WIND PRESSURE ON A MODEL OF A MILL BUILDING

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ABSTRACT

This paper describes some measurements of the distribution of wind pressure over a model of a mill building, carried out in the 10-foot wind tunnel of the National Bureau of Standards. The results for three wind speeds show little scale effect, and it is believed that the results are directly applicable to a full-scale building of the same shape. Tests were made with a plain roof of 20° pitch, and also with a monitor ventilator on the ridge of the roof. Three wind directions were used, one normal to a side wall, one normal to an end wall, and one at 45°. The effect of the ground was simulated by the use of a long platform on which the model was mounted.

The detailed results can not well be abstracted. The maximum average loads were obtained with the wind at 45°, and in many cases fairly large areas were subjected to loads as great as twice the average load on the whole face. The loads on the roof of the monitor were greater than those on the roof of the main building. The greater part of the model was subject to pressures lower than the static pressure, and for most circumstances all faces except the windward one would be subject to outward forces.

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I. INTRODUCTION

In Scientific Paper No. 523 and Research Paper No. 221 of the National Bureau of Standards, a general discussion has been given of the wind-pressure problem and of the results of some model experiments on the distribution of pressure over a tall building and over two circular cylinders in a uniform and steady wind. The second paper also gives some pressure measurements on a full-size chimney in natural winds. The present paper represents an extension of this work to a model of a mill or factory type of building.

The reader is referred to the earlier papers for the background necessary to understand the application of the results of model experiments to estimates of wind pressure on the full-scale structure in the natural wind. Some of the explanatory material found in those papers is here repeated so that the method of expressing the results of the measurements may be clear. It will, perhaps, be best at this point to again review briefly the conventional method of presenting aerodynamic data.

When an air stream blows against an object, the pressure, p, at any point on its surface may be regarded as consisting of two parts—the static pressure,[1] p_s, which in a natural wind is the barometric pressure; and the excess, $p-p_s$, caused by the presence of the object. This excess, $p-p_s$, arises solely from the motion of the air with reference to the model. It will be called simply the wind pressure, and will be denoted by p_w. If there is no wind or no object present, then $p=p_s$ everywhere, and the wind pressure is everywhere zero. The wind pressure may be either positive or negative or zero; that is, p, which by definition of p_w is equal to p_s+p_w, may be either greater or less than p_s or equal to it.

In the comparison of wind pressures carrying the negative sign, the lower numerical value corresponds to the higher absolute pressure. Thus -0.2 is a higher pressure than -0.4 (just as 10° below zero is a higher temperature than 20° below zero). p_w is the quantity usually measured, corresponding to the common practice of using "gauge" pressure in dealing with pressures in steam boilers, compressed air tanks, etc., rather than absolute pressure. Dimensional reasoning teaches that p_w will be given by an expression of the form

$$p_w/q=f\left(\frac{VL\rho}{\mu}\right)$$

where q is the velocity pressure ($\frac{1}{2}\rho V^2$), ρ the air density, V the wind speed, μ the viscosity of the air, and L a linear dimension fixing the scale. The expression applies only to geometrically similar bodies. The wind pressure, p_w, could be measured in any convenient units, but there are advantages in using the velocity pressure, $q=\frac{1}{2}\rho V^2$, as the unit. In the first place p_w/q is in many cases [2] independent of the wind speed and the size of model, so that from a single value of it for any given shape of body the pressure at the corresponding point on a similar body of any size at any wind speed can be readily computed with the aid of a table of velocity pressures. In many other cases the variation of p_w/q with the Reynolds number $\frac{VL\rho}{\mu}$ is small. The ratio is a pure number independent of the units used so long as the pressures are all measured in the same units.

The engineer is in most cases more directly concerned with the resulting forces than with the pressures themselves and their distribution. These resulting forces always involve the pressure acting on the opposite sides of the surface or object. In the case of a hollow object, such as a building, which is open to the outside at various places, air currents are set up within the building, and there is a distribution of wind pressure over the interior as well as the exterior surfaces of the walls. At any point of the wall the force per unit area tending to move the wall normal to itself equals the difference between the wind pressure on the two sides and is in the direction from the higher toward the lower pressure. Little is known at the present time as to the distribution of wind pressure over the interior

[1] The term static pressure is used to indicate the pressure which would be measured by a pressure gauge moving with the air and, therefore, "static" with respect to the air. In actual practice the measurement is made by means of holes in the side of a closed tube, the axis of which is parallel to the wind direction. The form of the tube is such that the air flows smoothly past the holes.

[2] B. S. Sci. Paper No. 523, Bull., 20, p. 697.

walls of actual buildings in high winds and in the presentation of data for the distribution over the exterior it is commonly assumed that the interior is at a constant pressure equal to the static pressure, p_s; that is, p_w is zero for the interior. If the pressure on the interior is constant, it has no effect on the resultant force tending to overturn the building, no matter what its value.

By definition, p_s is the same at every point of the surface and, hence, it contributes nothing to the resulting forces and may be ignored in the computations. The force on any element, dA, is equal to pdA and acts in the direction of the normal to the surface.[3] If θ is the angle made by the surface element dA, with the wind direction, s, then the component of force in that direction, F_s is given by $\int\int p\, dA \sin\theta$. Since p_s is constant and for closed surfaces $\int\int dA \sin\theta = 0$, the force coefficient for closed surfaces is also given by $\int\int p_w dA \sin\theta$. Dividing by q, we have $\frac{F_s}{q} = \int\int \frac{p_w}{q}\, dA \sin\theta$. It is found convenient to divide this expression by the area of projection, A_p, of the body on a plane normal to the direction, s. The quotient $F_s/A_p q$ is called the force coefficient.[4] It is the average force per unit projected area divided by the velocity pressure; that is, the ratio of the effective resultant pressure on the total projected area to the velocity pressure. The force in any particular case is obtained by multiplying the force coefficient by the projected area and by the velocity pressure.

For the convenience of the reader, the relation between the indicated speeds, as measured by 3-cup and 4-cup United States Weather Bureau anemometers, and the true speed is given in Table 1, and the velocity pressures at various true speeds for air of standard density are given in Table 2.

TABLE 1.—*Indicated wind speeds by Robinson cup anemometers* [a]

True speed (miles per hour)	Indicated speed, old 4-cup standard	Indicated speed, new 3-cup standard	True speed (miles per hour)	Indicated speed, old 4-cup standard	Indicated speed, new 3-cup standard
5	5	5	60	78	63
10	11	10	65	85	68
15	17	15	70	91	73
20	23	20	75	98	79
25	30	25	80	105	84
30	37	31	85	112	89
35	44	36	90	118	95
40	50	41	95	125	100
45	57	47	100	132	105
50	64	52	105	138	111
55	71	57	110	145	116

[a] Before Jan. 1, 1928, the U. S. Weather Bureau used the 4-cup instrument; after that date, the 3-cup.

[3] Excluding frictional effects, which are of importance only in special cases.
[4] The terms, resistance coefficient, drag coefficient, shape coefficient, are also used.

