The Kinematics of a Falling *Dipterocarpus Alatus* Seed

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Abstract

Dipterocarpus Alatus (Thai:ยางนา, Yang Na) is a tree found in Thailand and other Southeast Asian countries. The seeds have two wings and rotate as they fall. High-speed video analysis was used to determine the terminal velocity and spin frequency as a function of the mass of a seed. Values of wing velocity, lift force, and drag force were then determined. It was found that as the mass of the seed increased, terminal velocity, frequency, and lift force also increased. It was shown that 80-95% of the retarding force generated during the fall was from lift and that the coefficient of lift for the seed used was approximately 1.5.

***Keywords*:** Dipterocarpus Alatus, seed, mass, terminal velocity, lift force, coefficient of lift

I. INTRODUCTION

A *Dipterocarpus Alatus* seed has two wings that act like airfoils, rotating the seed as it falls. From the rotation, a stable leading-edge vortex is generated, creating a lift that slows the descent[1]. It has been shown that this slowed descent increases seed dispersion[2].

There have been qualitative studies on the kinematics of one-winged rotating seeds, including research on how maple seeds generate lift[1] and transition into helical motion[2]. However, there has been little quantitative research on the aerodynamic lift generated by single winged seeds and even less research conducted on two-winged seeds. This paper investigates the effect of *Dipterocarpus Alatus* seed mass on the terminal velocity, frequency of spin, and lift generated.

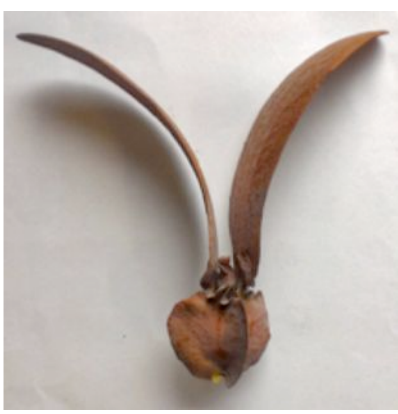

Figure 1. The *Dipterocarpus Alatus* seed selected for this investigation.

During the descent of the seed, two forces oppose the force of gravity: the drag and the lift generated by the wings. At terminal velocity the force of gravity equals the drag and lift combined. This can be modeled as,

$$F_g = \frac{1}{2} A_W \rho C_L v_W^2 + \frac{1}{2} A_B \rho C_D v_t^2 \qquad (1)$$

where A_W is the effective cross sectional area of the wing, A_B is the cross sectional area of the body of the seed, ρ is air density, C_L is coefficient of lift, C_D is the coefficient of drag, v_w is the effective wing velocity, and v_t is the terminal velocity[3,4]. Since the wings are angled, it is expected that with a greater terminal velocity, the wings will spin faster, increasing the velocity at the wing. Furthermore since the coefficient of lift increases as wing velocity increases[5], it is possible that as terminal velocity increases, the lift generated will increase as well. The Caldwell and Fales report concerns a rigid airfoil moving at high speed and may not apply to this seed with flexible airfoils moving at low speeds but when the seed weight, increases, it is expected that lift and terminal velocity will increase.

II. METHODS

The *Dipterocarpus Alatus* seed (Figure 1) was filmed as it fell from a height of approximately 2.9 m. As shown in Figure 2, a ruler was set up next to the drop zone to act as as a scale. A camera recording at 1000 fps was used to record the descent. After 3 trials of dropping the seed at its original mass, 3.70 ± 0.01 g, the inside of the seed was drilled out as much as possible then filled with different amounts of lead to vary the mass. The hole was drilled on the side and covered with tape to minimize any change in the aerodynamic profile of the seed. Three trials were conducted with masses ranging from 3.19 g to 4.99 g.

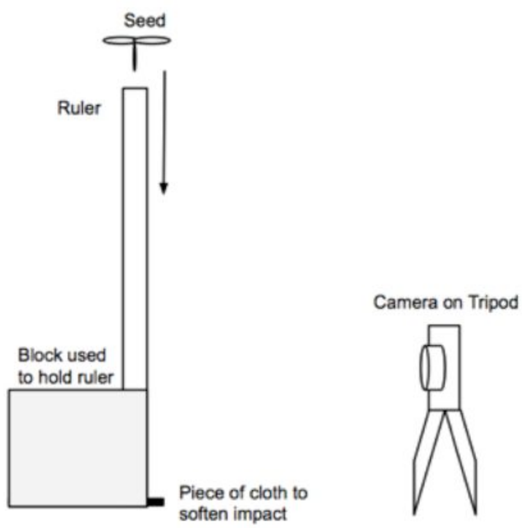

Figure 2. The experimental set up.

