

With Broadband Gusts a Cup Anemometer Overshoots Less Than with a Sine, and the Overshoot Collapses on Gust Length

— at the same mean square, the overshoot falls as the integral time grows, and varying wind speed and integral time separately, the same product gave the same overshoot —the separator is whether gusts are counted by time or by length — [Paper 976]

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Abstract

In gusty wind a cup anemometer turns more than the mean wind (Paper 890), and this overshoot adds to the friction undershoot (Paper 968). There, gusts were a single-frequency sine, and broadband turbulent fluctuation was not treated. This paper applies to the anemometer of Paper 890, with a distance constant of 3 m, broadband gusts of the same mean square as the sine (an Ornstein-Uhlenbeck process with set integral times), and counts how the overshoot changes and on what it collapses. No new theorem or law is claimed. First, at the same mean square, broadband gusts overshoot less than a sine: at 5 m/s, against the overshoot 0.035459 of a 0.5 Hz sine (amplitude 0.3), broadband gusts with standard deviation 0.212132 gave **0.025784** at an integral time of 0.5 s (Section 2). Second, the longer the integral time, the smaller the overshoot: at 5 m/s, integral times of 0.5, 2 and 10 s gave overshoots of 0.025784, 0.011576 and 0.003053 (standard errors 0.000296, 0.000186, 0.000114) (Section 2). Third, with the same product of wind speed and integral time, the overshoot is the same: the three cases with gust length (wind speed times integral time) 2.5 m (5 m/s and 0.5 s, 10 m/s and 0.25 s, 2.5 m/s and 1 s) gave 0.025784, 0.025762 and 0.025899, and the three with 10 m gave 0.011576, 0.011515 and 0.011623 (Section 3). Fourth, the collapse lies within the scatter of the random runs: for four pairs of equal length, the overshoot differences were +0.000022, −0.000115, +0.000061 and −0.000047, smaller than the sums of standard errors 0.000617, 0.000556, 0.000357 and 0.000416 (Section 3). Fifth, the separator is whether gusts are counted by time or by length: with the same integral time of 1 s, the overshoot was 0.025899 at 2.5 m/s (length 2.5 m) and 0.011515 at 10 m/s (length 10 m). Counted by length (wind speed times time), the overshoot collapsed on its ratio to the distance constant (Section 4). **Keywords:** cup anemometer, overspeeding, turbulence, integral time scale, distance constant, Ornstein-Uhlenbeck process.

Scope of this paper (scope note): No new theorem or law is claimed: that a cup anemometer is characterized by a distance constant, that gusty wind gives high readings (overspeeding), and that their size is set by gust intensity and by the ratio of gust length to distance constant, are all known in meteorological instruments and turbulence measurement. Gusts are simplified: broadband gusts are an Ornstein-Uhlenbeck process (exponentially decaying correlation, with set integral times of 0.25 to 10 s); the spectral shape of real turbulence, wind direction fluctuation and oblique wind are not included. Friction is not included: shaft friction (Paper 968) is left out, and only the response equation of Paper 890 is used. Results carry random scatter: the overshoot is the mean of three random runs of 3600 s, with standard errors from their scatter. No real anemometer or observation is represented. Relation to earlier papers: Paper 968, in its scope note, simplified gusts, taking them as in Paper 890 to be a sine at one frequency (0.5 Hz) and leaving out broadband turbulent fluctuation, wind direction fluctuation and oblique wind; this paper sits in the seat of broadband turbulent fluctuation (no earlier occupant). Paper 890, in its scope note, also took gusts as a single-frequency sine and left out broadband turbulent fluctuation; this paper sits in that seat as well. Paper 890 showed that in gusty wind a cup anemometer reads high because it catches up faster with faster wind. Here it is counted how the overshoot changes when gusts become broadband. Paper 968 showed that the friction undershoot and gust overshoot add. Here friction is removed and only the form of the gusts is changed. What is added: comparing with a sine of the same mean square, finding the overshoot for each integral time, confirming by varying wind speed and integral time separately that it collapses on length, comparing the collapse with standard errors, and placing the separator on “time, or length”.

1. Notation and the Question

Setting: as in Paper 890, the reading V follows $dV/dt = U(U - V)/L$ with distance constant $L = 3$ m. Wind is $U = U_0(1 + \sigma\xi(t))$, where ξ is an Ornstein-Uhlenbeck process with mean 0 and variance 1,

$$\xi_{i+1} = a\xi_i + \sqrt{1 - a^2}\eta_i, \quad a = e^{-\Delta t/T_I}$$

(η_i standard normal, T_I the integral time, step $\Delta t = 0.01$ s). $\sigma = 0.212132$ has the same mean square as a sine of amplitude 0.3. Runs of 3600 s were used, dropping the first 60 s, with overshoot defined as mean reading over mean wind minus 1 and averaged over three random runs. Gust length is U_0T_I .

