Calibration of a Portable Wind Tunnel for the Simple Determination of Roughness and Drag on Field Surfaces[1]

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THE problem of operating a portable wind tunnel to obtain desired and known levels of drag on varying field surfaces has not been solved previously. Neither has a workable method for determining the magnitude of the surface roughness been devised. This brief report presents a simple method of determining both of these interrelated variables. For a given tunnel, it is dependent upon calibration procedures. Subsequent use of the method for a tunnel of the duct type requires two pressure readings only.

Procedure

The experiment was conducted with a laboratory tunnel described previously (1). Laboratory and field units are interchangeable or identical except for the duct used. Laboratory and field ducts have the same dimensions. The one used in the laboratory is fabricated from wood and glass panels. The field duct is made of aluminum sheets. Both comprise surfaces which are "smooth" aerodynamically. Differences in the materials from which they are constructed do not, therefore, enter the problem. Relationships obtained in the laboratory are applicable to use of the tunnel over ground surfaces in the field. A detailed description of the portable tunnel has been published (2).

Fig. 1, a sketch, shows the schematic orientation of the tunnel and the variables measured. Calibration measurements comprised:

1. P_1, the pressure, in inches of water, at an arbitrary point in the diffusion and transition chamber between the blower and the screening and straightening devices located at the head of the duct.
2. P_2, the pressure drop, in inches of water, in a 26-foot length of a 30-foot section of 3-foot by 3-foot square duct.
3. V_c, the velocity, in miles per hour, at the center of the leeward end of the duct.
4. K, a roughness parameter, comprising a height dimension of the test surfaces, in inches.
5. τ, the surface drag or, for brevity, drag. It is defined as the force intensity of the wind per unit area of surface parallel to the wind direction. Measurements were made in grams per 11.5 square foot area of test surface on the tunnel floor near the leeward end of the duct, and converted to units of pounds per acre for subsequent use.

The level of the pressure, P_1, was controlled by an adjustable inlet vane on the blower unit. The roughness, K, was controlled by constructing ridges of definite height throughout the floor of the tunnel. A nonerodible gravel, passing a 1/4-inch screen and retained on a $^1/_6$-inch screen, was used as a vehicle to form the ridges. Height of the ridges was varied progressively from 1/2 to 6 inches. A ratio of ridge height to spacing of 1 to 4 was maintained throughout the experiment. The roughness was, therefore, similar geometrically and is also reproducible as a standard.

The drag per unit area of surface, τ, was measured by use of a floating tray. This is an experimental device described elsewhere.[3] Velocities, V_c, were measured with a standard pitot tube as registered on an alcohol

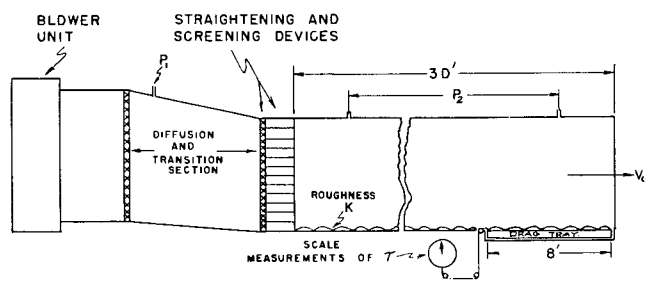

FIG. 1. — Sketch showing schematic orientation of the soil-blowing tunnel and the variables measured.

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[3]A. W. Zingg. Some characteristics of the expanding turbulent boundary layer in a wind tunnel designed for the study of soil erosion. Progress Report on Investigations of the Mechanics of Wind Erosion 1949. Manhattan, Kans. (Mimeographed).

manometer. During the calibration process all variables were measured simultaneously. The procedure was repeated several times to measure the error common to the methods used. The gravel ridges representing the roughness, K, were reconstructed for each series of determinations.

