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Comparative investigation of dynamic properties of some propeller vanes

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Abstract

The dynamic properties of three types of propeller vanes (Gill vanes type 8002D and 35003D, Koshin vane type MV-110) were investigated in a windtunnel. The distance constant, damping ratio and damped wavelenght of the various instruments compare well with the dynamic properties of a cup anemometer wind vane combination, as used at present on the 213 m mast at Cabauw in The Netherlands (Van Ulden et al, 1976; Driedonks et al, 1978).

Overspeeding of a cup anemometer in a turbulent airflow is one of its major disadvantages, especially when wind profiles with strong vertically varying turbulence intensity are studied, for example when the mixing height is small. Horizontal fluctuations affect a propeller and a cup anemometer equally. However, vertical fluctuations produce cup anemometer overspeeding of the same order of magnitude as overspeeding caused by horizontal fluctuations, but they do not affect a propeller.

This implies that an improvement of the acuracy of the wind measurements might be realised by replacing the cup anemometer wind vane combination by propeller vanes. Other advantages are:

- mutual interference from wind speed sensor and wind direction sensor is independent on wind direction.
- only a single instrument position is required.

Mainly for reason of sturdiness and compactness the Gill vane type 8002D was finally chosen to replace the cup anemometers and wind vanes on the 213 m mast.

1. Introduction

This report describes an investigation of the dynamic properties of three types of propeller vanes. Among others, the distance constant, damping ratio and damped wavelength were determined by means of wind-tunnel experiments.

This study has been undertaken because it was proposed to improve the accuracy of the wind measurements on the 213 m mast of the Royal Netherlands Meteorological Institute (KNMI) (Van Ulden et al, 1976; Driedonks et al, 1978) by the introduction of propeller vanes. At present cup anemometers and wind vanes are in use.

The overspeeding of a cup anemometer in a turbulent airflow is one of its major disadvantages, especially when wind profiles with vertically varying turbulence intensity are studied. A cup anemometer and a propeller do not respond in the same way to real turbulence. Horizontal fluctuations affect both instruments equally. Vertical fluctuations, however, produce cup anemometer overspeeding of the same order of magnitude as overspeeding caused by horizontal fluctuations, but they do not affect a propeller. The overspeeding of a cup anemometer with a distance constant of 2 m is about 7% for $z/L=0,2$ where z is the height of measurement and L the Monin-Obukhov length scale (Busch and Kristensen, 1976). This implies that an improvement of the accuracy of the wind measurements might be realised by replacing the cup anemometer wind vane combination by propeller vanes. Since a propeller vane combines the speed sensor and azimuth sensor into one instrument, other advantages of its introduction are:

- mutual interference from the two sensors is independent on the wind direction.
- only a single instrument position is required.

Out of the commercially available propeller vanes three types were chosen for further investigation. For reason of comparison the properties are given of some instruments, already being in use at the Institute and on the 213 m mast.

2. Description of the instruments

The properties of the following instruments were investigated.

- Two versions of the Gill propeller vane, manufactured by the R.M. Young Company, Traverse City, Michigan, U.S.A.
- Koshin propeller vane, manufactured by the Koshin Electrical Ind. Co. Ltd., Tokyo, Japan.

The properties of these instruments are compared with

- cup anemometer
- wind vane
- trivane (aeolivane)

These three instruments have been developed at the Institute. The trivane is an anemometer bivane, measuring total wind speed (propeller) plus simultaneous azimuth angle and elevation angle of the wind (WMO-232, 1976).

2.1. Gill vane type 8002D

Mechanical:

Three blade helicoid propeller made of ABS thermoplastic, diameter 20 cm, pitch 50 cm.

Aluminium fin, 20 x 23 x 0,04 cm.

Overall height 58 cm, overall length 71 cm, lenght behind the vertical shaft 50 cm.

Weight 2,5 kg.

Electrical:

The speed signal is generated by a photo-chopper (10 pulses per rotation).

The azimuth signal is given by a potentiometer.

The signals are transported to the mounting base by way of sliprings.

(Gill, 1974; 1975).

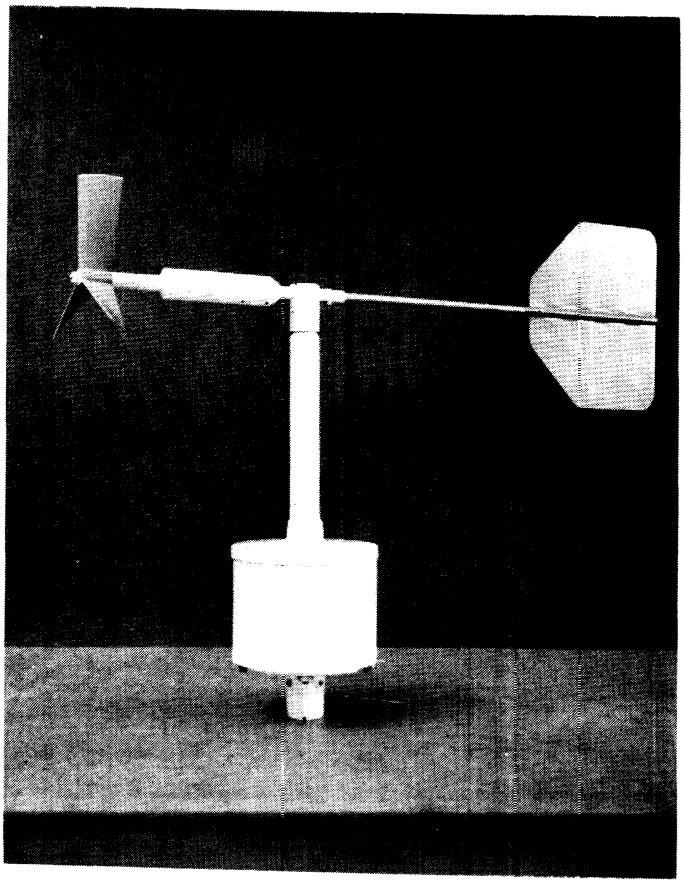

Fig. 1 Gill vane type 8002D

2.2. Gill vane type 35003D

Mechanical:

Four blade helicoid propeller made of foamed polystyrene, diameter 19 cm, pitch 30 cm.

Fin made of foamed polystyrene, 23 x 23 x 0,6 cm.

Overall height 53 cm, overall length 86 cm, length behind the vertical shaft 62 cm.

Weight 2,7 kg.

