Flight of a falling maple seed

Injae Lee and Haecheon Choi*

Department of Mechanical and Aerospace Engineering, Seoul National University, Seoul 08826, Korea

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In autumn, maple trees disperse their seeds by employing autorotation under windy conditions. Maple seeds equipped with a small wing begin to autorotate within 1 m after they are detached from trees, and the autorotating motion generates the lift force that slows down its descent [1,2]. From measurements using digital particle image velocimetry (DPIV), it was elucidated that a stable leading-edge vortex (LEV) is generated by the rotating wing, allowing it to attain a high lift force [1]. However, due to complex vortical structures behind maple seeds, their dynamic behaviors have not been fully understood.

To understand the falling mechanism together with the flow characteristics, we conduct an unsteady three-dimensional numerical simulation of a freely falling maple seed. For the simulation, a three-dimensional seed model [Fig. 1(a)] is obtained by scanning a maple seed (*Acer palmatum*), and we assume that the density of the maple seed is uniform over the nut and wing areas. We use an immersed boundary method in a noninertial reference frame [3] fixed to the center of mass of the seed. Numerical details are given in [4]. Figure 1(b) shows the time traces of descending and rotating velocities of the maple seed during free fall. Initially, the descending velocity increases almost linearly under the gravity, and then decreases as the rotating velocity develops (autorotation). Finally, the seed reaches a periodic state with terminal descending and rotating velocities.

Figure 2(a) shows the trajectories of the center of mass (CM) and wing tip (WT) of the freely falling seed model. After a transient period, the seed falls with the periodic rotating motion. Figures 2(b) and 2(c) show the instantaneous three-dimensional vortical structures around the seed at two different time instants. Before periodic autorotation, vortices are shed from the base edge of the seed and the wake zone is narrow [Fig. 2(b)]. In the periodic state, due to the rotating motion of the wing, the leading-edge (LEV), wing-tip (WTV), wing-root (WRV), and trailing-edge (TEV) vortices are generated, and the wake zone is broad [Fig. 2(c)]. In particular, the LEV remains stable along the span, rather than sheds into the wake. This creates a high lift force, resulting in a significant reduction of the descent velocity [1]. Therefore, all the vortices except the LEV dominate the wake behind the seed.

*Corresponding author: choi@snu.ac.kr

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FIG. 1. (a) Seed model constructed by three-dimensional scanning; (b) time traces of descending (u_d/u_g) and rotating ($\omega_d \bar{c}/u_g$) velocities of the maple seed during free fall. Here, $u_g = \sqrt{(\rho - 1)\bar{c}g}$ (characteristic terminal velocity), $\rho = \rho_s/\rho_f = 404.7$ (ratio of solid to fluid densities), $\bar{c} = A_w/s = 4.272$ mm (mean chord length), g is the gravitational acceleration, and A_w and s are the wing area and span of the seed, respectively. Colors in (a) denote the thickness distribution of the seed. DOI: <https://doi.org/10.1103/APS.DFD.2016.GFM.V0046>

FIG. 2. (a) Trajectories of the CM and WT of the seed model during $tu_g/\bar{c} = 0-400$; instantaneous three-dimensional vortical structures around the seed at (b) $tu_g/\bar{c} = 200$ (before periodic autorotation) and (c) $tu_g/\bar{c} = 1064$ (during periodic autorotation). Here, the vortical structures are identified by the isosurfaces of $\lambda_2 = -0.1$ [5]. DOI: <https://doi.org/10.1103/APS.DFD.2016.GFM.V0046>

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