Winged Seed Aerodynamics and Atmospheric Density: Preliminary Results

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Abstract

The relationship between atmospheric density and the aerodynamic behavior of two types of winged seeds, *Hopea odorata* and *Dipterocarpus alatus*, have been examined. The seeds were released in atmospheres of air, CO_2, and He and video recorded at 250 fps for analysis. There was an inverse proportional relationship between the atmospheric density and terminal velocity squared for both seeds. However, for reasons that are not understood, the inverse of atmospheric density was proportional to the spin frequency squared for air and CO_2, but not for He.

Keywords: *Hopea odorata*, *Dipterocarpus alatus*, winged seed, atmospheric density, aerodynamics

I. INTRODUCTION

Winged seed behavior presents a fascinating phenomenon that raises interesting questions about aerodynamics and flight dynamics. The similarity between the behavior of a falling winged seed and that of helicopter blades lies in the way they use air currents and generate lift. Just like helicopter blades generate lift by rotating rapidly, winged seeds also generate lift as they spin while descending. This mechanism allows them to disperse on windy days.

In the field of aerodynamics, understanding the behavior of winged seeds in atmospheres of different densities poses challenges similar to those faced by aerospace engineers designing aerial vehicles for extraterrestrial environments. One such challenge arises from the low-density atmospheres of planets like Mars. The atmosphere on Mars is only 0.0166 kg/m^3 which is only about 1/70 the density of Earth atmosphere. For NASA, designing the Ingenuity helicopter for the Mars mission has been a challenging task due to the need to adjust flight dynamics and aerodynamic principles to accommodate the unique atmospheric conditions of the Red Planet. The low density of the atmosphere provides less support for lift and propulsion, altering the flight characteristics and necessitating novel approaches to maintain stability and control.[1]

When winged seeds descend, there are three main forces acting on the seed: gravity, aerodynamic lift force, and drag force. Kun-Woo Song's study[2] of the effect of varying mass on the behavior of *Dipterocarpus alatus* seeds used the model:

$$F_g = \frac{1}{2} A_w C_L \rho v_w^2 + \frac{1}{2} A_T C_D \rho v_t^2 \qquad (1)$$

where F_g is force of gravity, A_w is the effective cross-sectional area of the wing, A_T is the total cross-sectional area of the entire seed, ρ is atmospheric density, C_L is the coefficient of lift, C_D is the coefficient of drag, v_W is the effective wing velocity, and v_t is the terminal velocity.

Equation 1 can be rearranged to isolate density, giving:

$$\left(\frac{1}{2} A_w C_L v_w^2 + \frac{1}{2} A_T C_D v_t^2\right) / F_g = 1/\rho \qquad (2)$$

Equation 2 indicates that if the coefficients of lift (C_L) and drag (C_D) remain constant (i.e., the aerodynamic behavior of the seeds remains the same across different densities), then density (ρ) is expected to be inversely proportional to the square of both terminal velocity and spin frequency.

Ikegami et al[3] studied the effect of varying mass on the aerodynamic behavior of *Pterocymbium Tinctorium* seeds. Both Song's and Ikegami's studies showed that there is a strong proportional relationship between terminal velocity and frequency, between weight and the square of terminal velocity, as well as between weight and the square of the spin frequency. They also showed that lift accounted for approximately 80 - 90% of the total retarding force.

Given the model proposed in equation 2, if the drag force is negligible and the model holds for atmospheres of different densities, then density would be inversely proportional to the square of the spin frequency. If the lift force is negligible, density would be inversely proportional to the terminal velocity squared. Since both are expected to be present to some degree, then the density would be inversely proportional to the squares of both terminal velocity and spin frequency only if the aerodynamic characteristics of both the drag and lift remain constant for all atmospheric densities.

Understanding the behavior of winged seeds in atmospheres of different densities is essential for a complete understanding of winged seed aerodynamics, but no studies of this have been published. The behavior of the winged seeds of *Hopea odorata* and *Dipterocarpus alatus* falling in atmospheres of air, carbon dioxide, and helium will be studied here. Given the experience of NASA in developing the Mars Ingenuity helicopter, it is expected that there will be differences in the aerodynamic behavior of winged seeds in a very low-density atmosphere.

