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VENTILATOR

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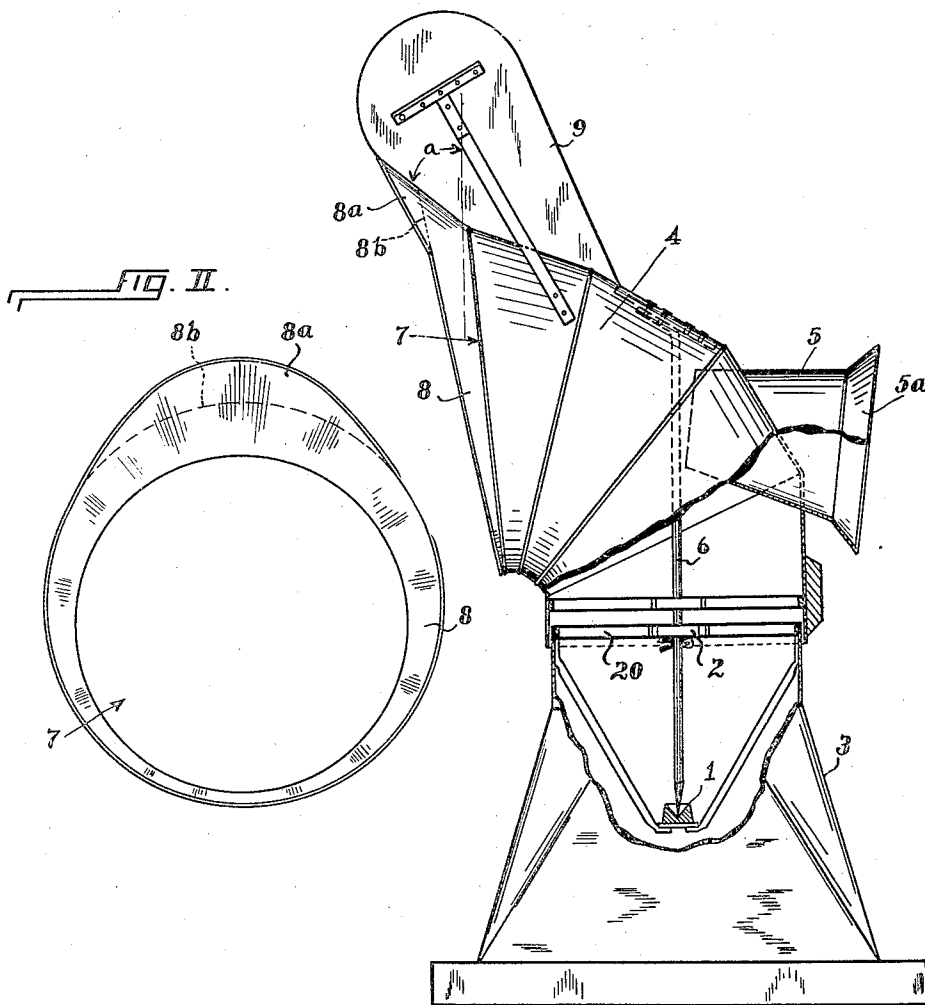


FIG. II.

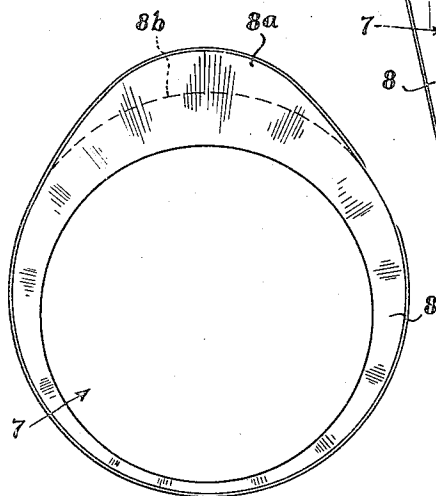


FIG. III.