TABLE 2.—*Velocity pressures at several wind speeds*

True wind speed (miles per hour)	Velocity pressure	True wind speed (miles per hour)	Velocity pressure
	Lbs./ft.²		*Lbs./ft.²*
5	0.064	65	10.81
10	.256	70	12.53
15	.575	75	14.39
20	1.023	80	16.37
25	1.600	85	18.48
30	2.302	90	20.72
35	3.133	95	23.08
40	4.092	100	25.58
45	5.179	105	28.20
50	6.394	110	30.95
55	7.737	115	33.83
60	9.208	120	36.83

NOTE.—Velocity pressure in lbs./ft.²=0.001189 $(V\times\frac{22}{15})^2$ where V is the true speed in miles per hour, and the density is that at 15° C., 760 mm. Hg.

II. APPARATUS

Figure 1 is a photograph of the model, which is 48 inches long, 24 inches wide, and 6 inches high to the lower edge of the roof. The roof, having a 20° pitch, measures 12.76 inches from the lower edge to the peak. There is no overhang of the roof. The monitor ventilator is 29 inches long, 1.6 inches high, 6 inches wide, and its roof has a pitch of 20° and an overhang of 0.1 inch. The model is made of aluminum plates one-quarter inch thick. For purpose of reference the faces are designated as shown in Figures 2 and 3. Face *A* of the model has 44 holes drilled in it, face *B* 177 holes, face *F* 72 holes, face *AA* 22 holes, face *BB* 55 holes and face *FF* 18 holes. The arrangement and location of the holes are shown in Figures 2 and 3.

The holes or pressure stations were prepared as follows: A hole approximately 0.25 inch in diameter was drilled and tapped at each station. A hollow cylindrical threaded plug about five-eighths inch long and closed at one end was screwed into the hole and the closed end carefully worked down so as to make it flush with the outer surface of the model. After polishing, a small hole approximately 0.040 inch in diameter was drilled along the axis of the plug from the outside face inward. By means of rubber tubing, connection through the interior of the model could then be made from each station to the pressure gauge.

The various plates of which the model is made are held together by screws. The bottom plate has a large circular hole through which the pressure tubes pass to the manometer. When testing the model with the monitor ventilator in place a rectangular piece was removed from the roof of the main model under the ventilator to accommodate the pressure tubes.

The wind stream was supplied by the 10-foot wind tunnel, which is described in Scientific Paper No. 523. The method of measuring wind speed, and the pressure gauge used for measuring pressures at the stations on the model were described in the same paper. In the present tests speeds up to about 55 miles per hour were used.

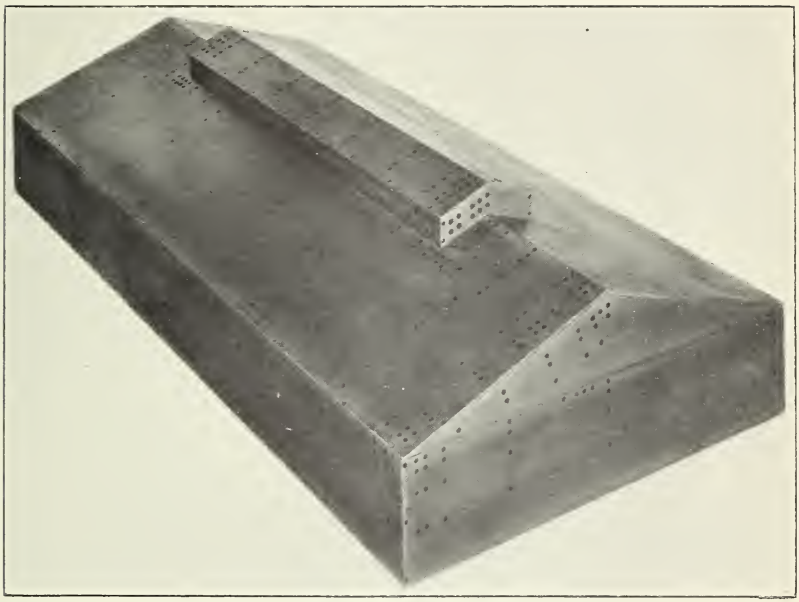

FIGURE 1.—*The model with monitor ventilator*

The dark circles are the ¼-inch plugs in which the 0.04-inch holes are drilled.

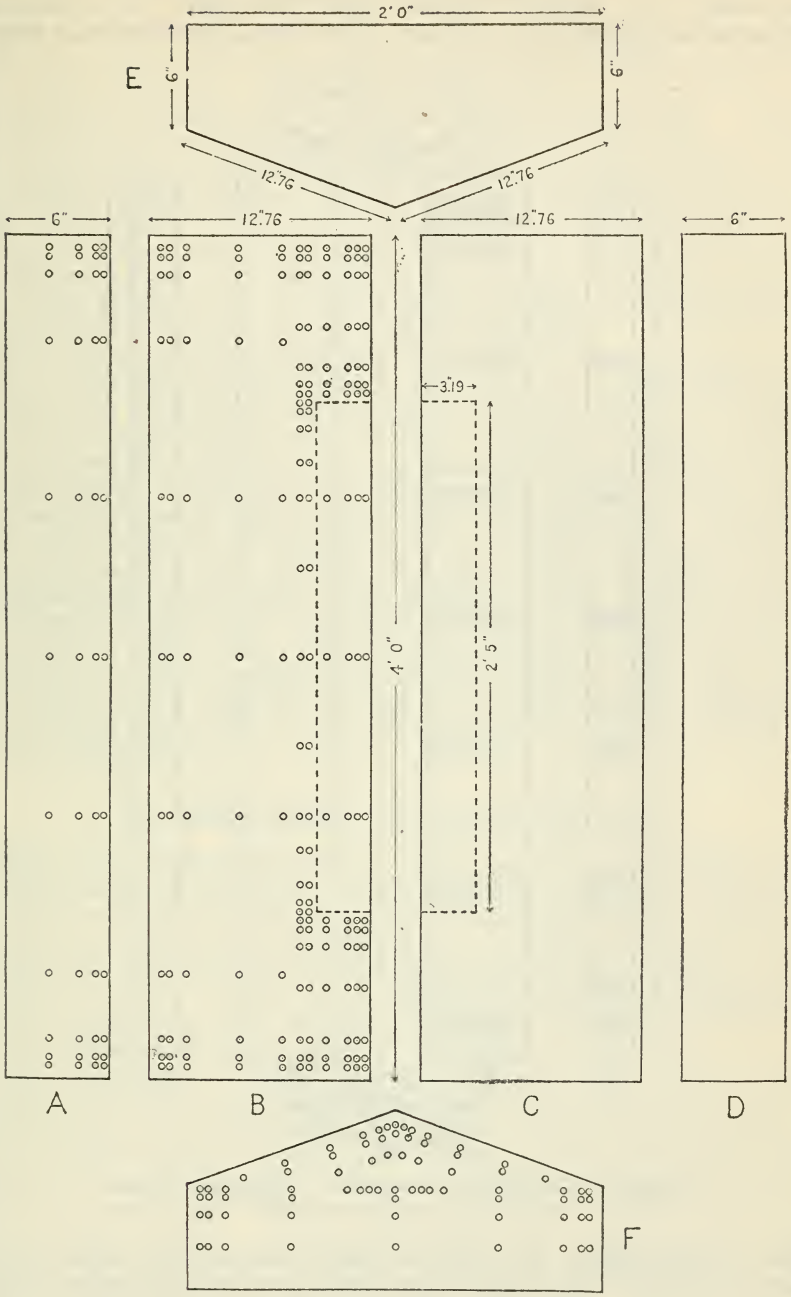

FIGURE 2.—*Location of holes and designation of faces for the model without the monitor ventilator*

The effect of the ground on which an actual building stands was simulated by a platform placed under the model. The platform extended completely across the tunnel and was 5 feet above the tunnel

FIGURE 3.—*Location of holes and designation of faces for the monitor ventilator*

floor at the center. Its length in the direction of the wind was 15 feet and its upstream edge was beveled so as to reduce the disturbance produced by it. The wind speed was uniform to within less than 2 inches of the platform.