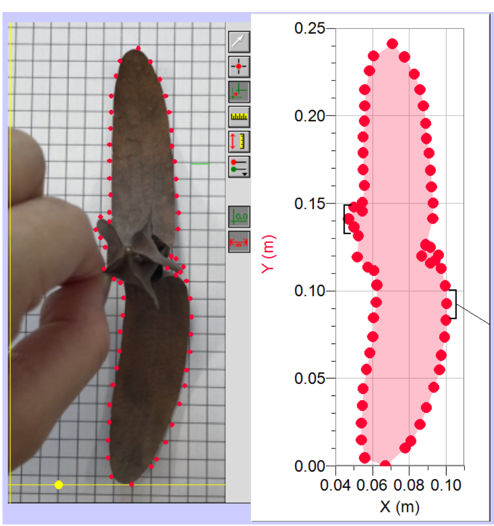

Figure 3. Measurement of the cross-sectional area of entire seed.

Figure 1. *H. odorata* **Figure 2**. *D. alatus*

II. METHODOLOGY

Seed Selection and Measurement

The winged seeds used, one *Hopea Odorata* and one *Dipterocarpus Alatus* are shown in figures 1 and 2.

Figure 3 shows the method of measuring the cross-sectional area of the entire seed, A_T using photo analysis in LoggerPro. To find the effective area of the wing, A_w, first the distance from the center to where the wings begin to become more horizontal, r_1, and the distance from the center to the tip of the wing, r_2, was measured, as shown in figure 4. The measurement of the effective area of the wing, between r_1 and r_2, is shown in figure 5.

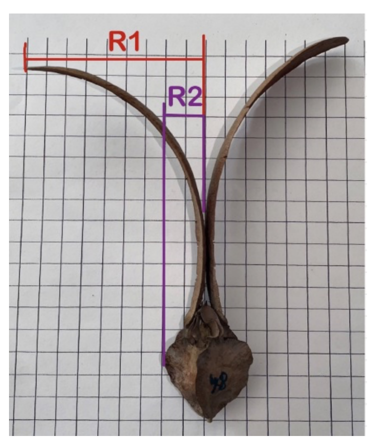

Figure 4. Measurement of $r_1$and r_2.

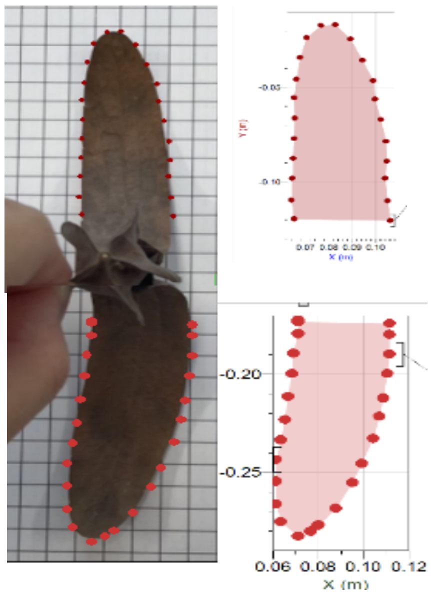

Figure 5. Measurement of the effective cross-sectional area of the wing.

Experimental Set Up

The gasses used were air, carbon dioxide (CO_2) and Helium (He), whose densities at atmospheric pressure and 26 °C are 1.20, 1.87 and 0.17 kgm^{-3} respectively. The winged seed was dropped in a 50 cm diameter, 1.20 m tall tube. For the gases air and carbon dioxide, the tube was placed on the ground with the open end facing up, as shown in figures 6 and 7. To fill the tube with CO_2, a 50 cm disc attached to a long stick was inserted to the bottom of the tube, with the CO_2 slowly released below the disc. A balloon filled with air was placed in the tube to show the level of the CO_2. As the balloon began to float, the disc was slowly lifted until the tube was full of CO_2. A mesh basket with attached strings was used to catch the seed at the bottom and retrieve it after each trial, to minimize disturbing the gas. The balloon was placed in the top of the tube and a small amount of gas was added to the tube after every trial to ensure that it was still full of CO_2. The seed was dropped from approximately 20 cm above the top of the tube, and the last 30 cm of its fall recorded at 250 fps. A spotlight was used to ensure clear video footage.

