Experimental results and a few surprises from the Malkus waterwheel

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Since its elegant demonstration by Malkus, the chaotic waterwheel has become a familiar nonlinear system, a simple mechanical analog of the Lorenz equations. Numerous theoretical and numerical investigations have appeared in the literature, but no systematic experimental data have yet been published. We will present a large collection of data taken with a research-grade waterwheel consisting of a vacuum-formed polycarbonate frame in which 36 cylindrical cells are mounted on an 18 inch (0.46 m) diameter. The wheel and its axis can be tilted, and water is fed into the top of the wheel and drains out through thin tubes at the bottom of each cell. An aluminum skirt at the wheel's periphery passes through a variable gap magnet to provide magnetic braking that is proportional to the angular velocity. Angular time series data are collected with an absolute rotary encoder. The data are smoothed and angular velocity and acceleration are calculated via fast Fourier transforms. The data show quasi-uniform rotation as well as periodic and chaotic reversals and agree in part with computer simulations of the idealized wheel equations. A fairly detailed bifurcation plot will be shown, using the magnetic brake strength as the adjustable parameter. Preliminary results indicate some differences between the data and numerical simulations. While the first bifurcation (from uniform rotation to pendulum-like oscillations) is predicted well by the simulations when the initial angular velocity is low, there is an initial condition dependence in the real system that is not present in the model. Second, there is a disparity in the brake value corresponding to the first transition to chaos. Finally, the simulations predict a large region of periodic motion for braking values higher than those in the chaotic region, but the experimental trajectories more closely resemble noisy periodic or even chaotic motion.