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Helicopter Toy and Lift Estimation

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A $1 plastic helicopter toy (called a Wacky Whirler) can be used to demonstrate lift. Students can make basic measurements of the toy, use reasonable assumptions and, with the lift formula, estimate the lift, and verify that it is sufficient to overcome the toy's weight.

As shown in Fig. 1, the toy consists of a propeller and a stem, which is used to launch the toy. The user holds the stem between her hands, outward away from the face, and quickly moves/slides the right hand over the stationary left hand to launch the toy. This action causes the toy to spin counterclockwise fast enough that it lifts off to a respectable height.

The toy is available from a variety of toy or online stores. It could probably be improvised by adding a dowel to a model airplane propeller or by gluing two popsicle sticks to a dowel. The toy reported here is an inexpensive and simpler version of an old wooden toy that had a holder which enabled the user to impart much faster spin by pulling on a string wound around the stem.

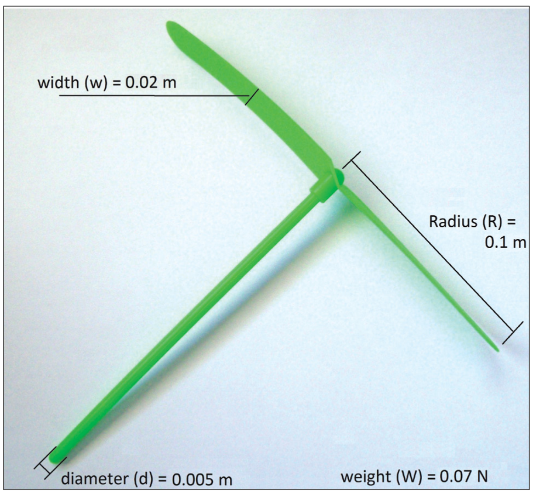

Fig. 1. Helicopter toy and its physical data.

Lift estimation

The toy's geometrical data and weight are rounded and shown in Fig. 1. Assume the distance the stem of the toy is spun between the hands up to the launch $D_L = 0.1$ m and spin duration $t = 0.3$ s, which was estimated by watching a video I recorded of the toy's launch.

With negligible slipping between the hands and toy, the toy's rotational speed (ω) at the moment of release can be calculated:

$$\omega = 2\pi\,(No.\ of\ revolutions)\left(\frac{1}{t}\right) = 2\pi\left(\frac{D_L}{\pi d}\right)\left(\frac{1}{t}\right)$$

$$= 2\ \text{rad} * \left(\frac{0.1\ \text{m}}{0.005\ \text{m}}\right) * \left(\frac{1}{0.3\ \text{s}}\right) = 133\frac{\text{rad}}{\text{s}}.$$

Therefore, the average speed of the propeller (V), at midpoint between the center and tip of the propeller, is:

$$V = \omega\left(\frac{R}{2}\right) = 133\frac{\text{rad}}{\text{s}} * \left(\frac{0.1\ \text{m}}{2}\right) \approx 7\frac{\text{m}}{\text{s}}.$$

The lift L depends on speed V, planform area A, air density ρ, and coefficient of lift C_L, which is a function of angle of attack and the shape of the propeller. The lift formula and coefficient of lift can be obtained from any aerodynamics textbook. Based on aerodynamics data, assuming 1 for the coefficient of lift is a reasonable estimate for the toy's propeller and its angle of attack.

$$L = \frac{1}{2}C_L\rho A V^2 = \frac{1}{2} * 1 * \left(1\frac{\text{kg}}{\text{m}^3}\right) * (2 * 0.1\ \text{m} * 0.02\ \text{m})$$

$$* \left(7\frac{\text{m}}{\text{s}}\right)^2 \approx 0.1\ \text{N}.$$

Therefore, the estimated lift (0.1 N) is sufficient to overcome the weight (0.07 N).

It should be noted that the estimated lift is probably conservative because square of average speed was used in the above equation. The correct procedure involves integration of the square of local speed, which varies with radius, over the length. A simple way to more accurately represent the effect of integration would be to use speed at 0.75 R rather than at 0.5 R in the above equation. Also, estimation of spin duration is critical. Because it happens so fast, it cannot be obtained just by unassisted watching. As mentioned earlier, a simple way to do this is by extracting the spin duration from replaying a video recording of the launch.

After this estimation, a more challenging problem could be assigned: estimate the flight time. One would need to consider propeller drag and minimum speed to cause a lift equal to weight, among other issues for that estimation.

A design firm, Lufdesign.com, recently has developed a prototype named FlyingStick based on this toy that has a five-blade propeller and an integrated camera at the bottom of its stem. Powered by hand, as with our plastic toy, the FlyingStick takes continuous photographs of its field below while flying. The camera has a stabilizer to compensate for a wide range of shake and spin frequencies for optimal focusing.

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