Forces of Oblique Winds on Telephone Wires

By J. A. CARR

In aerial line design it is advantageous to know the effect of oblique winds as well as cross winds. This paper gives the results of wind tunnel tests made on 0.104-inch and 0.165-inch diameter wires for each 10° angle of obliquity between 0° and 90° using wind velocities of 30 to 90 miles per hour in steps of 10 miles per hour. These results are then analyzed to determine (1) their compliance with the law of dynamic similarity and (2) the magnitudes of the various wind components. From these analyzed results an expression is developed for the force of oblique winds in terms of the component normal to the wires.

IN connection with studies of wire arrangements on open-wire lines [1] which Bell Telephone Laboratories have had under way for some time, it became necessary to evaluate the resistance of wires to winds. The method of evaluating the force of winds normal to the wires has been studied by many investigators and there is a considerable amount of data in the literature on this subject. The contrary was found to be true in the case of oblique winds or those not normal to the line. This latter case has been described briefly in the records of a test made in the National Physical Laboratories [2] (British) on a 0.375-inch diameter smooth wire at a wind velocity of 40 feet per second (27.3 m.p.h.) with the wire at angles to the wind ranging from 0° to 90° (normal) in steps of 10° and also in the records of M. Gustave Eiffel,[3] who made a similar test at somewhat higher velocities. Since the wires we are concerned with range from about 0.1 to 0.2 of an inch in diameter and the wind velocity ranges from about 30 to 90 miles per hour, it appeared desirable to conduct a series of wind tunnel tests that would extend these data and more fully meet our requirements. Tests along these lines were arranged with the Guggenheim School of Aeronautics at New York University.[4] Subsequently, a series of tests was made in the New York University wind tunnel on 0.104-inch and 0.165-inch diameter smooth copper wires for each 10° angle ranging from 0° to 90° using wind velocities of 30 to 90 miles per hour in steps

[1] "Motion of Telephone Wires in Wind," D. A. Quarles, *Bell System Technical Journal*, April 1930.

[2] Reports and Memoranda No. 307, January 1917, entitled "Tests on Smooth and Stranded Wires Inclined to the Wind Direction," by E. F. Relf and C. H. Powell.

[3] "Nouvelles Recherches sur La Résistance De L'Air et L'Aviation," book by M. G. Eiffel.

[4] These tests were conducted by Professor Alexander Klemin and his associates.

of 10 miles per hour. The readings so obtained are here studied and analyzed.

The wire set-up used in the wind tunnel is shown in the accompanying picture (Fig. 1) and is similar to that used by Eiffel.[3] It comprised a five-foot frame of 0.375-inch diameter steel in which five wires of either the 0.104-inch or 0.165-inch size were mounted. A spacing of 2.75 inches was used between the centers of the wires. The frame of wires

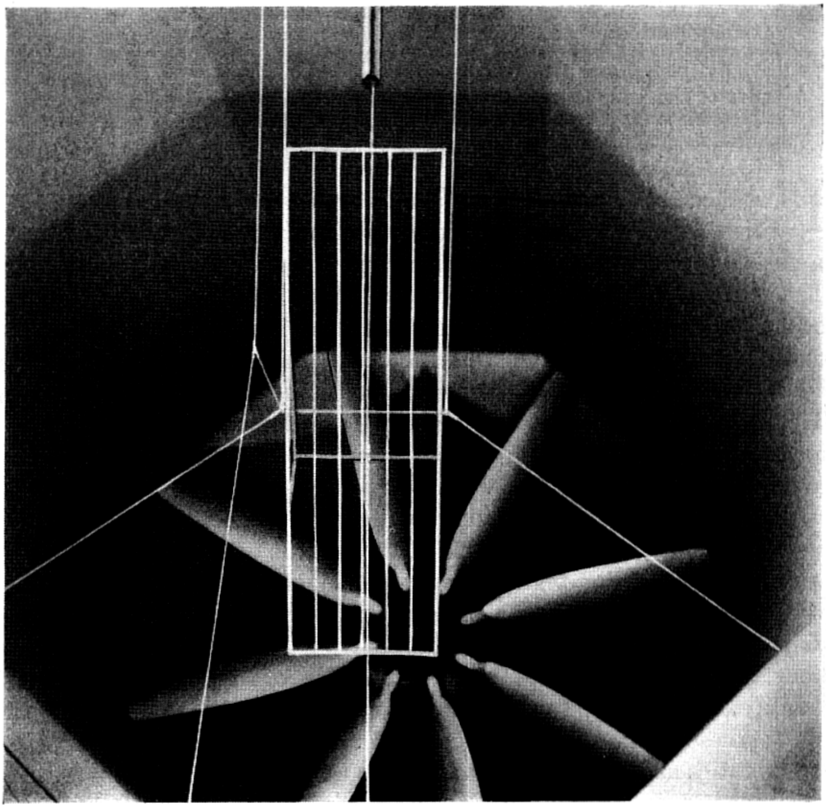

Fig. 1—Wind tunnel setup.

was installed in the approximate center of the nine-foot section of the tunnel with the shorter axis of the frame in a horizontal plane and perpendicular to the axis of the tunnel. This arrangement was convenient for connections to the weighing mechanism and permitted the frame to be rotated about its short axis.

