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P4 6 Let it slow: The terminal velocities of snowfall

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Abstract

In this paper we modelled the falling of snow respective to two different structure models of the snowflakes themselves. We model the terminal velocities of snowflakes of different density in a solid spherical mass model and compare the values to the terminal velocity of a normalised, $D = 1$ mm and $\rho_s = 30$ kgm^3, fractal flake. We determine that the fractal nature of snowflakes plays a strong role in suppressing the size dependence of terminal velocity, with max values of ≈ 0.64 ms^{-1} compared to solid model max values of ≈ 1.4 ms^{-1}.

Introduction

The image of gently falling snow is synonymous with Christmas, but how gently is the snow really falling? The motion of a snowflake through still air provides an accessible example of the balance between gravity and drag, and the influence that structure has in the dynamics of a falling object. In this paper we estimate the terminal velocity v_t as a function of snowflake diameter D and effective density ρ_s. Following [1], we first assume a compact (solid) particle, then introduce a fractal dimension $D_f < 3$ to represent the tenuous geometry of tree-like flakes and account for gaps present in the structure of the flake, then make a comparison between models.

Theory and Results

First we must find equations relating to the terminal velocity of our falling snowflakes. At terminal velocity, the downward weight equals the upward drag [2], see equation (1).

$$mg = \tfrac{1}{2}\rho_{\text{air}} C_D A v_t^2 \tag{1}$$

where C_D is the drag coefficient, A the projected area, and the density of air, $\rho_{air} = 1.225$ kgm^{-3} [3] Assuming $A = \pi(D/2)^2$; modelling the snowflake as a circular object and approximating the snowflake as an equivalent sphere of volume $V = \frac{4}{3}\pi(D/2)^3$, the terminal velocity becomes as follows in equation (2).

$$v_{t,\text{solid}} = \sqrt{\frac{4\rho_s g D}{3\rho_{\text{air}} C_D}} \tag{2}$$

For a fractal flake, the mass scales as $m \propto D^{D_f}$ [4] while the projected area continues to scale as $A \propto D^2$. Substituting this into Eq (1) gives the relation Eq (3).

$$v_{t,\text{frac}} \propto D^{(D_f-2)/2} \tag{3}$$

For $D_f = 3$ (compact solid - as it represents all 3 dimensions in full), Eq (2) is of correct proportions. Laboratory imaging suggests $D_f \approx$ 2.0–2.3 for dendritic snow [5], implying a weak size dependence; likely due to the natural porosity of snowflakes being very high. Using $C_D =$ 1.2 and $g = 9.81$ ms^{-2}, we evaluate Eq. (2) for effective densities $\rho_s = 10, 30$ *and* 100 kgm^{-3} over diameters $1 - 8$ mm.

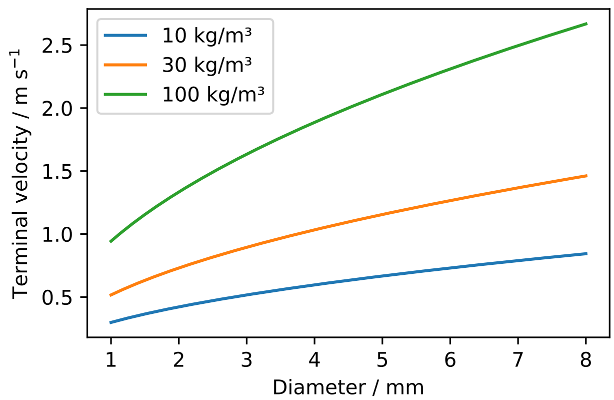

Figure 1: Predicted terminal velocity versus diameter for our three densities (solid lines).

For the fractal model, we normalised to match the solid model at $D = 1$ mm and $\rho_s = 30$ kgm^{-3} with $D_f = 2.2$ to compare the trend as diameter is increased.

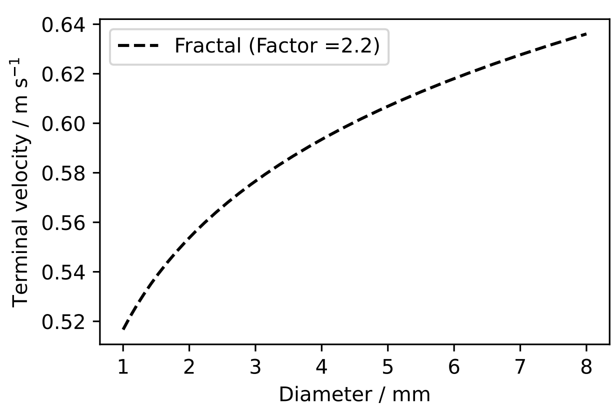

Figure 2: Predicted fractal model for $\rho_s = 30$ kgm^{-3} and $D_f = 2.2$, dashed). The fractal scaling suppresses the size dependence, yielding a narrower range of fall speeds.

Predicted values range from 0.3 ms^{-1} for low-density, small flakes to about 2.5 ms^{-1} for denser, large aggregates. These values are consistent with observational reports of typical snowflake velocities $0.5 - 2$ ms^{-1} [6][7].

Discussion

The solid mass model captures the plateauing increase of terminal velocity with increasing size (by extension, mass as well), while the fractal model captures the reduced sensitivity of v_t to flake size due to increased porosity, with mass not increasing in the same proportions as a solid volume. Real snowflakes experience turbulent drag, vary in shape, and sublimate, which may further limit velocity growth with size. Wind speeds and eddy currents in the atmosphere would also play a role in the manipulation of terminal velocity.

Conclusion

When modelling the snowflakes as a solid spherical masses, we receive terminal velocity profiles consistent with most other solid masses; however, when factoring in the fractal nature of snowflakes we see a very different terminal velocity relation with the sizes of snowflakes having a reduced impact on terminal velocity values. While many other factors come into play in determining snowfall speeds, it is clear that the porosity and structure of snowflakes play a large role in the descent of snow.

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