NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
FILED
JUN 2 1931
TO: Library, L.M.A.L.

JUN 6 - 1931

TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 380

A SUGGESTED METHOD FOR MEASURING TURBULENCE

By C. Fayette Taylor
Massachusetts Institute of Technology

FILE COPY
To be returned to
the files of the Langley
Memorial Aeronautical
Laboratory.

Washington
June, 1931

NASA Technical Library
3 1176 01425 5500

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE NO. 380

A SUGGESTED METHOD FOR MEASURING TURBULENCE

By C. Fayette Taylor

Summary

The desirability of a quantitative measure of turbulence is emphasized, and a possible method of attack on the problem is discussed. Data are presented to show that the hot-wire anemometer has possibilities as an instrument for measuring turbulence. An apparatus consisting essentially of two hot wires, one parallel to the air flow and one at right angles to it, is suggested. Further study of the possibilities of such an apparatus is recommended.

Introduction

The desirability of being able to make a quantitative measurement of turbulence in a moving air stream has long been felt. Even an instrument for quickly indicating the presence or absence of turbulence without attempting to measure it would be of considerable value in experimental aerodynamics.

Since turbulent motion of a fluid is very complex, it would seem well nigh impossible to develop a single instrument which would measure all aspects of a given turbulent motion.

For purposes of this discussion it is useful to divide the aspects of a turbulent motion into two classifications, namely:

1) Amplitude, which may be taken to be some characteristic dimension which determines the scale of the motion. It may be the average distance of particle motion across the general flow direction, or the average spread or size of vortices, or the amount of their path departure from the average path of flow.

2) Intensity, which refers to the dynamic property of the motion. It may be represented by the departure of the local velocity from the average velocity in respect to both direction and magnitude, or by the energy of such departure.

Smoke or other type of suspended particle seems to be the best available indicator of turbulence amplitude. On the other hand, no suitable apparatus appears to have been developed to serve as an indicator of turbulence intensity. It is to this aspect of the problem therefore, that this discussion is principally directed.

In aerodynamic work, one is usually dealing with a stream of air which has a fairly definite average translational velocity at the point where turbulence is to be measured, and therefore any instrument for measuring turbulence must take this velocity into account. Furthermore, it quite often happens that a change in the amplitude or intensity of turbulence changes the average velocity and the average direction of flow. In view of these facts, it would seem that an instrument ~~of~~ measuring turbulence intensity should also be able to measure the average speed and average direction of motion of the air stream, at the point where the turbulence is measured.

Development of Apparatus

It has been shown many times that the rate of heat transfer from a smooth metal surface to a moving air stream, changes rapidly with a change from the parallel direction of flow as well as with changes in velocity. Since turbulence causes changes in both direction and velocity at any given point in an air stream, it has long appeared to the writer that the rate of heat transfer from a smooth surface to air might be used as a measure of turbulence intensity.

In the fall of 1929, the problem of developing an instrument to utilize the heat transfer rate for the measurement of turbulence intensity was undertaken by Mr. Jean Rasse (Reference 1), a graduate student in the course in Aeronautical Engineering at Massachusetts Institute of Technology, to whom much of the credit for subsequent development is due. After some preliminary work, it was decided to experiment with an element of the hot-wire anemometer type, since an instrument of this kind would evidently be sensitive to variations in turbulence and at the same time could be used to indicate the average direction of air flow (Reference 2). The subsequent

program of experimental work was undertaken primarily to determine whether or not the idea of using the hot-wire anemometer as a turbulence meter had any practical merit. A high degree of precision was not considered necessary for this purpose, and the results obtained are of qualitative rather than of quantitative value. Units of measure, therefore, have been purposely omitted.

Apparatus

All of the experiments covered by this report were made in the four-foot Venturi type wind tunnel at the Massachusetts Institute of Technology (Reference 3). The average speed of flow through this tunnel was measured by the permanently installed calibrated piezometer located in the throat of the tunnel. The local average velocity near the hot-wire element was measured by means of a small Pitot-static tube calibrated from the piezometer.