III. GENERAL PROCEDURE

The tests to be described were divided into two groups. In the first group the model was tested without the monitor ventilator. The data required for the complete distrubution at a given angle to the wind were obtained by turning the model through 180°. In the second group of tests the model was tested with the monitor ventilator attached. In these tests only the distribution over faces *B* and *C* and over the monitor ventilator was measured, as it was believed that the presence of the monitor ventilator would not affect the distribution or the value of the pressure on faces *A*, *D*, *E*, and *F*. The model rested directly on the platform and a scale of angles was marked off on this platform. A thin strip of wood nailed to the floor at the back of the model prevented the wind from sliding it.

The procedure for making the observations was as follows: 12 pressure stations were connected to 12 tubes of a multiple-tube manometer, the reservoir of the manometer being connected to a small hole in a static plate located 12½ feet upstream from the model. When the wind speed was steady, an observer read the 12 tubes of the multiple gauge, which gave the differences in pressure between the holes at the surface of the model and the reference pressure. Readings were taken for speeds of approximately 47, 60, and 80 feet per second. Then 12 more pressure stations were taken and so on until all the available holes were tested. The model was then turned through 180° and the necessary holes tested to give the complete pressure distribution. The entire process was carried out for wind directions of 0°, 45°, and 90°, an angle of 0° denoting that the wind was perpendicular to the ridge of the roof. Next the monitor ventilator was attached and tested in the same way together with faces *B* and *C* of the main building.

IV. REDUCTION OF OBSERVATIONS

The results finally desired are p_w, the changes in pressure produced by the presence of the model. It was necessary, therefore, to measure the difference in pressure between the reference pressure and the static pressure in the tunnel (with the model removed) at the place previously occupied by the model and to add this value with proper sign to the observed pressure. It was also necessary to correct for the difference in wind speed between the place where the reference Pitot-static tube was located and the position of the model.

The procedure in reducing the observations was as follows: The gauge readings observed on the multiple-tube manometer were reduced to absolute pressure differences in pounds per square foot and were then expressed as fractions of the velocity pressure indicated by the reference Pitot-static tube. The two corrections mentioned above were then applied and the values at each station for the three wind speeds were averaged. At any one station the values for the three speeds were, in general, very nearly the same; rarely did that for any one speed differ from the mean by more than 0.02. The designation of faces is indicated in Figures 2 and 3 which show the model with the four walls opened out at 90° and the roof pressed down on the same horizontal plane. When the wind blows normal to face *A* the model is said to be at 0° to the wind. Rotating the model clockwise, as

viewed from above, through 90° so that face F is normal to the wind gives the position designated as 90°. The angle 45° is, of course, midway between these two positions.

V. RESULTS

The results are represented in the form of contour maps (figs. 4 to 12), the contour interval being one-tenth of the velocity pressure. At all points of any one contour p_w has the same value. When p_w is positive (sign not printed) p exceeds p_s, when it is negative p is less than p_s.

The average value of p_w/q on each face was computed by a process of graphical integration, namely, by measuring the area between adjacent contour lines, multiplying the area by the arithmetic mean of the pressures for the two contours, summing for the entire face, and dividing by the area of the face. The results of this computation are shown in Table 3. The force on any face (assuming the pressure in the interior to be equal to the static pressure, p_s) may be obtained by multiplying the average value of p_w/q by the area of the face and by the velocity pressure q.

The direction of the force on any face is normal to that face. To obtain the resultant force on the building it is necessary to resolve the forces parallel to the directions of three axes of reference. The system shown in Figure 13, fixed with respect to the model and turning with it, has been adopted. Since the areas of the various faces of the model are not equal, the force components can not be obtained by adding values of the average pressures, but the pressures must be weighted in proportion to the areas of the faces. The computation is made in two steps. The values of p_w/q are first multiplied by the cosines of the angles between the normal to the face and the axes of references to give what may be called the X, Y, and Z components of p_w/q or F/qA. These values are shown in Tables 4 and 5, together with the areas of the faces relative to face A. The component of the force in the direction of the Y axis, for example, may be obtained by multiplying the values tabulated under Y by the area of the face, and by the velocity pressure.

TABLE 3.—*The average values of p_w/q on each face of model*

Face	Without monitor ventilator			With monitor ventilator		
	0°	45°	90°	0°	45°	90°
A	+0.498	+0.255	−0.354	+0.498	+0.255	−0.354
B	−.381	−.441	−.381	−.238	−.245	−.340
C	−.563	−.774	−.381	−.584	−.691	−.340
D	−.518	−.517	−.354	−.518	−.517	−.354
E	−.620	−.449	−.205	−.620	−.449	−.205
F	−.620	+.372	+.615	−.620	+.372	+.615
AA				+.441	+.180	−.197
BB				−1.026	−1.312	−.251
CC				−.560	−1.370	−.251
DD				−.488	−.938	−.197
EE				−.913	−.762	−.250
FF				−.913	−.160	−.850

