Tests of the Friez Aerovane in the Natural Wind at Blue Hill Observatory

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SYNOPSIS

A new combination windmill anemometer and vane under the name of Aerovane, constructed by the Friez Instrument Division of Bendix Aviation Corp. was tested in the natural wind at Blue Hill Observatory. The anemometer was compared with a standard 3-cup, a 6-bladed duralumin windmill, a 3-bladed balsa windmill, and a pressure-tube anemometer. It was exposed to severe weather, including gale-driven rain, snow, sleet, hail, and freezing rain. The maximum wind measured was 94 mph. Although its starting speed of 2 mph is not as low as in other types, there are no essential differences, and its responsiveness to changes in speed and its capacity for indicating maximum gusts seems to be practically equal to those of mills and pressure-tube anemometers. The Aerovane, in common with other mill and pressure-suction types, appears to show no over-registration in gusty winds, an appreciable fault of the cup anemometer. The error due to variable angle of attack of the wind in its minor changes of direction seems to be held to negligible proportions, owing to the responsiveness but reduced overswing of the streamlined vane. Though it remains to be seen whether the Aerovane can hold together at maximum hurricane speeds that the cup anemometer can stand, the chances seem good because of the, aerodynamically speaking, "clean" lines of the instrument. The Aerovane seems to be the best all-purpose instrument for measuring wind yet devised.

THE ANEMOMETER tested was developed by Mr. L. E. Wood of the Friez Instrument Division, Bendix Aviation Corp., Baltimore, and has been described in his article that appeared in the November, 1945., BULLETIN, v. 26, pp. 361-370. On seeing this article, the Director of the Observatory obtained the loan of a laboratory model from the Friez division, in order to compare it with the somewhat similar Richard Frères' Anemo-Cinemograph and a gust recorder modeled after it, as well as a pressure-tube and cup anemometer at the Observatory. Most of these had already been subject to exhaustive tests (see S. P. Fergusson, Experimental Studies of Anemometers, Harvard Meteorological Studies, No. 4, 101 p., 1939). The model tested was equipped with a D. C. magneto connected to a windmill. Its output was indicated by a voltmeter calibrated in mph or recorded on an Esterline-Angus milliammeter with suitable resistance, so full-scale deflection, or fifty divisions on the chart, equalled 100 mph. Movements of the vane were transmitted and indicated by a midget, 110-volt, 60-cycle Selsyn motors. Directions were not recorded.

The Aerovane was mounted on a guyed two inch pipe approximately 15 feet above the parapet of the Blue Hill Observatory tower or 52 feet above the ground.

The Fergusson balsa-wood windmill is described in BULLETIN, Jan. 1943, v. 24, pp. 22-29.

FIG. 1. Friez Aerovane with temporary contact mechanism and Blue Hill Observatory anemometers. From left to right: the Friez Aerovane, combination standard 3-cup and wind vane, heated pressure tube, 3-bladed balsa wood mill and 6-bladed duralumin mill.
mounted on a similar pipe 10 inches higher but 7 feet to the southeast of the Aerovane. The 3-cup standard is also mounted at the same level but 7 feet to the east-northeast.

The 6-bladed duralumin windmill of our Richard Anemo-cinemograph is mounted 14 inches higher and 7 feet to the southwest of the Aerovane.

A heated pressure tube mounted 9 feet to the southeast of the Aerovane and at the same level and connected to a Friez Diaphragm recorder was also run during the high winds and one other test. Due to the slow time scale of the recorder the peaks were read currently.

These anemometers without their respective recorders are shown in Fig. 1.

FIGURE 2 shows the relative positions of anemometers and wind vanes atop the Observatory tower.

It was obvious from the start that the Aerovane was more sensitive than its indications on the Esterline-Angus recorder; therefore, with no better recorder available, it was necessary to measure rpm of the windmill. An aluminum ring was fastened to the rain cap at the back of the Aerovane mill. This ring was cut so that a slight back and forth motion could be imparted to a rod mounted behind the mill. The rod opened or closed an electrical circuit as it moved. The circuit was closed throughout half of each revolution of the mill and opened the other half. It is believed that the addition of this mechanism did not disturb the
flow of air enough to influence appreciably the speed of the wind in the vicinity of the mill or to add mechanical friction that would slow the mill a measurable amount at speeds above 5 mph.

