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Oscillation of a Deformable Wind Vane

by

Matao Sanuki, Shigeru Kimura, Kei Abe and Hiroaki Hayashi

University of Tokyo

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Abstract

It often happens that we observe the wind direction by means of natural objects such as tree branches and reeds which are flexible or deformable. The present experiment is conducted in the wind tunnel to see the change of oscillation mode of a wind vane with a hinged free flap of various chord lengths, which simulates the deformability. The results are expressed as the change of oscillation period and damping ratio, which shows the degradation of motion as the deformability increases. Also the effect of flexibility is considered qualitatively.

1. Objective of the experiment

In a wind we observe the swinging tree branches or nodding reeds as signs of the passing air stream. If the wind direction or speed changes, we accordingly notice the change of the swinging direction or nodding amplitude. However, we do not know exactly the behaviour or response of such flexible or deformale objects.

As a wind vane the flexibility or deformability makes no sense whatever, even if, in the field of aeronautics, the oscillation of a flexible or deformable aerofoil is treated as the flutter or buffeting phenomenon.

But it may be meaningful, from the above viewpoint, to investigate a wind vane provided with some flexibility or deformability, and we have conducted a series of wind tunnel experiments on a wind vane with a hinged free flap of various chord lengths. This vane should be called as a flapping one because it is neither provided with flexibility nor deformability of permanent nature. However, we call it deformable for the sake of convenience.

From a similar consideration, we formerly carried out an experiment on a streamer [SANUKI, KIMURA and TOYAMA, 1957] and then arrived at a temporary conclusion on its effectiveness in moderate winds and its laziness or aperiodic behaviour in breezes.

2. Experimental set-up

The model wind vane is the same as that we have used hitherto (Fig. 1), the sole modification being the hinges to attach the free flap, which are composed of nylon strips bonded to the aluminium vane and flap. The vane and flap are 1 mm thick and the clearance between them is 1 mm, too.

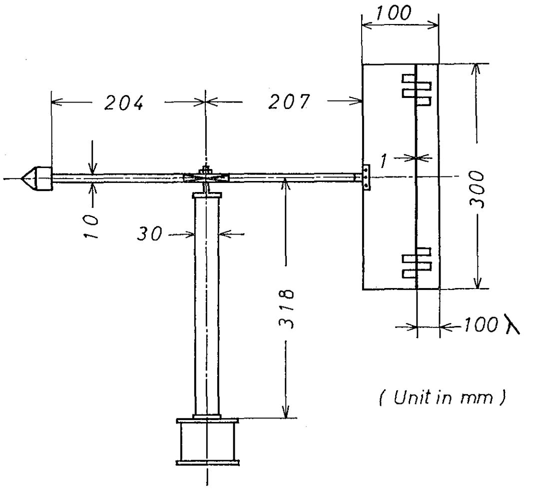

Fig. 1. Experimental set-up.

The flap chord length is varied according to its ratio λ to the vane chord length. We chose $\lambda=0$ (no flap), 0.3, 0.5, 0.7 and 1.0* (all-flying-tail type in the technical term of aeronautics).

There is neither a mechanical damper nor any similar device. The overall dimensions and weight are almost the same for no flap through all-flying-tail cases, and the moment of inertia about the vertical axis is nearly 1.8×10^{-3} kg ms^2.

The measurement of the oscillation amplitude in the wind tunnel stream is carried out as before, using a potentiometer wound around the stand neck and passing the current through a brush to a pen-writing oscillograph after D.C. amplification.

From the registered amplitudes it is quite straightforward to evaluate the period of oscillation starting from a certain initial deviation, which amounts to nearly 90°. The damping ratio is calculated from the relations

(1) logarithmic damping** $\Lambda=\ln\frac{\theta_n}{\theta_{n+1}}=2.303\log_{10}\frac{\theta_n}{\theta_{n+1}}$, where θ_n and θ_{n+1} are two consecutive amplitudes, and

(2) damping ratio $\zeta=\frac{\Lambda}{\sqrt{\pi^2+\Lambda^2}}$.

The chart to obtain ζ directly from θ_n/θ_{n+1} is given in Fig. 2.

3. Experimental result and discussion

In Fig. 3 the period T and damping ratio ζ are illustrated against the ratio λ of the free to the fixed wind vane portion. In other words, λ can be said to be the

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* In this case a hinge is incorporated in the vane fitting to the supporting boom.

** At times θ_n/θ_{n+2} or two consecutive amplitudes on the same side are are taken, but nothing changes at all concerning ζ except that Λ is doubled.

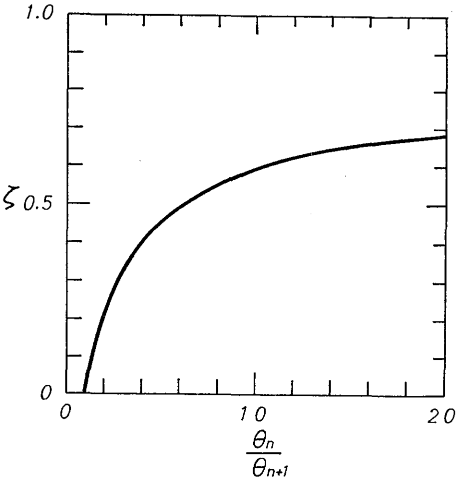

Fig. 2. Damping ratio as obtained from consecutive amplitudes.