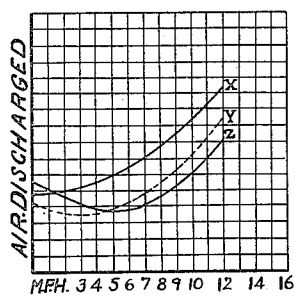


FIG. I.

INVENTOR

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UNITED STATES PATENT OFFICE

2,368,143

VENTILATOR

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1 Claim. (Cl. 98—70)

My invention relates to ventilators, particularly to exhaust ventilators of the sort illustrated and described in Letters Patent No. 1,639,187, granted to me August 16, 1927, and consists in certain refinements and elaborations in structure, by virtue of which, in accordance with the objects of the invention, maximum efficiency is obtained at low wind velocities.

A ventilator constituting an exemplary embodiment of the invention is illustrated in the accompanying drawing, in which:

Fig. I is a view of the ventilator partly in side elevation and partly in vertical section;

Fig. II is a view in front elevation of a certain flange that is arranged peripherally of the mouth or discharge opening of the ventilator;

Fig. III is a chart that indicates comparative efficiencies at low wind velocities.

In general, the construction of my improved ventilator compares with the ventilator of my above-noted patent, to which reference may be made for such features of structure as do not immediately concern my present invention. Briefly, the ventilator includes a tubular base 3 that in service is rigidly assembled over, or upon, the upper end of the duct or passage (not shown) that opens through the roof or deck of the building, or ship, or other enclosure, to be ventilated. Upon such base a curved cowl 4 is mounted for rotation on a vertical axis. In this case, the mounting consists in a spindle 6, rigid with the cowl, and a bearing block 1 that, borne by the base 3, vertically sustains the pointed end of said spindle. Lateral support for the spindle is provided by means of an anti-friction bearing 2, which bearing 2 is rigidly secured to the base 3, by means of a spider 20. As thus mounted, the cowl is adapted freely to rotate under the influence of the air currents or wind in the outer atmosphere in which the ventilator is in service situated, a vane 9 being instrumental in manifest and known way to maintain the cowl turned with its discharge opening or mouth 7 positioned down-wind. With the cowl maintained in such position, the air currents stream over the back and around the body of the cowl, and create an aspirating effect at the mouth of the cowl. Such aspirating effect, augmented by the buoyancy or stack effect of the air in the duct upon which the ventilator is mounted, produces the desired outward flow of air from the enclosure being ventilated.

An outwardly flaring flange 8, encompassing the discharge mouth 7, increases this aspirating

effect. As described in my said prior patent, an ejector tube 5 operates further to increase the air-exhausting capacity of the ventilator. The ejector tube is of frusto-conical form; and it projects through, and is rigid with, the posterior wall of the cowl, it is inclined to the vertical axis of the cowl, with its smaller end directed upward within the cowl and towards the mouth 7.

It will be perceived that the hollow base 3 of the structure is of substantially frusto-conical form, whereby the vena contracta effective upon air flowing upward into the cowl is minimized, and the flow is maintained as nearly streamline as may be.

Such is the character of the ventilator for which the improvements of my present invention have been particularly designed.

Before proceeding with a description of such improvements, it may be well to consider certain scientific data pertaining to natural (as distinguished from forced or mechanical) ventilation. Natural ventilation depends upon two factors—stack effect, and kinetic energy of wind. Stack effect is the buoyancy force that tends to move a column of air upward in a stack, the air in the stack being at higher temperature than the surrounding atmosphere. Stack effect is substantially independent of the action of wind in the outer atmosphere, and does not exist when the temperatures inside and outside of the stack are equal. An explanation of the effects of the kinetic energy of wind prevailing in the outer atmosphere is not so simple. Wind action follows different laws at different velocities.

In the flow of fluids in pipes, ducts, etc., it has been found that there are two critical velocities. Below the lower critical velocity the fluid moves in parallel lines and pressure-drop is due to viscosity only. Above the upper critical velocity the fluid moves in a turbulent manner, and pressure-drop grows as the square of the velocity. Between the upper and lower critical velocities the motion of the fluid is unstable and fluctuates between one or the other states of motion. These same circumstances apply to the movement of air in a ventilator.

