Symmetry-breaking in the wake of a rolling sphere

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ABSTRACT

The experimental and numerical investigation of the wake of a forward rolling sphere is undertaken. This flow is one of the most generic and natural of flows and yet has been little studied and understood. Recent experimental and numerical studies of this configuration [1,2] have shown a transition from steady to periodic flow at a Reynolds number *Re* (based on the sphere diameter and rolling speed) near 100. The unsteady flow involves the shedding of hairpin vortices, and the flow remained symmetric in the Reynolds number range considered, up to $Re = 200$. More recent experimental results near and beyond this range of flow speeds have indicated that a sinuous mode develops, where the hairpin vortices shed behind the sphere have an asymmetrical structure [3]. This is confirmed by performing numerical simulations using a spectral element method in three-dimensions; the force coefficients on the sphere are also calculated.

The viscous, incompressible Navier-Stokes equations were solved numerically, assuming a Newtonian fluid. The equations were discretised with the use of a semi-implicit spectral element scheme that incorporates time-splitting for the temporal discretisation, which takes place via a fractional step method. More details, with boundary conditions, are provided in [1,2]. Together with the numerical simulations, an experimental study was also undertaken in a water tank, using steel spheres of diameters 4.7 and 6.5 mm, rolling freely down a Plexiglas plate [3]. A 1-mm groove in the plate surface ensured a rectilinear path of the sphere. The angle between the plate and the horizontal was of the order of 0.5^o and could be fine-tuned for the sphere to reach the desired terminal velocity. Visualization was achieved using fluorescent dye and light from an argon ion laser.

An asymmetrical instability was found to develop as the Reynolds number approached 200. For *Re* significantly lower than 200, the wake of the rolling sphere is symmetric, consisting of a succession of vortex loops (hairpins) lifting up away from the wall. For $Re = 190$, first signs of asymmetry develop in the computed wake. At $Re = 240$, one observes a superposition of hairpins and a sinuous wake deformation, which is further amplified for even higher *Re*. The numerical simulations and observations indicate clearly the existence of a new asymmetric mode occurring near $Re = 200$. Variations of the wake frequencies and the drag, lift and lateral force coefficients during this transition are calculated. At Reynolds numbers above 270, the wake becomes increasingly irregular and chaotic.

Although the sphere is constrained in this study to travel in a straight line, the lateral forces that are found to increase with increasing Reynolds number would provide the basis for vortex-induced vibrations of the sphere; this case is currently being investigated.

REFERENCES

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