During each step in the test the horizontal (drag) and vertical (lift) forces on the frame of wires were measured at least three times. At the completion of the series of tests on each size of wire the test lengths were cut out of the frame leaving about 2 inches of each wire at each end and the series of tests repeated so that the net drag and net lift figures could be determined. The purpose of leaving the short lengths of wire at each end was to provide a correction for the interference effects introduced at the ends of the wires. This practice was probably effective as it will be shown later that, where comparisons could be made, the results obtained in these tests agree satisfactorily

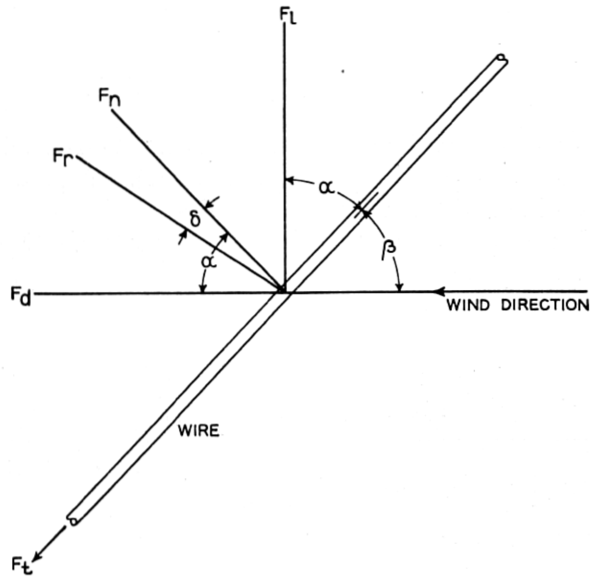

Fig. 2—Force components of wind on wires.

F_d = Force along the direction of wind—drag.
F_l = Force across the direction of wind—lift.
F_r = Resultant force.
F_n = Force normal to the wire.
F_t = Force along the wire—tangential.

with those previously obtained. This is true even though the frame comprised a fairly large proportion of the total resistance especially when the angle between the wind and the frame was small. The case when the wind and wires were parallel (tangential) has been omitted from the results because of the large proportion of the total resistance as well as the interference offered by the frame and because of its relative unimportance to this study.

Figure 2 shows the forces on the wires to which consideration has been given here. From this diagram it can be seen that with values of the net drag (F_d) and lift (F_l), the normal force (F_n), the resultant force (F_r), the tangential force (F_t) and the angle (δ) between the resultant and normal forces can be determined through the following relationships:

$$F_n = F_l \sin \alpha + F_d \cos \alpha = F_r \cos \delta, \tag{1}$$

$$F_r = \sqrt{F_d^2 + F_l^2} = \sqrt{F_n^2 + F_t^2}, \tag{2}$$

$$F_t = F_d \sin \alpha - F_l \cos \alpha = F_r \sin \delta, \tag{3}$$

$$\delta = \alpha - \text{arc tan} \frac{F_l}{F_d} = \text{arc tan} \frac{F_t}{F_n}. \tag{4}$$

The only term in these equations which is not defined above is α. This is the angle between the wire and the normal to the wind or between the wind and the normal to the wire.

The data determined through the use of these relationships are given in the accompanying Tables I (0.104-inch wire) and II (0.165-inch wire). The forces in these tables are given in terms of pounds per foot of wire.

TABLE I

0.104-Inch Diameter Wire

V	α	F_n	F_t	F_r	δ	$\frac{F_n}{(\cos \alpha)^2}$	K	
30	0	0.0194	0.000000	0.0194	0	0.0194	0.000207	
	10	0.0189	0.000431	0.0190	1.3	0.0195	0.000208	
	20	0.0177	0.001203	0.0178	3.9	0.0200	0.000214	
	30	0.0149	0.001940	0.0151	7.3	0.0198	0.000212	
	40	0.0119	0.002540	0.0122	12.0	0.0203	0.000217	
	50	0.0083	0.002650	0.0086	18.0	0.0200	0.000215	
	60	0.0047	0.002230	0.0052	25.4	0.0188	0.000201	$\bar{X}=0.000211$
	70	0.0021	0.001560	0.0026	36.7	0.0180	0.000194	
	80	0.0008	0.001050	0.0013	53.9	0.0265	0.000283	$\bar{X}=0.000217$
	90	—	—	—	90.0	—	—	
40	0	0.0358	0.000000	0.0358	0	0.0358	0.000215	
	10	0.0334	0.000570	0.0334	1.1	0.0345	0.000207	
	20	0.0300	0.001520	0.0301	2.9	0.0341	0.000204	
	30	0.0252	0.002510	0.0254	5.6	0.0336	0.000202	
	40	0.0199	0.003150	0.0202	9.0	0.0340	0.000204	
	50	0.0144	0.003360	0.0149	13.0	0.0350	0.000210	
	60	0.0087	0.003180	0.0093	20.0	0.0348	0.000210	$\bar{X}=0.000207$
	70	0.0041	0.002450	0.0049	30.0	0.0350	0.000211	
	80	0.0014	0.001450	0.0020	46.1	0.0467	0.000279	$\bar{X}=0.000216$
	90	—	—	—	90.0	—	—	

TABLE I—(*Continued*)