The paper feed on the disk-and-roller type of recorder connected to the balsa mill was speeded up to 60 cm per minute. Time marks on a line representing zero of the wind-speed scale were made automatically every half second at the bottom of the chart. In Figures 3 a portion of an actual record is reproduced. Figure 3 illustrates the response of the Aerovane and balsa mill when started from rest. At the top of the chart each revolution of the Aerovane mill was marked by a pen attached to an electromagnet. Directly below this trace the direct reading pen from the disk and roller recorder runs up and down vertically. Upon close inspection of the records it will be noticed that the time marks are not always evenly spaced; this is caused by slight irregularities in the paper feed; but as long as the pens are directly above one another this makes no difference in the measurements. Each mm of height above zero of this trace equals 1 mph. Each revolution of the Aerovane mill with this equipment could be recorded up to about 35 mph; above this speed the contacts came too close to be distinguished.

The timing gears of the Esterline-Angus recorder were changed so that most of the comparisons were made with a paper feed of 4 minutes per division, or 3/4 inch (29 cm per min), a rate which is still far too low for studying details above 10 mph.

**VANE CHARACTERISTICS AND STARTING SPEED OF THE AEROVANE IN THE NATURAL WIND**

The vane compares well with other wind vanes, turning at the same low wind speeds.

Even without the contact mechanism, the mill requires more wind than the ordinary 3-cup anemometer before it starts to turn. At Blue Hill Observatory the order in which anemometers in the natural wind start to turn when the wind increases slowly from zero is as follows:

1st: 6-bladed duralumin mill connected to Richard disk and roller cinemograph.

2nd: Standard 3-cup connected mechanically to recorder.

3rd: 3-bladed balsa-wood mill connected to Fergusson disk and roller recorder.

4th: Friez Aerovane with magneto head.

About a 2 mph wind is required to start the Aerovane; this figure may be ascertained much more accurately in the wind tunnel.

**SCALE READING**

The scale of the Aerovane was originally determined by the maker in a wind tunnel. It is linear, as expected for an anemometer of this type, and passes through a point corresponding to 87.1 mph at 1800 rpm.
This scale was checked in a number of ways in the natural wind. At low speeds the Aerovane revolutions were compared with other anemometers, as shown in Table 1. The abnormally low readings on the Esterline-Angus, as shown by the averages, were due to improper resistance in the line; this, of course, can be corrected.

Fergusson has stated that windmills having long tails, 36 inches, under-register at high speeds as compared with mills with short, 20-inch tails. The under-registering at high speeds is largely caused by the greater moment of inertia of the long-tailed vanes. As a result, they constantly over-swing and under-register because the mill is not normal to the wind.

The leading edge of the cinemograph mill tail is only 2$\frac{1}{2}$ inches behind the axis of rotation of the vane, as compared with 15 inches of the Aerovane. The total lengths of the tails are 16$\frac{1}{2}$ inches for the cinemograph and 24 inches for the Aerovane. Even though the Aerovane can hardly be classed as having a "long" tail it seemed advisable to compare its indicated speeds with those of the cinemograph mill, with its short-tailed vane.

Figure 4a shows the ratio of Esterline-Angus readings to wind speed by the six-bladed duralumin cinemograph mill (ordinates) vs the wind speed by the same cinemograph mill (abscissae). Speeds indicated by the six-bladed mill connected to the cinemograph are correct within 1 mph at all speeds up to at least 80 mph, according to a test in the Harvard wind tunnel early in 1946. Its starting speed is 0.7 mph. The calibration curve as determined in the wind tunnel is linear. It seems reasonable to assume that the closeness, shortness, and light weight of its tail keeps the cinemograph mill pointed into the wind so well that there can be little loss in recording speeds even in strong winds. The points plotted represent, for the most part, hourly averages, in a few cases, half-hourly averages. Apparently, the ratio is constant at 0.91, through speeds up to at least 50 mph, which indicates no greater slowing down of the Aerovane than of the cinemograph at high wind speeds. The ratio is below unity simply because the Esterline-Angus-Aerovane circuit contains excessive resistance.

The distance traveled by the wind when passing from the blades to the center of the Aerovane tail is 24 inches as compared with 15 inches on the cinemograph vane. Therefore, the time required before a change in wind direction could start to turn the vane so that the mill would be normal once again to the wind is slightly longer for the Aerovane than the cinemograph. However, the fact that the tail surface of the Aerovane is above the support of the instrument and highly streamlined apparently cancels out this disadvantage and prevents any appreciable over swing of the vane.