Electrical:

Same as type 8002D.

(Gill, 1974; 1975).

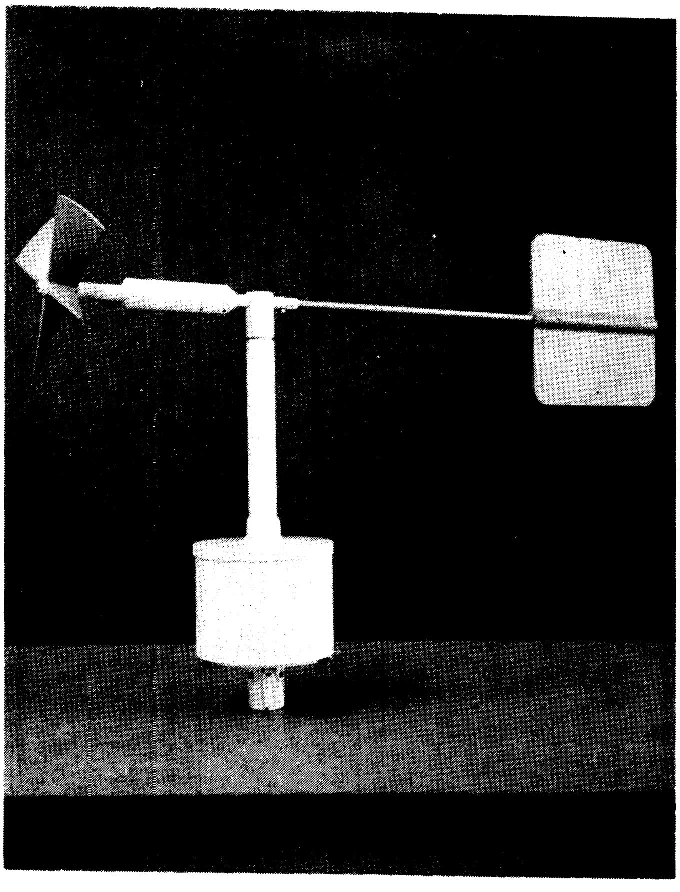

Fig. 2. Gill vane type 35003D

2.3. Koshin vane type MV-110

Mechanical:

Four blade propeller made of stainless steel, diameter 30 cm.

Fin made of reinforced plastic, 22 x 45 x 1 cm.

Overall height 72 cm, overall length 62 cm, length behind the vertical shaft 48 cm.

Weight 4,8 kg.

Electrical:

Speed signal by a DC-generator.

Azimuth signal by a synchro transmitter.

The signals are transported to the mounting base by way of sliprings.

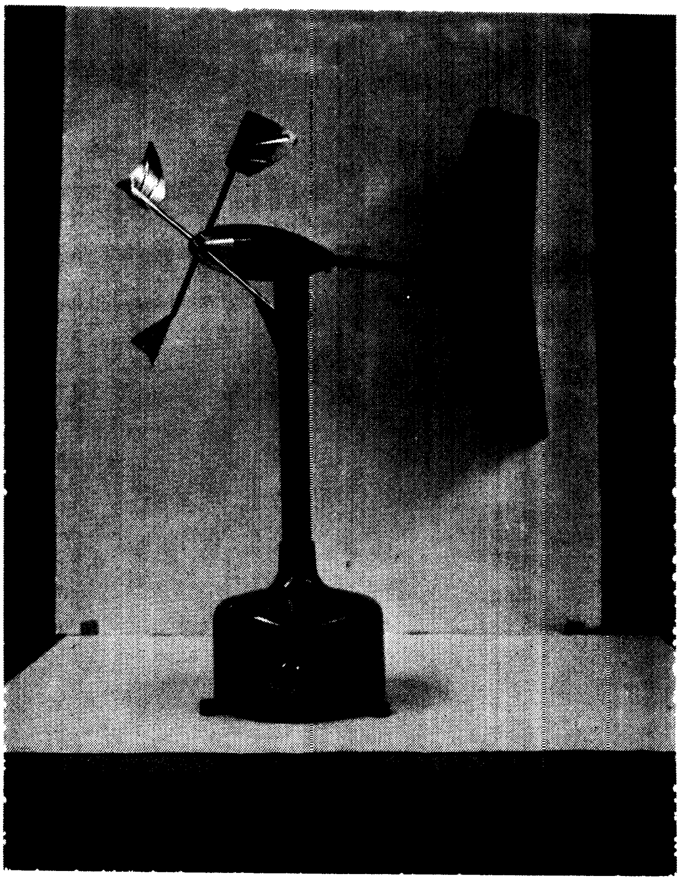

Fig. 3 Koshin vane type MV-110

2.4. Trivane (Aeolivane)

Mechnical:

Four blade propeller, made of aluminium, diameter 17 cm, flat blades, wind angle 10°.
Annular fin, made of PVC, diameter 20 cm, length 4 cm.
Overall height 63 cm, overall length 52 cm, length behind the vertical shaft 28 cm.
Weight 1,0 kg.

Electrical:

The speed signal is generated by a photo-chopper (32 pulses per rotation). The azimuth signal is given by a potentiometer.
The signals are transported to the mounting base by way of slip-rings. The possibility to measure the elevation of the wind vector with this instrument will be left our of consideration.
(WMO-232, 1976).

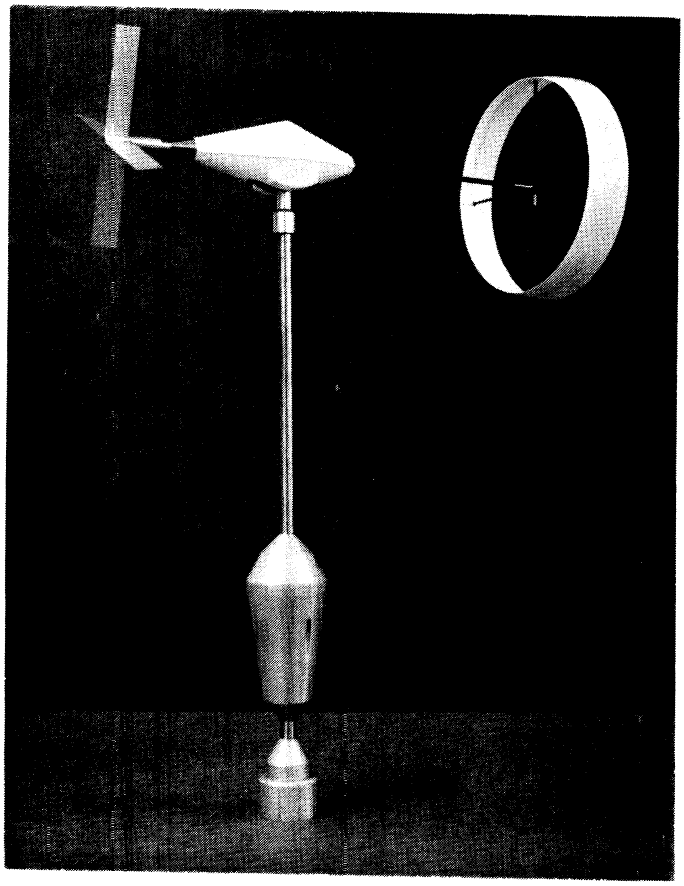

Fig. 4. Trivane (Aeolivane)

