

# A Proposed Wind Vane with Practically No Overshoot

by

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## Abstract

If a wind vane is devised which has practically no overshoot, considerable saving of effort will be achieved in reading and analyzing the indication and chart. A suitable device for this will be to incorporate a damper. In the present paper an oil damper is tested on a model wind vane in the wind tunnel. The degree of necessary damping of the oil damper increases exactly linearly with the wind speed, which fact suggests the necessity of a damper with variable damping. Fundamental design data of the damper and its possible configurations are given.

## 1. Objective of the test

Almost every wind vane or combination wind vane and anemometer have a tendency to make a decided overshoot. This feature is an inevitable consequence of design and has nothing to do with the wind speed.

The point is rather important and will be explained as follows. The overshoot is the tendency to swing to the other side of the present amplitude, its amount being defined as the ratio of  $(n+1)$ -th and  $n$ -th amplitude.

Usually when the term overshoot is mentioned the ratio of the second and first or initial amplitude is meant.

The logarithm(natural) of the reciprocal of overshoot amount is the logarithmic decrement which is theoretically a constant throughout the whole consecutive amplitudes of a damped oscillation. At times it is more convenient to employ the damping ratio  $\zeta$  that is related to the logarithmic decrement  $A$  through the equation

$$(1) \quad \zeta = \frac{A}{\sqrt{\pi^2 + A^2}}.$$

Here the equation of motion is expressed as

$$(2) \quad \ddot{\theta} + 2\zeta\omega_n\dot{\theta} + \omega_n^2\theta = 0,$$

where  $\theta$  is the amplitude, the dot means time derivative and  $\omega_n$  is the undamped natural frequency. If the  $n$ -th and  $(n+1)$ -th amplitudes are written respectively as

$\theta_n$  and  $\theta_{n+1}$ , we have

$$(3) \quad A = \ln \frac{\theta_n}{\theta_{n+1}},$$

where the reciprocal ratio  $\theta_{n+1}/\theta_n$  stands for the amount of overshoot.

Thus the amount of overshoot is uniquely defined by  $\zeta$  through the relation

$$(4) \quad \frac{\theta_{n+1}}{\theta_n} = \exp\left(-\frac{\pi\zeta}{\sqrt{1-\zeta^2}}\right).$$

On the other hand,  $\zeta$  can be expressed by the dimensions of the wind vane as follows [SANUKI, KIMURA and BABA, 1962].

$$(5) \quad \zeta = \frac{c}{2\sqrt{c'I}}.$$

Here  $I$  is the wind vane moment of inertia and the constants are given by

$$(6) \quad \begin{cases} c = \frac{1}{2}C_{N\alpha}\rho SVR^2 = 2I\zeta\omega_n, \\ c' = \frac{1}{2}C_{N\alpha}\rho SV^2R = I\omega_n^2, \end{cases}$$

where  $C_{N\alpha}$  is the normal to vane chord air force derivative with respect to the angle of attack in non-dimensional form,  $\rho$  the air density,  $S$  the vane surface area,  $V$  the wind speed, and  $R$  the arm length, *i.e.* the distance between the rotating axis and the vane aerodynamic center, or the point of action of air force.

From Equations (5) and (6) we get

$$(7) \quad \zeta = \sqrt{\frac{C_{N\alpha}\rho SR^3}{8I}}.$$

The moment of inertia  $I$  can be expressed approximately for conventional vanes as

$$(8) \quad I = kSR^2,$$

where  $k$  is a constant that represents a kind of vane surface density.

Now Equation (7) becomes

$$(9) \quad \zeta = \sqrt{\frac{C_{N\alpha}\rho R}{8k}}.$$

As  $C_{N\alpha}$ ,  $\rho$  and  $k$  can be considered constant for the same vane shape, atmosphere and vane-make, we can conclude

$$(10) \quad \zeta \propto \sqrt{R},$$

or, in other words, the damping ratio is proportional to the square root of the vane

arm length and independent of the wind speed\*  $V$ .