A similar plot, shown in Fig. 4b, indicates the over-registering of the standard 3-cup anemometer at high wind speeds as compared with the Aerovane. This verifies the earlier work of Fergusson. Over-registering of cup anemometers may largely be attributed to their speeding up under the influence of a higher wind speed more rapidly than they slow down with a decrease in wind speed. With increasing wind the concave sides of the cups offer more resistance versus that of the convex sides.

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Ibid., pp. 45-47.
than with decreasing wind speed. In general, the heavier the cup wheel the more it over-registers. From the curve drawn through these points we see that the 3-cup standard, even when the usual corrections, as determined in steady wind-tunnel tests, are applied, over-registers more and more with increasing speeds in the natural, gusty wind. Mr. Fergusson also noted that the percentage of over-registering of a smaller 3-cup anemometer was higher at 2 mph than at 20 mph. The same instrument was not compared at higher speeds, and no data were presented for a 3-cup wheel having exactly the same dimensions and weight as that used throughout this test. Preliminary inspection indicates that, on the average, the minimum percentage of over-registering occurs around 15 mph; however, this varies widely with different degrees of gustiness.

At Blue Hill Observatory over a period of 22 days of average winds having a mean speed of 15 mph the standard 3-cup anemometer over-registered relative to the windmills by 5%. In one case with a mean speed of 29 mph the cups over-registered by 9%.

Sensitivity

Comparison of the sensitivity of anemometers should be done strictly between the parts of the instrument exposed to the wind and not through their readings on a recorder. Unfortunately, very sensitive recorders are often coupled to insensitive instruments. The results are most misleading. On the other hand, it is sometimes advantageous to have a very sensitive instrument connected to a relatively sluggish recorder.

An example is the sensitive 6-bladed mill connected to the intentionally sluggish cinemograph at Blue Hill Observatory. The mill does not over or under-register in various degrees of gustiness, so its readings of wind mileage, obtained by gearing alone, are far more accurate than the 3-cup anemometer. The cinemograph, which also indicates mph directly, was designed and constructed to have a large lag in order to smooth the gusts out and trace a moderately steady line rather than one perhaps 10 to 20 mph wide when the usual time scale is employed. The record shows the mean wind speed over approximately the preceding three-minute period. In this way tendencies and oscillations over several minutes or hour are easily perceived by the meteorologist.

Fergusson⁵ has shown that for each type of rotation anemometer the number of rotations required to accelerate from rest to equilibrium is constant regardless of wind speed.

In Figure 5 the successive half-second average wind speeds as measured by the Aerovane contacts and balsa-wood mill are plotted. Since the anemometers are a few feet apart, the differences between anemometers as shown by the curves are probably real differences in simultaneous wind speeds and not so much the differences between the anemometers themselves.

Five-second average wind speeds are plotted in Figure 6. In a few cases, the time required for a gust of wind to travel from one anemometer to another checked closely with the records.

⁵ Ibid., pp. 70–77.

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Fig. 5. Half second average wind speeds; solid line—balsa mill, dashed line—Aerovane contacts.
The number of rotations required to reach equilibrium after a sudden increase in wind speed have already been determined by Ferguson for the standard 3-cup and 6-bladed duralumin-mill anemometers and are shown in Table 2. Corresponding values were obtained by the author for the 3-bladed balsa-wood mill and the Aerovane, both in the natural wind in connection with this work. For decreasing speeds the number of rotations to reach equilibrium is slightly higher. The number of rotations corresponding to one mile of wind and the distance corresponding to one rotation are also tabulated in Table 2. Relative sensitivities of the anemometers may be calculated by simply multiplying the number of rotations required to reach equilibrium by the distance corresponding to one rotation. This figure is the amount of wind that will pass the instrument while it is acquiring the new speed. The acceleration measurements on the 3-bladed balsa-wood mill were made with a load comparable with its normal load (slowly rotating aluminum tubing to the recorder). Measurements of the Aerovane acceleration were made including the drag of the magneto. It seemed best to do this because in this instrument the mill will always have a magneto or other motor connected to it.

The Friez Instrument Division states that when an Autosyn motor is connected to the mill through a 25 to 1 open-gear reduction, friction is less than with a direct connection to a magneto. Such a model was not available for test at Blue Hill.

