Mass and Terminal Velocity of a falling *Crepis vesicaria L.* Seed

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Abstract
The seed of the *Crepis vesicaria L.* plant has evolved a fuzzy disc at one end to aid in wind dispersal. The mass of a seed was varied and its terminal velocity was determined using video analysis. It was shown that the terminal velocity is proportional to the 0.62 power of the mass of the seed. It was further shown that the behavior of the seed can be effectively modeled as a solid disc experiencing airflow in the transition region between laminar and turbulent flow.

Keywords: *Crepis vesicaria L.* seed, terminal velocity, mass, drag coefficient, Reynolds number

I. INTRODUCTION

To enhance seed dispersal, many plants have evolved specialized features. Some have developed feather-like bristles around their seeds which aids in wind dispersal. An example is the *Crepis vesicaria L.* seed. This species is native to the Mediterranean region of Europe and is also widespread in North America.[1] As shown in Figure 1, the seeds have bristles that form a fluffy disc at the top with a diameter of around 3 cm. The fluffy disc on top increases the drag force, leading to a decrease in the velocity at which it falls from the plant. This allows the seed to be more widely dispersed in windy conditions.

The effect of mass on the terminal velocity of the seed was studied, allowing the type of flow regime that the seed experiences — whether turbulent, laminar or in the transition region between purely turbulent flow or laminar flow — to be inferred. Turbulent flow for solid objects usually occurs at higher velocities where the fluid flow becomes chaotic and unpredictable. Laminar flow, on the other hand, happens generally at very low speeds, such as a dust particle drifting through the air. In between, there is a transition region in which both characteristics are mixed.[2]

Figure 1. Typical *Crepis vesicaria L.* seeds.

As the seed falls, some air flows through the bristles while the rest moves around the disc—similar to how wind moves past windbreaks in open fields. Experimental and theoretical studies on windbreaks, such as rows of trees or fences, suggest that when porosity is low enough, most air is deflected around rather than through the structure. This creates a wind-shadow and generates significant drag.

In a study conducted by L. J. Hagen and E. L. Skidmore on how wind interacts with barriers of different porosities, it was found that when porosity drops below 40%, airflow through the barrier decreases rapidly, and most of the wind is forced to travel around it.[3] Additionally, in a study on tree windbreaks by Bitog et al., it was observed that as the aerodynamic porosity decreased from 91% to 42%, the drag coefficient increased from 0.55 to 1.08.[4] This increase in drag suggests that at low porosity, porous structures begin to aerodynamically behave more like solid objects, as they deflect more airflow and experience greater resistance.

These findings suggest that the seed, despite its porous, bristled structure, may be reasonably modeled as a solid disc under certain conditions. If the drag coefficient of the seed is close to the typical value for a solid disc of approximately 1.1,[5] and its Reynolds number supports the flow behavior, then applying the solid disc drag equation under turbulent flow may be a reasonable approximation.

For falling objects, whether they experience a flow that is turbulent, laminar or in the transition region depends on the Reynold's number (Re) which takes into account the diameter and terminal velocity of the object, and kinematic viscosity of the fluid.[6] While these values vary depending on a number of factors, generally, a Reynolds number above 3000 indicates turbulent flow, while below 1000 corresponds to laminar flow.[7,8] When the Reynolds number is between 1000 and 3000, the flow is considered transitional, neither fully laminar nor turbulent.

To test whether the seed behaves as a solid disc in turbulent flow, Equation 1 will be used. During the seed's descent at terminal velocity, the forces of drag (F_d) will balance with the forces of gravity (F_g), giving:

$$mg = \frac{C_d A \rho v^2}{2} \tag{1}$$

where A is the effective cross-sectional area, ρ is the air density, C_d is the coefficient of drag, and v is velocity.[9]

If the terminal velocity is found to be as equation 1 predicts, proportional to the square root of mass, it would support the assumption that the seed behaves like a solid object in turbulent flow. Furthermore, if the value of the drag coefficient found from this equation also closely matches the drag coefficient of a solid disc of approximately 1.1,[5] it would further strengthen the validity of modeling the seed as a solid disc.

Sun Bo-Hua and Xiao-Lin Guo conducted a similar study using dandelion (*Taraxacum officinale)* seeds, a species with fuzzy bristles in a more spherical shape. They found that the terminal velocity of the seed was proportional to the 0.75 power of its weight, indicating that its behavior may be effectively modeled as a solid sphere, following a flow within the transition region.[10] If the *Crepis vesicaria L.* seed behaves similarly, a flow within the transition region is more likely.

This paper aims to determine the effect of mass on the terminal velocity of *Crepis vesicaria* L. seeds, and to evaluate the validity of modeling their aerodynamic behavior during their descent as that of a solid disc.

II. METHODS

Seed Measurement

A photograph was taken of the seed on a 2 mm square grid from directly overhead, as shown in Figure 2. The diameter of 30.2 ± 1.2 mm was found using the average of five diameters measured using LoggerPro. Since the seed mostly had the same overall bristle length, the diameter allowed for the effective cross-sectional area to be found as well.