2.5. Cup anemometer type KNMI 01.00.018

Mechanical:

Three nylon conical cups, diameter 10 cm, arm length 5 cm.
Overall height 22,5 cm, outer radius 30 cm.
Weight 0,78 kg.

Electrical:

The speed signal is generated by a photo-chopper (32 pulses per rotation).

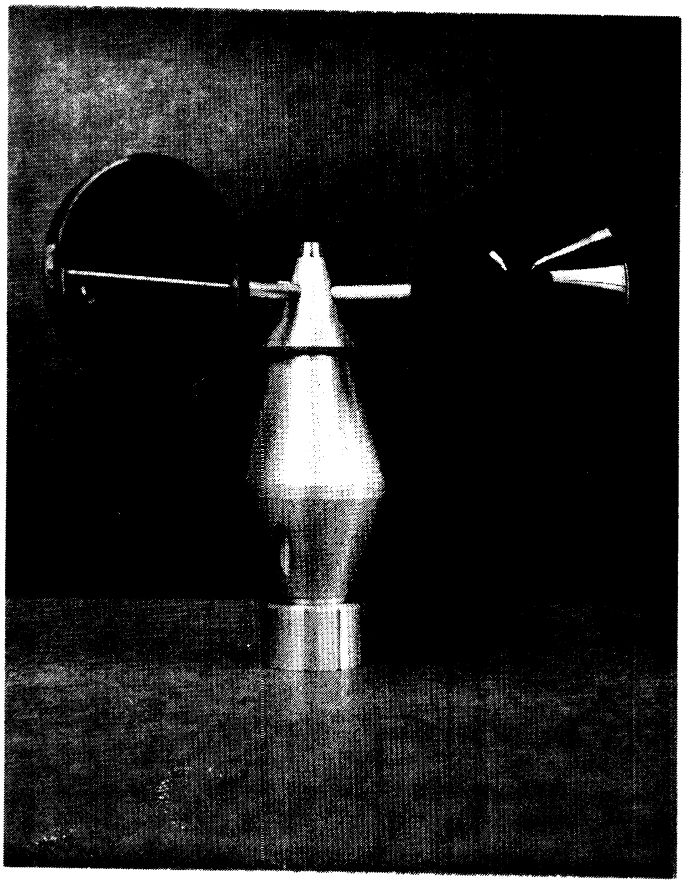

Fig. 5. Cup anemometer type KNMI 01.00.018.

2.6. Wind vane type KNMI 01.00.521

Mechanical:

Aluminium fin 20 x 7 x 0,3 cm.

Overall height 38 cm, overall length 39 cm, length behind the vertical shaft 32 cm.

Weight 0,5 kg.

Electrical:

The azimuth signal is given by a potentiometer.

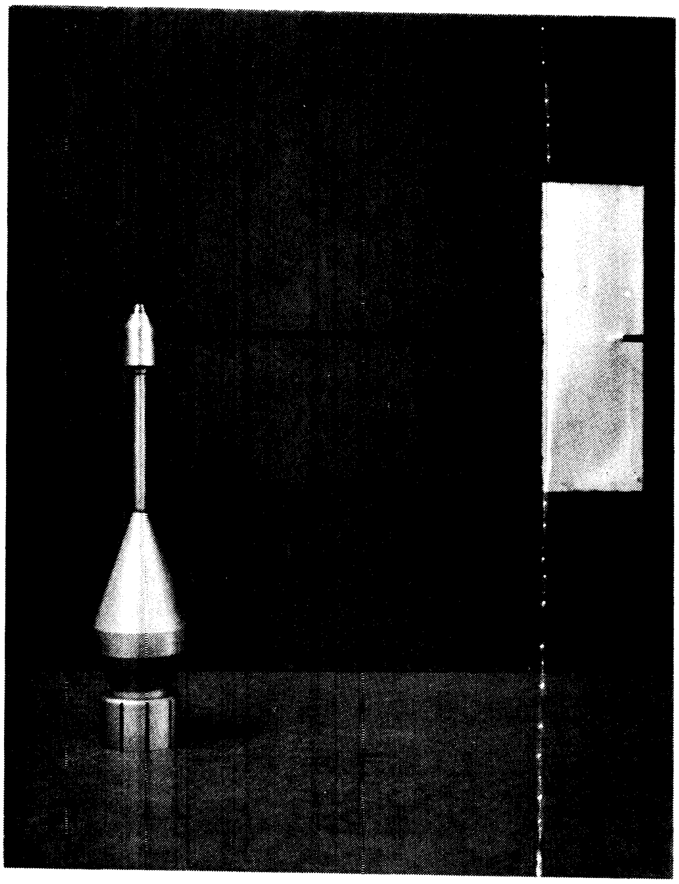

Fig. 6. Wind vane type KNMI 01.00.521

3. Theory

A mathematical model of the dynamic response of a sensor can only be given for simple and small fluctuations. A step function will be used to study the response to horizontal wind fluctuations, because verification of a model is then possible by means of windtunnel experiments.

3.1. Response of a cup anemometer and a propeller to a step change in wind speed

It can be shown that the equation of motion of a cup anemometer and a propeller have the same form, by approximation written as (Jelinek, 1876; MacCready and Jex, 1964)

$$\frac{dn}{dt} = - C_1 un + C_2 u^2 \qquad (1)$$

where

n = revolutions per second.

t = time.

u = wind speed.

C_1 and C_2 are constants depending on the instrument and the density of air.

