An open question in mechanics of a spinning egg

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Abstract

It is surprising that a hard-boiled egg rises from the horizontal to the vertical when spun sufficiently rapidly on a table: the centre of mass rises against the gravity. This counter-intuitive motion is easy for everyone to observe in a kitchen without any special tool, but for a long time it had been remaining as a big challenge to be solved, while the flip-flop movement of a "tippe-top" was theoretically explained half a century ago. However, an outline explanation of this rising-egg phenomenon was proposed by Keith Moffatt and Yutaka Shimomura who is the author of the present paper. Their theory [1] provides a rare example of a system in which a dissipative force (here the force of slipping friction) is responsible for a visible instability. Later, Moffatt and Shimomura, together with Michal Branicki published a substantial paper [2], which provides detailed justification for the theory.

Shimomura, Moffatt and Branicki published another paper [3] on this rising-egg phenomenon, which focuses on the fluctuating motions of the body: rapid oscillations accompanying the rise. They found that the rapid oscillations of normal reaction grow and may eventually reach zero when the egg-shaped body is spun sufficiently rapidly. As a result, they analytically made a prediction that the body can spontaneously lose contact with the table during the course of its rising motion. This prediction may be hard to believe, but in the paper they confirmed by numerical simulations that the body does in fact jump off the table when spun sufficiently rapidly.

There is an interesting toy called "spinny", which actually shows by a similar mechanism many jumping motions from a table like a grasshopper. However, there has existed a need for experimental confirmation of the theoretical prediction about jumping of a spinning egg. One jump leads to another, and the behaviour can be recognised in practice by the rattling sound that accompanies this behaviour, but the experimental confirmation has been a big challenge, for it is much harder than observing the rising motion from two reasons. One is that the jump is extremely small: the height and the duration are of the orders of a fraction of a millimetre and of 0.1 second, respectively. The other is that the body should be rapidly spun (at a spin rate of order 1000 revolutions per minute) with its axis of symmetry initially horizontal without any significant noise: artificial noise would inevitably be introduced if we spin it by hand.

In 2006, Takahisa Mitsui, Kesao Aihara, Chikako Terayama and Hiromichi Kobayashi overcame the two difficulties described above: a tool was devised for mechanically spinning an egg-shaped body at various controllable spin

rates, and a measurement system was constructed to simultaneously observe optical, acoustic and electric signals, which can detect even a very small jump of a spinning body made of metal. Finally they published the paper "Can a spinning egg really jump?" [4] to claim that the answer to the question of the title is YES. Furthermore, they found that the measured durations of the first loss of contact after jumping show very good agreements with numerical simulations for various initial spin rates and for three bodies of a different shape. Many jumps subsequent to the first one are also observed, a topic which is not within the scope of the previous study by Shimomura et al. [3]. Lastly, they presented a sequence of snapshots in the paper and a movie clip in the online supplementary material, both of which show that a spinning hard-boiled egg can spontaneously jump.

If we spin a hard-boiled egg on a carbon sheet, the trace of the point of contact between the egg and the table shows how the egg rises. It is found that the trace becomes discontinuous in the course of the rising motion: a trace circle is broken at many points, which has a time period of order 0.01 second. It is hard to attribute this discontinuity to jumping of a spinnng egg, because the time period of jumping is of order 0.1 second. In numerical simulations, it does not seem either that the transition from slipping to rolling of the point of contact causes this discontinuity. Therefore, the discontinuity of a carbon trace is an open question in mechanics of a spinning egg.

In the present lecture, the study on mechanics of a spinning egg is going to be reviewed as above, and the open question in it is going to be proposed for anyone to solve it.

References

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