Results

A summary of data derived from the experiment is given in Table 1. Values of P_2, τ, and V_c represent the average for five determinations. It will be noted that drag values were not obtained for the 6-inch ridges. The device used to measure drag is not adaptable for roughness of this magnitude due to its large overturning moment.

The ratios of P_2 to P_1 are constant for a given value of K within a small range of error. Fig. 2 illustrates the fact that their proportionality varies with the value of K. Mathematically, $K = f\frac{P_2}{P_1}$. The relationship of K to τ and P_1 is also plotted in Fig. 2. It is apparent

TABLE 1.—*Wind tunnel calibration data (average of five determinations).**

K	P_1	P_2	T	V_c
Formed with sieved gravel (⅙ to ¼ inch)	Inches of water	Inches of water	Pounds per acre	Miles per hour
Smoothed	0.20	0.0177	176	17.0
	0.40	0.0352	341	24.4
	0.60	0.0518	531	29.4
	0.80	0.0692	738	34.0
	1.00	0.0878	954	38.4
½-inch ridges	0.20	0.0232	264	16.7
	0.40	0.0433	527	23.5
	0.60	0.0643	793	29.3
	0.80	0.0853	1,078	33.9
	1.00	0.1078	1,375	38.4
1-inch ridges	0.20	0.0260	319	16.5
	0.40	0.0514	626	23.5
	0.60	0.0760	976	29.1
	0.80	0.1028	1,321	34.1
	1.00	0.1272	1,675	38.2
1½-inch ridges	0.20	0.0273	401	16.3
	0.40	0.0540	751	23.6
	0.60	0.0818	1,171	29.1
	0.80	0.1094	1,579	33.9
	1.00	0.1372	1,963	38.3
2-inch ridges	0.20	0.0333	420	16.3
	0.40	0.0652	860	23.6
	0.60	0.0962	1,343	29.3
	0.80	0.1272	1,743	34.1
	1.00	0.1584	2,182	38.4
3-inch ridges	0.20	0.0363	543	16.0
	0.40	0.0732	1,050	23.4
	0.60	0.1091	1,644	29.2
	0.80	0.1438	2,114	33.7
	1.00	0.1814	2,626	38.2
6-inch ridges	0.20	0.0507	Not measured	16.1
	0.40	0.1063		23.4
	0.60	0.1593		28.8
	0.80	0.2100		34.0
	1.00	0.2643		37.9

*Symbols defined in body of text.

[4]Ibid.

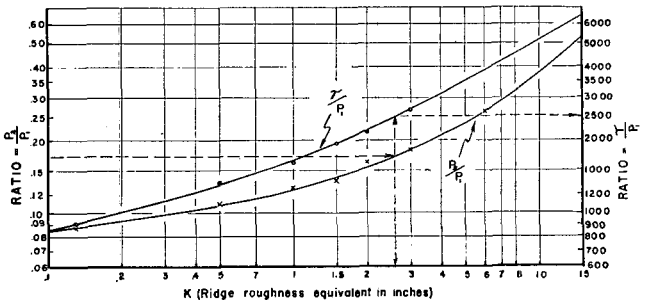

FIG. 2.—Graphs of average values of $\frac{P_2}{P_1}$ and $\frac{\tau}{P_1}$ in relation to the roughness K.

that $K = f\frac{\tau}{P_1}$. It follows that drag is a function of the pressure drop in the duct, or $\tau = f P_2$.

The above functions are of a complex nature; however, their mathematical determination is not germane to their use by graphical methods. The broken lines of Figure 2 illustrate the method. In this example $\frac{P_2}{P_1} = 0.17$, which from the lower curve indicates the roughness, K, to be equivalent to approximately 2.7 inches. For this value of K, the value of $\frac{\tau}{P_1} = 2500$, as read from the upper curve. Both ratios, $\frac{P_2}{P_1}$ and $\frac{\tau}{P_1}$ are nearly constant as long as the surface does not change in roughness. For the value of K = 2.7 inches, we then have $\tau = 2500\ P_1$, which can be determined readily for measured levels of P_1.

