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Parametric study of freely falling and ascending oblate spheroid of variable aspect ratio

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Abstract

Recent numerical results brought significant progress in understanding the intriguing variety of trajectographies of disks and flat cylinders freely falling or ascending under the action of gravity and buoyancy in a quiescent Newtonian fluid. The topic, brought to the spotlight by the Nature paper by [1], was taken up recently by numerical means of [2] and [3]. An exhaustive parametric study of the transition scenario in the wake of oblate spheroid with variable body shape classified from a thin disk to almost a sphere is implemented to establish a link between these two prototypical objects. The flatness of spheroids is characterized by the aspect ratio χ defined as $\chi = d/a$ with d the diameter and a the length of the polar axis. The other two parameters of interest are non-dimensionalized mass $m^* = m/(\rho d^3)$ (m being the mass of the body and ρ the fluid density) characterizing the inertia of the body and the Galileo number $G = \sqrt{|m^* - V^*|gd^3}/\nu$ (g being the gravitational acceleration and ν the kinematic viscosity of the fluid) expressing the ratio between effects of gravity and viscosity. We find significant variation among scenarios of spheroid with different aspect ratio. At large aspect ratios ($\chi \geqslant 5$) an intermittent state without periodicity lying between fluttering and tumbling regions is presented whose domain area decreases as the aspect ratio decreases, while for small aspect ratios ($2 \leqslant \chi \leqslant 4$) the region of this state is difficult to specify. The resulting three parameter space is swept in planes of constant χ going from infinity to 1.1 in which G is varied from the critical value at which the vertical trajectory loses its stability (30 – 100) to 300 and m^* varies from zero to 5.

Références

[1] Field, S., Klaus, M., Moore, M., 1997. Chaotic dynamics of falling disks. Nature 388, 252–254.

[2] Chrust, M., Bouchet, G., Dušek, J., 2013. Numerical simulation of the dynamics of freely falling discs. Physics of Fluids 25, 044102.

[3] Auguste, F., Magnaudet, J., Fabre, D., 2013. Falling styles of discs. J. Fluid Mech. 719, 388–405.

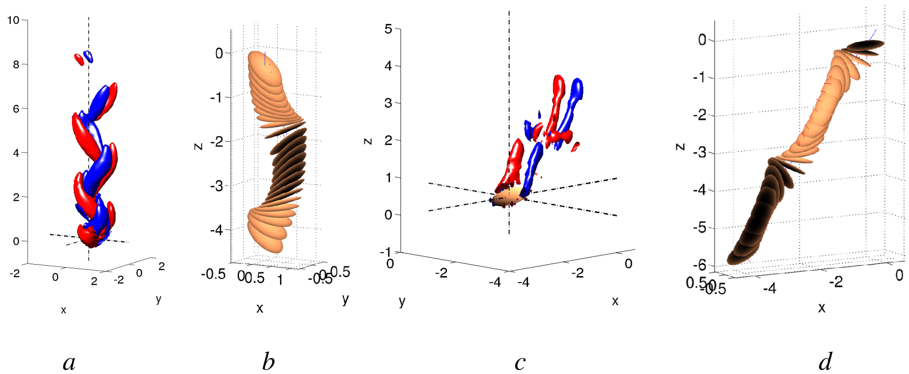

Figure 1: a, b: fluttering spheroid ($\chi = 10$, $m^* = 0.25$, $G = 115$); c, d: tumbling spheroid ($\chi = 10$, $m^* = 0.75$, $G = 200$); a, c: vorticity structure in wake; b, d: motion kinogram over one period.

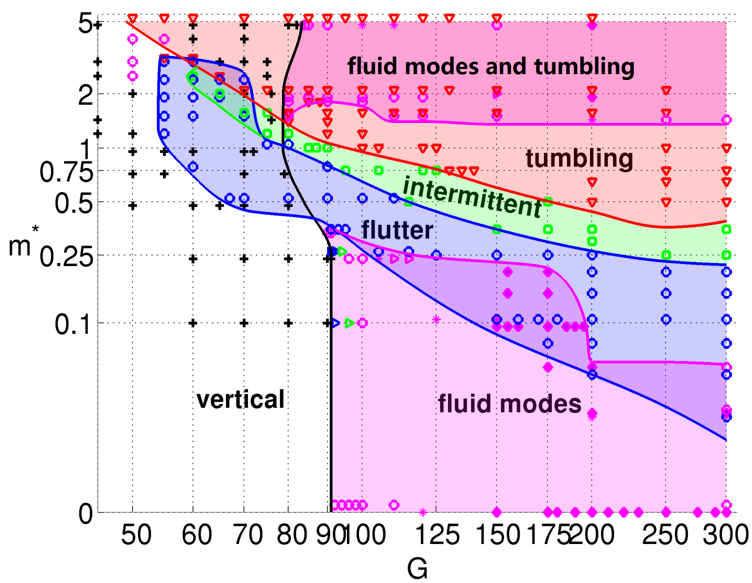

Figure 2: State diagram for aspect ratio $\chi = 10$. Each symbol corresponds to a simulation. Note the many domain of coexistence of different regimes (fluid modes: regimes with small oscillation amplitudes).