Seed Mass Manipulation

After four trials of dropping the seed at its original mass, the weight of the seed was increased by adding hot glue to the end of the seed. To reduce the mass to less than the original mass, the end of the seed was cut. Four trials were conducted for each of eight different masses, with the mass ranging from 4.12 mg to 27.16 mg. The original mass of the seed was 10.82 mg.

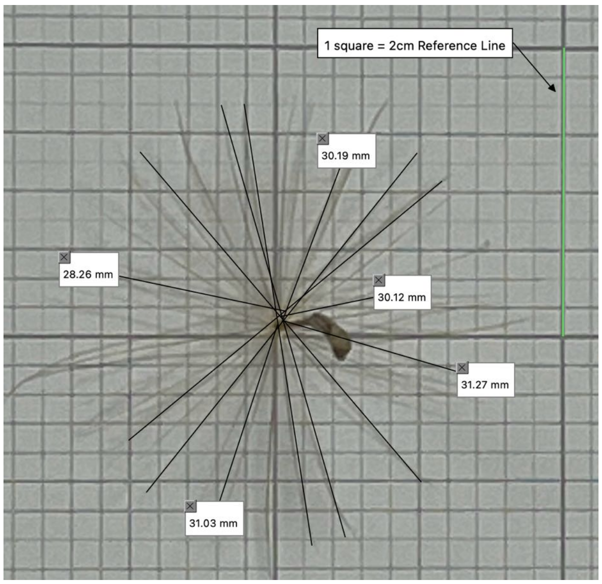

Figure 2. Top-View of seed with diameters measured by LoggerPro.

<u>Experimental Setup</u>

The camera, recording at 60 fps, was positioned 1.42 m from the landing zone and aligned to capture the last 0.5 m of the fall before the seed hit the floor, using a vertically mounted meter stick as a reference, as shown in Figure 3. Only trials in which the seed landed in the landing zone, within 0.1m of the meter stick, were used. Barriers were placed surrounding the drop zone to protect the falling seed from stray air currents. The videos were then analyzed in LoggerPro to determine the terminal velocity of the seed.

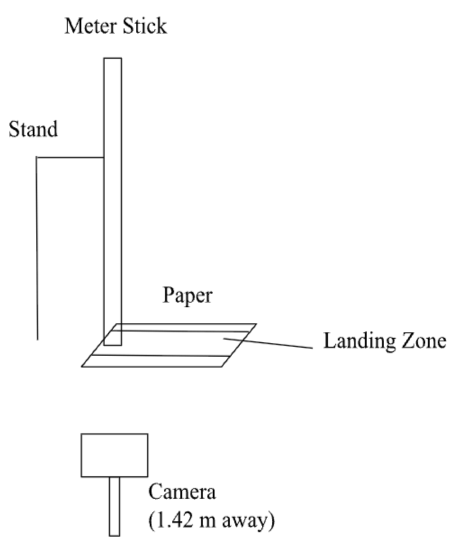

Figure 3. Experimental setup to record seed descent.

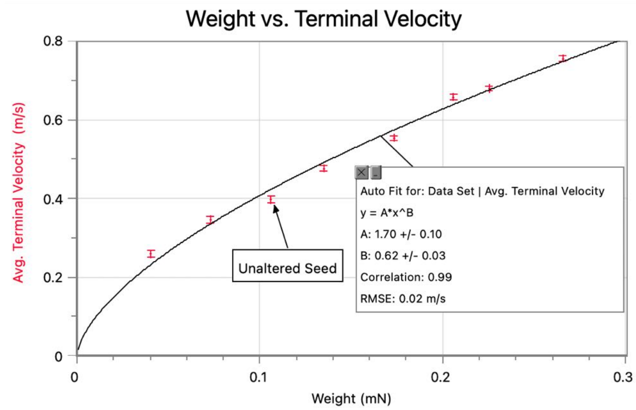

Figure 4. Relationship between Weight and Average Terminal Velocity

III. RESULTS & DISCUSSION

The seed was likely experiencing airflow in the transition region between laminar and turbulent flow. This is supported by the calculated Reynolds number for the falling seed, which ranged from 491 to 1434, values which fall within the typical transition region.

This flow behavior is further reflected in the relationship between the weight of the *Crepis vesicaria L.* seed and the terminal velocity. As seen in Figure 4, the terminal velocity of the seed increased proportionally to the 0.62 power of the weight of the seed. This relationship can be modeled as:

$$v = (1.7 \pm 0.1 \frac{\text{ms}^{-1}}{\text{mN}})\,(mg)^{(0.62 \pm 0.03)} \quad (2)$$

The terminal velocity and weight does not share a square root function, as would be expected according to equation 1 if the seed were experiencing purely turbulent flow. However, since the terminal velocity of the seed is proportional to mass raised to the power of 0.62, modeling it as a solid disc falling through air under turbulent flow is a reasonable approximation.