The error of the graphical estimate of roughness is relatively large for small values of K. The standard deviation of K, using all the measurements for the several surfaces and tests, was found to be 0.27 inch. The deviation for the 0.5- and 1-inch ridges was 0.16 inch. For the larger ridges it was 0.3 inch. The standard deviation of the estimate of drag proved to be 5.8%.

Velocity measurements, V_c, made in the center of the duct at the leeward end of the tunnel, illustrate the fact that the drag at the walls, associated with surfaces of varying roughness, is independent of the velocity in the central regions of flow. The depth of the expanding turbulent boundary layer at a point 30 feet downwind in the tunnel is from 6 to 9 inches. This depth is dependent on the roughness, K, as found in another study.[4] In other words, velocity measurements made at heights greater than the depth of the expanding turbulent boundary layer are not in themselves indicative of the drag on test surfaces.

It is of interest that values of V_c and P_1 are related. This relationship is approximately $V_c = 38\sqrt{P_1}$. Measurements of V_c may be substituted for those of P_1 where due regard is given the functional relationship. This procedure would have certain advantages. In field use, however, it would require additional tubing

to transfer such pressures to a usable location near the controls of the wind-making unit at the opposite end of the tunnel.

Discussion

The surfaces used in this experiment, i.e., those comprised of ridged gravel of a known size, represent a standard to which any "rough" surface within the limits of the study may be equated. In subsequent use, this standard will be identified as K, the *ridge roughness equivalent* measured in inches. Thus, a given surface of, say, one-wayed wheat stubble ground would yield a value of K equivalent to a specific height of the standard ridged surface used as a base. This concept of roughness is somewhat different from the usual one of aerodynamic roughness. In this case, it is an index of roughness in relation to the average elevation of the ground surface. Evaluations used previously have attempted to ascribe a linear dimension of roughness to an aerodynamic surface. For example, the roughness of land covered with grass would be the height value of the projection of a velocity distribution curve to the point of zero velocity. This height measurement of roughness would be relatively small and associated with the micro-roughness of the top of the grass. The base for such determination would be some distance above the soil surface. From the standpoint of erosion of the soil by wind, the magnitude of roughness from the average elevation of the soil surface appears to offer a more easily evaluated and applicable parameter of roughness.

One point which has not been touched upon is the systematic variation of drag over a surface in the 30-foot length and 3-foot width on the floor of the tunnel. The tray used to measure drag was approximately 8 feet long and about 18 inches wide, or half the width of the tunnel. The drag decreases somewhat with tunnel length. Again, it is probable that the drag on a rough surface on the tunnel floor decreases from the center toward the sidewalls of the tunnel. Suffice to say, these are compensating trends, and, until more exact knowledge is obtained, it appears advisable to estimate the general level of drag according to the procedures described herein. Its precise determination on all portions of the tunnel floor is possible only through very extensive research.

Use of a wind tunnel in evaluation work in the field requires that the duct be placed over the ground surface to be tested. Experience has shown that large losses of air between the junction of the sidewalls and the ground surface are capable of affecting pressure readings considerably. A prerequisite to successful operation is the maintenance of a reasonably tight seal.

The error common to the derivation of the graphs used for estimating roughness is relatively large for small values of K. A standard deviation of 0.16 inch for a 0.5-inch ridge is equivalent to 32%. A large portion of the error appears to be associated with differences common to the precise construction of small ridges of a given height in the laboratory. Slight differences in height and alignment can cause relatively large changes in the dynamic characteristics of air flow. Another factor contributing to the error was atmospheric wind movement experienced during the course of the tests.

Summary

A simple method of operating a portable wind tunnel to obtain known levels of drag on varying field surfaces is presented. Given also is a simple method of evaluating the roughness of a field test surface in terms of a standard surface of known characteristics.

Literature Cited

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2. ———. A portable wind tunnel and dust collector developed to evaluate the erodibility of field surfaces. Agron. Jour., 43: 189–191. 1951.