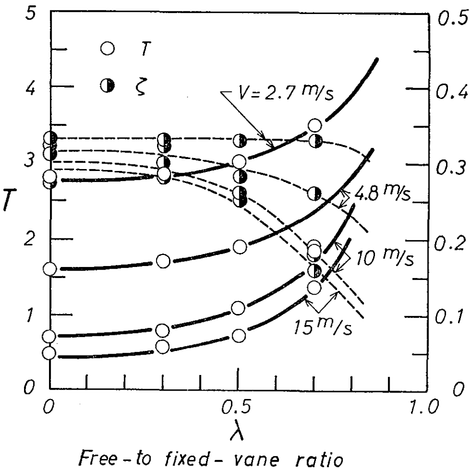

Fig. 3. Variation of oscillation period T and damping ratio ζ.

free-flap ratio. As said before, $\lambda=0$ stands for the no-flap case, or the ordinary wind vane, and $\lambda=1$ stands for the no-fixed-vane-portion case, or all-flying-tail in the aeronautical term.

As shown in Fig. 3 there is a markedly regular tendency in the change of the oscillation mode or, it can be said, a degradation of the motion, although a very casual behaviour is observed for the case $\lambda=1$ as will be described later. This regularity is the reason why the authors publish the present report. In general, both T and ζ change at smaller λ values in high winds than in low ones.

The degradation of motion originates partly from the inertial effect of the freely flapping flap. As a high wind speed produces more inertia than a low wind speed, the inertial effect is more pronounced in the former case. And, as practised in aeronautics, the best way to avoid the degradation of motion, or, what comes to the same thing, to lower the flutter-causing wind speed, is the use of a lighter flap or a mass balance attached as a horn of the flap, both of which act to mitigate the inertial effeect.

With the $\lambda=1$ configuration (all-flying-tail) the oscillation is quite casual as shown in Fig. 4. At times the vane amplitude θ passes from one side of the true wind direction ($\theta=0$) to another subsiding to a certain amplitude θ_1. In other cases the vane reaches a steady amplitude θ_2 directly, i.e. never crossing the true wind direction. The subsiding amplitudes θ_1 and θ_2 are different in both cases. The direct subsidence or aperiodic behaviour seems to have been caused by the small inertia compared to the air force acting on the all-flying-tail type flap. In the case of a streamer, similar observation was obtained as stated before and cited in the reference.

As a supplement we conducted a test on a wind vane with a spring flap to simulate the flexibility. The results are, as might be expected, intermediate between no-flap case and free-flap one.

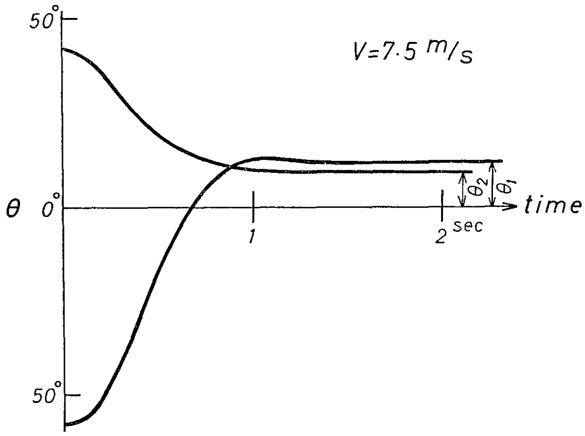

Fig. 4. Behaviour of wind vane. $\lambda=1$ (all-flying-type)

One thing more should be noted, i.e. the possibility of controlling or improving the oscillation by means of the swinging flap, which, in case of free motion, influenced the instrument so decidedly.

4. Conclusions

1) A wind vane with a freely flapping flap has a markedly regular deteriorating tendency, i.e. longer oscillation time T and smaller damping ratio ζ for increasing free-flap ratio λ.
2) The deterioration is more pronounced for high wind speed.
3) The all-flying-tail type flap ($\lambda=1$) shows an extremely casual behaviour approaching $T=\infty$ and $\zeta=0$.
4) Even if the present experiment represents rather inadequately the behaviour of natural objects in the winds, the general tendency observed deserves attention.

Reference

M. Sanuki, S. Kimura and S. Toyama, 1957: The time constant of a streamer. Pap. Met. Geophys., 7, 390-392.

変形する風向計の振動

佐貫亦男，木村　茂，阿部　圭，林　弘明

東京大学

自然物たとえば樹木の枝や草の動きによって風向風速を測定するとき，それらの応答が問題になる。ここでは風向計の風板の一部（フラップ）を自由にヒンジ止めしたものについて風洞実験を行ない，その振動周

期 T と減衰比 ζ を，風速と自由フラップ対風板全弦長比 λ について求めた。その結果は，λ が増すにつれて，T は長くなり，ζ は減小して，特性が劣化することがわかった。また風速が大きくなると，ζ は λ の小さいところで減少する。

$\lambda=1$ すなわち，飛行機でオールフライングテールと称する，固定風板のない風向計は，はなはだ予測し難い特性，たとえば風速の低いときは，ある初期振幅から真風向線を越えて他の側にゆかず，非周期的振動を行なうことがわかった。