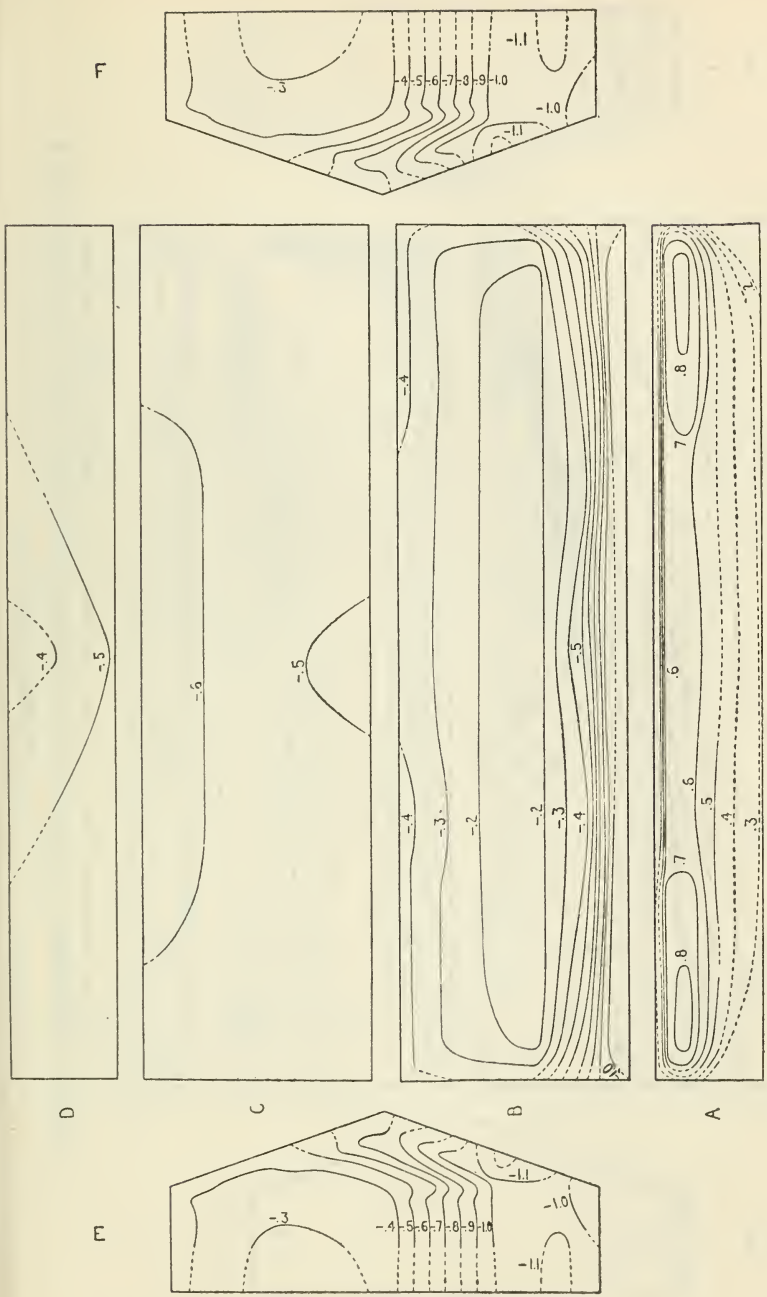

FIGURE 4.—*Distribution of pressure over the model without the monitor, wind normal to face A*

The pressures are measured from the static pressure as base, and expressed as ratios to the velocity pressure. Minus signs denote that the pressure is lower than the static pressure

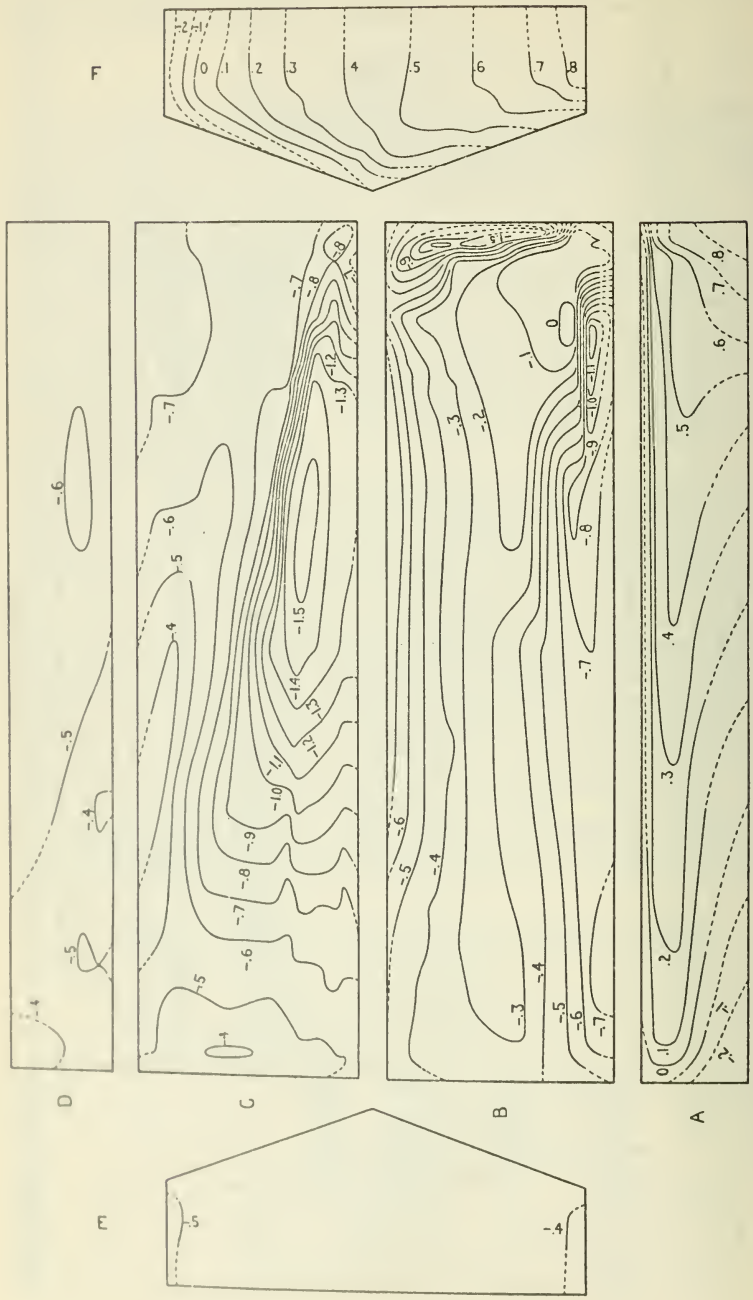

FIGURE 5.—*Distribution of pressure over the model without the monitor, wind at 45° to faces A and F*

See legend of Figure 4.