V	α	F_n	F_t	F_r	δ	$\frac{F_n}{(\cos\alpha)^2}$	K	
50	0	0.0578	0.000000	0.0578	0	0.0578	0.000222	
	10	0.0550	0.000863	0.0551	0.9	0.0570	0.000218	
	20	0.0494	0.001980	0.0495	2.3	0.0565	0.000215	
	30	0.0412	0.003170	0.0414	4.4	0.0550	0.000211	
	40	0.0323	0.003970	0.0325	7.0	0.0550	0.000207	
	50	0.0233	0.004350	0.0235	10.7	0.0565	0.000217	
	60	0.0147	0.004010	0.0153	15.2	0.0586	0.000226	$\bar{X}=0.000217$
	70	0.0070	0.003000	0.0076	23.2	0.0600	0.000230	
	80	0.0026	0.002120	0.0033	40.0	0.0867	0.000339	$\bar{X}=0.000232$
	90	—	—	—	90.0	—	—	
60	0	0.0854	0.000000	0.0854	0	0.0854	0.000228	
	10	0.0787	0.000950	0.0788	0.7	0.0812	0.000217	
	20	0.0708	0.002350	0.0710	1.9	0.0801	0.000214	
	30	0.0592	0.003730	0.0595	3.6	0.0790	0.000210	
	40	0.0475	0.004960	0.0476	6.0	0.0811	0.000211	
	50	0.0346	0.005340	0.0352	8.7	0.0842	0.000224	
	60	0.0221	0.005100	0.0230	12.8	0.0884	0.000236	$\bar{X}=0.000220$
	70	0.0117	0.004270	0.0125	20.0	0.1000	0.000267	
	80	0.0039	0.002710	0.0047	35.3	0.1288	0.000345	$\bar{X}=0.000239$
	90	—	—	—	90.0	—	—	
70	0	0.1183	0.000000	0.1183	0	0.1183	0.000233	
	10	0.1130	0.001180	0.1131	0.6	0.1170	0.000225	
	20	0.1020	0.002860	0.1023	1.6	0.1155	0.000227	
	30	0.0873	0.004950	0.0873	3.2	0.1164	0.000228	
	40	0.0650	0.005800	0.0652	5.1	0.1105	0.000217	
	50	0.0467	0.006070	0.0472	7.4	0.1130	0.000222	
	60	0.0298	0.005900	0.0306	11.1	0.1190	0.000234	$\bar{X}=0.000227$
	70	0.0159	0.004930	0.0168	17.0	0.1370	0.000267	
	80	0.0063	0.003730	0.0072	31.3	0.2100	0.000410	$\bar{X}=0.000251$
	90	—	—	—	90.0	—	—	
80	0	0.1570	0.000000	0.1570	0	0.1570	0.000236	
	10	0.1510	0.001310	0.1510	0.5	0.1565	0.000232	
	20	0.1390	0.003400	0.1392	1.4	0.1575	0.000237	
	30	0.1213	0.005720	0.1215	2.7	0.1617	0.000243	
	40	0.0918	0.007050	0.0920	4.4	0.1560	0.000235	
	50	0.0615	0.007100	0.0618	6.6	0.1485	0.000223	
	60	0.0385	0.006600	0.0392	9.7	0.1540	0.000231	$\bar{X}=0.000234$
	70	0.0208	0.005600	0.0216	15.0	0.1778	0.000267	
	80	0.0086	0.004500	0.0096	28.0	0.2865	0.000428	$\bar{X}=0.000259$
	90	—	—	—	90.0	—	—	
90	0	0.2010	0.000000	0.2010	0	0.2010	0.000239	
	10	0.1921	0.001670	0.1921	0.5	0.1990	0.000235	
	20	0.1788	0.003740	0.1790	1.2	0.2020	0.000240	
	30	0.1546	0.005950	0.1550	2.2	0.2060	0.000245	
	40	0.1190	0.008220	0.1192	3.9	0.2030	0.000241	
	50	0.0840	0.008500	0.0844	5.8	0.2040	0.000241	
	60	0.0514	0.007930	0.0518	8.8	0.2060	0.000168	$\bar{X}=0.000230$
	70	0.0281	0.006530	0.0288	13.1	0.2400	0.000285	
	80	0.0127	0.005500	0.0136	24.0	0.4210	0.000500	$\bar{X}=0.000266$
	90	—	—	—	90.0	—	—	

TABLE II

0.165-Inch Diameter Wire

V	α	F_n	F_t	F_r	δ	$\frac{F_n}{(\cos \alpha)^2}$	K	
30	0	0.0328	0.000000	0.0328	0	0.0328	0.000221	
	10	0.0319	0.000559	0.0319	1.0	0.0329	0.000222	
	20	0.0287	0.001153	0.0287	2.3	0.0325	0.000219	
	30	0.0243	0.001710	0.0245	4.0	0.0324	0.000218	
	40	0.0187	0.002158	0.0188	6.6	0.0319	0.000215	
	50	0.0133	0.002450	0.0136	10.4	0.0322	0.000217	
	60	0.0074	0.002540	0.0078	19.0	0.0296	0.000199	$\bar{X}=0.000216$
	70	0.0032	0.001900	0.0037	30.8	0.0276	0.000184	
	80	0.0010	0.001330	0.0018	47.7	0.0331	0.000223	$\bar{X}=0.000213$
	90	—	—	—	90.0	—	—	
40	0	0.0606	0.000000	0.0606	0	0.0606	0.000230	
	10	0.0570	0.000800	0.0570	0.8	0.0580	0.000223	
	20	0.0508	0.001600	0.0508	1.8	0.0575	0.000218	
	30	0.0427	0.002235	0.0428	3.0	0.0570	0.000216	
	40	0.0342	0.002990	0.0343	5.0	0.0582	0.000221	
	50	0.0240	0.003880	0.0243	9.2	0.0580	0.000220	
	60	0.0155	0.004150	0.0160	15.0	0.0620	0.000235	$\bar{X}=0.000223$
	70	0.0074	0.003500	0.0082	25.2	0.0637	0.000240	
	80	0.0023	0.001840	0.0029	39.2	0.0760	0.000289	$\bar{X}=0.000232$
	90	—	—	—	90.0	—	—	
50	0	0.0969	0.000000	0.0969	0	0.0969	0.000235	
	10	0.0907	0.001110	0.0908	0.7	0.0940	0.000226	
	20	0.0819	0.002145	0.0820	1.5	0.0925	0.000235	
	30	0.0692	0.003260	0.0693	2.7	0.0923	0.000224	
	40	0.0562	0.004330	0.0563	4.4	0.0956	0.000232	
	50	0.0408	0.005060	0.0410	7.1	0.0986	0.000229	
	60	0.0259	0.005490	0.0265	12.0	0.1035	0.000251	$\bar{X}=0.000233$
	70	0.0119	0.004635	0.0127	21.4	0.1025	0.000247	
	80	0.0043	0.002790	0.0049	34.0	0.1430	0.000346	$\bar{X}=0.000247$
	90	—	—	—	90.0	—	—	
60	0	0.1425	0.000000	0.1425	0	0.1425	0.000240	
	10	0.1350	0.001420	0.1350	0.6	0.1393	0.000234	
	20	0.1250	0.002900	0.1251	1.3	0.1415	0.000238	
	30	0.1059	0.004250	0.1060	2.3	0.1410	0.000238	
	40	0.0862	0.005740	0.0866	3.8	0.1470	0.000246	
	50	0.0607	0.006680	0.0610	6.3	0.1470	0.000246	
	60	0.0372	0.006750	0.0378	10.3	0.01485	0.000251	$\bar{X}=0.000242$
	70	0.0180	0.005960	0.0190	18.3	0.1550	0.000259	
	80	0.0071	0.003900	0.0081	29.2	0.2360	0.000398	$\bar{X}=0.000261$
	90	—	—	—	90.0	—	—	
70	0	0.1970	0.000000	0.1970	0	0.1970	0.000244	
	10	0.1850	0.001608	0.1850	0.5	0.1908	0.000236	
	20	0.1660	0.003260	0.1660	1.1	0.1990	0.000233	
	30	0.1420	0.004960	0.1420	2.0	0.1895	0.000233	
	40	0.1180	0.006600	0.1185	3.2	0.2010	0.000249	
	50	0.0845	0.007860	0.0850	5.3	0.2050	0.000253	
	60	0.0528	0.008270	0.0535	8.9	0.2110	0.000261	$\bar{X}=0.000244$
	70	0.0270	0.007230	0.0280	15.0	0.2310	0.000285	
	80	0.0118	0.005310	0.0129	24.3	0.3940	0.000484	$\bar{X}=0.000275$
	90	—	—	—	90.0	—	—	

