RESEARCH MEMORANDUM

for the

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WIND-TUNNEL OSCILLATION TESTS OF THE

BENDIX-FRIEZ AEROVANE ANEMOMETER

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SUMMARY

A Bendix-Friez Aerovane Anemometer was oscillated in the streamwise direction at several frequencies for each of several low wind-tunnel airspeeds. Records were obtained, during oscillation, of the displacement of the anemometer and the velocity indicated by the instrument.

In order to transmit these data as rapidly as possible to interested persons, analysis of the data was held to a minimum. This analysis, however, indicates that the over-registration of this anemometer is much smaller than predicted by theory.

INTRODUCTION

It has long been recognized that certain types of anemometers, when exposed to an airstream which is fluctuating in velocity, will register a mean air velocity which is higher than the velocity it would register in a steady airstream. Reference 1 presents a rather complete discussion of this phenomenon.

At the request of the Evans Signal Laboratory, U. S. Army Signal Corps, a Bendix-Friez Aerovane Anemometer was placed in the Langley stability tunnel test section and oscillated in the streamwise direction through a range of frequencies at each of several tunnel airspeeds. A continuous record was made, during oscillation, of the longitudinal displacement and of the indicated velocity measured by the anemometer.
The tests were conducted in order to obtain data from which may be determined the over-registration of the anemometer under controlled conditions of frequency and wind speed and the phase relationships between the displacement and the indication of the anemometer. The data are presented with only a rough preliminary analysis in order that its transmittal to interested persons be made as rapidly as possible.

**SYMBOLS**

D \(\text{propeller diameter, ft}\)

f \(\text{frequency of oscillation, cps}\)

P \(\text{period of oscillation, sec}\)

t \(\text{time, sec}\)

\(\Phi\) \(\text{amplitude of the fluctuating airstream velocity, ft/sec}\)

V \(\text{instantaneous airstream velocity, ft/sec}\)

\(V_i\) \(\text{indicated airstream velocity, ft/sec}\)

\(V_o\) \(\text{steady-state airstream velocity, ft/sec}\)

\(X_i\) \(\text{indicated position, ft}\)

\(\phi\) \(\text{phase angle, deg}\)

**MODEL, APPARATUS, AND TESTS**

The Bendix-Friez Aerovane Anemometer is designed to measure wind direction and wind velocity. A propeller-driven generator in the instrument provides direct current whose voltage is proportional to the rotary speed of the propeller and calibrated in terms of wind velocity. An airplane-like vertical tail on the instrument provides directional stability and an indication of wind direction. For the present tests, however, the anemometer was restrained in yaw and aligned with the wind stream at all times.

The oscillation equipment consisted of the bell-crank mechanism shown in the photographs of figure 1. A small motor-generator set supplied direct current for a one-horsepower motor which provided the
driving torque through a 6-to-1 speed-reducer gear box. The harmonic motion was generated by an eccentric on the gear-box output shaft and was transmitted to the anemometer by means of push rods. The frequency of oscillation was varied by a speed control which governed the output voltage of the motor-generator set.

The eccentric was part of a large-inertia flywheel whose purpose was to minimize any irregularities in the sinusoidal motion which might be caused by bearing loads and inertia moments. The off-set of the eccentric was such as to generate an amplitude of 13 inches travel for the anemometer.

A continuous and simultaneous record was made, during an oscillation run at constant frequency, of the voltage output of the anemometer generator and of the displacement of the instrument, measured by means of a slide-wire displacement indicator operating on the Wheatstone bridge principle. The data were graphically recorded by a Consolidated recorder which also supplied a continuous time record on the oscillograph paper.

Tests were made for five oscillation frequencies between 0.17 and 2.20 cycles per second for each of eight tunnel airspeeds between 13.0 and 62.8 feet per second. The resulting ratios of the velocity amplitude to the tunnel speed \( \frac{u}{V_0} \) varied from 0.02 to 0.86.

PRESENTATION OF DATA

For an anemometer placed in a sinusoidally fluctuating airstream, the instantaneous velocity of the instrument is given by

\[
V = V_0 \left( 1 + \frac{u}{V_0} \sin 2\pi ft \right)
\]  

(1)

Because the rotary velocity of the anemometer propeller does not vary linearly with airspeed, the incremental propeller speed due to the forward motion of the anemometer is different from, and generally larger than, the incremental propeller speed due to the rearward motion. As a result, during oscillation, the propeller speed is greater than it would be in a steady airstream of the same velocity.

It is shown analytically in reference 1 that the difference in propeller speed between the steady and the unsteady conditions is proportional to the square of the amplitude of the unsteady portion of the velocity in the manner
\[ \Delta n = \frac{V_o}{D} \left( \frac{\bar{u}}{V_o} \right)^2 \] (2)

and that the velocity which is indicated by the anemometer in the unsteady condition is

\[ V_1 = V_o \left[ 1 + \frac{1}{2} \left( \frac{\bar{u}}{V_o} \right)^2 \right] \] (3)

The recorded data are presented in the form of oscillograph records for each frequency and airspeed condition as figures 2 to 41. In order to expedite the transmittal of these data to interested persons, only a few over-registration factors \( V_1/V_o \) were determined for comparison with the values predicted by equation (3) from reference 1. These points, shown in figure 42, indicate that the over-registration of the Bendix-Friez Aerovane Anemometer is much smaller than predicted by reference 1. In fact, the relationship between the indicated velocity and the amplitude appears to be very nearly linear rather than the parabolic variation derived in reference 1.