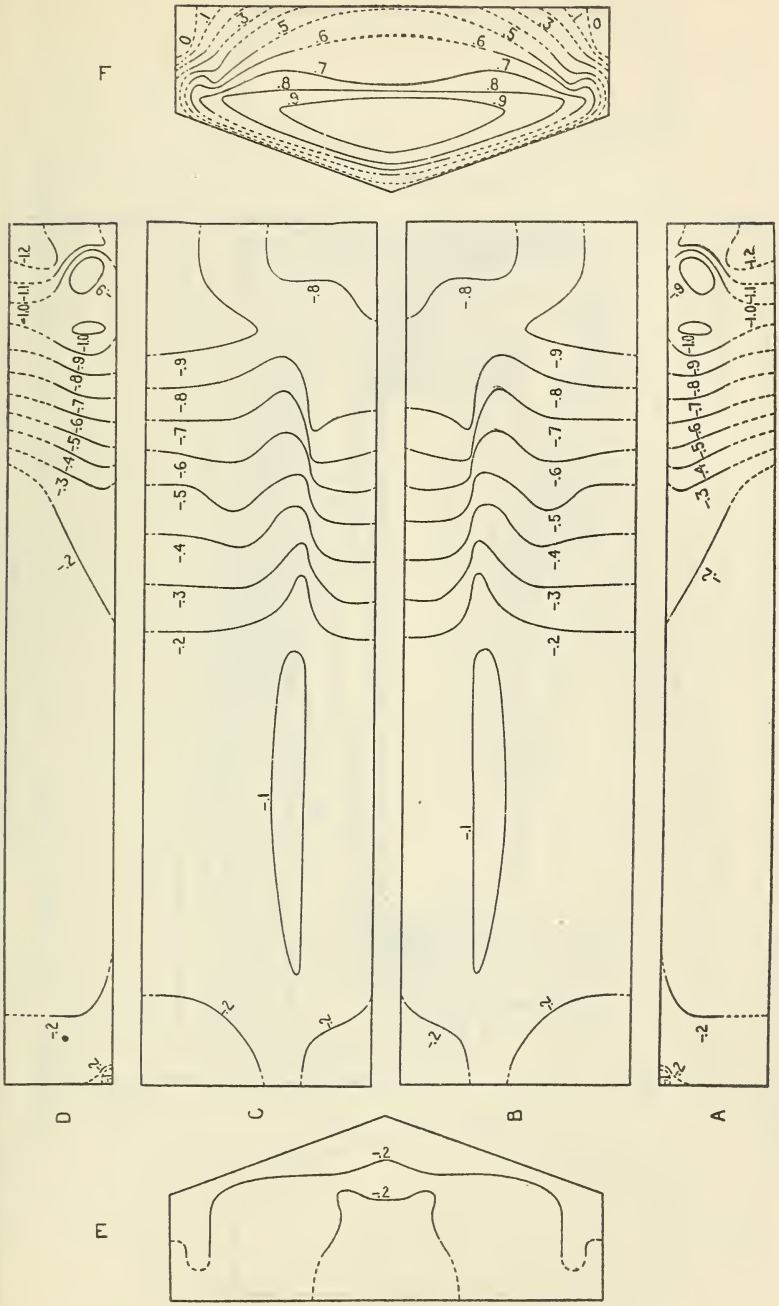

FIGURE 6.—*Distribution of pressure over the model without the monitor, wind normal to face F*

See legend of Figure 4

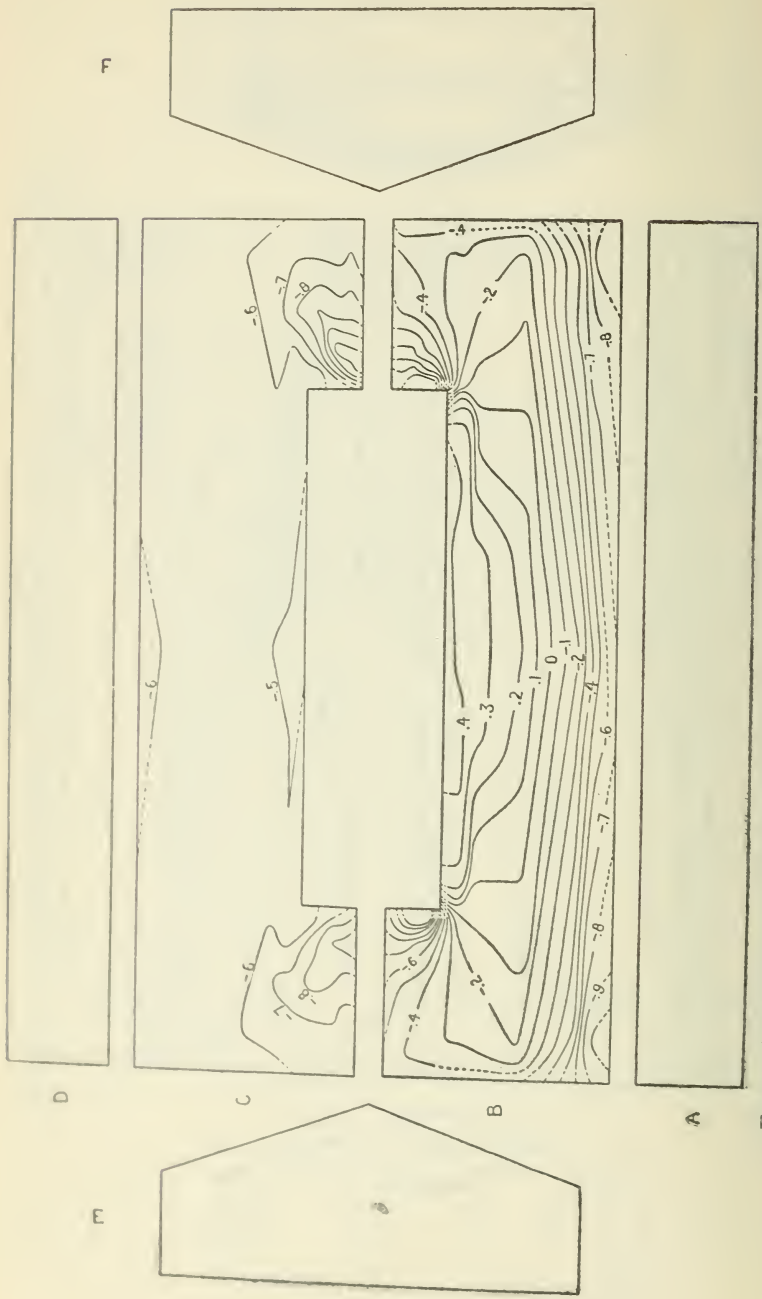

FIGURE 7.—*Distribution of pressure over the model with the monitor, wind normal to face A*

See legend of Figure 4. See also Figure 10

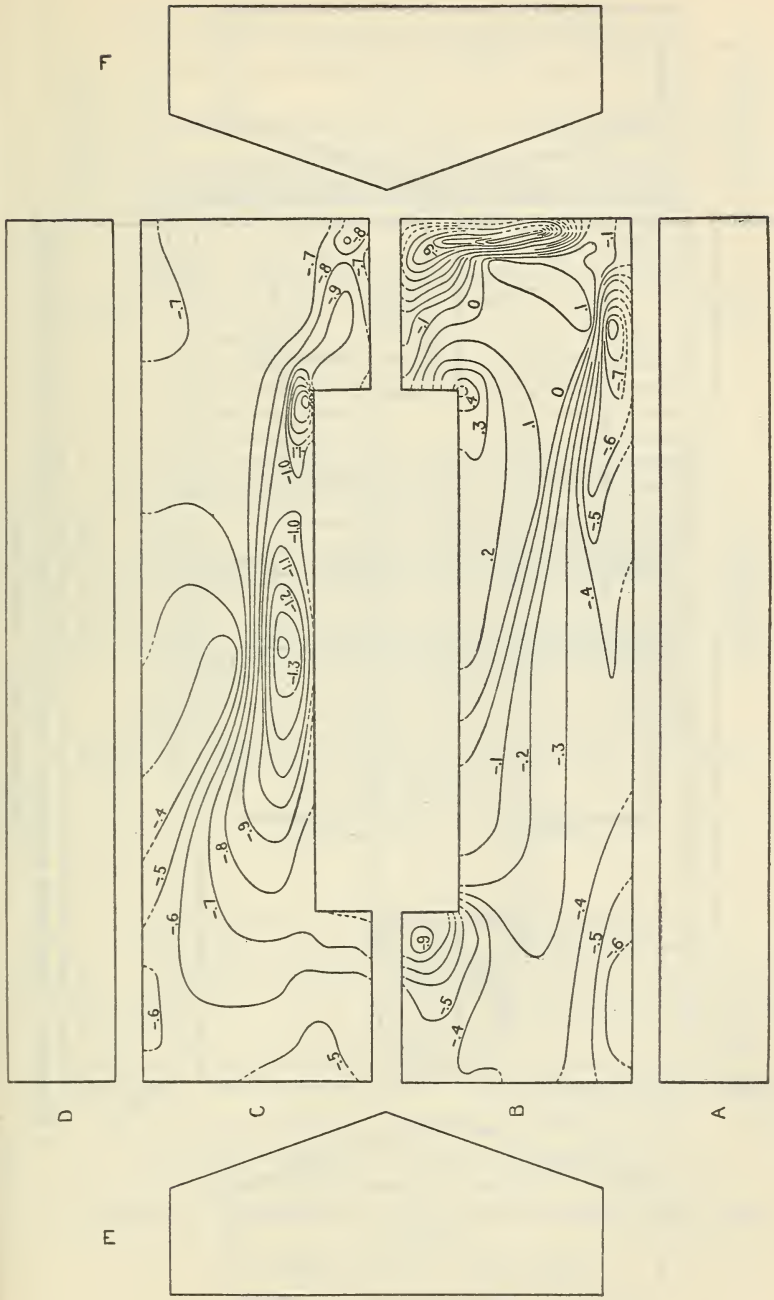

FIGURE 8.—*Distribution of pressure over the model with the monitor, wind at 45° to faces A and F*
See legend of Figure 4. See also Figure 11