For the helium, the tube was placed between two tables, with its open side facing downwards, as shown in figure 8. The tube was filled using the same technique as for the CO_2. To release the seed in He, a rod with a 5 cm diameter disc attached to the end was used. The seed was placed on the disc and raised to the top of the tube. Then the rod was pulled quickly to the side, causing the seed to slide off the disc and fall. Five trials were recorded for each condition.

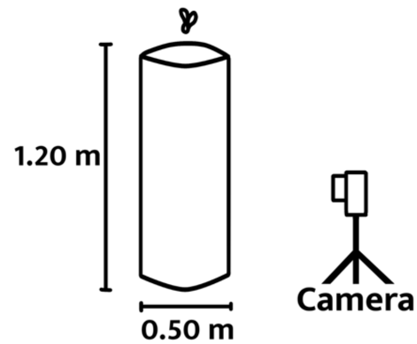

Figure 6. Set up of the air atmosphere.

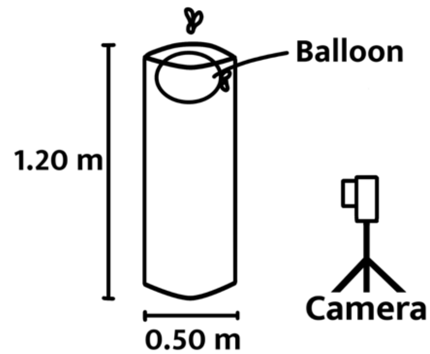

Figure 7. Set up of the CO_2 atmosphere.

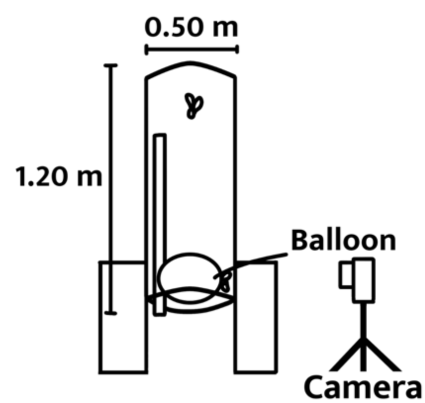

Figure 8. Set up of the He atmosphere.

Analysis

All parameters in equation 2, except the coefficients of lift and drag, can be determined from video analysis or directly measured. The coefficient of drag was assumed to be 1 and 0.5, for finding the range of the expected maximum and minimum drag force respectively, following Song.

Effective wing velocity was calculated, again following Song, using

$$v_w^2 = \frac{\int_{r_1}^{r_2} 4\pi^2 f^2 (r_2 - r_1)^2}{r_2 - r_1} dr \quad (3)$$

where r_1 and r_2 were measured as described above. From effective wing velocity the coefficient of lift can be determined.

III. RESULTS AND DISCUSSION

The mass, total cross-section area, r_1, r_2 and wing area of the seeds are shown in Table 1.

Seed	Mass (g)	r_1 (m)	r_2 (m)	Wing area (m^2)	Total area (m^2)
H. oderata	0.15	0.073	0.031	0.00078	0.00098
D. alatus	3.85	0.104	0.067	0.00742	0.00816

Table 1. Data from seed measurement

Figure 9 shows that there is an inversely proportional relationship between the density of the atmosphere and the terminal velocity squared for both species of seed in all three of the gasses tested.

