The effect of Reynolds number on the dynamics of freely rising and falling spheres

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— In this study, we investigate the effect of Reynolds number on the dynamics and vorticity patterns of spheres rising or falling freely through a fluid. Initially, our experiments focused on two Reynolds numbers, $Re = 450$ and 10,000. At both $Re$, all falling spheres, with a mass ratio (or density relative to the fluid), $m^* > 1$, are found to descend rectilinearly. For rising spheres, we observe that contrary to previous studies, rectilinear trajectories persist until some critical mass ratio, $m^*_{crit}$, below which the spheres suddenly begin to vibrate vigorously in a vertical plane. At $Re \approx 10,000$, we find $m^*_{crit} = 0.61$, while at $Re = 450$, the critical mass is distinctly lower, $m^*_{crit} = 0.36$. To explore the dynamics of spheres over a wide range of $Re$, we controlled the fluid viscosity using glycerin-water mixtures, and considered over 130 cases of $m^* = 0.08$-1.5 and $Re = 100$-15,000. For all $Re$ studied, we find a wide range of spheres that rise rectilinearly, yielding $m^*_{crit}$ significantly below 1.

The only regimes observed in our study are rectilinear motion and periodic zigzag vibration. The vortex wakes for the rectilinear regime resemble those of a fixed sphere at similar $Re$, either a single-sided chain ($Re = 450$), or a double-sided chain ($Re \approx 10,000$) of vortex rings. However, for the whole range of $Re$ studied, we discover that the periodic zigzag regime is associated with a new vortex formation mode comprising four vortex rings per cycle of oscillation.

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