TABLE II—(*Continued*)

V	α	F_n	F_t	F_r	δ	$\frac{F_n}{(\cos\alpha)^2}$	K	
80	0	0.2610	0.000000	0.2610	0	0.2610	0.000247	
	10	0.2520	0.001765	0.2520	0.4	0.2610	0.000246	
	20	0.2330	0.003560	0.2330	0.9	0.2640	0.000250	
	30	0.2030	0.005310	0.2031	1.5	0.2710	0.000256	
	40	0.1650	0.007200	0.1652	2.5	0.2807	0.000266	
	50	0.1130	0.008310	0.1136	4.2	0.2740	0.000259	
	60	0.0722	0.008850	0.0727	7.0	0.2890	0.000273	$\bar{X}=0.000257$
	70	0.0400	0.008500	0.0409	12.0	0.3450	0.000324	
	80	0.0178	0.006860	0.0190	21.2	0.5930	0.000559	$\bar{X}=0.000298$
	90	—	—	—	90.0	—	—	
90	0	0.3335	0.000000	0.3335	0	0.3335	0.000250	
	10	0.3262	0.001920	0.3263	0.3	0.3380	0.000251	
	20	0.3050	0.003670	0.3050	0.7	0.3450	0.000258	
	30	0.2720	0.005680	0.2730	1.2	0.3627	0.000271	
	40	0.2235	0.007640	0.2240	1.9	0.3815	0.000285	
	50	0.1525	0.008950	0.1530	3.3	0.3690	0.000276	
	60	0.0982	0.009690	0.0985	5.6	0.3930	0.000294	$\bar{X}=0.000269$
	70	0.0562	0.009480	0.0570	9.6	0.4840	0.000359	
	80	0.0252	0.008430	0.0266	17.6	0.8400	0.000625	$\bar{X}=0.000319$
	90	—	—	—	90.0	—	—	

In characterizing the normal force of oblique winds, curves were plotted between the normal force (F_n) and the angle (α) between the wind and the normal to the wires. Figures 3 (0.104-inch wire) and 4 (0.165-inch wire) show these curves.

In studying the significance of these curves and the underlying data, consideration was first given to the extent to which the case of normal winds ($\cos\alpha = 1$) followed the law of dynamic similarity. This law states, in effect, that for any two geometrically similar bodies moving through a fluid,

$$F = \rho V^2 f\left(\frac{VD}{\nu}\right). \tag{5}$$

Here, F is the unit force at either of two similarly situated points on the two bodies, ρ is the fluid density, V is the velocity of the body, D a linear quantity depending on the dimensions of the body and ν is the kinematic viscosity of the fluid. The function (VD/ν) is the well known Reynolds number and the key to dynamic similarity requirements in model experiments made at ordinary velocities. The principle of dynamic similarity is satisfied as long as the Reynolds number is held constant.

In Report No. 102 [5] of the National Physical Laboratories is given an

[5] Reports and Memoranda No. 102, November 1914, entitled "Discussion of the Results of Measurements of the Resistance of Wires" by E. F. Relf.

empirical curve of the resistance of smooth wires to winds normal to the wire. In preparing this curve equation (5) was rewritten in terms of the total force on a diameter length of wire, namely

$$F_c = \rho V^2 D^2 f\left(\frac{VD}{\nu}\right). \tag{5a}$$

Then $F_c/\rho V^2 D^2$ was plotted as the ordinate and $\log_{10}(VD/\nu)$ as the

