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P1_4 Five Centimeters Per Second?

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Abstract

In Makoto Shinkai's romantic drama '5 Centimeters per Second', it is said that 'The speed cherry blossoms fall [is] 5 centimeters per second' [1]. In this paper, we attempt to find the speed that cherry blossoms fall at through use of the Rayleigh Drag Equation and the Archimedes Principle.

Introduction

Cherry blossoms fall from the trees in early spring, yet simple observation shows that they do not take the same amount of time to fall to the ground as, for instance, a rock would. As such, it is reasonable to assume that there must be some additional forces acting upon the cherry blossoms in order to slow their descent. In this paper, we shall assume that both a buoyant force and a drag force act upon the cherry blossom.

The force of gravity acting upon the cherry blossom is simply its mass, m, multiplied by the gravitational acceleration $g = 9.81$ m/s^2 [2]. This can be changed to Eq. (1) by substituting in the volume of the petal, V, and its density ρ_p.

$$F_g = (\rho_p V)g \tag{1}$$

The buoyant force that acts upon the cherry blossom is calculated from the Archimedes Principle - the mass of fluid displaced provides an upward force on the displacing object [3]; thus the buoyant force is given by Eq. (2);

$$F_b = (\rho_f V)g \tag{2}$$

where ρ_f is the density of the fluid.

Lastly, the drag force caused by air resistance is given by the Rayleigh Drag Equation [4], given below:

$$F_d = \frac{1}{2}\rho_f v^2 C_d A \tag{3}$$

Where v is the velocity the object is moving at relative to the fluid it is in, C_d is the drag coefficient of the object, and A is the object's cross-sectional area.

Balancing the forces in Eq. (1), Eq. (2), and Eq. (3) gives the equation below:

$$(\rho_p V)g = (\rho_f V)g + \frac{1}{2}\rho_f v^2 C_d A \tag{4}$$

Which can be rearranged to find the terminal velocity of an object falling in a fluid:

$$v = \sqrt{\frac{2gT(\rho_p - \rho_f)}{\rho_f C_d}} \tag{5}$$

where T is the petal thickness, as volume V can be thought of as the cross-sectional area A multiplied by the thickness T of an object.

Analysis

Eq. (5) shows that the terminal velocity of an object falling is determined by its thickness T, density ρ_f, and drag coefficient C_d. The drag coefficient and density for a cherry blossom is assumed to be similar to that of R. Damascena; taking average values from Table 1 in the paper by *Yilmaz, D.* and *Ekinci, K.*, (also provided in Fig. 1) gives the density of a cherry blossom to be $\rho_f = 16.25$ kg/m^3 (4 S.F.), and the drag coefficient $C_d = 0.5713$ (4 S.F.). Assuming that the cherry blossom is of similar thickness to a piece of paper (0.09 mm) [5], the terminal velocity of a falling cherry blossom is calculated to be 0.05350 m/s (4 S.F.) - (approximately) 5 Centimeters per Second.

Assumptions

It is assumed that the buoyancy equation for spherical objects is applicable to non-spherical objects such as a cherry blossom.

It is assumed that a cherry blossom is of comparable thickness to a piece of paper; a typical piece of 70 GSM A4 paper is 0.09 mm thick. [5]

It is assumed that the Archimedes Principle, Gravity and the Rayleigh Drag are the only forces applied to the falling cherry blossom.