The hot-wire anemometer (Reference 4) consisted of a straight piece of platinum wire .0035 inch in diameter, and 2.85 inches long, stretched between two flattened wire supports which served also as electrical conductors. These supports were made as small as possible in order to minimize their aerodynamic effect, and were flattened to a knife edge at the ends where the hot wire was attached. The anemometer was mounted, near the axis of the wind tunnel, at the end of a small metal tube, and was so arranged that the angular position of the wire could be varied within a vertical plane intersecting the tunnel axis. A dial, graduated in degrees of angle, was used to indicate the angular position of the hot-wire element with respect to the tunnel axis. Figure 1 shows the general appearance of the anemometer and a diagram of the electrical circuit. In operation, the current passing through the wire was held constant, the wire temperature varying with changes in the air flow. The temperature of the wire controlled its ~~conduc~~ resistivity, which was indicated by a Wheatstone bridge circuit as shown in the figure. With this method of operation the rate of heat loss from the wire, per degree temperature difference between wire and air, will be an inverse function of the ~~conduc~~ resistivity of the wire, assuming the air temperature to remain constant. Increasing ~~conduc~~ resistivity indicates increasing temperature, and therefore a decreasing rate of heat loss per degree of temperature difference.

Procedure

"Smooth flow condition."- For purposes of this report, the flow through the wind tunnel was assumed to be free from turbulence. This, of course, was not strictly the case, although the flow was reasonably smooth. For more accurate work it would be necessary to move the measuring element through a body of still air in order to establish the nonturbulent calibration. The "smooth flow" condition mentioned in this report is simply the normal flow through the wind tunnel without any attempt to create additional turbulence.

"Turbulent flow condition."- In order to give a markedly turbulent condition around the hot-wire element, a flat metal plate 14 in. high by $6\frac{1}{2}$ in. wide was fastened to the entrance honeycomb of the wind tunnel in such a position that the stream of vortices from one of the long edges of the plate would pass over the hot wire. When in this position, the plate edge was approximately three feet "upstream" from the hot-wire element. In both "smooth" and "turbulent" flow, the average velocity of the air in the vicinity of the hot-wire element was measured by the calibrated Pitot tube. The following runs were made:

Series 1.- Readings of hot-wire ~~conduct~~resistivity at various angles in smooth flow at different air speeds (Fig. 2).

Series 2.- Readings of hot-wire ~~conduct~~resistivity at various angles in turbulent flow at different air speeds.

Both series of tests gave curves which showed a sharp maximum ~~conduct~~resistivity at a certain angle for each combination of air speed and turbulence. This angle is apparently that at which the wire is parallel to the average air flow.

The striking fact brought out by a comparison of the Series 1 and Series 2 tests was the negligible difference between the hot-wire readings in turbulent flow and in smooth flow, at a given air speed, except when the wire was nearly parallel to the air stream. A typical example of this is shown in Figure 3 which is a comparison of the Series 1 and Series 2 runs at 44 m.p.h. This result led to the belief that the readings of the anemometer at a given average air speed would be independent of turbulence if the wire were normal to the air stream. The following runs were made to verify this:

Series 3.- Readings of hot-wire ~~conduct~~resistivity at various air speeds with wire at right angles to air stream, with smooth flow and with turbulent flow. The results of this series are shown by curve 3 of Figure 4.

To summarize the results of Series 1 and 2, the readings of hot-wire ~~conduc~~ resistivity at the maxima points were replotted against air speed, giving curves 1 and 2, plotted in Figure 4 for purposes of comparison with each other and with Series 3.