For a step change in wind speed from u to $u + \Delta u$ at $t = 0$ the solution to (1) is

$$n = \gamma \left(u + \Delta u \left(1 - e^{-t/\tau} \right) \right) \qquad \text{for } t \geqslant 0 \qquad (2)$$

where

$$\gamma = \frac{C_2}{C_1} \qquad (3)$$

and

$$\tau = \frac{1}{C_1 (u + \Delta u)} \qquad (4)$$

The time constant τ is inversely proportional to the new wind speed. We now define the distance constant d

$$d \equiv (u + \Delta u) \tau \qquad (5)$$

So, through (4), we may write

$$d = \frac{1}{C_1} \qquad (6)$$

For a specified anemometer this parameter depends only on the air density.

For a step change in wind speed from zero to u at $t = 0$ the solution to (1) is

$$n = \gamma u (1 - e^{-ut/d}) \qquad \text{for } t \geq 0 \qquad (7)$$

Through (7) the distance constant can be determined from a wind-tunnel experiment (MacCready and Jex, 1964).

The constant γ is the calibration of the instrument, since we may write

$$\gamma = \frac{n}{u} \qquad \text{for } t = \infty \qquad (8)$$

3.2. Response of a wind vane to a step change in azimuth

The wind vector u causes a lifting force F_L on the vane fin, resulting in the normal effective force F_e.

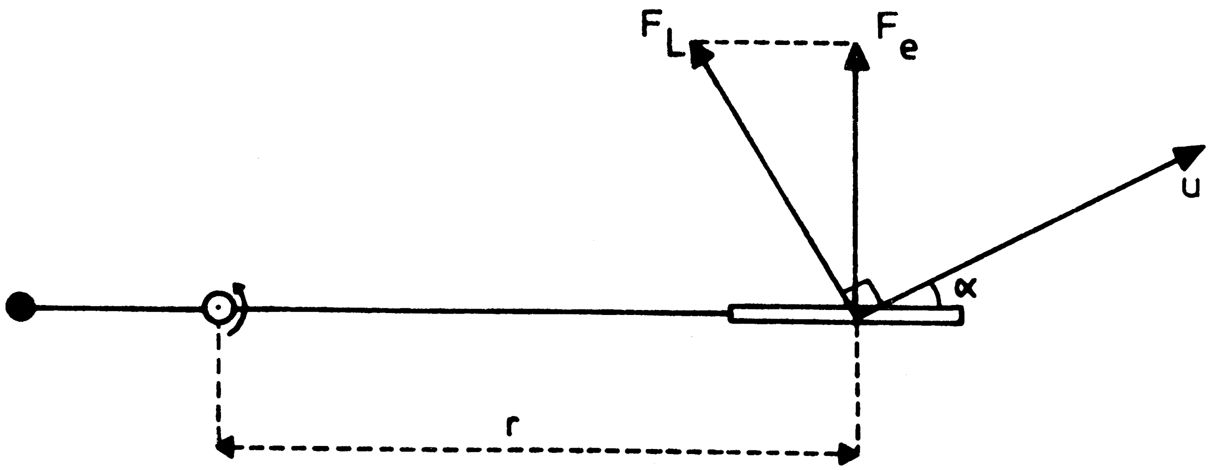

fig. 7 Forces acting on a vane fin

The effective force F_e produces a torque T per unit angle of attack, for small angles equal to

$$T = \frac{F_e\ r}{\alpha} \tag{9}$$

where

r = distance between the vertical shaft and the aerodynamic centre of the fin.

α = angle between the vane axis and the wind.

Supposing the lifting force F_L can be written for small angles as

$$F_L = K\ \alpha\ u \tag{10}$$

and since for small angles of attack

$$F_e \approx F_L \tag{11}$$

we can rewrite (9) to

$$T = K\ r\ u^2 \tag{12}$$

So T is proportional to u^2.

When α_e is the effective angle of attack for a moving vane, its equation of motion can be written for small fluctuations as (Wieringa, 1967)

$$- I \frac{d^2\alpha}{dt^2} = T\alpha_e \qquad (13)$$

where

I = moment of inertia of the vane.

It has been calculated (Barthelt and Ruppersberg, 1957), that for a moving vane

$$\alpha_e \approx \alpha + \frac{r}{u}\frac{d\alpha}{dt} \qquad (14)$$

Through (14) equation (13) can now be rewritten to

$$- I \frac{d^2\alpha}{dt^2} = T\alpha + \frac{Tr}{u}\frac{d\alpha}{dt} \qquad (15)$$

where we define

$$\frac{Tr}{u} \equiv D \qquad (16)$$

as the aerodynamic damping of the vane (Wieringa, 1967).

For a constant wind speed the solution to (15) can be written

$$\alpha = (a \cos(2\pi t/t_d) + b \sin(2\pi t/t_d)) \exp(-Dt/2I) \qquad (17)$$

where a and b are determined by the initial conditions, and

$$t_d = \frac{2\pi}{\sqrt{\frac{T}{I} - \left[\frac{D}{2I}\right]^2}} \qquad (18)$$

is the damped oscillation period of the vane.