From the standpoint of wind vane indicator reading and chart analysis, excessive overshoot is cumbersome and preferably to be got rid of. But a design allowing of little overshoot will lead to a long-armed vane and be found quite troublesome to handle.\*\* One remedy is to incorporate a damper within the wind vane. However, this damper must practically suppress the overshoot to be encountered at all wind speeds. This necessitates some special device as the damper will change  $\zeta\omega_n$  instead of  $\zeta$ , and, contrary to  $\zeta$ ,  $\omega_n$  has nothing to do with the damper.

The aim of the present paper is to test the damper in the wind tunnel and investigate its actual feasibility.

## 2. Experimental set-up

A conventional wind vane with a rectangular flat plate is used for the test (Fig. 1). The plate is of aluminium of thickness 1 mm and connected to the counterbalance by means of an aluminium pipe. The total weight of the rotating part including the drag-cup is 0.656 kg and its moment of inertia is calculated to be  $1.81 \times 10^{-3} \text{ kgms}^2$ . The damper is an oil-immersed drag-cup type, damping being effected mainly with the oil film of thickness about 0.5 mm contained between the cup's outside surface and the container's inside wall. We tried some other oil damper types such as the paddle wheel, but the most effective one is the aforementioned.

The essential thing for effective damping is to provide such a thin oil film that it rises to a certain height (in our case, about 5 mm) above the container oil level by capillary action. The drag-cup has four holes on the top surface to balance the inside and the outside air pressure. The cup and container are both fabricated from brass.

The damper oil is Silicone KF 96, a product of the Shin-Etsu Chemical Industry Co., Tokyo. The kinematic viscosity is 2,000 centistokes at 25°C, which was found appropriate for the present damper. The specific gravity is nearly 1 at 25°C.

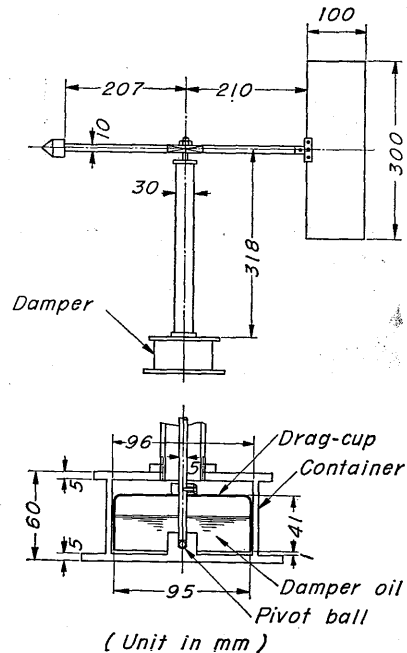


Fig. 1. Experimental set-up.

\* On the contrary, from Equation (6) it can be seen that  $\omega_n$  is proportional to  $V$  and inversely proportional to  $\sqrt{R}$ .

\*\* Concerning the performance of such a long-armed vane, the oscillation feature will not differ from that of a short-armed one if the wind speed remains the same. This can be seen by the fact that  $1/\zeta\omega_n$  remains the same which represents the time during which the envelope of amplitudes diminishes to  $1/e$ .

The vane-supporting shaft rests on a pivot ball at the bottom and is centered within a bushing housed at the stand neck.

A ring rheostat is wound at the stand neck on which a sliding brush of the wind vane boss slides. The current passed between the rheostat and the brush is D.C.-amplified and registered on a penwriting oscillograph. The test was conducted in the 1.5 m wind tunnel at the Department of Aeronautics, University of Tokyo.

The experimental procedure is first to see the performance of the wind vane with various damper oil quantity including the case of no oil, at a constant wind speed. Then the wind speed is raised and the same procedure is repeated. The maximum wind speed tested was  $V=20$  m/s but in this case the present oil damper capacity was found insufficient and no concrete data were available.

