Egg Dynamics: Internal Viscous Damping of Rotation and Aerodynamic Drag Stabilize Pendulum Motion

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This study elucidates the physical mechanisms behind the self-stabilizing behavior of liquid-filled eggs, which suppress motion more effectively than solid-filled ones. Although this phenomenon is qualitatively recognized, the underlying hydrodynamic and aerodynamic interactions remain unquantified. Using eggs as pendulum weights, experiments were conducted with raw, hard-boiled, and fluid-filled eggs to evaluate the interplay between internal viscosity, external air drag, and energy dissipation. Dissipation was quantified by the number of oscillations for the pendulum amplitude to decay from 60° to 30°, complemented by high-speed photography and internal tracer visualization to characterize fluid-structure interaction. The results reveal that at moderate Reynolds numbers ($500 < Re < 15000$), solid-filled eggs undergo unstable oscillations, with their long axes rotating or wobbling about the pendulum string. This occurs because, while airflow drag torque tends to align an ellipsoid perpendicular to the external flow, any initial rotation prevents a stable orientation due to the conservation of angular momentum. Conversely, liquid-filled models consistently adopt a transversal orientation relative to the motion. This alignment maximizes the frontal area projection, significantly increasing aerodynamic drag and accelerating energy dissipation. Furthermore, internal flow visualization confirms that the fluid dynamically shifts to stabilize the center of gravity while suppressing rotational perturbations through viscous shear. These findings demonstrate that internal fluidity acts as an efficient control mechanism rather than a source of instability. This research offers a physical foundation for advanced posture control in aerospace and biomimetic packaging technology.

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