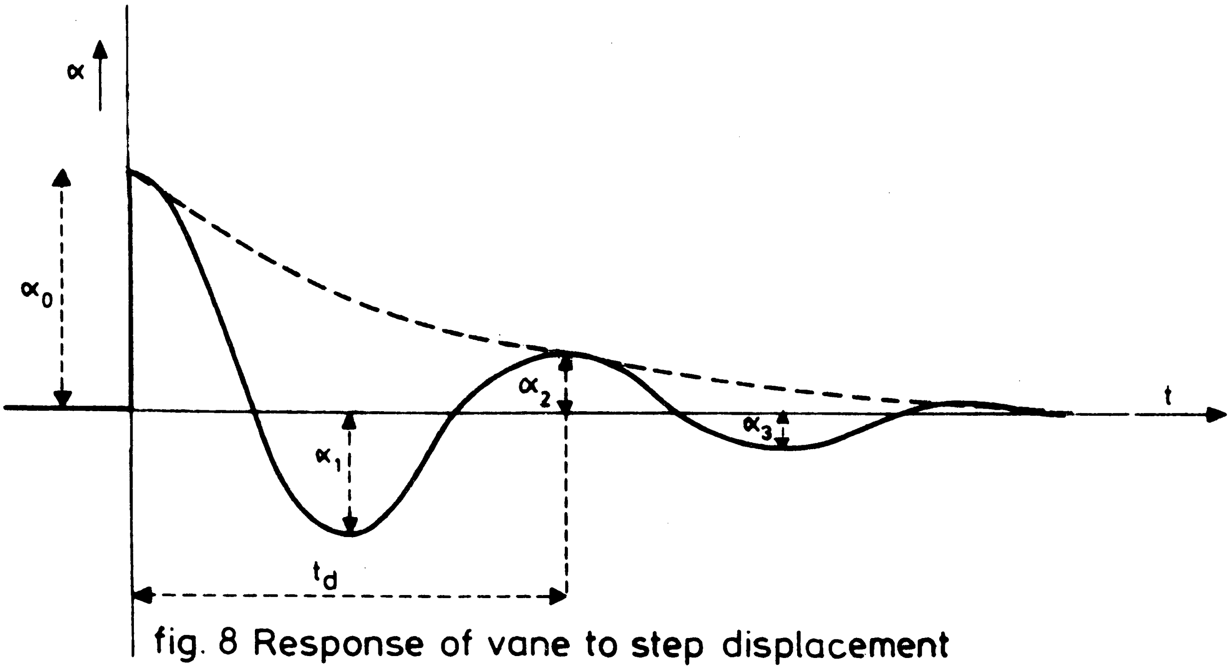

fig. 8 Response of vane to step displacement

If D = 0 (18) reduces to the natural oscillation period t_o

$$t_o = \frac{2\pi}{\sqrt{\frac{T}{I}}} \tag{19}$$

The damping is critical if $t_d = \infty$, then through (18) we have

$$\left[\frac{D_o}{2I}\right]^2 = \frac{T}{I} \tag{20}$$

where D_o is the critical damping.
A characteristic constant for a specified vane is the damping ratio ζ

$$\zeta \equiv \frac{D}{D_o} \tag{21}$$

or, through (16) written as

$$\zeta = \frac{2\,T}{u\,D_o} \tag{22}$$

Through (12) and (20), (22) can be rewritten to show that ζ is constant.
Using (19) and (20), we can rewrite (22) to

$$\zeta = \frac{\pi r}{u t_o} \tag{23}$$

Another characteristic constant is the damped wavelength l_o

$$l_o \equiv u t_d \tag{24}$$

Through (18), (16) and (12) it can be shown from (24) that l_o is constant.
Equation (24) can be rewritten to

$$l_o = u t_o \sqrt{1 - \zeta^2} \tag{25}$$

Finally the overshoot h is introduced

$$h \equiv \frac{\alpha_i}{\alpha_{i-1}} \qquad \text{(fig. 8)} \tag{26}$$

which can be rewritten to

$$h = \exp\left(- \frac{\pi \zeta}{\sqrt{1 - \zeta^2}} \right) \tag{27}$$

Characteristic parameters of the vane motion are damped wavelength and damping ratio. By means of a windtunnel experiment it is possible to determine damped wavelength and overshoot. The damping ratio can then be computed through (27) (MacCready and Jex, 1964).

3.3. Propeller-revolutions-per-second as a function of its orientation to the wind

When the azimuth of a windvector is fluctuating, the propeller axis of a propeller vane will not always be oriented parallel to the wind. The resulting error in the wind speed measurement depends on the decrease of the angular velocity of the propeller, when the angle between azimuth and axis of rotation increases.

The angle-dependece of the propeller-revolutions-per-second can be measurea in a windtunnel (Hicks, 1972; Gill, 1975).

3.4. Threshold sensitivity of anemometers and vanes

A sensor at rest will only start to move if the aeordynamic torque is larger than the internal frictional torque. The aerodynamic torque may depend on the initial position of the instrument (cup anemometer and vane). The corresponding threshold of the wind speed can be determined in a windtunnel.

It is possible that the threshold sensitivity increases as the environmental temperature decreases, the lubricating oil in the bearings becoming more viscous.

4. Measurements and results

4.1. Description of the windtunnels

Windtunnel experiments were carried out in order to determine the instrumental parameters mentioned before.

Two windtunnels were used:

1. Windtunnel at the Royal Netherlands Meteorological Institute (KNMI) at De Bilt.
   This tunnel is of the open Eiffel-type with closed intrument compartment, measuring 0,4 x 0,4 x 0,4 m.
   Minimum workable wind speed 0,2 m/s, maximum wind speed 30 m/s.
   This tunnel was used to determine the distance constant of cup anemometer and propellers. The instrument compartment of this tunnel being too small for swinging propeller vanes, a larger tunnel was used to carry out the other experiments.
2. Windtunnel of the National Aerospace Laboratory (NLR) at Amsterdam.
   This is a closed-circuit tunnel with an open instrument compartment of 2,0 m wide, 1,2 m height and 3,0 m length.
   Minimum workable wind speed 3 m/s, maximum speed 40 m/s.

4.2. Determination of the distance constant of cup anemometer and propeller

Since the windtunnels being at our disposal can not produce a step change in wind speed, another method was chosen to determine the distance constants.

The instrument was placed in the windtunnel. The cup wheel or propeller was prevented from rotation by a thin wire, streched through the tunnel. At a constant wind speed the wire was suddenly removed sideways. This arrangement worked satisfactory and was simple to construct.

The output signal of the instrument was recorded in such a way, that the time interval between the successive pulses of the rotation transducer output could be measured. For that purpose a direct recording light beam oscillograph, the Honeywell-Visicorder 2206-AC, was used. This recorder has a frequency range from 0-10 kHz. The registration was stopped as soon as the angular velocity of the anemometer had become stationary.

The Koshin vane does not have a pulse-shaped output. In order to be able to use the same recording-system, a lamp and a photo-electric cell were fixed in the windtunnel in such a way, that the lightbeam was interrupted by the propellerblades.

The anemometer response to this (simulated) step-change in wind speed now could be computed, and by means of the method of least squares the best fitting exponential curve, describing the response, was computed. Through equation (7) the distance constant could be determined.

In table 1. the distance constant of the various instruments is given.

Table 1. distance constant in meters

	measured value	spec's by manufacturer
Gill vane 8002D	2,2 ± 0,1	2,4
Gill vane 35003D	1,1 ± 0,05	0,8
Koshin vane MV-110	2,2 ± 0,1	3,4
Trivane	0,5 ± 0,03	–
Cup anemometer 018	2,9 ± 0,4	–

The given accuracy is based on the standard deviation of a series of five measurements.