The damper oil was put into the container up to 320 cc, in which case the drag-cup is wholly immersed in the oil.

As the last test the wind vane plate is replaced by a bob of the same weight and the system is rotated in one direction until it comes to a standstill. By this test the pure damper action is measured and compared with the pure aerodynamic damping which can be deduced from the wind tunnel test of the wind vane with no damper oil.

### 3. Experimental result and discussion

In Fig. 2 the measured amplitude is plotted against time for various damper oil quantity at wind speed  $V=5.0$  m/s. The damping ratio  $\zeta$  can be calculated from the curves and is illustrated in Fig. 3. There is also shown the oil-wetted height of the drag-cup out-side surface as it is a measure of the damper effective area and must have a close correlation with  $\zeta$ . Really the two curves run nearly parallel to each other, which fact suggests the linear change of  $\zeta$  with the oil-wetted height. Further it is noticed that the existence of the slightest amount of oil, say, less than 10 cc, enhances the damping considerably. Beyond that amount, however,  $\zeta$  increases with the oil quantity.

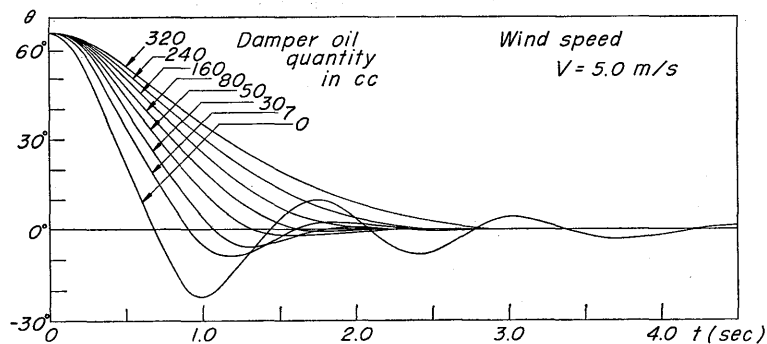


Fig. 2. Amplitude versus time of the wind vane for various quantity of damper oil.

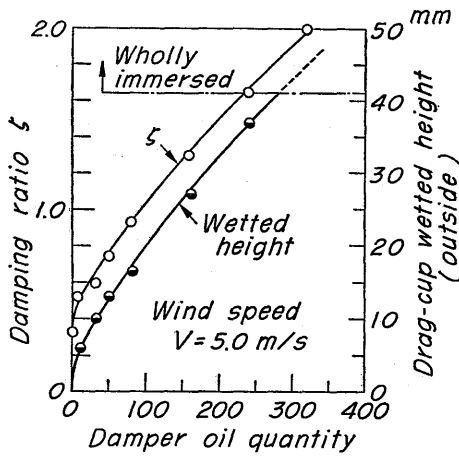


Fig. 3. Influence of damper oil quantity on the damping ratio and drag-cup wetted height.

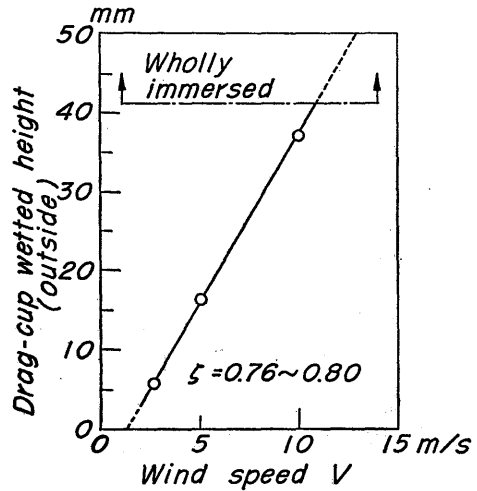


Fig. 4. Necessary drag-cup wetted height to obtain  $\zeta = 0.76 \sim 0.80$  or overshoot 2.4~1.5%.

