Samaras Fly in the Transverse Wind

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The experiments are conducted to reveal the flight performances of samaras in transverse winds by use of the blow-down wind tunnel. Samara samples are taken from a maple *Acer crataegifolium* and a tulip tree *Liriodendron tulipifera*. Samaras are found to set to auto-rotation from rest in shorter time in transverse winds than no wind. In some cases of transverse-wind experiments, lift force grows significantly larger than lift in free fall. The results show that in transverse winds samaras can fly further than conventional estimates based on terminal velocities using the vertical wind tunnel.

1. INTRODUCTION

Samaras, winged seeds, are dispersed by winds. In the evolutionary process for gaining the necessary flight range, plants have acquired forms and functions such as wing shapes, heights of branches to have samaras, and mechanisms of detaching samaras from parent plants. There are a lot of researches from the viewpoint of aeronautics, *e.g.*, Azuma & Yasuda[1)], Rosen and Seter[2)], and others[3)-7)]. These studies reveal rates of rotation, terminal velocities, and flow structures by use of vertical wind tunnels. Aoki[8)] successfully challenges numerical simulations of auto-rotating samaras, tumbling cards and so forth. From the viewpoint of plant ecology Green[9)] examines terminal velocities of maples and tulip trees; Greene & Johnson[10)] and Nathan *et al.*[11)] propose estimation methods of the flight range.

Dispersal of samaras, however, begins with wind blows, and hence we have to know the influences of transverse winds upon dispersing samaras in order to reveal the mechanisms of wind dispersal. There are three points for considering the influences of transverse winds upon dispersing samaras.

(1) Mechanism of samara detachment from parent plants: samaras are attached to parent plants by way of fibers, or stored in cones and capsules; we think these organs function as a launcher when winds blow off samaras from parent plants.

(2) Transient growth of lift acting on samaras just after detachment from parent plants: careful field observation reveals the fact that some samaras can fly upwards in strong winds; we can understand this phenomenon by examining the influences of transverse winds upon flying samaras.

(3) Motions of flying samaras after collision with branches in woods: branches act not only as obstacles to prevent dispersing samaras but also as spring boards for samaras flying farther.

These points must be proven experimentally. The present study pays its attention to the early stage of falling that is the second point above to be considered. We conduct a series of experiments by use of actual samaras in blow-down and vertical wind tunnels, and reveal the influence of transverse winds upon flight dynamics of samaras from the release to the steady-state auto-rotation.

2. MATERIALS AND METHODS

2.1 Samaras

We collected samaras directly from their parent plants, a gourd maple *Acer crataegifolium* and a tulip tree *Liriodendron tulipifera*, in Minami-Minowa Village, Kami-Ina District, Nagano Prefecture. The time of collection corresponds to the dispersal period of both kinds, and we had kept samaras for a month in a paper box in the laboratory to prevent distortion and deformation until the time of wind tunnel experiments.

We chose the 50 immaculate samaras for each tree for the use in the experiments. We labeled numbers upon all the samaras and measured weight, a projected area, span, and the maximum chord length of each samara.

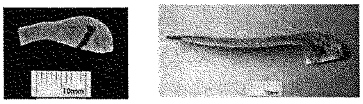

Fig.1 Samaras: a maple (left) and a tulip tree (right)

2.2 Wind tunnel experiments

First we conduct the experiments in transverse winds by use of the blow-down wind tunnel of Kanagawa University. The wind tunnel has transparent side walls and its cross section is 0.9 m high and 1.2 m wide. We set the release point of the samaras in the center of the ceiling 3 m upstream the outlet. We use a Pitot static tube and a manometer to measure the wind velocity and conduct the experiments at the following velocities: 0.0 m/s, 1.1 m/s, 2.1 m/s, 2.7 m/s, and 3.8 m/s; these constitute of the lower bound of the wind speed in which samaras start to leave their parent plants.

We drop the samaras one by one through the small hole at the release point of the wind tunnel ceiling without accelerating them; to reproduce natural conditions we release the samaras of a gourd maple with their seeds over wing-tips, while we release the samaras of a tulip tree with their wing-tips over seeds. We measure the flight range by observation with the aid of the scale on the tunnel floor, and we analyze the video data to know the time history from the release via start of auto-rotation to landing.

We use two video cameras: one is set perpendicular to the side wall of the wind tunnel; another is set downstream the outlet to look up the release point in the ceiling and have the frame with its base edge corresponding to the floor of the outlet.

Subsequently, as for the samaras of a gourd maple, we measured their terminal velocities by use of the vertical wind tunnel.

3. RESULTS AND DISCUSSION

3.1 Time to start of auto-rotation from rest

First we summarize the results of a gourd maple: its samaras rotate as they fall (Fig.2). In case of no wind the average time to start of auto-rotation from rest is 0.39 s (Table 1), which correspond to around 40 cm fall from the ceiling as shown in Fig.3. In case of the 1.1 m/s wind, the average time to start of auto-rotation from rest is shortened to 0.27 s; the loss of altitude is also shortened to about 20 cm. In case of the 2.1 m/s wind, the average time to start of auto-rotation from rest is farther shortened to 0.25 s. The samaras of a gourd maple were blown out of the wind tunnel by the winds at the 2.7 m/s and faster velocity.