Table 2. Sensitivities of Different Anemometers

<table>
<thead>
<tr>
<th></th>
<th>3-Cup Standard</th>
<th>Friez Aerovane</th>
<th>6-Bladed Duralumin Mill</th>
<th>Ferguson 3-Bladed Balsa Wood Mill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotations per mile of wind</td>
<td>640</td>
<td>1240</td>
<td>1609</td>
<td>3218</td>
</tr>
<tr>
<td>Wind flow corresponding to one rotation</td>
<td>2.5 m</td>
<td>1.3 m</td>
<td>1.0 m</td>
<td>0.5 m</td>
</tr>
<tr>
<td>Number of rotations to reach equilibrium from zero</td>
<td>3.3</td>
<td>3.4</td>
<td>3.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Wind flow required to bring equilibrium after a change in wind speed (values in line 2 multiplied by those in line 3)</td>
<td>8.2 m</td>
<td>4.4 m</td>
<td>3.5 m</td>
<td>2.0 m</td>
</tr>
</tbody>
</table>
The lower the number in the last line of Table 2, the more sensitive the anemometer. From the table it is clear that though the Aerovane mill plus magneto is slightly less sensitive than the 6-bladed mill, it is nearly twice as sensitive as the 3-cup. The 3-bladed balsa-wood mill is still by far the most sensitive rotation anemometer yet devised for continuous exposure in the open.

When the balsa-wood mill is connected to the Fergusson gust recorder the lag of the recorder must be added to that of the mill; but together the lag is still very small.

For peak speeds only, the indicating voltmeter when connected to an Aerovane with magneto agrees well with the balsa-wood mill connected to the Fergusson disk and roller recorder, and with the pressure-suction anemometer and Friez Diaphragm recorder. Some values are shown in Table 3. A careful watch of the Esterline-Angus recorder and the Fergusson disk and roller recorder revealed that the Esterline-Angus recorder did not have time to show all the irregularities in the wind speed, even with pen pressure adjusted to a minimum. A high speed disk and roller model, especially with rectilinear coordinates, would be more suitable for recording purposes.

CONSTRUCTION, WEATHERPROOFING, ETC.

The Friez Aerovane is strong and so shaped as to offer a minimum of windage. This is an important factor when endurance is required. The most destructive forces on a windmill anemometer occur at high wind speeds of variable directions. The gyroscopic effect of the rapidly rotating blades will tear a poorly constructed mill apart when its plane of rotation is changed rapidly with a change in wind direction. The centrifugal force is even greater, but is in a direction such that additional tension is placed on the blades. Even relatively small round rods are able to withstand tensions greater than the centrifugal force produced at maximum rates of rotation.

After exposure of approximately two months the instrument was removed from its standard. Examination showed no signs of water around the magneto bearing or slip rings; however, water had driven up under the rain cap of the vane and run down the wires into the space housing the leads and electrical socket. The spaces cut to hold these wires should be sealed with wax otherwise short circuits will eventually occur below that point, due to moisture or the freez-
At Blue Hill Observatory small baffles placed inside the rain cap by Ferguson have successfully prevented rain and snow from driving up into the bearings of the vanes. When the Aerovane was replaced the gasket that normally fits between it and its support would not fit; it had shrunk badly. Therefore, this gasket should be made from a non-shrinkable material. In this case, the gasket was recut and made to fit, in order to keep out moisture. The plug-in socket, which obviates the necessity of connecting seven wires every time the instrument is put up, is a distinct advantage. A reference pin eliminates the possibility of making incorrect connections and orienting the vane incorrectly.

After taking the Aerovane down and putting it back up several times, occasionally in very stormy weather, the guide pin at the junction of the two parts became loose. This pin should be threaded and screwed into the casting rather than driven in.

The weight and size of the instrument make it extremely difficult to take down and put up in windy weather. In fact, mounting the instrument without the mill getting out of hand and spinning against some solid object is a two man job in a 70 mph wind. (We did not want to put the vane and magneto up first and attach the mill afterward because of the heavy rain that might have driven into the front bearing of the magneto.)

However, a reduction in size and weight seems inadvisable, in view of the fact that some power from the vane and mill now required to drive the Selsyn motor and magneto would be lost. Lighter construction would lead to a definite weakness.

The paint on the Aerovane is not very durable. It is easily chipped if the instrument, especially the vane is hit lightly. During a 48-hour gale when gusts reached 76 mph a very small amount of paint was actually scoured off the nose of the mill by the driving rain, sleet and snow. The loss of paint over an aluminum surface even though anodized will be serious in the salty atmosphere near sea coasts. A better paint job is recommended.