In Fig. 4 the necessary oil-wetted height is plotted against wind speed to obtain practically no overshoot, or, to be precise, the amount of overshoot  $\theta_2/\theta_1 = 2.4 \sim 1.5\%$  which is equivalent to  $\zeta = 0.76 \sim 0.80$ . These figures are chosen as being appropriate for actual purposes.

The exact linearity of the curve is no matter of incidental nature. Returning to Equation (2), the damping  $\zeta\omega_n$  is composed of two parts, *i.e.* the aerodynamic damping of the vane and the oil damping. The former is proportional to  $V$ , if other things are the same, as the consequence of linear dependence of  $\omega_n$  on  $V$ . Therefore, to keep the total  $\zeta$  constant, the oil-damping part of  $\zeta\omega_n$ , or the oil-wetted height must increase linearly with  $V$ .

To explain this we shall break down  $\zeta\omega_n$  (we call this quantity as "damping" to distinguish it from  $\zeta$ )

$$(11) \quad (\zeta\omega_n)_{\text{total}} = (\zeta\omega_n)_{\text{aerodynamic}} + (\zeta\omega_n)_{\text{oil}},$$

and notice that, in the first part,  $\zeta$  is independent of  $V$  and  $\omega_n$  is proportional to  $V$ , while, in the second part  $(\zeta\omega_n)_{\text{oil}}$ , as a whole, is proportional to the oil-wetted height. To keep  $(\zeta)_{\text{total}}$  constant, it is self-evident that  $(\zeta\omega_n)_{\text{oil}}$  must change linearly with  $V$ .

The last point to be discussed is the actual realization of the features of Fig. 4. A suggestion will be a device to change the damper oil level linearly with  $V$ , which seems easily realizable, for instance, by means of a container piston. Another suggestion is some electric damper with variable damping.

#### 4. Conclusions

- 1) The amount of overshoot is uniquely defined by the damping ratio of a wind

vane  $\zeta$  [Eq. (4)], and to suppress the former is equivalent to increasing the latter.

- 2) The damping ratio increases nearly proportionally to the square root of the vane arm length, but is independent of the wind speed.
- 3) With a given arm length, the damping (not damping ratio) can be increased by means of an oil damper incorporated within the wind vane.
- 4) By increasing the damper oil quantity, or, to be precise, by increasing the oil-wetted area of the damper proportionally to the wind speed, a large and constant  $\zeta$  can be realized and practically no overshoot results.
- 5) A device to change the oil-wetted area in proportion to wind speed is suggested.

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#### *Reference*

- M. SANUKI, S. KIMURA and M. BABA, 1962: Wind tunnel experiment on a spherical wind vane, Pap. Met. Geophys. 13, 23-27.

### ほほゆきすぎの無い風向計の提案

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ゆきすぎ（オーバーシュートともいう）すなわち、真風向を横切って他側へ振動しない風向計が実現すると、風向指示計の読みとりや自記記録の解析に便利であろうと思われる。

ゆきすぎ量というのは、初期振幅でそのつぎの振幅を割った比をいうが、普通の風向計は単純な減衰振動に近くて、ゆきすぎ量は相隣る振動についてほぼ一定である。このとき、ゆきすぎ量は減衰比だけで表わすことができる。

減衰比を大きくすれば、ゆきすぎ量は減る [(4) 式]。減衰比は風向計の腕長の平方根に比例して増し、風速には関係しない。与えられた腕長の風向計では、油減衰器を装置すれば減衰（減衰比と非減衰固有周波数の積）を増すことができる。

減衰器に満たす油量に応じて減衰は増すが、風速いかにかわらず、一定でかつ大きい減衰比すなわち小さいゆきすぎ量を実現するには、風速に比例して油量、正確には減衰油面積を増す必要があることを立証した。

ただし、この実用的装置の詳細には触れなかつた。