The drag coefficient calculated for each seed mass using equation 1 ranged from 1.1 to 1.7. The general trend showed that as the mass increased, the drag coefficient decreased. The coefficient of drag for a solid disc is approximately 1.1.[5] Despite some variation due to the porous structure of the seed, the calculated values support the assumption that the seed behaves similarly to a solid disc, especially at higher masses. This also aligns with the calculated Reynolds numbers, which mostly fall within the transitional flow region. Thus, while the seed is not experiencing fully turbulent flow, the drag coefficient and the terminal velocity–mass relationship exponent of 0.62, which is close to 0.5, both support the idea that assuming turbulent flow and applying equation1is a reasonable approximation for modeling the motion of the seed. This indicates that the seed's structure, like a low-porosity windbreak, reduces airflow through its surface enough that it can be approximated as a solid disc, even while falling within the transition flow region.

Figure 6 and Figure 7 provide closer inspections with a light microscope of what the porous gaps between the bristles look like. The many smaller branches of bristles on the main long bristles could contribute to the reason why the fuzzy disc acts as if it were solid.

Comparing these results to Sun Bo-Hua and Xiao-Lin Guo's results, it is evident that the two species behave similarly. While *Taraxacum officinale* seeds show a 0.75 power relationship, a 0.62 relationship is present for this species.[10] This difference could be due to the *Taraxacum officinale* seeds in Sun's study having less mass causing it to fall more slowly, with the air flow being closer to the laminar region.

A factor that could have affected the estimated values of coefficient of drag, as well as the Reynolds numbers, is uncertainty in measuring the diameter of the seed. Since the bristled edge of the seed is not a perfectly uniform circle, the effective diameter was estimated and assumed to be roughly consistent across seeds. However, in reality, some bristles extended noticeably further than others, introducing variation in the actual cross-sectional area.

Further research is suggested for a variety of seeds with this specific type of adaptation for wind dispersal needs to be tested. Although *Taraxacum officinale* and *Crepis vesicaria L.* seeds seem to experience airflow within the transition region, this may not apply to all porous bristle seeds. Studying more seed species will build a more comprehensive understanding of how these types of seeds behave.

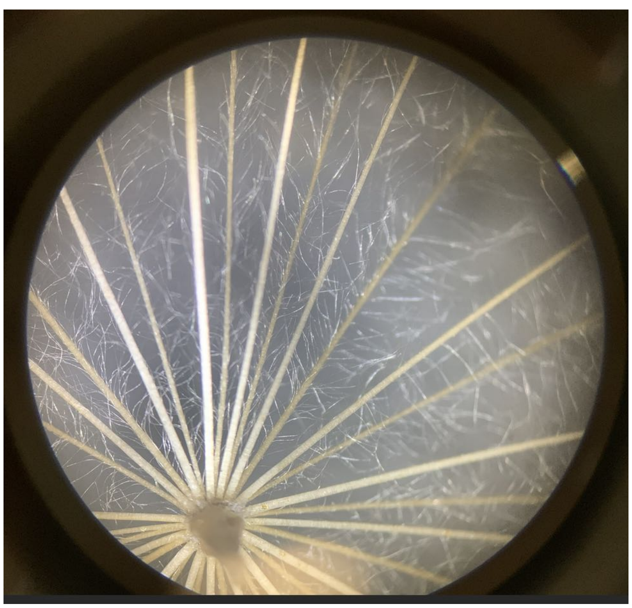

Figure 6. Image of the fibers near the center of the disc taken at magnification 40x.

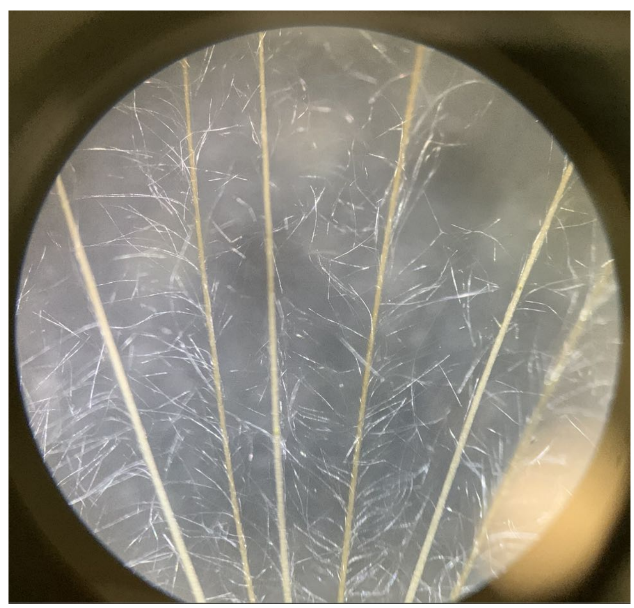

Figure 7. Image of the fibers near the edge of the disc taken at magnification 100x.

IV. CONCLUSION

It was shown that *the* terminal velocity of the *Crepis vesicaria L.* seed was proportional to the 0.62 power of its weight, indicating airflow in the transition region between laminar and turbulent flow. The Reynolds number ranging from 491 to 1434 supported the seed following a flow within the transition region. The calculated drag coefficient ranged from 1.1 to 1.7. Although the seed falls within the transition region, the 0.62 exponent is relatively close to the 0.5 expected in turbulent flow, supporting the approximation that the seed behaves similarly to a solid disc under turbulent conditions.

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