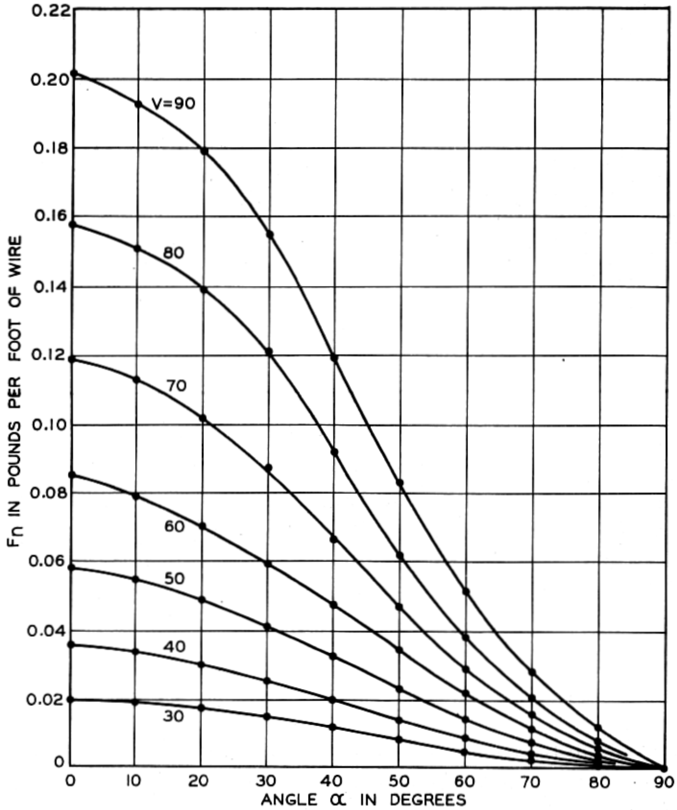

Fig. 3—Graphic relation between the force (F_n) normal to the wire and the angle (α) of wind direction from normal—0.104-inch diameter wire.

abscissa. If the normal wind data obtained in the studies of Bell Telephone Laboratories were consistent with those given in this Report No. 102 [5] a plot of the points determined through the use of equation (5a) should lie reasonably close to this curve. Figure 5 gives this curve and a plot of the normal wind results. These points appear to show satisfactory agreement.

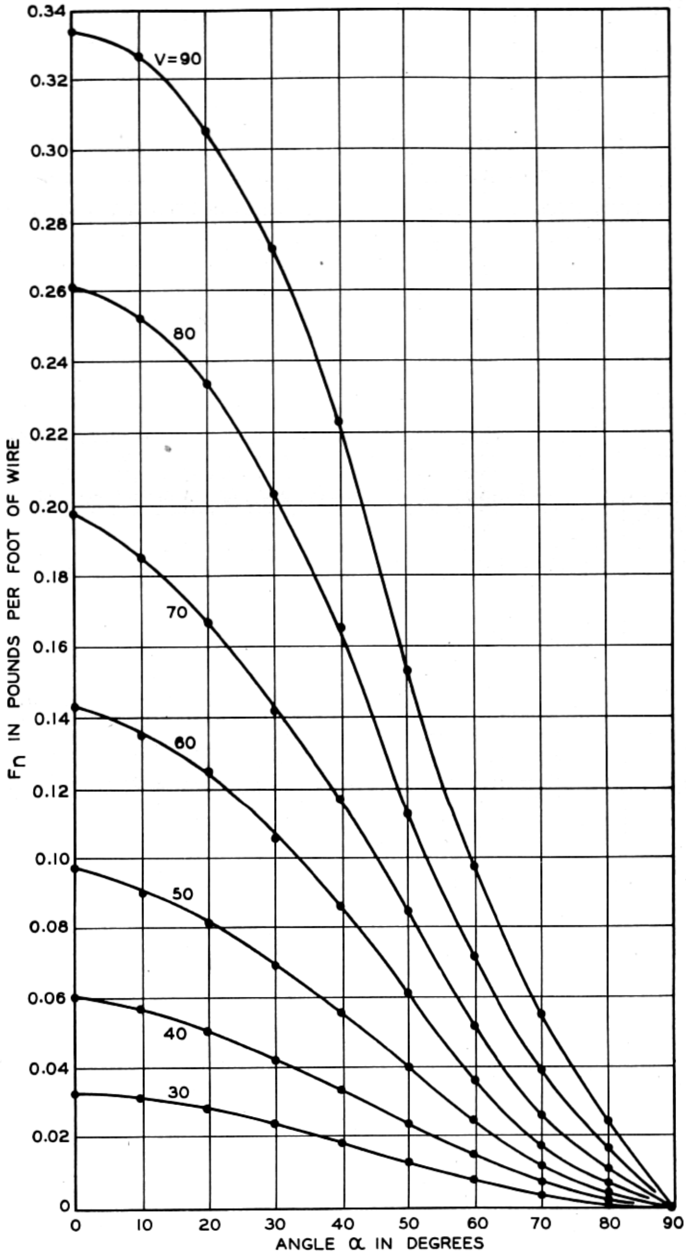

Fig. 4—Graphic relation between the force (F_n) normal to the wire and the angle (α) of wind direction from normal—0.165-inch diameter wire.

In the case of oblique winds it was found from an analysis of the data that the normal component of the force was closely proportional to $\cos^2 \alpha$ over a range of angles from 0° to 60° from normal in the case of each actual velocity and each size of wire. The values of $F_n/\cos^2 \alpha$ are given in the accompanying Tables I (0.104-inch wire) and II (0.165-inch wire). This agrees with the results obtained by Relf and Powell.[2] However, they used only one size of wire and one wind velocity in their tests. Expressing this result in terms of the normal force gives,

$$F = (K' \cos^2 \alpha)_{V,\ D=\text{constant}}.$$

This empirical expression suggested that a form of relation existed similar to that for the case of normal winds (equation 5a). Studying

