude of radial oscillations, A, versus Reynolds number, Re.

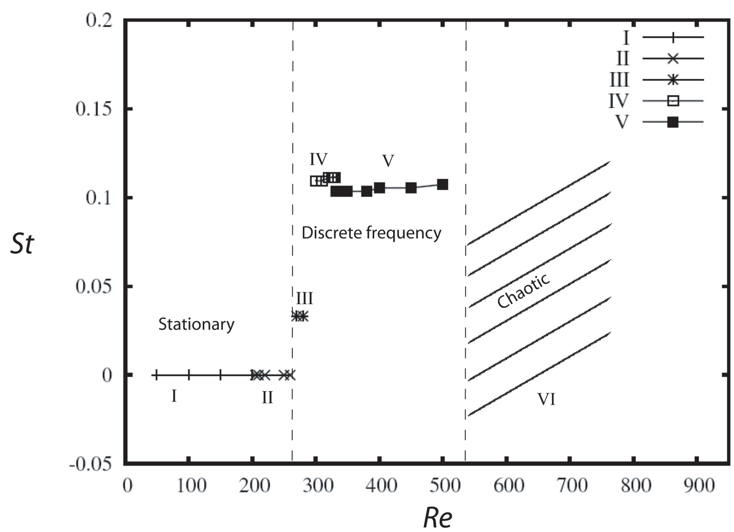

Figure 2. Strouhal number of oscillations, St, versus Reynolds number, Re.

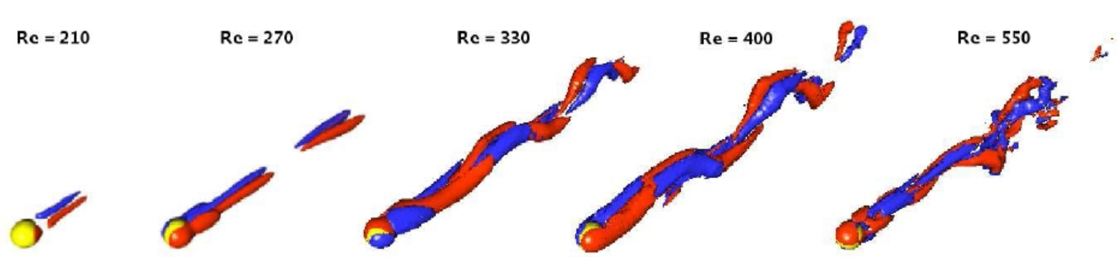

Figure 3. Streamwise wake vorticity (blue and red denote opposite signed vorticity). Plots represent Regimes II, III, IV, V and VI, successively, from left to right.