Discussion of Results

The need for more complete and more accurate data is obvious. This report is made to suggest a possible method of attack on the measurement of turbulence, not as a finished or conclusive piece of work. For instance, there is no definite evidence that the instrument is responsive to intensity only, although theory would indicate this to be the case. The effect of varying frequency of the direction and velocity changes in turbulent flow also needs to be studied. A complete theoretical study of these questions has already been initiated and further experiments will be carried on as rapidly as time and facilities permit.

Several rather definite facts may be stated on the basis of the tests thus far. It seems proven, for example, that a change in turbulence has a decided influence on the coefficient of heat transfer from a small wire placed parallel to the average flow, while there is little, if any, effect due to a change in turbulence if the wire is normal to the average flow. It also appears to be established that the hot-wire anemometer is an effective indicator of the average flow direction in turbulent air as well as in the relatively smooth air flow of Simmons and Bailey (References 2 and 5).

These considerations immediately suggest the possibility of an instrument made up of two hot wires, one set at right angles to the other. Such an instrument might fulfill the requirements of a complete turbulence meter, as specified earlier in this report, because

1) It would furnish an accurate indication of the direction of average flow, which would be the direction for minimum rate of heat loss from one of the wires;

2) It would furnish an indication of the average velocity of the air stream, which would be indicated by the rate of heat loss from the wire <u>normal</u> to the average path, (for example, curve 3 of Figure 4);

3) It would furnish a measure of some quality of the turbulence (probably its intensity) which would be indicated

by the magnitude of the difference in heat loss rate between the two wires, (for example, the ordinate difference between curves 1 and 3, or 2 and 3, of Figure 4).

In using such an instrument, it would be inserted in the air stream and rotated about two axes to the point where one of the wires showed a minimum rate of heat loss. Readings would then be taken in this position.

In case it proves impossible to reduce the readings of such an instrument to absolute units, it would appear feasible to specify an arbitrary scale of turbulence based on the readings of a standardized instrument of this character.

For certain purposes it might prove desirable to use three hot wires, one parallel to the average flow and two normal to the average flow at right angles to each other.

Massachusetts Institute of Technology,

Cambridge, Mass., May, 1931.

References and Bibliography

1. Rasse, J. : A Possible Apparatus to Measure Turbulence. Thesis on file in Library of the Massachusetts Institute of Technology, Cambridge, Mass.

2. Bailey, A. : A Directional Hot-Wire Anemometer. British A.R.C. R&M No. 777, Jan., 1922.

3. : The Four Foot Wind Tunnel at Massachusetts Institute of Technology. Aviation, March 13, 1922.

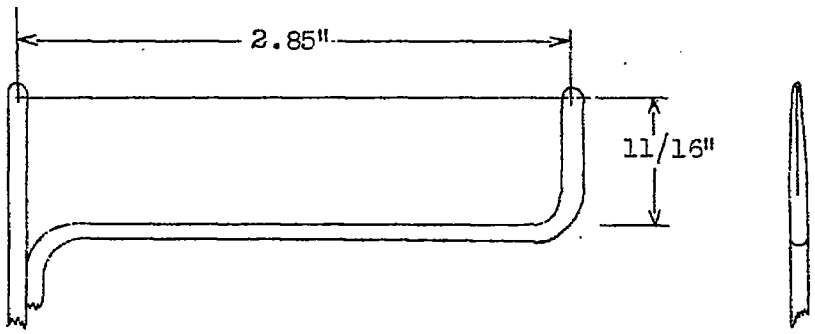
4. King, Louis Vessot : On the Convection of Heat from Small Cylinders in a Stream of Fluid; Determination of the Convection Constants of Small Platinum Wires, with Applications to Hot-Wire Anemometry. Phil. Trans. Roy. Soc., Vol. 214, pp. 373-432, 1914.

   King, Louis Vessot : Precision Measurement of Air Velocity by Means of the Linear Hot-Wire Anemometer. Phil. Mag., Vol. XXIX, pp. 556-577, 1915.

5. Simmons, L. F. G. and Bailey, A. : Notes on a Hot-Wire Speed and Direction Meter. British A.R.C. R&M No. 1019, Feb., 1926.