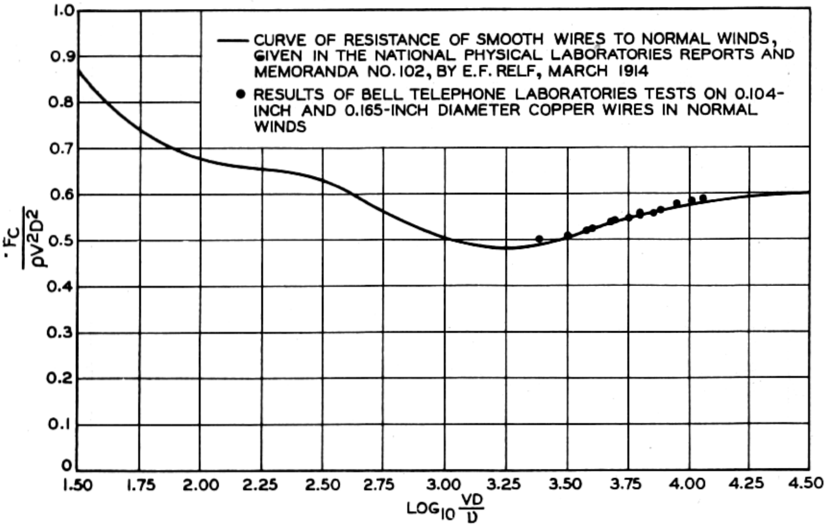

Fig. 5—Comparison of Bell Telephone Laboratories results for normal winds with the National Physical Laboratories (British) results.

the results with this in mind the following equation was obtained,

$$F_c = \rho V^2 \cos^2 \alpha D^2 f\left(\frac{VD}{\nu}\right).$$

This form of expression holds over the range of Reynolds number (VD/ν) covered and, also, over the range of angles from 0° to 60° from normal.

Since ρ (air density) and ν (kinematic viscosity of air) are constant for a particular atmosphere this equation becomes

$$F_n = K(V \cos \alpha)^2 D. \tag{6}$$

Here, F_n (the normal component of wind force) is measured in pounds per foot of wire. The diameter (D) of the wire is in inches and the actual wind velocity (V) is in miles per hour. This is the familiar equation for the force of normal winds with the addition of the term, $\cos^2 \alpha$.

Values of the constant (K) found for each value of the actual velocity (V) and angle are given in Table I (0.104-inch wire) and Table II (0.165-inch wire). The arithmetical averages ($\bar{X}$) of the constants for angles up to and including 60° and for angles up to and including 80° in the case of each velocity (V) are also given in these tables. As in the case of normal winds and as indicated by equation (6) K varies with the product of velocity and wire diameter (VD).

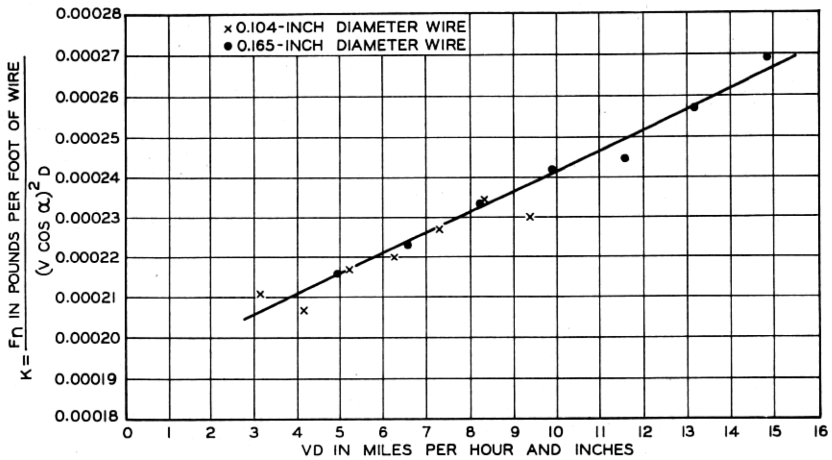

Fig. 6—Values of the Constant (K) in Equation $F_n = K(V \cos \alpha)^2 D$ for variations of the angle (α) of wind direction from normal—range, 0° to 60°, inclusive.

The relation between the average constant (K) for angles up to and including 60° and the product of velocity and wire diameter (VD) is summarized in the accompanying Fig. 6.

While our interest was centered mainly in evaluating the normal force of an oblique wind as stated above, some consideration has been given to the tangential force of an oblique wind and the variability of the angle between the normal and resultant wind forces.

The tangential forces of the oblique winds were determined by equation (3). Curves, for both sizes of wire, of tangential forces plotted against the angle α are given on Figs. 7 and 8 for all velocities (30 to 90 m.p.h.) used in the tests. The tangential force, of course, is a relatively small quantity as compared to the normal force. For this reason some inconsistencies in the data and non-uniformity in the curves might be expected, particularly when plotted to such a large scale as used in these graphs. In Reports and Memoranda of the National Physical Laboratories [2] it appeared from their results that this force was not only small but fairly constant. The results of the tests reported here indicate that while the force is low in magnitude, it varies with the obliquity and the velocity of the wind and the diameter

