Experiments on a Marine Combination Wind Vane and Anemometer in Pitching or Rolling Motion

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Abstract

A combination wind vane and anemometer model (Marine Speedovane) is tested in wind tunnel, as to its mode of oscillation and variation of rotational speed in pitching or rolling motion with wind on. According to this model experiment the pitching motion of period of 8 seconds (actual weather ship's value) has nothing to do with the indication of the wind vane, but it seriously affects the rotational speed of the anemometer windmill, which is oscillating with the same period as that of the pitching motion and with a certain phase lag. The mean rotational speed is found remarkably lower than that without pitching at the same wind speed. In the rolling motion of the same period, however, the mean rotational speed of the anemometer windmill agrees well with that without rolling at the same wind speed. No definite periodicity and phase lag of the rotation are found in this case except a certain band width of fluctuations.

1. Object of the experiment

Since the installation of the combination wind vane and anemometer Marine Speedovane* [1] aboard weather ships of the Central Meteorological Observatory, the effects of ship's pitching and rolling motion upon the indications of wind direction and speed have been discussed here and there. They seem especially pronounced for the weather ships of smaller tonnage staying under most unfavourable conditions on rough seas of the Pacific, while well over a hundred of similar equipments are used without any appreciable claims aboard larger and more agreeable vessels. The present experiments are aimed at clarifying the said effects.

2. Test set-up

The Speedovane model (approximately to scale 1:2.5, Fig. 1) fitted with a four-bladed windmill of aluminium alloy is mounted on the top of a tubilar pole which can be swung by a variable-speed motor through a rod (Fig. 2). The length of the pole in comparison with the model dimension is not so large as in the actual case (some 15m from the ship's center of buoyancy, while the Speedovane pole

* It differs from the ordinary Speedovane only in the water-proof indicators and terminal box.
Fig. 1. Marine Speedovane with four-bladed windmill. (Blade angle 60° at 75% radius, clockwise rotation viewed from model tail).

Fig. 2. Oscillation set-up in the wind tunnel (seen from the tunnel nozzle). Rolling state. In pitching state, the tunnel nozzle positions at the left.
length is 1.120 m) owing to the restriction of the space available.

The amplitude of the pitching motion, i.e., along the wind tunnel flow direction, or of the rolling motion, i.e., across the flow is 24°30' to 23°04', which in actual cases surpasses 60°. The period of the motion, i.e., the time to cover from one extremity to another and back again to the original position, simulates the mean actual values of 8 seconds.

The rotational speed of the Speedovane windmill is transmitted as a contact for every three rotations to a recording drum. The direction of the model is recorded on an electromagnetic oscillograph by means of resistors arranged stepwise within its fixed base housing, along which a sliding arm connected with the model rotating-shaft sweeps.

It is to be noted that the pitching and the rolling motion of the model do not necessarily coincide with those of the ship, because the longitudinal axes of the Marine Speedovane and the ship intersect in winds, especially when the ship rolls in side wind, in which case the instrument is in a pitching motion.

3. Experimental results

1) Fundamental characteristics of the Marine Speedovane model.

The rotational speed $N$ r.p.m. vs. wind speed $V$ m/s is illustrated in Fig. 3. The speed ratio for free running is given at $V=10$ m/s by

$$A_0 = \frac{V}{\omega R} = 1.30^*,$$

where $\omega = 2\pi N/60$ and $R = 0.14$ m is the radius of the windmill. The speed ratio for free running is chiefly dependent upon the blade form, and the present value is in good coincidence with that of the actual Speedovane.

The rotational speed in yaw is illustrated in Fig. 4 as the ratio $N_\phi/N_0$ where $N_\phi$ is the rotational speed for yaw angle $\phi$ and $N_0$ that for $\phi = 0$, each at a given wind speed of 10 m/s.

The transcendental characteristics, i.e., the start and stop of the windmill are illustrated in Fig. 5 for various wind speeds $V$ and for the initial rotatio-

* In the preceding report of the authors [2] p. 44, the fifth line from bottom, for 0.30 m/s, read 0.23 m/s, and p. 52, the fourth line, for $\lambda_0 = 1.69$, read $\lambda_0 = 1.30$. 
nal speeds $V_0$ expressed in wind speed, respectively.

In this connection, it should be added that the moment of inertia around the rotational axis of the windmill complete with its retaining nut is 0.701 grcms$^2$.

2) Rotational speed during the free oscillation.

The model is let to perform its free oscillation in the tunnel current, and the rotational speed $\omega$ of the windmill is measured as illustrated in Fig. 6.

The time is shorter for the complete damping of the free oscillation than for the speeding up to the ultimate rotational speed, so that only a slight retardation can be found from the steady state of Fig. 5 (a).

The moment of inertia of the model complete with windmill around the rotational axis of the fuselage is 17.0 grcms$^2$.

3) Rotational speed in the pitching motion.

A pitching motion of period 8 seconds is given to the model directed initially to the tunnel current according to the configuration pictured in Fig. 2, and the rotational speed of the windmill is measured for various wind speeds as illustrated in Fig. 7.

The rotational speed changes almost sinusoidally with a period of 8 seconds, but its mean value is definitely lower by $\Delta \omega$ than that for steady state for the
same wind speed. Further the phase is shifted by 110° from the angular speed $\Omega$ of the supporting pole, which is quasi-sinusoidal owing to the link geometry.

The under-estimation of the wind speed due to the pitching, i.e., $\Delta \omega / \omega_0$, where $\omega_0$ stands for the case without pitching, is of the order of 10~15% for the wind velocities experimented. This effect, which is the most important and conspicuous feature, can be explained from the yawing of the model during the pitching, as the amount of under-estimation agrees fairly well with the result of Fig. 4 if the mean pitching angle between the extremities is estimated to be $(24°30'+23°04')/2 = 23°18' = 15°$.

The model does not change its direction during the pitching motion.

4) Rotational speed in the rolling motion.

Now a rolling motion of period 8 seconds is bestowed to the model without initial yaw angle in the tunnel current. The rotational speed is measured as illustrated in Fig. 8.

In contrast with Fig. 7, no
under-estimation of the wind speed is practically observed in this case, even if the fluctuations of the observed rotational speed are quite irregular and lie within a certain band width. No definite periodicity and therefore no phase lag can be recognized. This fact is due to smaller side wind (yaw) effect than the case of pitching, for instance, the yaw angle $\phi \approx 6^\circ$ with the maximum rolling speed passing the central position at the wind speed $V=3.4 \text{ m/s}$ ($\phi=0^\circ$ at both extremities, and becomes smaller as the wind speed increases).

Here again the model does not change its direction during the rolling motion.

4. Conclusions

1) Pitching motion has nothing to do with the indication of wind direction of the Marine Speedovane model.

2) Pitching motion causes under-estimation of the mean wind speed of the order of $10\sim 15\%$ for wind speed up to $10 \text{ m/s}$.

3) Rolling motion has nothing to do with the indication of wind direction of the said model.

4) Rolling motion does not cause any under-estimation of the mean wind speed.

5) Pitching or rolling motion causes oscillating or fluctuating indication of instantaneous wind speed, especially for the former case, coupled with a certain phase lag.

6) The above conclusions are valid for the special configuration of installation experimented here and cannot be regarded as generally valid.

References