The suction or aspirating effect of the ventilator depends upon the impact pressure of the wind upon the ventilator cowl and upon the viscous drag of the air, and it would appear that the force tending to discharge air from the ventilator is equal to the sum of stack effect and suction. And on such assumption it is possible to derive a pseudo-rational formula for the amount of air discharged through a ventilator mounted

on a roof. Other factors which would have to be assumed are, that the air inlet openings are all on the windward side of the building and that these openings are very large in comparison with the throat area of the ventilator.

The force produced by the buoyancy of a column of air H feet high, having an average temperature t_1 when the air temperature outside is t_0 , is

$$P_1 = H \text{ feet} \times$$

$$(\text{density of air in lbs. per cubic foot at } t_0) \times$$

$$\frac{t_1 - t_0}{t_0 + 460} \text{ degrees F.}$$

If P_1 is expressed in inches of water and t_0 is taken at 70° F., then

$$P_1 = \frac{H(t_1 - t_0)}{36,250}$$

where 36,250 is the ratio of the weight of 144 cubic inches of water to the weight of 1 cubic foot of air, multiplied by 530, which is equal to t_0 plus 460.

The force produced by the impact of the wind on the building and transmitted through the inlet opening to the interior is

$$P_2 = \frac{(\text{wind velocity})^2 \times \text{density}}{2g}$$

where g is the acceleration due to gravity or 32.2 feet per second per second; the wind velocity is expressed in feet per second; the density of the air is expressed in pounds per cubic foot, and the force P_2 in pounds per square foot of the area on which the wind is effective. In order that P_2 may be expressed in inches of water and the velocity of the wind expressed in the equation in miles per hour, the velocity of wind in miles per hour is multiplied by

$$\frac{5280 \text{ (=feet in mile)}}{3600 \text{ (=seconds in hour)}}$$

and the density of air (.0756 pound per cubic foot) is multiplied by

$$\frac{12 \text{ (=inches in foot)}}{62.4 \text{ (=wt. of water per cu. ft.)}}$$

or $1/5.2$. Thus, the equation becomes:

$$P_2 = \frac{V \text{ in miles per hour} \times \frac{5280^2}{3600} \times .0756}{5.2 \times 2 \times 32.2} = \frac{V^2}{2060}$$

The force produced by the suction of the ventilator is

$$P_2' = \frac{k_1 \times V^n \times \text{density}}{2g}$$

where k_1 is a constant depending on the type of ventilator, ranging from 0.0 in the poorest types to 0.5 for the best types. The exponent n depends on both the wind velocity and the type of ventilator, ranging between the limits of 1.0 for very low velocities to 2.0 for high velocities and efficient ventilators. Taking k_1 as 0.5 and n as 2.0, the equation

$$P_2' = \frac{k_1 \times V^n \times \text{density}}{2g}$$

thus becomes

$$P_2' = .5 \times V^2 \times \frac{\text{density}}{2g}$$

From the calculations above it will be seen that when the velocity of the wind is expressed in

miles per hour, and P_2 in inches of water, V^2 in the equation is multiplied by $1/2060$. Thus,

$$P_2' = .5 \times V^2 \times \frac{1}{2060} = \frac{V^2}{4120}$$

hence the total dynamic force would be

$$P_2 + P_2' = \frac{V^2}{1370}$$

In accordance with well-known formulae the velocity of air in feet per second equals $\sqrt{2g \cdot h}$, where h is the head of air, or the differential pressure between the upper and lower ends of the air column divided by the density of the air; that is

$$V = \sqrt{\frac{2g \times \text{differential pressure in pounds per sq. ft.}}{\text{density of air in pounds per cu. ft.}}}$$

The velocity of the air under the three pressures P_1 , P_2 and P_2' may thus be expressed:

$$V \text{ (in ft. per sec.)} = \sqrt{\frac{2g(P_1 + P_2 + P_2') \cdot 5.2}{\text{density in pounds per cu. ft.}}} = 0.348 \sqrt{H(t_1 - t_0) + 26.5 V^2}$$

A vena contracta is formed when the air enters the base of the ventilator, hence the quantity of air discharged is less than the product of velocity and area. There is, furthermore, some additional outlet resistance in the ventilator.

