

A Cup Anemometer's Friction Undershoot and Gust Overshoot Add, and They Cancel at a Higher Wind the Weaker the Gusts

— the friction undershoot is the square of the starting speed over the mean wind, and subtracting it from the gust overshoot matched within 0.000122 —the separator is whether a bias falls with the square of wind speed or is a fraction nearly independent of it — [Paper 968]

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Abstract

In gusty wind a cup anemometer catches up faster with faster wind and turns more than the mean wind (Paper 890), but that paper left out shaft friction, which makes the reading lower. This paper adds a constant friction deceleration (set from a starting speed of 0.5 m/s) to the response of Paper 890 with a distance constant of 3 m, and counts how the two biases combine and at what mean wind they cancel. No new theorem or law is claimed. First, in steady wind, the friction undershoot falls with the square of wind speed: with a friction deceleration of 0.083333 m/s^2 , the reading at 5 m/s was 4.950000 m/s (matching the formula), and at 0.45 m/s, below the starting speed, the reading was 0. The undershoot fraction is the square of the starting speed over the mean wind (Section 2). Second, in gusty wind, the two biases nearly add: for six mean winds from 1 to 8 m/s with gust amplitude 0.3 at 0.5 Hz, the bias with friction differed from the frictionless overshoot minus that squared ratio by at most **0.000122** (Section 3). Third, weak wind reads low and strong wind reads high: at gust amplitude 0.3, the bias with friction was -0.205592 at 1 m/s, -0.019469 at 2 m/s, $+0.013136$ at 3 m/s and $+0.025360$ at 5 m/s (Section 3). Fourth, the wind at which they cancel is higher the weaker the gusts: the mean wind giving zero bias was **10.6926**, **3.8133** and **2.4345** m/s for gust amplitudes 0.1, 0.2 and 0.3, within 0.05 m/s of the starting speed divided by the square root of the overshoot there, **10.6776**, **3.8078** and **2.4309** m/s (Section 4). Fifth, the separator is whether a bias falls with the square of wind speed or is a fraction nearly independent of it: the friction undershoot is inversely proportional to the square of the mean wind and is large in weak wind. The gust overshoot changed only from $+0.044530$ to $+0.026708$ between 1 and 8 m/s. The bias vanished at the wind where the two are equal (Section 5). **Keywords:** cup anemometer, shaft friction, starting threshold, overspeeding, distance constant, measurement bias.

Scope of this paper (scope note): No new theorem or law is claimed: that a cup anemometer is characterized by a distance constant, that shaft friction gives a starting speed and low readings in weak wind, and that gusty wind gives high readings (overspeeding), are all known in meteorological instruments. Friction is a constant deceleration: friction is a deceleration independent of rotation speed, set by U^2/L from a starting speed of 0.5 m/s. The real form of bearing friction (dependence on speed, static versus kinetic) is not included. Gusts are simplified: as in Paper 890, gusts are a sine at one frequency (0.5 Hz); broad-band turbulence, wind direction changes and oblique wind are not treated. No real instrument is claimed: the distance constant of 3 m and the starting speed are model values matching no anemometer. Relation to earlier papers: Paper 890, in its scope note, did not include cup shape or wind direction, leaving out cup shape, wind direction fluctuation, shaft friction and oblique wind; this paper sits in the seat of shaft friction (no earlier occupant). Paper 890 showed that in gusty wind a cup anemometer turns more than the mean wind because it catches up faster with faster wind, with an overshoot of 0.035459 at gust amplitude 0.3, 0.5 Hz and 5 m/s. Here the friction undershoot is laid over that overshoot and the mean wind at which they cancel is counted. What is added: matching the friction undershoot in steady wind to the formula, confirming at six wind speeds that the two biases add, finding the cancelling wind for three gust amplitudes, expressing that wind by the starting speed and the square root of the overshoot, and placing the separator on “inverse square of wind speed, or a fraction”.

1. Notation and the Question

Setting: as in Paper 890, wind is $U(t) = U_0(1 + I \sin 2\pi ft)$ and the reading is V , with the response $dV/dt = U(U - V)/L$ for a distance constant $L = 3$ m, to which a constant friction deceleration a is added while turning.

$$\frac{dV}{dt} = \frac{U(U - V)}{L} - a \quad (V > 0), \quad a = \frac{U_{th}^2}{L}$$

When stopped, it does not start until $U^2/L > a$. The starting speed $U_{th} = 0.5$ m/s is a set value, giving $a = 0.083333$ m/s². In steady wind the balanced reading is $V = U - aL/U$, an undershoot fraction of $(U_{th}/U)^2$. As in Paper 890, the model runs 600 s at 0.002 s steps, averaging after the first 60 s, and the bias is defined as mean reading over mean wind minus 1.

Question: how do the friction undershoot and the gust overshoot combine, and at what mean wind do they cancel?

