SHORTER CONTRIBUTIONS

551.508.5

Notes on the Design of Combination Wind Vane and Anemometer

by

M. Sanuki and S. Kimura

Meteorological Research Institute

(Received January 6, 1953)

Abstract

Wind tunnel experiments on the static directional sensitivity of Speedovane (an experimental combination wind vane and anemometer) and also on the blade shape of its anemometer windmill are described.

1. The relation between the static directional sensitivity and the number of windmill blades

In the preceding report [1] we have illustrated the superiority of the four-blader windmill to the three-blader when installed on a Speedovane (an experimental combination wind vane and anemometer). The decrease of the rotational speed of the former was less than the latter for a given yaw angle of the vane.

The two types of windmill, however, gave almost the same oscillatory merit, i.e. the logarithmic decrement divided by the oscillation period, in the oscillation test conducted in a wind tunnel.

This oscillation test will indicate the *dynamic sensitivity* of the vane, but, from the consideration of its start from rest, the *static sensitivity* defined later should, at the same time, be taken into account, just as in the study of airplane stability (*static and dynamic stability*). Therefore the Speedovane with and without windmill is placed with a certain yaw angle in the stream of the 1 m wind tunnel of the Central Meteorological Observatory (C.M.O.) and also of the 1.5 m wind tunnel of the Institute (M.R.I.), and its static tail moment about the rotational axis is measured by means of a single-component aerodynamic balance. The results are illustrated in Figs. 1~3. Here the tail moment coefficient C_m is defined as

$$C_m = \text{static tail moment} / \frac{1}{2} \rho V^2 F R ,$$

Fig. 1. Tail moment coefficient at various angle of yaw of Speedovane without windmill. (By courtesy of C.M.O. Instruments Section).

Fig. 2. Tail moment coefficient at various angle of yaw of Speedovane with running three-blader windmill. ("Left" means windmill yawed left toward wind, M.R.I. wind tunnel).

Fig. 3. Tail moment coefficient at various angle of yaw of Speedovane with running four-blader windmill. ("Left" means windmill yawed left toward wind, M.R.I. wind tunnel).

where ρ is the air density, V the wind speed, F the vane (tail) area and R the distance of the vane leading edge* from the rotating axis.

From the comparison of the figures we can conclude:

- i) the value of C_m per radian of the yaw angle or $dC_m/d\phi$ which we designate as the *static sensitivity* of the vane, is, especially for small yaw angle, larger for the four-bladed Speedovane than the three-bladed one,
- and
- ii) in each case, the static sensitivity is diminished by the presence of the windmill, which, without doubt, retards the air flow to the vane.

* As the representative value, the midpoint leading edge of the tail is chosen by which $R=294$ mm.

2. The effect of the plan- and profile-form of the anemometer windmill blade upon the rotational speed

Some of the recent airplane propellers have almost uniform blade width along the blade radius to the tip section. This feature comes from the effort to keep the blade's thickness-to-width ratio reduced over outer radius to avoid the air compressibility effect. We now applied this aspect of blade plan-form to the windmill of the Speedovane from the standpoint of easy workmanship from solid anti-corrosive aluminium alloy as illustrated in Fig. 4. The windmill is four-bladed and its blade width is decided so as to give the same blade area as that of the three- or four-blader*.

According to the practice of propeller design the integrated capacity of the plan-form of a single blade for absorbing the power is expressed by the *activity factor* (AF), i.e.,

$$AF = \frac{10^5}{16} \int_{0.2}^1 \left(\frac{b}{D} \right) \left(\frac{r}{R} \right)^3 d\left(\frac{r}{R} \right),$$

which is a non-dimensional function. Here b denotes the blade width, $D=2R$ the propeller diameter and r the radius of any blade element.

According to this definition the activity factor of the single blade of the three-blader is 315, that of the four-blader 233, and 195 for the present four-blader with uniform blade width (Fig. 4, also Fig. 5). The last blades are tested in the 1 m wind tunnel of the Central Meteorological Observatory equipped on the Speedovane. The comparison of the rotational speed of two four-bladers with ordinary plan-form as explained above and that with uniform blade width is shown in Figs. 6 and 7. It is observed that the four-blader with uniform blade width shows a slightly more rotational speed N

Fig. 4. Anemometer windmill with uniform blade width equipped on the Speedovane.

Fig. 5. Developed plan-form of solid four-blader with uniform blade width. (Uniform pitch distribution when set at 60° at 75% radius.)

* The developed plan-form of the blade is given in polar coordinates (r, θ) by

$$r^2 = R^2 \cos p\theta,$$

where R is the blade radius and p denotes the number of blades. The total blade area is therefore given by

$$A = p \int_{-\pi/2p}^{\pi/2p} \frac{1}{2} r^2 d\theta = R^2,$$

i.e., A is independent of p .

Fig. 6. The rotational speed of Speedovane. Solid four-bladed set at 60° at 75% radius.

Fig. 7. The rotational speed of Speedovane. Solid four-bladed windmill with uniform blade width set at 60° at 75% radius. (C.M.O. wind tunnel.)

test was stimulated by the recent research on current meter by R. TAKEDA [2], who concluded the inferiority of the "propeller section" to the windmill one. In our experiment too, the "propeller section" is surpassed by the windmill one, as seen from the comparison of Figs. 7 and 8.

The Windial of Bendix-Friez Company in U.S.A. employs this "propeller section," but it seems that nothing is gained by this design, though some Japanese tried to extract some instruction from it.

We conclude in this Section:

- iii) the anemometer windmill blade with uniform blade width is serviceable but its start is not favourable in a breeze,

than that with the ordinary plan-form for given wind speed V , despite of its less activity factor. The cause is due to the larger thickness-to-width ratio of the former blade. The moment of inertia about the rotational axis of the complete four-blader with uniform blade width is $0.000244 \text{ kg m s}^2$, a little less than that of the four-blader of the ordinary plan-form, i.e., $0.000273 \text{ kg m s}^2$. The start of the former, however, was not so favourable as in the case of the latter, in the wind tunnel experiment, probably owing to its aerodynamically too simple blade plan-form.

As the last experiment, the rotational speed of another four-blader with uniform blade width is investigated in the wind tunnel, with the profile set in normal position* to the wind, i.e. the camber (circular arc) side is now directed to the wind, just in the same way as the propeller. We designate it as "propeller section" in comparison with the windmill one. This

*. All our preceding anemometers employ profiles "reversed" to the wind, as in the case of usual windmills.

Fig. 8. The rotational speed of Speedovane. Solid four-blader windmill with uniform blade width and "propeller section" set at 60° at 75% radius. (C.M.O. wind tunnel.)

and

- iv) the anemometer blade profile with its camber or convex side directed to the wind ("propeller section"), is quite unsatisfactory for the start.

References

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- [2] TAKEDA, R. 1951: Experimental Research on Current Meters (in Japanese), Bulletin of the Faculty of Engineering, Hiroshima University, **1**, p. 47.