   Taylor, C. F. and Rehbock, A. : Rate of Heat Transfer from Finned Metal Surfaces. N.A.C.A. Technical Note No. 331, Jan., 1930.

   Dryden, H. L. and Kuethe, A. M. : The Measurement of Fluctuations in Air Speed by the Hot-Wire Anemometer. N.A.C.A. Technical Report No. 320, 1929.



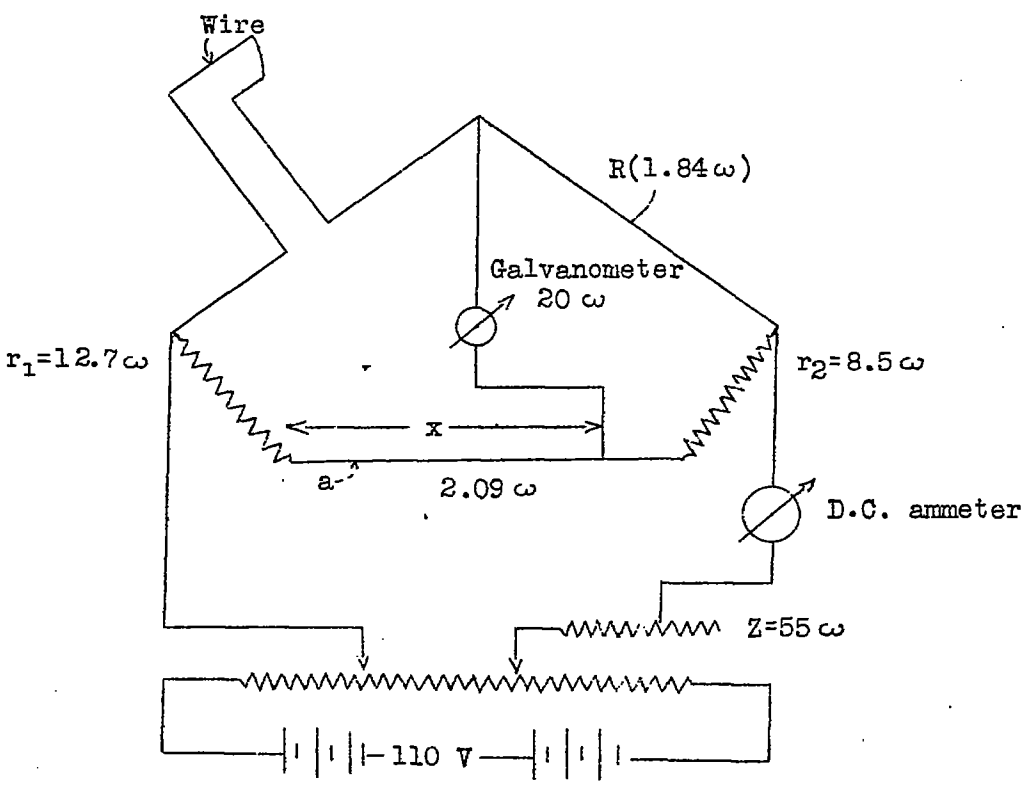


Fig.1 Hot wire anemometer and diagram of Wheatstone Bridge circuit.