References

[1] M. Shinkai, 5 Centimeters per Second, 2007

[2] P. A. Tipler and G. Mosca, *Physics for Scientists and Engineers* (2008), 6th Edition, p. 43

[3] P. A. Tipler and G. Mosca, *Physics for Scientists and Engineers* (2008), 6th Edition, p. 432

[4] `https://www.chemeurope.com/en/encyclopedia/Drag_equation.html` (Accessed 29/10/2021)

[5] `https://www.imcolorprint.com/paper-thickness-conversion-from-gsm-to-mm/` (Accessed 13/10/2021)

[6] D. Yilmaz and K. Ekinci, *Physico-mechanical characteristics of rose petals dealing with the pneumatic harvest of Rosa damascena* (Spanish Journal of Agricultural Research, 05-2011)

Appendix

	S1**	S2**	S3**	S4**
Terminal velocity (m s^{-1})				
H1**	1.572 ± 0.029	1.565 ± 0.025	1.560 ± 0.019	1.548 ± 0.015
H2**	1.536 ± 0.023	1.377 ± 0.018	1.367 ± 0.014	1.353 ± 0.017
H3**	1.378 ± 0.021	1.329 ± 0.018	1.311 ± 0.015	1.258 ± 0.012
H4**	1.370 ± 0.018	1.320 ± 0.023	1.301 ± 0.018	1.257 ± 0.016
Average	1.464[a]	1.398[b]	1.385[b]	1.354[c]
Picking force (N)				
H1*	1.005 ± 0.109	0.873 ± 0.082	0.668 ± 0.039	0.539 ± 0.064
H2*	0.905 ± 0.023	0.796 ± 0.047	0.775 ± 0.057	0.564 ± 0.042
H3*	0.787 ± 0.077	0.761 ± 0.081	0.564 ± 0.038	0.515 ± 0.039
H4*	0.752 ± 0.033	0.751 ± 0.049	0.554 ± 0.030	0.501 ± 0.043
Average	0.862[a]	0.796[ab]	0.640[bc]	0.530[b]
Mass (g)				
H1**	0.122 ± 0.003	0.076 ± 0.003	0.073 ± 0.004	0.062 ± 0.004
H2**	0.094 ± 0.001	0.069 ± 0.002	0.068 ± 0.002	0.059 ± 0.002
H3**	0.061 ± 0.003	0.057 ± 0.003	0.056 ± 0.003	0.053 ± 0.003
H4**	0.056 ± 0.003	0.052 ± 0.002	0.050 ± 0.002	0.049 ± 0.002
Average	0.083[a]	0.063[ab]	0.062[ab]	0.056[b]
Projection area (cm^2)				
H1**	11.793 ± 0.431	12.005 ± 0.511	13.499 ± 0.577	13.830 ± 0.463
H2**	7.674 ± 0.403	8.086 ± 0.276	8.286 ± 0.424	10.716 ± 0.462
H3**	7.407 ± 0.257	7.778 ± 0.241	7.989 ± 0.247	8.697 ± 0.482
H4**	7.071 ± 0.364	7.470 ± 0.369	7.644 ± 0.256	8.537 ± 0.255
Average	8.486[b]	8.835[b]	9.354[ab]	10.445[a]
Density (g mL^{-1})				
H1**	0.022 ± 0.003	0.018 ± 0.004	0.017 ± 0.002	0.016 ± 0.003
H2**	0.020 ± 0.002	0.017 ± 0.003	0.015 ± 0.003	0.015 ± 0.002
H3**	0.020 ± 0.003	0.016 ± 0.003	0.015 ± 0.003	0.015 ± 0.002
H4	0.016 ± 0.003	0.015 ± 0.002	0.014 ± 0.003	0.014 ± 0.003
Average	0.019[a]	0.016[b]	0.015[b]	0.015[b]
Drag coefficient				
H1**	0.634 ± 0.082	0.392 ± 0.047	0.342 ± 0.056	0.287 ± 0.076
H2**	0.790 ± 0.053	0.684 ± 0.044	0.663 ± 0.034	0.457 ± 0.055
H3**	0.663 ± 0.011	0.635 ± 0.016	0.618 ± 0.028	0.584 ± 0.033
H4**	0.645 ± 0.065	0.604 ± 0.089	0.592 ± 0.021	0.549 ± 0.066
Average	0.683[a]	0.579[b]	0.554[b]	0.469[c]

*,**: Significant at the 5% and 1% probability levels, respectively.

Figure 1: The characteristics of rose petals, [6]