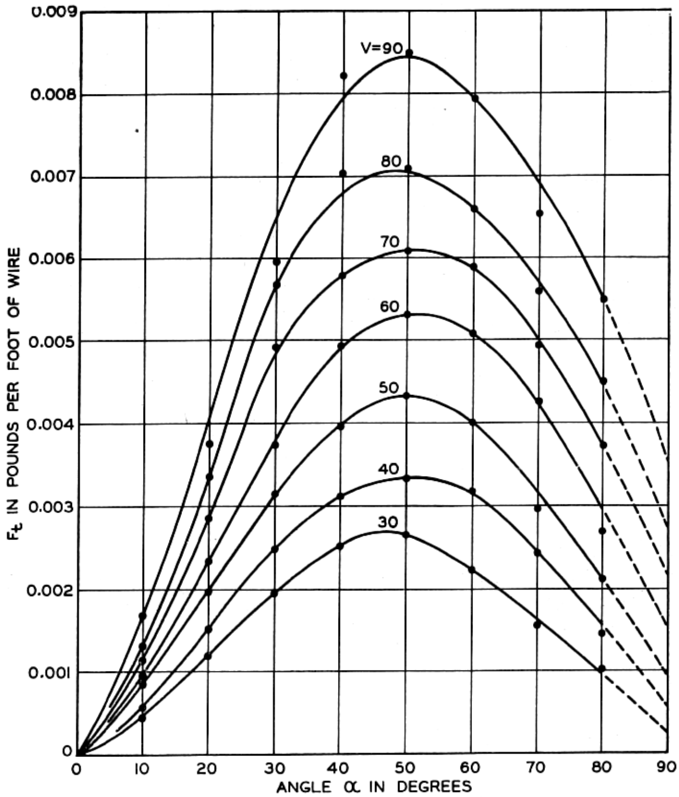

Fig. 7—Graphic relation between the wind force along the wire (tangential-F_t) and the angle (α) of wind direction from normal—0.104-inch diameter wire.

of the wire. In the case of 0.104-inch wire it increases from zero until the angle α (between the wind and the normal to the wire) is about 50° and then decreases as this angle increases. The action is similar in the case of 0.165-inch wire except the maximum is reached when α is about 60°. Whether this shift in the maximum with the wire diameter is real, and how far it would continue, is not clear since only two diameters of wire were tested. For 0.104-inch wire the variation in the force with wind velocity when α equals 50° ranges from 0.00265 to 0.00850 pound per foot of wire for a range of velocities from 30 to 90 m.p.h. In the case of 0.165-inch wire and an angle (α) of 60° the variation ranges from 0.00254 to 0.00969 pound per foot of wire for the same range of velocities. As mentioned above the frame in which the wires were

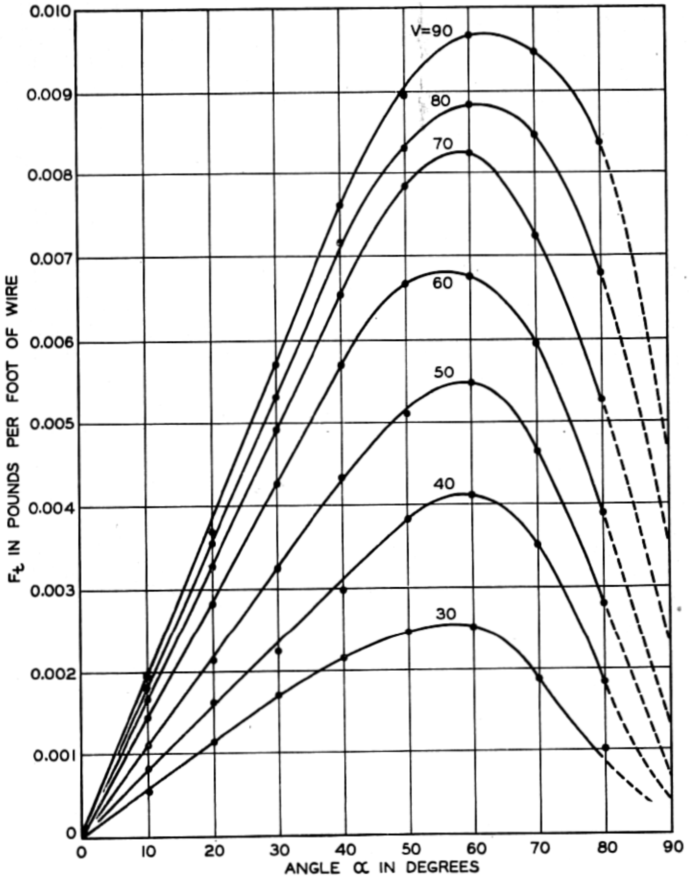

Fig. 8—Graphic relation between the wind force along the wire (tangential-F_t) and the angle (α) of wind direction from normal—0.165-inch diameter wire.

tested comprised such a major portion of the total resistance when the angle α approached 90° or the wind and wires were about parallel that the data for these cases were not considered reliable. In plotting the curves in Figs. 7 (0.104-inch wire) and 8 (0.165-inch wire) the tangential force for 90° was estimated and to indicate this the curves are dotted between the angles α of 80° and 90°.