4.3. Determination of the damping ratio and the damped wavelength of (propeller) vanes

The instrument was placed in the windtunnel and at a constant wind speed, the vane was pulled out of its equilibrium. Then we released the vane, taking care the wire did not introduce any extra damping while the vane was returning into its equilibrium. This experiment was repeated several times for various wind speeds and various initial deflection angles. While the vane returned into its equilibrium, the oscillating azimuth signal was registrated on a fast recorder. So the overshoot and the damped oscillation period could be measured directly out of the registration. Then the damping ratio and the damped wavelength could be determined, by means of the equations (27) and (24).

It should be mentioned that the damping ratio has only been computed for small initial deflection angles ($\alpha < 15^o$). The lifting force on the fin decreases rapidly for larger angles, and a to small value for the overshoot would be found, causing an over-estimation of the damping ratio (Wieringa, 1967).

In table 2. the damping ratio and the damped wavelength of the various instruments is given.

Table 2. damping ratio, and damped wavelength in meters

	damping ratio		damped wavelength	
	measured	specified	measured	specified
Gill vane 8002D	0,4 ± 0,08	0,34	3,8 ± 0,2	-
Gill vane 35003D	0,6 ± 0,12	0,49	7,6 ± 0,4	7,2
Koshin vane MV-110	0,3 ± 0,06	0,23	3,6 ± 0,2	7,3
Trivane	0,56 *	-	4,0*	-
Wind vane 521	0,36 *	-	3,8*	-

* Result of previous measurements (Wieringa and Van Lindert, 1971; WMO-232, 1976).

The given accuracy is based on the standard-deviation of a series of more than 20 measurements.

It is difficult to perform an accurate determination of the damping ratio. Since the initial displacement should be less than 15°, a well-damped vane will only have a very small first overshoot-angle. It is however doubtfull whether a more accurate determination of damping ratio and distance constant would be of more than theoretical use.

4.4. Determination of propeller-revolutions-per-second as a function of its orientation to the wind

The propeller vane was pulled out of its equilibrium by a thin wire and the relative propeller-revolutions-per-second was measured as a function of the angle between the vane axis and the wind. The azimuth signal was used to measure this angle. Meanwhile the wind speed was carefully kept at a constant level of about 5 m/s.

The figures 9-12 show the propeller-revolutions-per-second as a function af the wind angle **for the various instruments. A cosine** curve has been drawn in the figures for comparison.

4.5. Determination of the threshold sensitivity of the anemometers and vanes

The threshold sensitivity of the various instruments was determined by observing the instrument, while the wind speed was slowly increased from zero upwards. By reading the wind speed at which the instrument began to move, the threshold sensitivity was determined. The influences of the initial position and the environmental temperature were not investigated.

Because of the size of most of the instruments this experiment had to be carried out **in the large windtunnel at Amsterdam. In spite** of its limited accuracy at wind speeds below 3 m/s it was clear that the threshold sensitivities of all instruments were below 1 m/s.