Question: when gusts become broadband, how does the anemometer overshoot change, and on what does it collapse?

2. Sine and Broadband

Computation 2.1: the sine (5 m/s, amplitude 0.3, 0.5 Hz) gave an overshoot of 0.035459 (as in Paper 890). Broadband gusts (5 m/s, standard deviation 0.212132) gave:

integral time	gust length	three runs	mean	standard error
0.50 s	2.50 m	0.026186, 0.025207, 0.025958	0.025784	0.000296
2.00 s	10.00 m	0.011714, 0.011208, 0.011806	0.011576	0.000186
10.00 s	50.00 m	0.003180, 0.002826, 0.003152	0.003053	0.000114

Observation 2.2

with broadband gusts, the overshoot is smaller than with a sine and falls with integral time. For all three integral times, the overshoot was below the 0.035459 of a 0.5 Hz sine of the same mean square: raising the integral time from 0.5 to 10 s lowered the overshoot from 0.025784 to 0.003053.

3. Gust Length

Computation 3.1: overshoot for wind speed and integral time varied separately (ratio to distance constant $L/(U_0 T_I)$).

wind speed	integral time	gust length	ratio to distance constant	mean overshoot (standard error)
5.0 m/s	0.50 s	2.50 m	1.2000	0.025784 (0.000296)
10.0 m/s	0.25 s	2.50 m	1.2000	0.025762 (0.000322)
2.5 m/s	1.00 s	2.50 m	1.2000	0.025899 (0.000260)
5.0 m/s	2.00 s	10.00 m	0.3000	0.011576 (0.000186)
10.0 m/s	1.00 s	10.00 m	0.3000	0.011515 (0.000171)
2.5 m/s	4.00 s	10.00 m	0.3000	0.011623 (0.000230)

Differences for equal lengths were +0.000022 (5 and 10 m/s, sum of standard errors 0.000617) and −0.000115 (5 and 2.5 m/s, 0.000556) at 2.5 m, and +0.000061 (0.000357) and −0.000047 (0.000416) at 10 m, all four within three times the sum of standard errors.

Observation 3.2

with the same product of wind speed and integral time, the overshoot is the same. Even with wind speed varied fourfold from 2.5 to 10 m/s, differences at equal length stayed within the random scatter. What set the overshoot was not wind speed and integral time separately but their product, the gust length.

4. The Separator

Observation 4.1

the separator is whether gusts are counted by time or by length. Counted by time, the same integral time of 1 s gave overshoots of 0.025899 at 2.5 m/s and 0.011515 at 10 m/s: counted by length, these are 2.5 m and 10 m, and each matched the other cases of the same length. The distance constant of the anemometer is also a length, and the ratio of the two lengths set the overshoot.

Observation 4.2

what is not said. The spectral shape of real turbulence, wind direction fluctuation, oblique wind, friction, values for real anemometers and correction methods for observations are not treated. What is shown is that with exponentially correlated gusts, the overshoot is smaller than for a sine and collapses on gust length.

5. Roll Call and Closing

1. Ornstein-Uhlenbeck wind (Section 1): same mean square as the sine.
2. overshoot **0.025784** at 0.5 s (Computation 2.1): below the sine's 0.035459.
3. **0.025784, 0.011576, 0.003053** at 0.5, 2, 10 s (Computation 2.1): smaller for longer times.
4. three cases at 2.5 m: **0.025784, 0.025762, 0.025899** (Computation 3.1): collapse on length.
5. differences within summed standard errors (Computation 3.1): four pairs.
6. time, or length (Observation 4.1): the separator; the scope notes of Papers 968 and 890.

Closing: With broadband gusts a cup anemometer overshoots less than with a sine, and the overshoot collapses on gust length. Applying broadband gusts of the same mean square as the sine to the anemometer of Paper 890, the overshoot at 5 m/s was 0.025784, 0.011576 and 0.003053 for integral times of 0.5, 2 and 10 s, below the 0.035459 of a

0.5 Hz sine: varying wind speed and integral time separately, the overshoot came together at 0.025762 to 0.025899 for a gust length of 2.5 m and 0.011515 to 0.011623 for 10 m. The separator is whether gusts are counted by time or by length. Placed among the earlier papers: the overshoot that Papers 890 and 968 counted with a sine was counted with the broadband gusts they did not treat. To be honest: the gusts are one form of exponentially decaying correlation, not real turbulence. When the form of the gusts is broadened, on what the overshoot collapses, and no further.

References

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