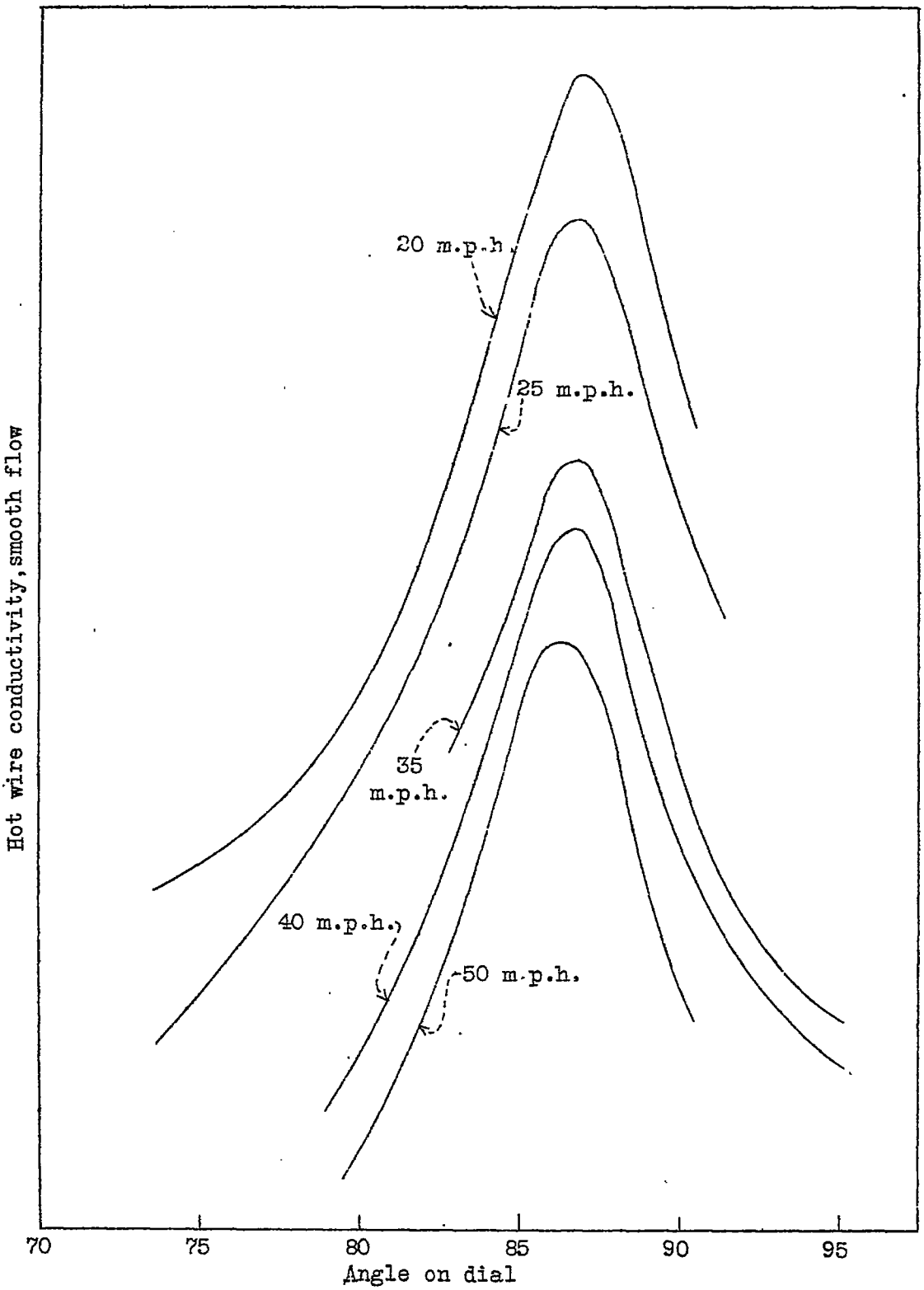


Fig.2 Curves of ~~conduct~~ resis tivity vs. angle of hot wire in smooth flow.