From the recorded video, terminal velocity was determined for the last 30 cm of the seed's descent, and spin frequency of the seed during its descent was determined.

The effective cross-sectional area of the wing was determined by comparing the mass of a full sheet of A4 paper with the mass of a printed 1:1 ratio top view cut-out photo of the seed. The seed had varying horizontal drift during its fall, resulting in different landing distances from the camera. To compensate for trials in which the seed did not drop next to the ruler, distance adjustments were made using similar triangles, to determine the terminal velocity.

III. RESULTS AND DISCUSSION

The relationship between weight and terminal velocity squared is shown in Figure 3. Although the variability is high, a positive linear trend between weight and terminal velocity squared is strongly suggested.

Interestingly, although the seed is spinning and generating lift, the descent follows a pattern similar to an object that does not generate lift. This implies

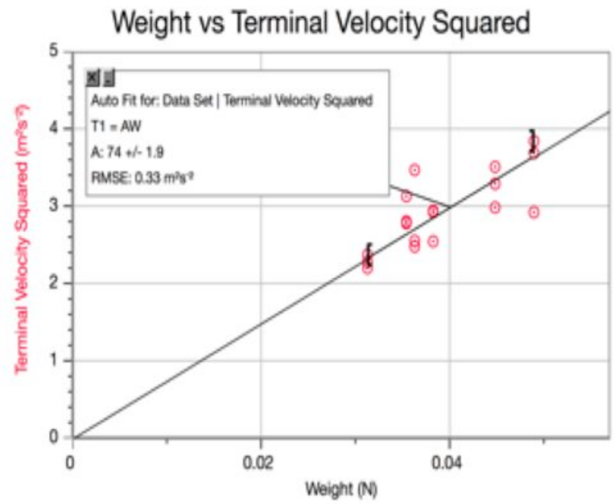

Figure 3. A positive linear correlation between seed weight and terminal velocity is evident.

that there may be a relationship between terminal velocity and wing velocity. This will be shown in Figure 5.

The relationship between the weight of the seed and the frequency of rotation squared is shown in Figure 4 (below). The graph shows a positive linear trend, which reflects the initial expectation that as terminal velocity increases the spin frequency will increase as well. From this, along with Figure 3, a positive correlation is expected between terminal velocity and frequency. This is shown in Figure 5.

In Figure 4, it is interesting to note that for 0.036 N, which was the original weight, the data point lies above the general linear trend, as highlighted by the red circle. It is possible that the weight modification, which involved drilling the seed and loading the hole with lead pellets, affected the weight distribution of the seed, changing the way

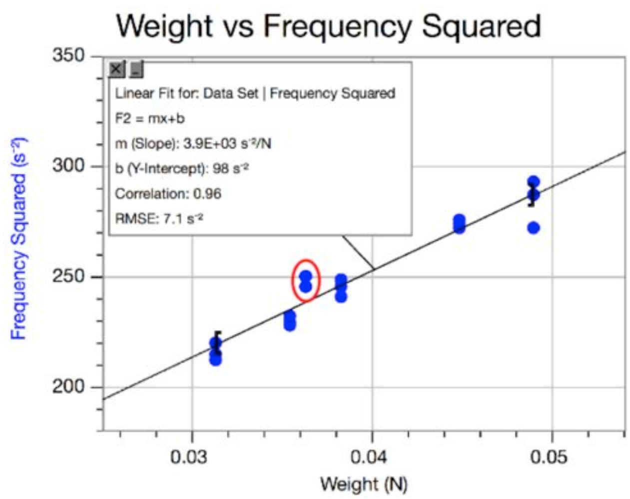

Figure 4 The spin frequency depends linearly on the weight of the seed. Data for the original seed is circled in red.

the seed spun as it fell and resulting in a lower spin frequency compared to the original seed.

Figure 5 shows a clear positive correlation between terminal velocity and frequency. A linear fit was used to model the relationship, however, the large variation of the data from the linear fit indicates that the relationship between terminal velocity and frequency may not be linear.