Song and Ikegami et al showed that terminal velocity and spin frequency were proportional over all seed masses tested, with coefficient of lift staying fairly constant, implying that the aerodynamic characteristics of the wing interacting with the atmosphere as it spun was consistent. Figure 10 shows inverse density versus the square of the spin frequency of the seed as it fell. Frequency squared was close to inversely proportional to density for only air and CO_2, but the seeds falling in He spun at much lower rates. This indicates that the aerodynamic characteristics of the wings in He were very different from their behavior in air. The aerodynamic behavior of the seeds is consistent in air and CO_2 (with their similar density), but in He with its very low density, the wings do not behave at all the same aerodynamically. The very low spin frequency shown in He, compared to that predicted from the behavior in air and CO_2 is quite unexpected, but not entirely surprising, given NASA's experience in the designing of the Mars Ingenuity helicopter. Unfortunately, the nature of and reasons for the difference in the aerodynamic characteristics of the seeds in He cannot be determined from the results presented here.

Further research on winged seed aerodynamics and gas density is recommended. As only pure gasses were used here, no tests were done for gas densities

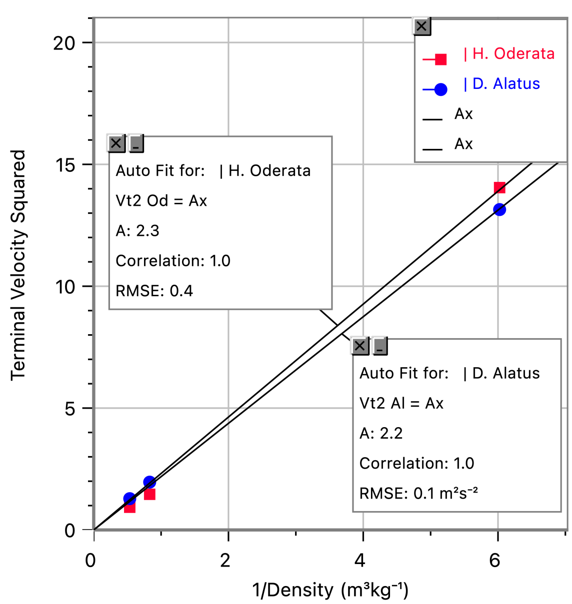

Figure 9. Relationship between terminal velocity squared and inverse density

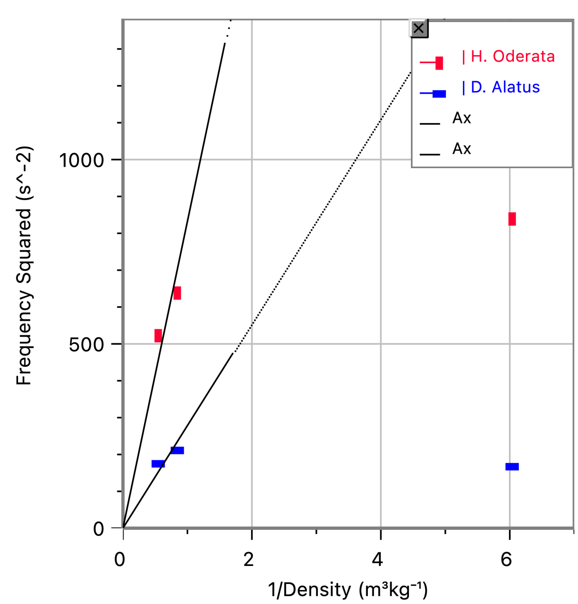

Figure 10. Relationship between spin frequency squared and inverse density.

between air and He. It is recommended that gas mixtures with densities varying from 1.20 to 0.20 kgm^{-3} be tested. The distance of fall is recommended to be longer, as here the seeds in He had just reached terminal velocity before leaving the tube. Finally, the use of a wind tunnel is suggested to observe the flow of gases across the wings at low densities to enable a complete understanding of the aerodynamics to be developed.

IV. CONCLUSION

The aerodynamic behavior of the winged seeds of *Hopea odorata* and *Dipterocarpus alatus* has been shown to be very different in Helium than in air or CO_2, While the terminal velocity squared was inversely proportional to the gas density for both seeds, the spin frequency in He for both seeds was much lower than expected. This implies that the coefficient of lift, a measure of how the wing interacts with the atmosphere aerodynamically, was higher in He than in the other two gasses. The reasons for this are not know.

V. REFERENCES

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