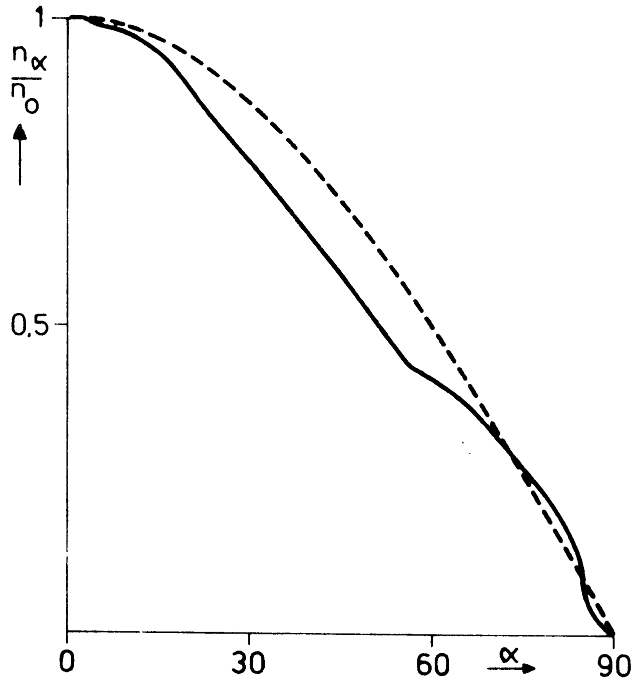

fig. 9 Gill vane type 8002 D

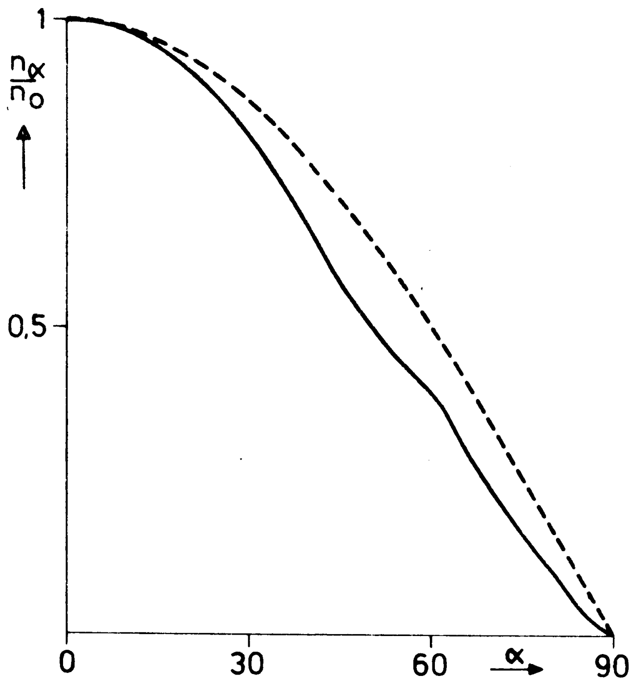

fig. 10 Gill vane type 35003 D

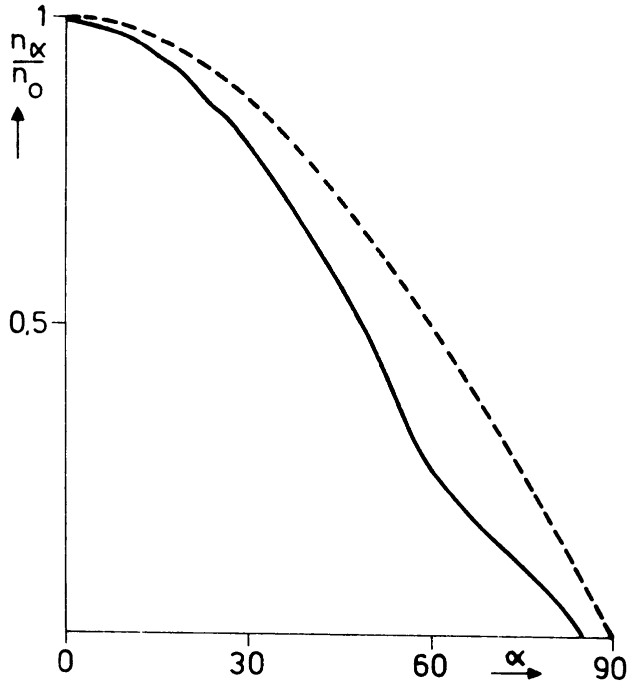

fig. 11 Koshin vane type MV-110

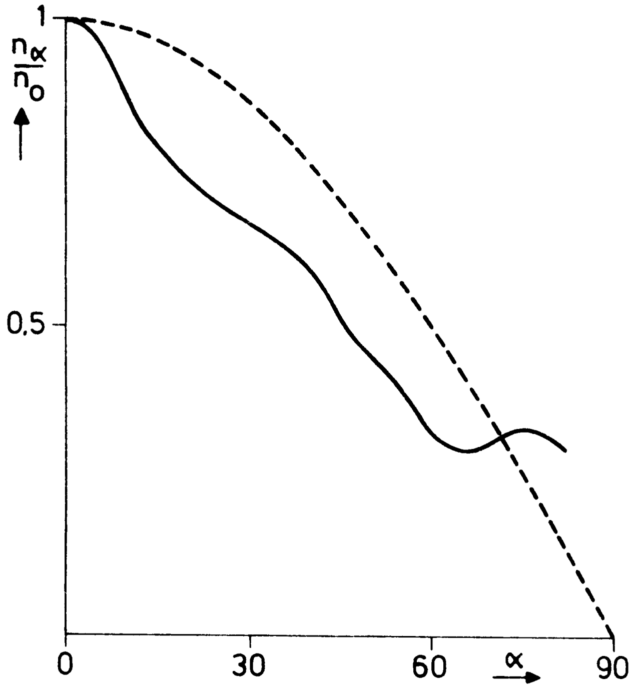

fig. 12 Trivane (Driedonks 1976)

fig. 9-12 Propeller-revolutions-per-second as a function of the wind angle α (degrees)

It should be mentioned that the threshold sensitivity of the available Gill vanes originally was worse, because they had vertical shaft bearings with sealingrings, which introduced extra friction. Only after removal of these sealingrings the threshold sensitivity was below 1 m/s. The alternative manufactures option with frictionless shielded bearings is therefore to be preferred.

4.6. Calibration of the propellers

For the Gill propellers and the Koshin propeller a calibration is given by the manufacturers; individual calibration would not be necessary. Since only one propeller was available of all three types, a full verification of this statement was not possible. An independent calibration of the propellers was carried out.
The standard vane-anemometer of the National Aerospace Laboratory was used as a reference-instrument.

A lineair calibration was computed by the method of least squares. The result is given in table 3.

Table 3. individual calibration with respect to manufacturers specification.

	slope deviation in %	constant in m/s
Gill vane 8002D	- 1,4	0,13
Gill vane 35003D	+ 1,8	0,20
Koshin vane MV-110	- 3,1	0,22

Lineairity was quite good in all three cases: the coefficient of determination was better than 0,9998 (Baynton; 1976).

5. Response of a propeller vane to fluctuations of the wind vector

In case of simultaneous fluctuations of length and azimuth of the windvector, the responses of the propeller and the vane are not independent. While the vane is oscillating into its new equilibrium, the propeller axis will not always be oriented parallel with the wind. So the recovery time of the propeller to the new wind speed increases. Only a propeller having a calibration independent on the wind angle will not show this phenomenon.

Since the distance constant of a propeller will be also dependent on the wind angle, the overall-response of a propeller vane is even more complicated. This last phenomenon however, has not been taken into account.

In order to determine the propeller vane response to a simultaneous step-change in wind speed and azimuth, the responses of the speed sensor and azimuth sensor were computed step by step, while the dependence of the propeller calibration on the wind angle was taken into account. Then the apparent wind vector was computed for sequent time-steps.

In fig. 13 the overall-response to a step-change in wind speed and azimuth is given for various instruments. It shows that the response of propeller and vane are well matched for all instruments.