Since calculating an exact value of lift or drag was not possible with the data available, a range of minimum and maximum estimated drag and lift was calculated. An estimate of the seed's coefficient of drag was made by characterizing the shape of the

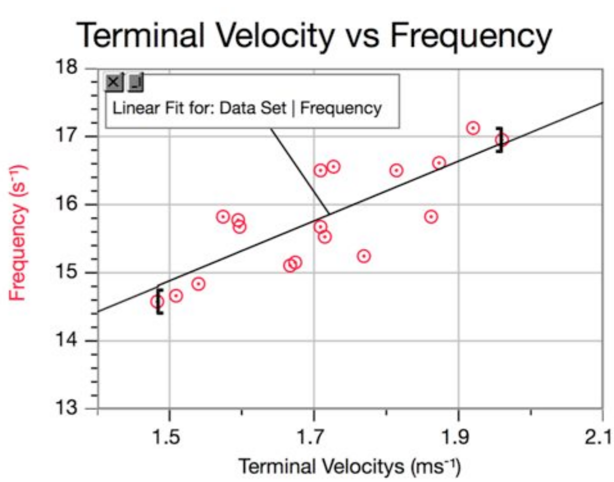

Figure 5. The spin frequency and terminal velocity of the seed have a positive correlation.

seed between two extreme shapes, a cone and a cube. A minimum coefficient of drag of 0.5 (cone) and a maximum of 1.0 (cube) were assumed. By subtracting the possible drag forces from the weight, the possible range of lift forces was determined.

The possible maximum and minimum lift, along with drag force, for each weight is shown in Figure 6. Since this graph shows only the average values, refer to the appendix for values for each trial. The graph shows that 80-95% of the retarding force when the seed reached terminal velocity is the lift generated from the wings. Figure 6 also shows that as weight increases, the lift generated increases as well most likely due to the increased spin frequency.

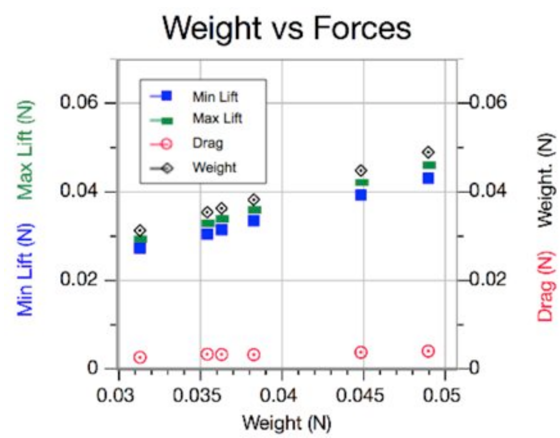

Figure 6 The major component of the retarding force is lift.

To calculate the coefficient of lift, first an estimation of the effective surface area of the lift generating part of the wings was made. For this seed, this was estimated as between 2 and 7 cm from the center of the seed as shown in Figure 7. The average wing velocity squared was calculated using the following formula,

$$Velocity\ Squared = \frac{\int_{0.02}^{0.07} 4\pi^2 f^2 r^2 dr}{0.07-0.02} \quad (2)$$

where f is the spin frequency and r is the distance from the seed's center in meters. Using the velocity squared and the minimum and maximum lift shown in figure 6, the possible minimum and maximum values for coefficient of lift were calculated.

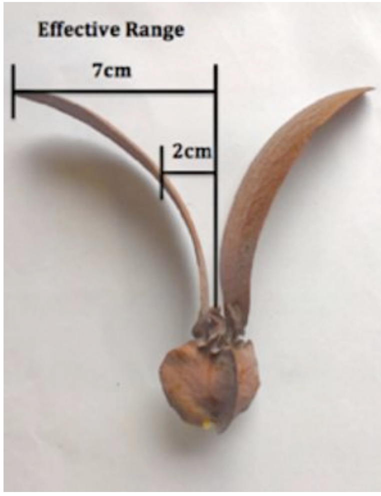

Figure 7 Estimated effective radii of the lift-generating part of the wings.

The relationship between wing velocity and maximum and minimum coefficient of lift is shown in figure 8. It can be seen that as wing velocity increases, the coefficient of lift increases. The data points circled in red for the unmodified original seed deviate from the general trend. This dip in the trend is most likely due to the higher frequency, seen in Figure 4. A higher spin frequency means increased wing velocity, which would decrease the calculated value of coefficient of lift.

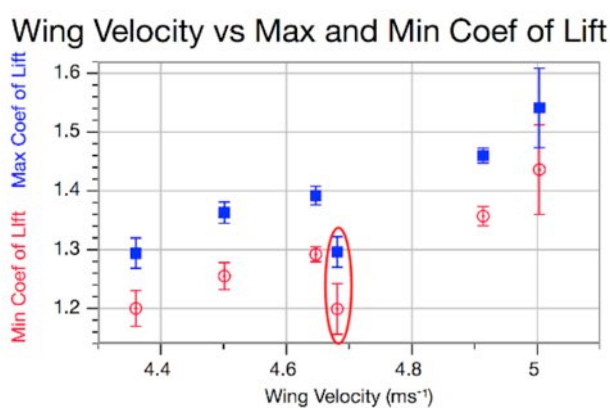

Figure 8 As wing velocity increases, the coefficient of lift also increases. Data for the original seed is circled in red.