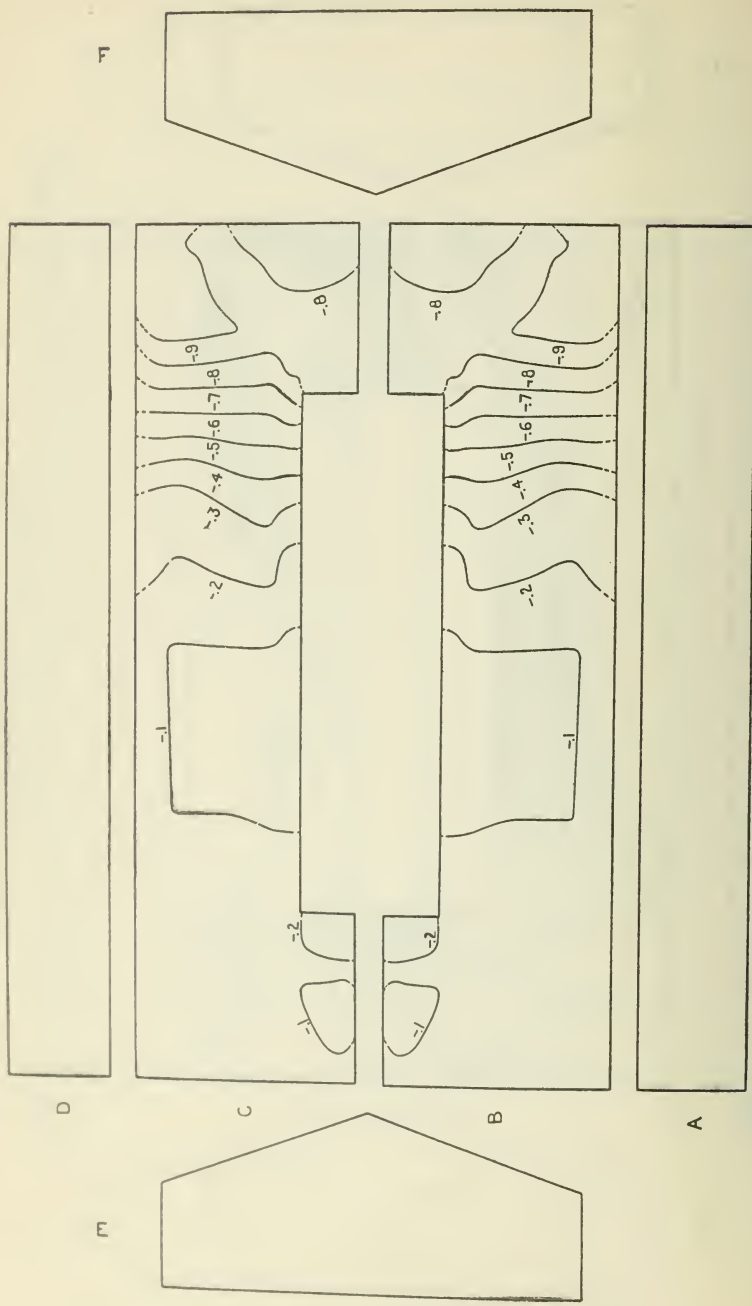

FIGURE 9.—*Distribution of pressure over the model with the monitor, wind normal to face*

See legend of Figure 4. See also Figure 12

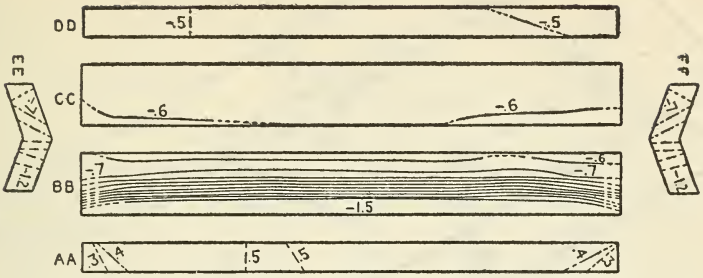

FIGURE 10.—*Distribution of pressure over the monitor, wind normal to face A*

See legend of Figure 4. See also Figure 7

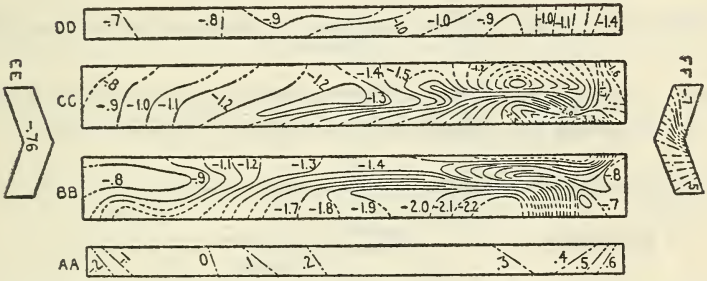

FIGURE 11.—*Distribution of pressure over the monitor, wind at 45° to faces A and F*

See legend of Figure 4. See also Figure 8

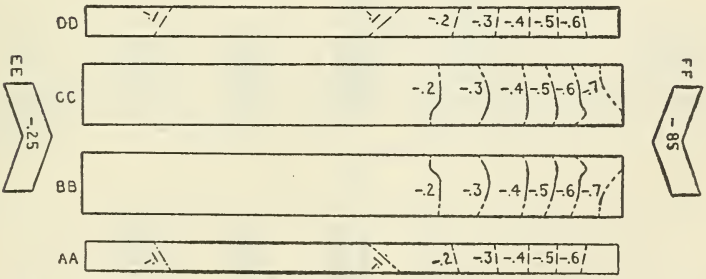

FIGURE 12.—*Distribution of pressure over the monitor, wind normal to face F*

See legend of Figure 4. See also Figure 9.