The samaras of a tulip tree are larger than those of a gourd maple. The tulip tree's samaras develop a rotation pattern different from that of a gourd maple: the tulip tree's samaras rotate and tumble at the same time (Fig.2). Hence the tulip tree's average time to start of auto-rotation from rest is longer than that of a gourd maple. In case of no wind it takes 0.53 s to start rotating. However the average time to start of auto-rotation from rest is significantly shortened in the transverse winds: 0.27 s in the 3.8 m/s wind and 0.24 s in the 2.7 m/s wind, respectively.

Table 1: Time to start of auto-rotation from rest

Wind Speed [m/s]		0	1.1	2.1	2.7	3.8
Maple	ave.[s]	0.39	0.27	0.25		
	sd.[s]	0.01	0.07	0.06		
Tulip Tree	ave.[s]	0.53			0.27	0.24
	sd.[s]	0.09			0.10	0.11

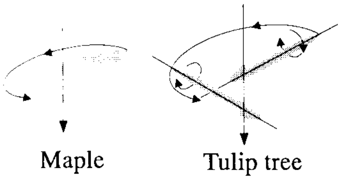

Fig. 2 Rotating patterns of samaras

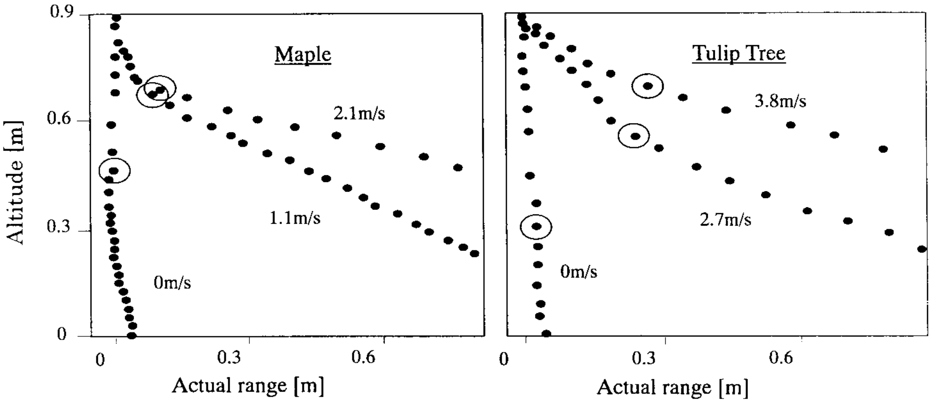

Fig.3 Side view of flight trajectories

Dots denote locations of samaras at every 0.03 seconds; circled dots indicate start of auto-rotation. The velocities adjacent to dots designate the corresponding wind speeds.

3.2 Lift generation in the initial stage of auto-rotation

To see how lift grows in the initial stage of falling, we compare the actual flight ranges with the conventional estimate; the definition is given by

$$R = HU/w, \tag{1}$$

where R, H, U, and w denote the conventional estimate of flight range, height of release, the velocity of the transverse wind, and the terminal velocity of a samara, respectively; botanists substitute measured H, U, and w for (1). As mentioned in the previous section w is measured for all the 50 samaras of a gourd maple by use of the vertical wind tunnel: its average value is 0.81 m/s, while the standard deviation is 0.080 m/s.

Figure 4 summarizes the results of the comparison between the experiments and the conventional estimates. The definition (1) assumes that samaras are in steady-state auto-rotation from the start, and hence the conventional estimate R may well be larger than the experimental values. As for a gourd maple, however, seven cases out of the 50 experimental results exceed the conventional estimate in the 1.1 m/s wind; 17 cases out of the 50 experimental results exceed the conventional estimate in the 2.1 m/s wind.

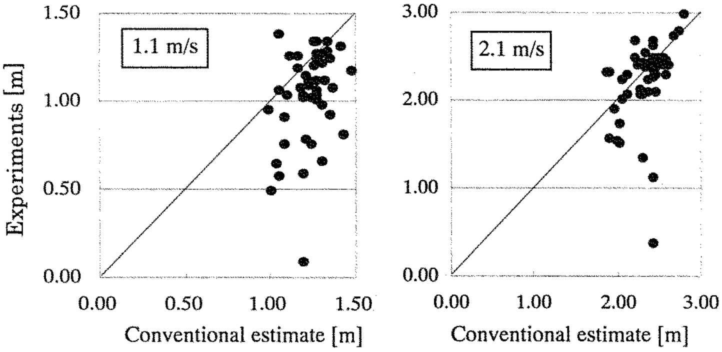

Fig.4 Experiments vs. conventional estimates: maples
Insets designate wind speeds.