This result is in agreement with Caldwell and Fales' wind tunnel study[5], which showed that coefficient of lift increases with wing velocity until Mach 1. This is interesting, given that the conditions here are very different from their study, as they tested fixed airfoils at high wind speeds, and a flexible wing at low speeds is studied here.

Only a small range of weight was used in this investigation as the seed's spinning became unstable when the seed became too light or too heavy. Because of this, the data has a limited range. Nonetheless, general trends and correlations can be concluded. It seems that the seed has an optimized mass distribution that yields stable descent. Figures 4 and 8 show that the modified seed behaved a little differently from the original seed. This suggests that the stability of the spinning motion may have been affected by the drilling of the seed, which changed the mass distribution. It is likely that the seed has evolved with an optimized mass distribution for a stable descent, which may be more advantageous for a wider dispersal.

For further research, measurements on the drag force on seeds of *Dipterocarpus Alatus* in fixed and spinning conditions in a wind tunnel would greatly improve the accuracy of the calculation of lift provided by the wings of the seed. Also a further study using different seed specimens of the same species or different species of two-winged seeds could further shed light on this topic.

IV. CONCLUSION

A proportional relationship was found between the weight of the seed and its terminal velocity squared. The weight and frequency of spin squared also had a positive linear relationship, which suggested a linear relationship between terminal velocity and frequency. Although a clear relationship could not be established due to the small range of weights tested, a positive correlation between terminal velocity and frequency is suggested.

As the weight increased, the aerodynamic lift force generated by the spinning wings increased. Most of the retarding force, about 80-95% was provided by the lift force. Using this, the coefficient of lift was estimated to be between 1.3 and 1.6.

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APPENDIX

Mass (g)	Weight (N)	Frequency (s^{-1})			Terminal Velocity (ms^{-1})		
		T1	T2	T3	T1	T2	T3
3.19	0.0313	14.8	14.6	14.7	1.54	1.48	1.51
3.61	0.0354	15.1	15.2	15.2	1.67	1.67	1.77
3.70	0.0363	15.7	15.8	15.8	1.60	1.57	1.86
3.90	0.0383	15.7	15.8	15.5	1.71	1.60	1.72
4.57	0.0448	16.6	16.5	16.6	1.73	1.81	1.87
4.99	0.0490	16.9	16.5	17.1	1.96	1.71	1.92

Table 1. Mass, Weight, Frequency, and Terminal Velocity3.70g was the original mass

Weight (N)	Maximum Drag (N)			Minimum Drag (N)		
	T1	T2	T3	T1	T2	T3
0.0313	0.00370	0.00343	0.00355	0.00184	0.00172	0.00178
0.0354	0.00434	0.00437	0.00488	0.00217	0.00219	0.00244
0.0363	0.00398	0.00386	0.00541	0.00199	0.00193	0.00270
0.0383	0.00456	0.00397	0.00459	0.00228	0.00198	0.00229
0.0448	0.00465	0.00513	0.00547	0.00233	0.00257	0.00274
0.0490	0.00599	0.00456	0.00575	0.00250	0.00228	0.00288

Table 2. Weight and Maximum and Minimum Drag

Weight (N)	Maximum Lift (N)			Minimum Lift (N)		
	T1	T2	T3	T1	T2	T3
0.0313	0.0294	0.0296	0.0295	0.0272	0.0276	0.0274
0.0354	0.0332	0.0332	0.0330	0.0307	0.0306	0.0302
0.0363	0.0343	0.0344	0.0336	0.0321	0.0321	0.0304
0.0383	0.0360	0.0363	0.0360	0.0332	0.0340	0.0333
0.0448	0.0425	0.0423	0.0421	0.0397	0.0393	0.0390
0.0490	0.0460	0.0467	0.0461	0.0425	0.0441	0.0427

Table 3. Weight and Maximum and Minimum Lift

Weight (N)	Max. Coefficient of Lift			Min. Coefficient of Lift		
	T1	T2	T3	T1	T2	T3
0.0313	1.27	1.32	1.30	1.17	1.23	1.20
0.0354	1.38	1.37	1.34	1.27	1.26	1.23
0.0363	1.32	1.30	1.27	1.24	1.21	1.15
0.0383	1.39	1.38	1.41	1.28	1.29	1.31
0.0448	1.47	1.47	1.44	1.37	1.37	1.34
0.0490	1.51	1.62	1.49	1.40	1.53	1.38

Table 4. Weight and Maximum and Minimum Coefficient of Lift