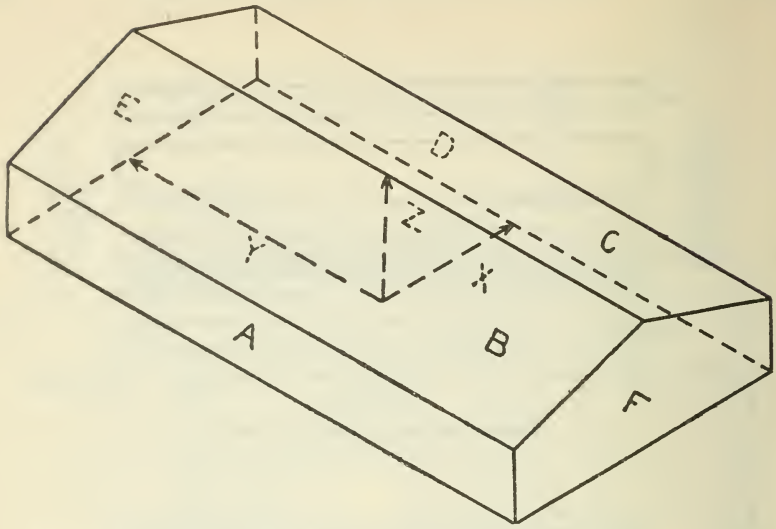

FIGURE 13.—*Direction of reference axes for components of the total force coefficient*

TABLE 4.—*Model mill building at various angles without monitor ventilator*

[The average and component values of p_w/q, and relative areas for each face]

Face of model	Relative area	p_w/q			
		Normal	X	Y	Z
0°					
A	1.000	+0.498	+0.498		
B	2.127	−.381	−.130		+0.358
C	2.127	−.563	+.191		+.529
D	1.000	−.518	+.518		
E	.681	−.620		+0.620	
F	.681	−.620		−.620	0
45°					
A	1.000	+.255	+.255		
B	2.127	−.441	−.150		+.415
C	2.127	−.774	+.263		+.728
D	1.000	−.517	+.517		
E	.681	−.449		+.449	
F	.681	+.372		+.372	
90°					
A	1.000	−.354	−.354		
B	2.127	−.381	−.130		+.358
C	2.127	−.381	+.130		+.358
D	1.000	−.354	+.354		
E	.681	−.205		+.205	
F	.681	+.615		+.615	

TABLE 5.—*Model mill building at various angles with monitor ventilator*

[The average and component values of p_w/q and the relative areas for each face]

Face of model	Relative area	p_w/q			
		Normal	X	Y	Z
0°					
A	1.000	+0.498	+0.498	----------	----------
B	1.805	−.238	−.081	----------	+0.224
AA	.161	+.441	+.441	----------	----------
BB	.346	−1.026	−.351	----------	+.965
CC	.346	−.560	+.192	----------	+.526
DD	.161	−.488	+.488	----------	----------
C	1.805	−.584	+.200	----------	+.549
D	1.000	−.518	+.518	----------	----------
E	.681	−.620	----------	+0.620	----------
EE	.033	−.913	----------	+.913	----------
FF	.033	−.913	----------	−.913	----------
F	.681	−.620	----------	−.620	----------
45°					
A	1.000	+.255	+.255	----------	----------
B	1.805	−.245	−.083	----------	+.230
AA	.161	+.180	+.180	----------	----------
BB	.346	−1.312	−.446	----------	+1.234
CC	.346	−1.370	+.466	----------	+1.288
DD	.161	−.938	+.938	----------	----------
C	1.805	−.691	+.235	----------	+.650
D	1.000	−.517	+.517	----------	----------
E	.681	−.449	----------	+.449	----------
EE	.033	−.762	----------	+.762	----------
FF	.033	−.160	----------	−.160	----------
F	.681	+.372	----------	+.372	----------
90°					
A	1.000	−.354	−.354	----------	----------
B	1.805	−.340	−.116	----------	+.320
AA	.161	−.197	−.197	----------	----------
BB	.346	−.251	−.086	----------	+.236
CC	.346	−.251	+.086	----------	+.236
DD	.161	−.197	+.197	----------	----------
C	1.805	−.340	+.116	----------	+.320
D	1.000	−.354	+.354	----------	----------
E	.681	−.205	----------	+.205	----------
EE	.033	−.250	----------	+.250	----------
FF	.033	−.850	----------	−.850	----------
F	.681	+.615	----------	+.615	----------

TABLE 6.—*Illustration of the computation to give the resultant value of the X, Y, and Z components of the force coefficient for the complete model with monitor ventilator, wind direction 0°*

X component of p_w/q		Y component of p_w/q		Z component of p_w/q	
Face	p_wA/q	Face	p_wA/q	Face	p_wA/q
A	1.000(+0.498) = +0.498	E	0.681(+0.620) = +0.422	B	1.805(+0.224) = +0.404
B	1.805(− .081) = − .146	EE	.033(+ .913) = + .031	BB	.346(+ .965) = + .334
AA	.161(+ .441) = + .441	FF	.033(− .913) = − .031	CC	.346(+ .526) = + .182
BB	.346(− .351) = − .121	F	.681(− .620) = − .422	C	1.805(+ .549) = + .990
CC	.346(+ .192) = + .066		0		+1.910
DD	.161(+ .488) = + .079				
C	1.805(+ .200) = + .361				
D	1.000(+ .518) = + .518				
	+1.696				
Total relative area projected on YZ plane		Total relative area projected on XZ plane		Total relative area projected on XY plane	
A	1.000×1.000=1.000	E	0.681×1.000=0.681	B	1.805×0.940=1.696
B	1.805× .342= .617	EE	.033×1.000= .033	BB	.346× .940= .325
AA	.161×1.000= .161		.714	CC	.346× .940= .325
BB	.346× .342= .118			C	1.805× .940=1.696
	1.896				4.042
Average $F_x/A_{yz}q=\frac{1.696}{1.893}=+0.894$		Average $F_y/A_{xz}q=\frac{0}{0.714}=0$		Average $F_z/A_{xy}q=\frac{1.910}{4.042}=+0.472$	

TABLE 7.—*The three components of the force coefficients for the entire model*

	Without monitor ventilator			With monitor ventilator		
	0°	45°	90°	0°	45°	90°
$\frac{F_x}{A_{yz}q}$	0.664	0.587	0.000	0.894	0.651	0.000
$\frac{F_y}{A_{xz}q}$	.000	.821	.820	.000	.811	.755
$\frac{F_z}{A_{xy}q}$	.472	.608	.381	.472	.608	.326

The second step is illustrated at length for one case in Table 6. The X, Y, and Z components of the average p_w/q for each face are multiplied by the area of the face relative to face A and the results summed. The areas of projection of the model on the YZ, XZ, and XY planes relative to the area of face A are then computed and the results of the summations are divided by the appropriate areas of projection to give the force coefficients for the X, Y, and Z directions. The components of the total force are denoted by F_x, F_y, and F_z and the actual areas of projection on the YZ, XZ, and XY planes by A_{yz}, A_{xz}, and A_{xy}. The final results for the whole model are given in Table 7.

VI. DISCUSSION

Some of the more striking features of the distribution will be described for purposes of emphasis.

Referring to Figure 4 for 0° (wind normal to face A), the distribution is substantially symmetrical with respect to the XZ plane. The pressure was measured at all of the stations on faces A, B, C, D, and F, but no measurements were made on face E, the results shown for this face being a copy of those for face F. Attention is called to the fact that the lowest pressures occur near the upstream edges of faces B, E, and F and that the pressure rises toward the rear. For face B it then falls again. The pressures over faces C and D show only small gradients. The highest pressures are on the windward face, A, but the largest forces are outward and are found on the end faces, where the average p_w is $-0.62\ q$.