2. Friction in Steady Wind

Computation 2.1: without friction, at 5 m/s with gust amplitude 0.3 at 0.5 Hz, the overshoot was +0.035459, matching Paper 890 within 10^{-6} . With friction and no gusts, the reading at 5 m/s was 4.950000 m/s, matching $U - aL/U = 4.950000$, and at 0.45 m/s the reading was 0.000000.

Observation 2.2

in steady wind the friction undershoot falls with the square of wind speed. The undershoot fraction $(U_{th}/U)^2$ is 0.250000 at 1 m/s, 0.062500 at 2 m/s, 0.010000 at 5 m/s and 0.003906 at 8 m/s: below the starting speed the cups do not turn.

3. Two Biases in Gusty Wind

Computation 3.1: biases at gust amplitude 0.3 and 0.5 Hz.

mean wind	overshoot without friction	bias with friction	additive estimate	difference
1.0 m/s	+0.044530	−0.205592	−0.205470	−0.000122
1.5 m/s	+0.043945	−0.067287	−0.067166	−0.000121
2.0 m/s	+0.043150	−0.019469	−0.019350	−0.000120
3.0 m/s	+0.041028	+0.013136	+0.013250	−0.000114
5.0 m/s	+0.035459	+0.025360	+0.025459	−0.000099
8.0 m/s	+0.026708	+0.022727	+0.022801	−0.000074

The additive estimate is “overshoot without friction $-(U_{th}/U)^2$ ”, and the largest difference over the six winds was 0.000122.

Observation 3.2

the two biases nearly add; weak wind reads low and strong wind reads high. The bias was negative at 2 m/s and positive at 3 m/s, so the cancelling wind lies between: the departure from addition was negative at every wind, of size 0.000074 to 0.000122.

4. The Cancelling Wind

Computation 4.1: the mean wind giving zero bias with friction, found by bisection between 1 and 40 m/s.

gust amplitude	cancelling wind (m/s)	overshoot without friction there	$U_{th}/\sqrt{\text{overshoot}}$ (m/s)
0.1	10.6926	+0.002193	10.6776
0.2	3.8133	+0.017242	3.8078
0.3	2.4345	+0.042307	2.4309

For all three gust amplitudes, the cancelling wind was within 0.05 m/s of $U_{th}/\sqrt{\text{overshoot}}$.

Observation 4.2

the cancelling wind is the starting speed divided by the square root of the overshoot, and is higher the weaker the gusts. Because the biases add, the bias vanishes where $(U_{th}/U)^2$ equals the overshoot: at gust amplitude 0.1 the overshoot was only +0.002193, and the cancelling wind rose to 10.6926 m/s.

5. The Separator

Observation 5.1

the separator is whether a bias falls with the square of wind speed or is a fraction nearly independent of it. The friction undershoot is inversely proportional to the square of the mean wind, changing greatly from 0.250000 at 1 m/s to 0.003906 at 8 m/s: the gust overshoot changed only from +0.044530 to +0.026708 over 1 to 8 m/s. The difference in form between the two produced the low reading in weak wind, the high reading in strong wind and the cancelling wind between.

Observation 5.2

what is not said. The real form of bearing friction, turbulent gusts, wind direction and oblique wind, cup shape and which anemometer is correct are not treated. What is shown is that in a model with constant friction and single-frequency gusts, the two biases add, and the cancelling wind is set by the starting speed and the overshoot.

6. Roll Call and Closing

1. constant friction added to the response (Section 1): undershoot $(U_{th}/U)^2$.
2. reading 4.950000 at 5 m/s (Computation 2.1): matches the formula.
3. largest departure from addition 0.000122 (Computation 3.1): the biases combine.
4. negative at 2 m/s, positive at 3 m/s for gust 0.3 (Computation 3.1): weak wind reads low.
5. cancelling winds 10.6926, 3.8133, 2.4345 m/s (Computation 4.1): higher for weaker gusts.
6. inverse square, or a fraction (Observation 5.1): the separator; the scope note of Paper 890.

Closing: A cup anemometer's friction undershoot and gust overshoot add, and they cancel at a higher wind the weaker the gusts. Adding constant friction to the response of Paper 890, at six winds with gust amplitude 0.3 at 0.5 Hz, the bias matched the frictionless overshoot minus $(U_{th}/U)^2$ within 0.000122: the mean wind giving zero bias was 10.6926, 3.8133 and 2.4345 m/s for gust amplitudes 0.1, 0.2 and 0.3, within 0.05 m/s of the starting speed divided by the square root of the overshoot. The separator is whether a bias falls with the square of wind speed or is a fraction nearly independent of it. Placed among the earlier papers: onto the gust overshoot that Paper 890 counted without friction, the shaft friction that Paper 890 did not include was laid. To be honest: both friction and gusts are set in their simplest forms. How the two biases combine and where they vanish, and no further.

References

1. World Meteorological Organization (2008). *Guide to Meteorological Instruments and Methods of Observation* (7th ed.). WMO.
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