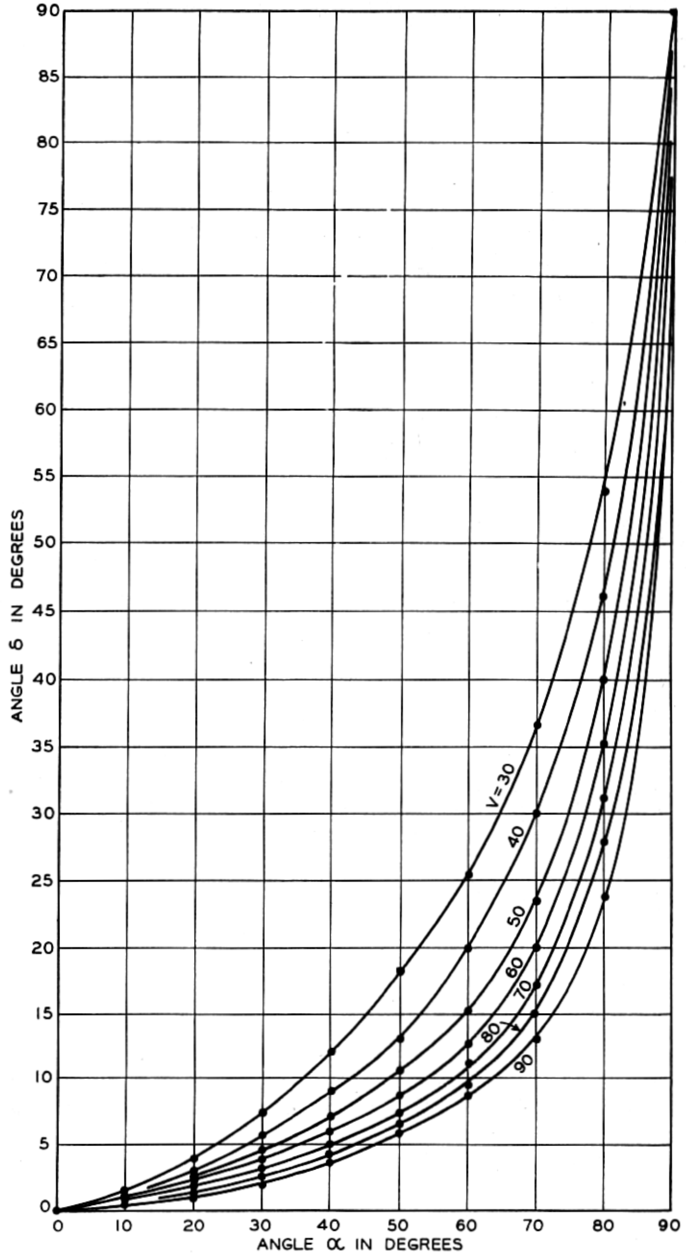

Fig. 9—Graphic relation between the angle (δ) of direction of resultant force from normal to the wire and the angle (α) of wind direction from normal—0.104-inch diameter wire.

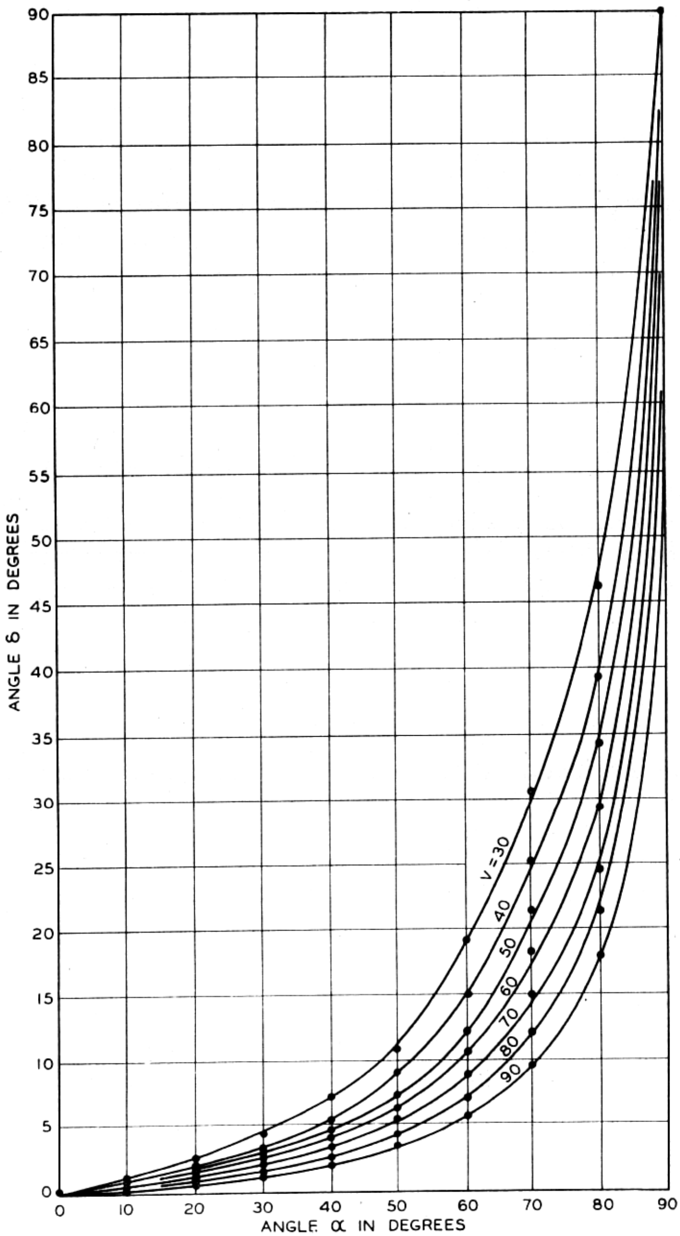

Fig. 10—Graphic relation between the angle (δ) of direction of the resultant force from normal to the wire and the angle (α) of wind direction from normal—0.165-inch diameter wire.

The angle (δ) between the resultant and normal wind forces was determined through the use of equation (4). The variations in this angle with the obliquity of the wind or the angle α are given for both sizes of wire in Figs. 9 (0.104-inch wire) and 10 (0.165-inch wire). From these graphs the following relations appear to exist in this range:

(*a*) For a given angle α the magnitude of the angle δ is inversely proportional to the product of velocity and wire diameter (VD),

$$\delta = \left(\frac{K_1}{VD}\right)_{\alpha=\text{constant}}.$$

This relation can be written

$$\delta = \left(\frac{K_2}{\left(\frac{VD}{\nu}\right)}\right)_{\alpha=\text{constant}},$$

where VD/ν is the familiar Reynolds number.

(*b*) For each size of wire and a given actual wind velocity the angle δ increases with the angle α. Hence, $\delta = f(\alpha, V, D)_{V, D=\text{constant}}$. Since the Reynolds number can also be considered constant

$$\delta = \varphi(\alpha, VD/\nu)_{V, D, \nu=\text{constant}}.$$

Conclusion

These tests indicate that the normal force on a wire due to an oblique wind is proportional to the square of the resolved component of the actual wind velocity for angles up to 60° from the normal to the wire. The expression for the normal force per unit length of wire is $F_n = K(V \cos \alpha)^2 D$, where V is the actual wind velocity and D is the wire diameter. The tangential component is relatively small as compared to the normal component.