At 45° (fig. 5) the windward faces, A and F, show the highest pressures near the upstream corner, and the pressure falls toward the rear, finally reaching values below the static pressure. The lee faces, D and E, again show nearly uniform values. The distributions over faces B and C illustrate the necessity of having a large number of stations if the distribution is to be accurately determined. The minimum pressures are found near the upstream corner of face B and near the ridge of the roof in face C. The largest force is outward and is found on face C, the average p_w on this face being $-0.77\ q$, but over a fairly large area, p_w, is lower than $-1.3\ q$, and hence that area is subject to forces per unit area nearly double the average for the face.

At 90° (fig. 6) the largest force occurs on the windward face F, the average pressure being $p_w = 0.62\ q$. The lowest pressures on faces A, B, C, and D are again concentrated near the upstream edges and appreciable areas are subject to loads approaching and somewhat exceeding twice the average loading.

A comparison of Figure 7 with Figure 4 shows that when the monitor is placed on the model (the wind being normal to face A) the distribution on face B is greatly modified. The lowest pressure is still near the junction of the roof and the wall, but the pressure changes fairly rapidly to a value of $p_w = 0.2\ q$ near the center and then more slowly to $p_w = 0.4\ q$ near the monitor. There is a great concentration of the contour lines at the corner of the monitor, the pressure changing rapidly from $p_w = 0.2\ q$ to $-1.0\ q$ as the corner is turned. The force on face B is reduced in magnitude by the presence of the monitor, the average pressure changing from $p_w = -0.38\ q$ to $-0.24\ q$.

The effect of the monitor on the distribution on face C at 0° is not so great. The principal change is the building up of a region of reduced pressure between the ends of the monitor and the ends of the building. The effect of these regions is to increase the force on the face by a small amount.

Comparing Figure 8 with Figure 5, with the wind at 45° the effect of the monitor is again to cause the absolute pressure over a considerable area of face B to be greater than the static pressure. The concentrated low pressures near the upstream edges are changed very little. There is a marked reduction in the force on face B, but the existence of the low pressure regions immediately adjacent to high pressure regions represents a rather severe type of loading. The force on face C also is reduced by the presence of the monitor.

The effect of the monitor at 90° (figs. 6 and 9) is very small. It is especially to be noted that the monitor does not in this case build up a region of increased pressure on the windward side.

Figure 10 shows the distribution over the monitor at 0°. The pressure on the windward face is nearly uniform and but little greater than the pressure on the roof of the main building adjacent to it. (Fig. 7.) The pressure on the lee faces of the monitor is nearly constant. The end faces *EE* and *FF* are subject to fairly large forces, the average pressure being $p_w = -0.91\ q$, but the greatest force is on face *BB* where the average pressure is $p_w = -1.03\ q$. The lowest pressures on face *BB* occur near the upstream edge.

At 45°, the pressures on the vertical faces of the monitor (fig. 11) follow in a general way the pressures on the adjacent parts of the roof. Faces *BB* and *CC*, however, show very complicated distributions. The forces on both faces are quite high, $p_w = -1.31\ q$ and $-1.37\ q$, and a minimum pressure of $p_w = -3.3\ q$ is observed on face *CC*. This is the lowest pressure which we have ever observed in measurements of wind pressure. Rather large areas are subject to pressures lower than $p_w = -2.0\ q$.

At 90° (fig. 12) the distribution over the monitor follows in a remarkable way the distribution over the main roof of the building. The most astonishing fact is that the windward face *FF* is subject to a pressure lower than the static pressure. It appears that the air deflected by the front face of the building is swept entirely clear of the monitor.

VII. NUMERICAL EXAMPLES

In order to illustrate the method of utilizing the data, a few numerical examples will be given for an angle of 45° for the complete model with the monitor. It will be assumed that the wind speed is 98 miles per hour as recorded by a Robinson 4-cup anemometer. Table 1 gives the true speed as 75 miles per hour and Table 2 gives the velocity pressure at this true speed as 14.39 lbs./ft.^{2} From Table 7, the *X* force coefficient is 0.651, the *Y* force coefficient 0.811, the *Z* force coefficient 0.608, and, hence, the resultant force on the building may be found by combining a pressure of 9.37 lbs./ft.^{2} on the area of projection on the *YZ* plane, a pressure of 11.70 lbs./ft.^{2} on the area of projection on the *XZ* plane, and a pressure of 8.75 lbs./ft.^{2} on the area of projection on the *XY* plane.

If it is desired to compute the resultant load on an individual face, some estimate must be made of the pressure within the building. By studying the diagrams and considering the probable location of windows and other openings, it appears that the pressure within the building might be anything from $p_w = 0.8\ q$ to $p_w = -1.4\ q$. Table 3 gives the values of p_w/q on the outer surfaces of the building. For example, for face *CC* at 45° with the monitor ventilator, the value given is $p_w = -1.37\ q$ corresponding to an upward force of 19.7 lbs./ft.^{2} at a true speed of 75 miles per hour. If the pressure within the building were $p_w = -1.4\ q$ caused by an open window in the monitor face *DD* (fig. 11), the average pressure on the face would be $p_w = +0.03\ q$, corresponding to a downward force of 0.4 lbs./ft.^{2} at a true speed of 75 miles per hour. If the pressure within the building were $p_w = +0.8\ q$ the differential pressure would be $p_w = -2.17\ q$, corresponding to an upward force of 31.2 lbs./ft.^{2}

VIII. SCALE EFFECT

As previously stated, measurements were made at three speeds, approximately 47, 60, and 80 feet per second. The ratios of the observed wind pressure to the velocity pressure for the three speeds were, in general, in very good agreement, the departure of a single observation from the mean of the three rarely exceeding 0.02. In a few instances in regions where the pressure gradient was very steep and the pressure was unsteady, there were systematic changes with speed. The number of such stations and the area represented by them is so small, however, as to be of no importance in computing the force coefficient. Over the range of speeds covered by the tests, the observations indicate that the scale effect is small.

It is the judgment of the authors that the results obtained on the model can be applied directly to full-scale structures without causing errors of any consequence. At present, this judgment can not be proved experimentally in a direct manner. It is based on studies of the available information, including actual experiments on bodies of many types, and under widely different conditions. The mechanism of scale effect is gradually becoming understood, and the reason for the large scale effect on bodies of rounded form, such as spheres, cylinders, and airship hulls is found in the development of the boundary layer theory. From the same reasoning, it is believed that the scale effect on bodies with sharp edges can not be very large, and is probably absent altogether. The engineer must accept the judgment of the aerodynamical physicist on this point unless he is willing to qualify as an expert in aerodynamics by study and experimentation.

IX. CONCLUSION

The experiments described in the paper show the distribution of pressure over a model mill building, with and without a monitor, when resting on a plane surface with the wind blowing parallel to the surface and at 0°, 45°, and 90° to the end of the building. The greatest wind loading occurred when the wind was at 45° to the walls. The loads on the roof of the monitor were greater than those on the roof of the main building, and were directed outwardly. The loads on appreciable areas of a face were often as great as twice the average over the entire face.

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