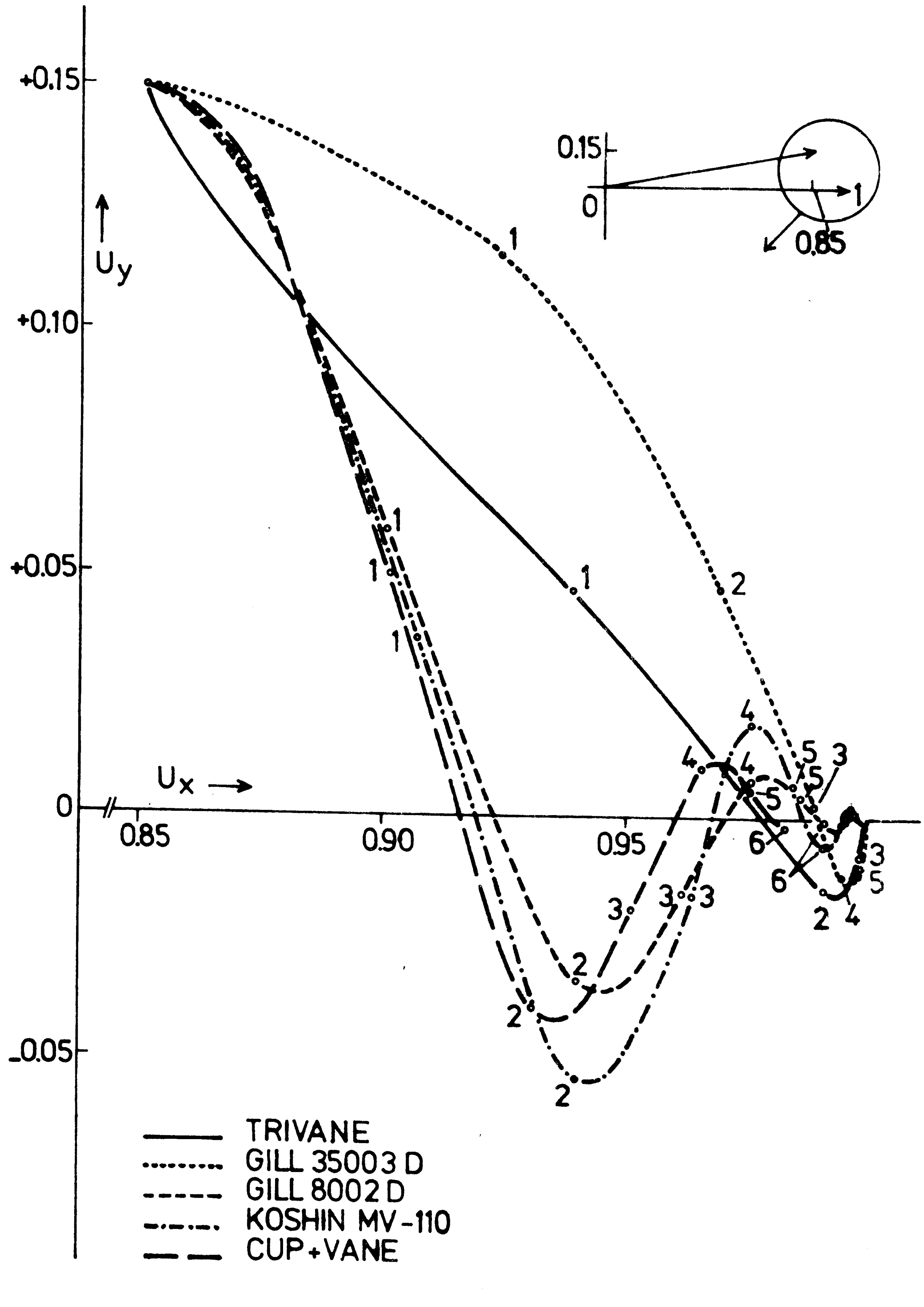

Fig. 13 Response of the measured wind vector to a vectorial step change from $(U_x, U_y) = (0.85, 0.15)$ to $(1, 0)$. Each meter wind run is indicated as a dot.

6. Overspeeding

The nonlinear response of a cup anemometer and a propeller to horizontal wind fluctuations introduces an overestimation of the mean wind speed, the so called overspeeding (Schrenk, 1929; MacCready 1966; Kaganov and Yaglom, 1976). Since the equation of motion of a cup anemometer and a propeller have, in goed approximation, the same form in the case of a horizontal wind flow (1), the expression for the overspeeding will also have the same form for both instruments.

A relation between relative overspeeding $\Delta S/S$ and the horizontal turbulence intensity I_s is given by Busch and Kristensen (1976) for a cup anemometer as

$$\frac{\Delta S}{S} = J_s I_s^2 \qquad (28)$$

where J_s is a function of the distance constant d and the horizontal length scale λ of the turbulence. Since J_s is believed to be less than unity, we can write

$$\frac{\Delta S}{S} \leqslant I_s^2 \qquad (29)$$

For the reason mentioned before, (28) is also valid for a propeller.

Though not using exactly the same equation of motion, Ower and Pankhurst propose a similar formula for the overspeeding of a propeller

$$\frac{\Delta S}{S} \leqslant \frac{\varepsilon^2}{2} \qquad (30)$$

caused by the harmonic wind fluctuation

$$u = u_o (1 + \varepsilon \sin pt) \qquad (31)$$

Vertical wind fluctuations hardly introduce any extra error when a propeller is used. The phenomenon described in 3.4, causes only a very small underspeeding.

However, when a cup anemometer is used, the measurement of the mean wind speed is affected by vertical fluctuations. When these are also taken into account, the equation of motion of a cup anemometer becomes more complicated than (1). Taking the work of Wyngaard et al (1974) as starting point, Busch and Kristensen (1976) show that the overspeeding of a cup anemometer in real wind is given by

$$\frac{\Delta S}{S} = J_S I_S^2 + c I_W^2 \qquad (32)$$

where

I_W = vertical turbulence intensity.

c = constant, about unity.

So, the error caused by overspeeding in a real fluctuating wind, is basicly larger for a cup anemometer than for a propeller, in case both instruments have the same distance constant.

Using (28), Busch and Kristensen (1976) have calculated the overspeeding error of a cup anemometer due to horizontal fluctuations. These results represent the total overspeeding error of a propeller in real turbulence. To calculate the total overspeeding error of a cup anemometer, we suppose c in (32) to be unity, and (32) simplifies to

$$\frac{\Delta S}{S} = J_s I_s^2 + I_w^2 \qquad (33)$$

So the first term now represents the overspeeding of a propeller, already calculated by Busch and Kristensen, and the second term gives the extra overspeeding of a cup anemometer, induced by vertical fluctuations. This holds for a cup anemometer and a propeller which have the same distance constant. The second term can be estimated for the atmospheric surface layer under several stability conditions, when we adopt the expression for the vertical profile of mean wind speed, and the expression for the nondimensional vertical variation (σ_w/u_*) as given by Businger (1973). Here σ_w is the standard deviation of the vertical wind and u_* is the friction velocity.

As an example, the overspeeding of a cup anemometer (28) and a propeller (33) is given in table 4. as a function of height for several values for the Monin-Obukhof length L.

Table 4. percentage overspeeding for a cup anemometer and a propeller as a function of height z for several stabilities (surface roughness length z_o = 0,1 m). Distance constant of the instruments is 2 m.

	L = - 10		L = - 5	
z (m)	prop	cup	prop	cup
1,5	6	8	9	13
3	3	5	5	8
5	2	5	3	7
10	1	4	2	7
20	1	5	2	8

7. Conclusions

When we concern only the dynamic properties, none of the three types is clearly preferable to the others, as far as application on the 213 m mast is the major objective.
Since the Gill vane type 35003D is less sturdy then type 8002D, a choice had to be made between the Koshin vane and the Gill vane type 8002D.

Because of its compactness, its small weight and for some other practical reasons, it was finally decided to choose the Gill vane type 8002D for application on the 213 m mast at Cabauw.

Since the instruments are to be used at temperatures between - 20° C and + 35° C, it was decided to have the pulse-shaping integraded circuit in the photo chopper replaced by a Mil.spec. type.

Furthermore it is advisable to have the propeller shaft housing and the pulse generator housing anodized before painting, in order to prevent corrosion of the screwthread. Both extra features are available as a manufactorers option.

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