**GENERAL COMMENTS**

After the minor improvements suggested above have been made, we believe that the Friez Aerovane would be a very satisfactory new standard anemometer for general use, except where icing is frequent. This anemometer will indicate the degree of gustiness in absolute units better than any cup or bridled anemometer, in spite of the excellent indicating or recording mechanisms connected to them, and as well as any other mill or pressure tube anemometers compared with it. It requires a minimum of maintenance. No corrections are necessary, and correct readings may be obtained without timing or calculations. Due to these characteristics and the fact that indicators may be installed remotely, with wire connections only, it is obviously an instrument needed by all airports.

At Blue Hill Observatory the practice has been to keep a 3-cup anemometer as a standard for several reasons: (1) it has been the most rugged; (2) we have had fewer failures with this simple instrument, which is entirely mechanical, than with various windmills and recorders, electrical-contact registration having been abandoned a few years after the beginning of observations at Blue Hill; and (3) average wind speeds from a different anemometer would not be comparable with those of U. S. Weather Bureau stations. Nevertheless, it was recognized some fifty years ago at this Observatory that the windmill connected to a cinemograph was the most suitable type of anemometer for studying variations in the wind speed. A long "duration" test will be the only positive proof that the Aerovane has fewer failures than our purely mechanical 3-cup anemometer.

We recommend the installation of gearing and contacts immediately behind the magneto for every mile and 10th mile of wind. In this way, the usual records of wind movement could be maintained at most sta-

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5 The Friez Division has recently replaced the original, short, flaring raincap with one 5 in. long.

6 A non-shrinkable neoprene gasket has been provided.
tions without additional anemometers and yet full advantage of the characteristics of this instrument could be utilized. Addition of four contacts for wind direction might also be made, for the same reason.

ACKNOWLEDGMENTS

The writer is indebted to Mr. S. P. Ferguson for his constructive criticisms during the anemometer tests, and to Dr. C. F. Brooks for his assistance in editing this paper.

POSTSCRIPT

After 10 months of continuous operation, the starting speed of the Aerovane has increased slightly relative to those of the other anemometers and there is radio interference due to sparking of the magneto brushes. Since the bearings are still in excellent condition and since preliminary tests with paper condensers at the magneto have been unsuccessful in eliminating the arcing, a cleaning of the brushes seems to be in order at the time this paper goes to press.

Landing Aids Experiment Stations

Safe landings for planes in bad weather, still an unsolved problem and one of the most serious facing air transportation, is the object of intensive experimentation now under way in which government agencies, the aviation industry and transportation companies are cooperating. All the war-developed flying aids and landing systems will be carefully reexamined and converted to commercial uses if practical. These include runway lighting, ordinary radio and very high frequency radio devices, radar ground approach systems, fog dispersal methods and others. Considerable development in landing aids is expected from work being started at Areata on the northern California coast on the site of an airfield established by the Navy during the war. It is operated under contract by United Air Lines in conjunction with a Steering Committee from the Army, Navy, Civil Aeronautics Board, Civil Aeronautics Administration, Air Transport Association and the Air Line Pilots’ Association, organized under the auspices of the A/N Aeronautical Board.

Another transport company is making contributions to the solution of the problem with a flying laboratory in a giant plane in the New York area. The principal problem under study by this company, American Airlines, is radar in its applications to commercial flying. Radar and certain other new navigation devices have not yet been developed to a point for general commercial airline use, an official of the company stated. However, tests already made show that airborne radar can now be used to prevent collision with mountains and earth, to aid in instrument low approaches, to determine altitude above ground, and to show whether the plane is climbing, descending or turning.

Civil Aeronautics Administration is continuing its testing and development of landing aids at its experiment station at Indianapolis. The NACA is making progress at Langley Field with its work in the fundamental principles of aerodynamics which will have application, and both Army and Navy are studying landing techniques at some of their flying fields. Voluntary cooperation of these various organizations with exchange of information gives hopes that the problem will be solved. The All Weather Flying Center of the AAF at Wilmington, Ohio, is testing methods and equipment for the Air Forces, and the Navy has similar experiments at Banana River, Fla. The AAF has just set up its experimental all-weather airline from Wilmington, O., to Andrews Field, near Washington, D. C.