The phase angles between the displacement of the anemometer and the indicated velocity of the instrument are shown in figure 43. The phase differences between the recorded displacement and velocity curves were measured as time increments in seconds and were converted to phase angles, in degrees, by the formula:

\[ \phi = \frac{\Delta t}{P} \times 360 \]

Where the indicated velocity leads the displacement, the phase angle between them is considered to be positive. The phase angle between the indicated velocity and the actual velocity of the anemometer would, of course, be the difference between 90° and the points plotted in figure 43.

**CONCLUDING REMARKS**

A Bendix-Friez Aerovane Anemometer was oscillated longitudinally at various frequencies for each of several low wind-tunnel speeds. A
rough preliminary analysis of the results indicates that the over-
registration of this anemometer due to the unsteady wind is much smaller
than had been indicated by one available theory.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., July 17, 1953.

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REFERENCE

(a) Looking downstream.

Figure 1.- Test anemometer and oscillation equipment in Langley stability tunnel.
(b) Looking upstream, left side.

Figure 1.- Continued.
Figure 1.- Concluded.

(c) Looking upstream, right side.

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Figure 2. Recorded data. $V_0 = 15.0 \text{ ft/sec}$; $P = 5.80 \text{ sec}$. 
Figure 3.- Recorded data. $V_0 = 13.0$ ft/sec; $P = 2.28$ sec.
Figure 4. Recorded data. $V_0 = 13.0 \text{ ft/sec}; P = 1.32 \text{ sec.}$
Figure 5.- Recorded data. $V_0 = 13.0$ ft/sec; $P = 0.87$ sec.
Figure 6.- Recorded data. $V_o = 13.0$ ft/sec; $P = 0.61$ sec.
Figure 7.- Recorded data. $V_0 = 10.4$ ft/sec; $P = 5.73$ sec.
Figure 8.- Recorded data. $V_0 = 18.4$ ft/sec; $P = 2.15$ sec.
Figure 9 - Recorded data.
\[ V_0 = 18.4 \text{ ft/sec}, P = 1.27 \text{ sec} \]
Figure 10. - Recorded data. $V_0 = 18.4$ ft/sec; $P = 0.83$ sec.
Figure 11.- Recorded data. $V_0 = 18.4$ ft/sec; $P = 0.57$ sec.
Figure 12.- Recorded data. $V_0 = 25.4$ ft/sec; $P = 4.80$ sec.
Figure 13. Recorded data. $V_0 = 23.4$ ft/sec; $P = 2.22$ sec.
Figure 14.- Recorded data. $V_o = 23.4$ ft/sec; $P = 1.16$ sec.
Figure 15.- Recorded data. \( V_0 = 23.4 \text{ ft/sec}; P = 0.78 \text{ sec}. \)
Figure 17.- Recorded data. $V_0 = 31.8$ ft/sec; $P = 4.65$ sec.
Figure 18.- Recorded data. \( V_0 = 31.8 \) ft/sec; \( P = 1.92 \) sec.
Figure 19.- Recorded data. \( V_0 = 31.8 \text{ ft/sec}; P = 1.21 \text{ sec.} \)
Figure 20. - Recorded data. $V_o = 31.8$ ft/sec; $P = 0.92$ sec.
Figure 21.- Recorded data. $V_o = 31.8$ ft/sec; $P = 0.74$ sec.
Figure 22. - Recorded data. $V_o = 37.8$ ft/sec; $P = 4.35$ sec.
Figure 23.- Recorded data. $V_0 = 37.8$ ft/sec; $P = 2.20$ sec.
Figure 24.- Recorded data. $V_0 = 37.8$ ft/sec; $P = 1.38$ sec.
Figure 25. - Recorded data. \( V_0 = 37.8 \, \text{ft/sec}; \ P = 0.86 \, \text{sec}. \)
Figure 26.- Recorded data. $V_o = 37.8 \text{ ft/sec}; P = 0.58 \text{ sec}$.
Figure 27.- Recorded data. $V_0 = 45.9$ ft/sec; $P = 5.61$ sec.
Figure 28.- Recorded data. $V_o = 45.9$ ft/sec; $P = 1.88$ sec.
Figure 29. - Recorded data. $v_0 = 45.9$ ft/sec; $P = 1.06$ sec.
Figure 30. - Recorded data. \( V_0 = 45.9 \text{ ft/sec}; \ P = 0.65 \text{ sec} \).
Figure 31. Recorded data. $V_0 = 47.6$ ft/sec; $P = 0.60$ sec.
Figure 32. Recorded data: $V_0 = 55.0 \, \text{ft/sec}$; $P = 4.62 \, \text{sec}$.
Figure 33.- Recorded data. \( V_0 = 55.0 \text{ ft/sec}; P = 1.85 \text{ sec.} \)
Figure 34.- Recorded data. \( V_0 = 55.0 \text{ ft/sec} \); \( P = 0.90 \text{ sec} \).
Figure 35. - Recorded data. $V_o = 55.0$ ft/sec; $P = 0.67$ sec.
Figure 36.- Recorded data. $V_0 = 55.0$ ft/sec; $P = 0.52$ sec.
Figure 37.- Recorded data. \( V_0 = 62.8 \, \text{ft/sec}; \, P = 5.15 \, \text{sec}.\)
Figure 38. Recorded data. $V_0 = 62.8$ ft/sec; $P = 1.65$ sec.
Figure 39. Recorded data. $V_o = 62.8 \text{ ft/sec}; P = 0.96 \text{ sec}$. 
Figure 40.- Recorded data. $V_o = 62.8$ ft/sec; $P = 0.61$ sec.
Figure 41. - Recorded data. $V_o = 62.8$ ft/sec; $P = 0.45$ sec.
Figure 42.- The over-registration of the Bendix-Friez Aerovane Anemometer.
Figure 43.- The phase angles between the displacement and the indicated velocity of the tested anemometer.