The overall coefficient of discharge depends on the location of the ventilator, whether located on a flat roof or a ridge; also on the form of the ventilator base, whether flaring or cylindrical, and on the freedom of exit of air. A high value for this coefficient is 0.69, which is obtainable only in a ventilator with a practically unrestricted outlet. In this case the discharge Q in cubic feet of air per hour would be

$$Q = 0.69A \times 0.348 \times \frac{3600}{144} \sqrt{H(t_1 - t_0) + 26.5 V^2}$$

where A = the area of the ventilator throat in square inches; or

$$Q = 6.4A \sqrt{H(t_1 - t_0) + 26.5 V^2}$$

Through careful tests, however, it has been found that these assumptions are incorrect, and that the formula must be empirically modified. The fact is that the two forces of suction and a stack effect do not add directly, for reasons with which this invention is not immediately concerned. Indeed, it appears that in combining these two forces there is introduced a resistance (a negative force) that makes the resultant force less than the sum of the two, and oddly enough at very low wind velocities there is actually a slight reduction in the discharge, below the point of discharge produced by temperature difference alone. This action, being the result of natural forces, has a tendency to take place in all ventilators. The less efficient the ventilator the greater is this reduction, and the greater is the wind velocity required to overcome it. The physical reason for this may be explained as follows: At low wind velocities there is a partial blanking-off of flow, due to the convergent streaming of wind currents around the outlet opening of the ventilator. This holds true for ventilators of both the rotary and stationary types. This blanking-off has its greatest effect in very low wind velocities. In the velocity range between one and four miles per hour, depending on the ventilator type, the critical velocity, known as the Osborne Reynolds velocity, is reached. This is the velocity at

which the fluid flow of air changes from the sinuous or stream-line form to the turbulent or eddying form of motion. If the wind velocity increases beyond this point areas of discontinuity are then formed in the wind stream around the ventilator, and the suction effect is much increased while the blanking-off effect is much reduced, or may even disappear altogether.

Whereas the flange 3 and the ejector tube 5 of my patented structure have done much to nullify this blanking-off effect at low wind velocities, the particular improvements of my present invention carry the nullification to the optimum. Specifically, I form on the upper limb of the eccentric, outwardly flaring flange 8 a lobe or flange extension 8a. Such lobe provides immediately above the top of the cowl, in position directly over the discharge mouth 7, a localized accentuation of the effect of the flange in the currents of air that stream externally from the back to the front of the cowl. Additionally, I flare outwardly the outer and larger end of the ejector tube 5, the effect being obtained by means of an outwardly flaring peripheral flange 5a. By virtue of these refinements practical perfection is realized.

The chart in Fig. III affords a ready appreciation of the situation. The abscissa represents velocity in miles per hour, and the ordinate the volume of air discharged per unit of time. The curve Z was plotted with data obtained in tests, under typical conditions in the field, on a conventional stationary ventilator, and the curve Y with the data obtained from a conventional rotary ventilator. It will be noted that both of these curves show a marked drop in discharge with wind velocities of between 0 and from 3 to 5 miles per hour, thus indicating that in the usual types of ventilators the negative effect produced by the external wind actually causes a drop in discharge below that which would be obtained with no wind at all. The X curve shows the results with the improved ventilator of my present invention. Significantly, there is no sag in the curve, and for all wind velocities of from 1 mile per hour upward a much greater discharge is obtained. At velocities above 12 miles per hour there may be ventilators in the art that will yield greater discharge than mine, but whether or not this is the case is of no controlling importance, because there never has been any problem in designing ventilators that are adequate in high wind velocities.