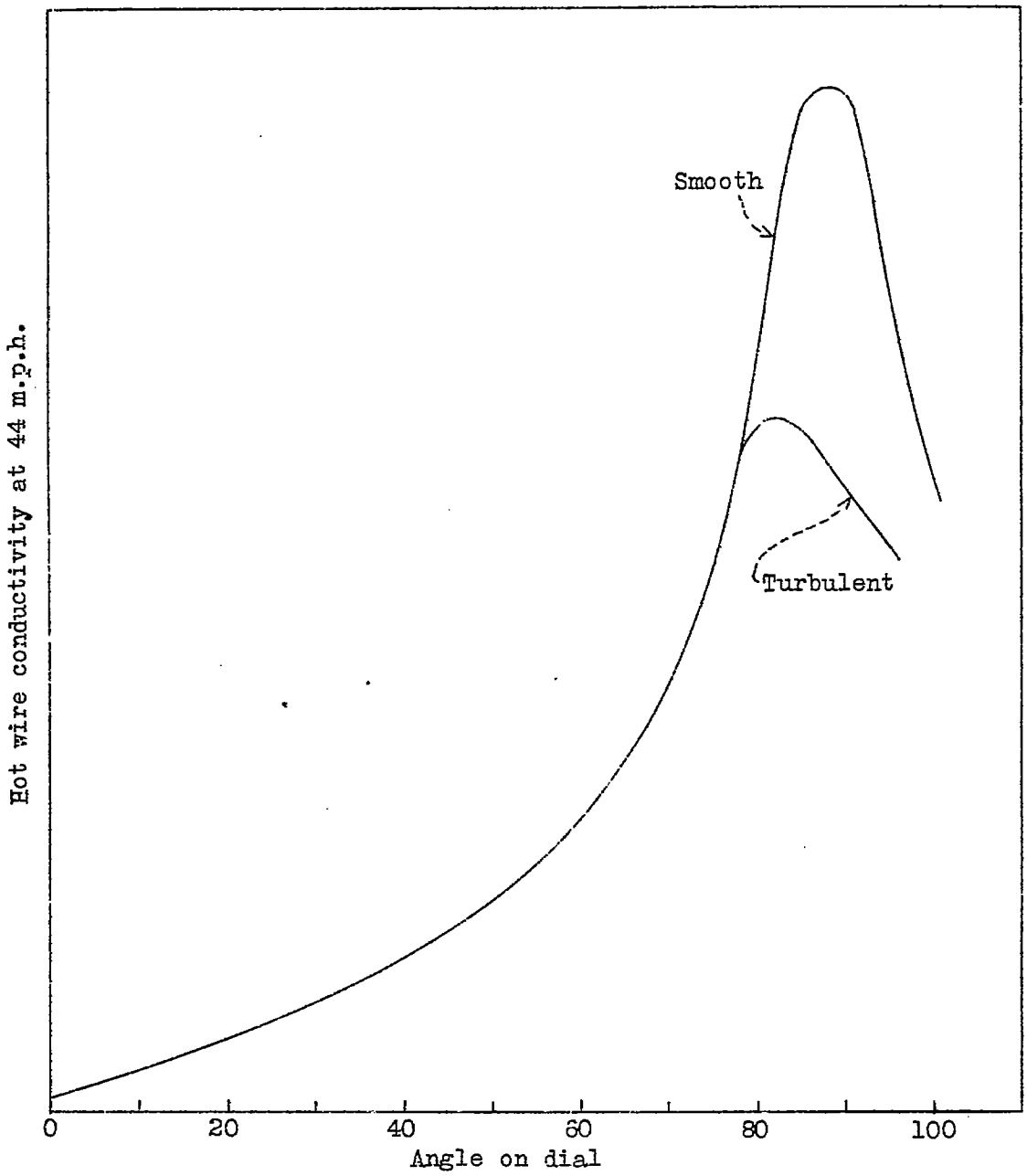
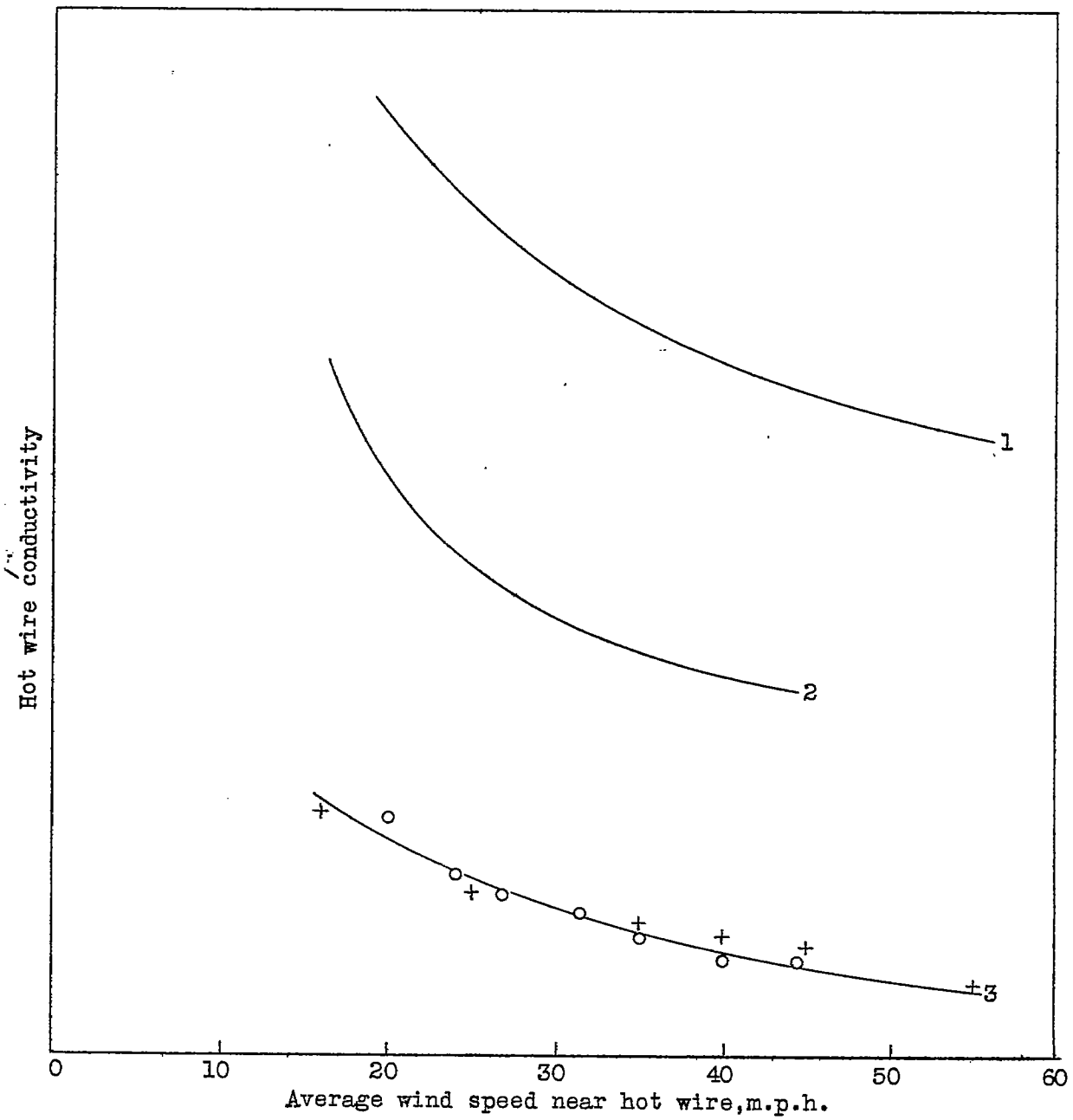


Fig.3 Comparison of ~~conduc~~resis tivity vs. angle curves at 44 m.p.h., smooth flow and turbulent flow.



1. Smooth flow,wire parallel to air flow.
2. Turbulent flow,wire parallel to air flow.
3. Wire perpendicular to air stream,in smooth flow"+"and turbulent flow"O".

Fig.4 Curves of ~~conduc~~resistivity of hot wire parallel and normal to air stream in smooth and turbulent flow.