Figure 5 shows schematically the side view of a typical flight trajectory for samaras flying farther than the conventional estimate. We note that lift once grows larger than the terminal value.

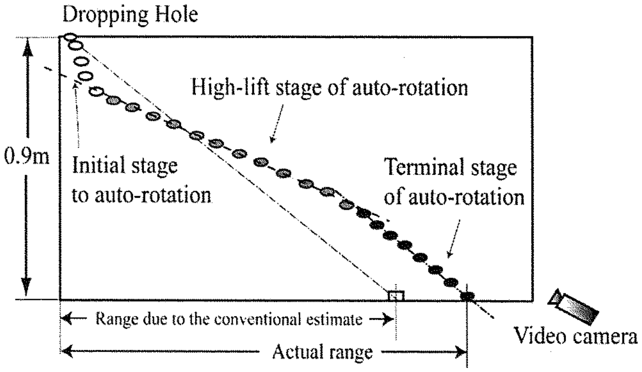

Fig.5 Flight trajectory of the samara flying farthest

Figure 6 shows the downstream view of flight trajectories in two extreme cases of the samaras of a

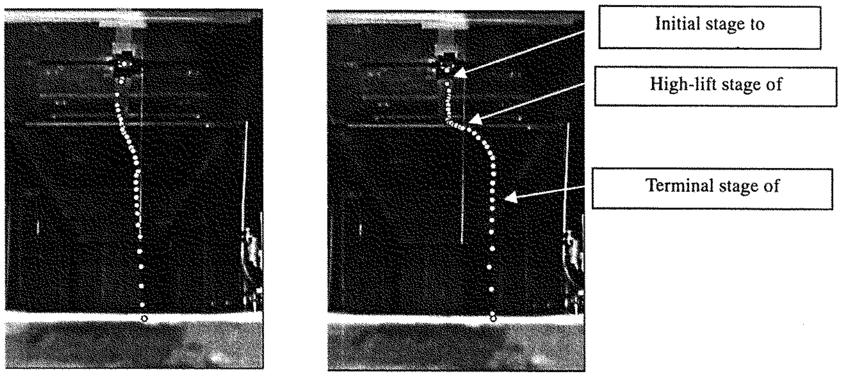

Fig. 6 Samara flight-trajectories: the poor performance (left); the good performance (right)
Samaras of a gourd maple at $U = 1.1$ [m/s].

gourd maple at U = 1.1 m/s. The photo on the right shows the case that R is larger than the actual range; the photo on the left shows the case that R is smaller than the actual range. White dots correspond to the locations of samaras in flight at every 0.03 seconds; the total number of dots corresponds to the flight duration and hence the flight range. Apparently the number of dots in the photo on the right is greater.

3.3 Discussion

The experimental results reveal the tendency that the time to start of auto-rotation from rest becomes shorter in stronger winds. It is also shown by the experiments in transverse winds that lift acting on samaras grows lager than that of the terminal state; hence the actual range exceed the conventional estimate in such cases; there is a tendency that the number of the good flight-performances grows as the wind velocity rises. Both the factors act favorably to lengthen flight range of samaras.

We annotate the presence of high-lift stage as follows: aerodynamic forces are in proportion to velocity squared; initially samaras experience the large relative speed, and in the end samaras move with the wind; therefore lift developed at the early stage of falling becomes larger than that acting on a samara moving with the wind.

The samaras that can generate not only drag but lift at the very early stage of falling can fly farther, because such samaras experience the large relative speed and the larger aerodynamic forces. The poor performance is due to lag in generation of lift during the falling. The luck depends on whether a wing is in good attitude for lift generation just in the wind tunnel.

The individual characteristics of samaras may affect the deviations in the time to start of auto-rotation as well as the range. As mentioned above another factor that affects the deviations is the initial conditions of samaras dropping into the wind tunnel. Apparently both factors closely interact with each other: samara's shape, weight, and initial attitude determine the falling speed, the time to start of auto-rotation, and the direction of rotation (clockwise or counter-clockwise), which consequently result in the range and the sideway drift (right or left). Deviations in the aerodynamic forces apparently grow as the wind speed rises.

Samaras drop vertically into the wind tunnel in our experiments, while in the fields samaras are exposed to the wind before leaving their parent plants. In the latter case it is not surprising to observe samaras start to fly horizontally or even soar up away from their parent plants.

4. CONCLUSIONS

We conducted the experiments to examine flight performances of samaras in transverse winds. The main findings are the following:

(1) The time to start of auto-rotation from rest is shorter in transverse winds than without winds;
(2) In transverse winds lift acting on samaras grows larger that that in the steady state.

Both are the cause of the large relative speed between the samaras and the transverse wind at the early stage of falling.

Actually in Japanese fields samaras depart from their parent plants in the much stronger winds than the present experiments, say 10-30 m/s. Hence the effects of stronger winds need examination.

It is also important to reveal detailed mechanism of transient dynamics of samaras in the early stage of flight in the transverse winds.

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