Since the blanking-off effect, if it occurs at all in my ventilator, is negligible, I have been able to arrive at a reliable equation for discharge capacity. The equation is:

$$Q = A \frac{36\sqrt{H(t_i - t_o)}}{6 + V} + 20 \times V$$

where the symbols represent the variables already defined. It is evident that in very few cases will the air inlets be always on the windward side of the structure being ventilated. Usually there are openings on the opposite side also and in this case the pressure P2 will be only a fraction of the impact pressure corresponding to the wind velocity. The inlet openings may also be shielded from the wind action by surrounding obstacles. Again, these openings are of finite size and some resistance therefore exists to the flow of air through them, slightly reducing the net or effective air-moving force. For the average conditions encountered in actual practice, with inlet openings of reasonable size,

this formula is conservative and allows a considerable margin for the factor of safety.

Obviously, the application of this formula should not be extended too far beyond the range of conditions for which it was developed. This range includes heights up to 75 feet, temperature differences up to 25° F. and wind velocities up to 15 miles per hour. On account of the regular form of the discharge curves resulting from the formula, it is believed, however, that there will occur no appreciable error in its use for extensions of as much as 50 per cent of these limits. This is of importance in some cases because of advantages to be gained through an elevated position of the ventilator, to make use of the greater wind velocities which prevail at higher levels.

In order that my improvements in ventilator structure may be fully understood and may be readily applied to ventilators of different sizes, I shall express the principal dimensions in percentage, with the diameter of the mouth of the cowl as the unit. The diameter of the flange 8 is substantially 122.9% the diameter of the mouth 7; the interval at which the center of the flange is spaced above the center of the mouth 7 is substantially 8.1%, and the extent of the lobe 8a above the crest of flange 8 is substantially 11.6% of the diameter of mouth 7. The outward flare of the flange and lobe will be understood by reference to the angle α between surface of such parts and a vertical line through the center of the mouth of the cowl, the value of the angle α being substantially 52°. The overall length of the ejector tube 5 is substantially 53.5% of the diameter of the cowl mouth, while the length of the ejector tube without the flange is substantially 44.2%. The diameter of the inner end of the ejector tube is substantially 28%; the diameter of the tube at the region of junction with the flange 5a is substantially 44.2%, and the diameter at the outer end of the flange is substantially 58.2%, of the diameter of the mouth of the cowl.

The lobe 8a is symmetrical with respect to the vertical center line of cowl mouth 7, and, extending through substantially 28% of the periphery of the flange 8, the lobe is at its edge curved to merge with the curved edge of flange 8.

As above indicated the ventilator of the invention has been designed with efficiency at low wind velocities given foremost consideration. While the laws of aerodynamics have been given precedence over artistic merit, it will be perceived that the latter has not been sacrificed. This is a matter of practical importance, inasmuch as the ventilator in service will be exposed to view on the roofs of buildings, or above the decks of ships, or in other locations where architectural merit is required. Within the ambit of the appended claim certain modifications are permissible.

I claim as my invention:

In a ventilator comprising a base, a cowl mounted on said base for rotation on a vertical axis, the mouth of said cowl extending in an approximately vertical plane, an upwardly flaring flange extending peripherally of and arranged eccentrically of said mouth, the breadth of such eccentric flange being maximum at the top of said mouth, and an ejector tube opening through the wall portion of the cowl opposite to said mouth; the improvements herein described that afford increased ventilator efficiency at wind velocities of six miles per hour and less,

said improvements comprising an outwardly flaring peripheral flange on the outer end of said ejector tube, and a flange portion or lobe integral with said eccentric flange, said flange portion or lobe being centered above the mouth of said cowl and flaring upwardly and outwardly from said eccentric flange, said flange portion or

lobe being of maximum breadth on a vertical plane that bisects said mouth of the cowl and of gradually decreasing breadth on opposite sides of said plane and merging with the periphery of said eccentric flange at points spaced substantial intervals from said point of maximum breadth.

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