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Wind Effect on Fans

By

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Introduction:

Air flows through a building as a result of the difference in pressure set up across its openings. This pressure is due to the effect of one or more of three agencies, namely (a) wind effect, (b) thermal effect (temperature difference) and (c) fan effect.

Wind effect and thermal effect are natural agencies, but fans are artificial means which may be controlled to move a certain volume of air through the building. Fans work against resistance offered by surfaces (e.g. of ducts) over which the air has passed, and inlets and outlets though which it must move. Therefore a fan is selected accordingly, able to overcome these resistances and provide the designed rate of air flow.

The effect of wind manifests itself as a pressure or suction on building surfaces. In a fan ventilated building, pressure head across an opening in the building caused by wind effect may represent several times that caused by the fan or thermal effect. consequently the design conditions of this building can be obtained if the external wind situation is calm.

Wind pressure effects are known seriously to interfere with fan working (kloeppel 1969) and may impair fan efficiency. This problem is thought to be the major reason for the failure to maintain the optimum temperature in buildings (7).

The ways by which the wind can affect a fan ventilated system can be written as:-

a) Change in the resistance set up on the fan due to the change in the internal building pressure.

b) Change in external pressure as follows:-

   1- "Back pressure" set up on the fan. In a very high wind this pressure may seriously affect the fan causing damage.

   2- Wind pressure on the plane of the openings affecting the air flow rate through these openings and in turn the internal flow pattern and velocity distribution.

   3- In high wind cases, the possible reversal of direction of air flow through the building openings.

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C. 92 A.H.A. REHEEM

The interaction between wind effect and fan ventilation systems was a subject investigated through a series of tests. Models of buildings were employed and an artificial air stream was obtained using a boundary layer windtunnel. The tunnel used a one metre square cross - section. The validity of using models in these tests had been confirmed in previous work by comparision of results obtained from a full scale outdoor building and its model(2).

One of the main points in the study was the resistance set up on the fan due to wind effect. Measurements were made on a model constructed from perspex sheet being 297mm long, 196mm wide and 157mm to the ridge; eaves height was 107mm. The model was equipped with removable panels in the windward and leeward walls. A pair of panels, was prepared each with 23mm diameter opening and a further pair with pressure tappings could be substituted. Measurements of the internal and external pressures could, therefore, be made on the same model.

LIST OF SYMBOLS:

CP_t	Internal pressure coefficient of fan ventilated building.
CP	Wind pressure coefficient at the plane of the opening, suffixes wand L refer to the coefficient at the windward and leeward openings respectively, $CP = \frac{P}{\frac{1}{2}\rho V_h^2}$
P_0	Free stream static pressure
P	Wind pressure at the plane of an opening with respect to the static pressure Po, suffixes wand L refer to windward and leeward openings respectively.
ΔP_f	Internal pressure of fan ventilated building under wind effect with respect to the free stream static pressure P_0.
Q_f	Extracted or pressurized volume rate of air flow by the fan corresponding to ΔP_f.
R_d & R_s	Resistance set up on the fan due to wind effect.
R_t	The actual resistance set up on the fan due to wind effect, a function of R_d and R_s.
V_h	Free stream wind speed.
ρ	Mass density of air.

EXPERIMENTAL TECHNIQUE:

If a fan in a building has to move a constant quantity of air Q_f corresponding to static pressure SP_1 as shown in the volums pressure curve of the fan Fig. (1), then under wind conditions the fan should overcome the increase or resistance occurring as a result of the wind effect. If the total pressure of the fan is, therefore, increased (perhaps by raising the fan speed) to overcome the increase in resistance, a new fan characteristic curve is obtained. The total static pressure in this case becomes SP_2' the increase in resistance therefore being $SP_2 - SP_1$.

This concept was utilized to facilitate the experimental measurements made using the model building in the wind tunnel where the use of a small scale fan is not possible. The experiments were made for an extraction ventilation system but the analysis includes both extraction and pressurized systems. The model was connected to a vacuum pump as shown in Fig. (2). While the tunnel fan was stationary, air was extracted at a constant rate and the corresponding internal pressure Δp_f measured. This represented the case of the fan working in still air. For the case of wind effect, the wind-tunnel was switched on and the speed V_h of the free stream measured. Since the vacuum device was then working under the effect of the tunnel static pressure the extraction rate was accordingly changed. This could be seen in the reading of the manometer connected with an orifice plate tubs (Fig. 2). The extraction rate then corrected to restore the original flom Q_f. The effect of the wind-tunnel pressure on the vacuum pump was thus eliminated.

The wind speed V_h of the tunnel was varied over the range of 2 m/sec to 9m/sec for each speed the internal pressure ΔP_t was recorded after correction of the extraction rate (i.e.the Q_f.).

Wind pressure measurements were made while the model was equipped with the pressure tapping plates. The pressures ΔP_w and ΔP_1 were taken at the centre of the windward and leeward openings respectively.

The internal and external wind pressures were measured with respect to the free stream static pressure P_o as a datum. The free stream velocity pressure $\frac{1}{2} \rho V_h 2$ was used for obtaining the dimensionless internal and external pressure coefficients.

The experiments were made with the wind direction normal to the long sides of the model.

BUILDING INTERNAL PRESSURE:

Internal pressure for a building with two equal openings can be expressed as shown in equations (1) and (2) Ref (1) as:-

$$\Delta P_t = \Delta P_f + \frac{\rho^2 V_h^4}{64 \; \Delta P_f} (CP_w - CP_1)^2 + \frac{\rho V_h^2}{4} (CP_w - CP_1) \quad ..(1)$$

and

$$\Delta P_t = \frac{\rho V_h^2}{4} (CP_w + CP_1) \pm \tfrac{1}{2} \left[-16 \Delta P_f^2 - 4 \Delta P_f \rho V_h^2 (CP_w - CP_1)\right]^{\frac{1}{2}} \quad ..(2)$$

The first equation (1) is to be applied in conditions defined as low wind. Here the flow direction through the openings is dominated by the fan.

The second equation is to be applied in cases of high wind, i.e., where the airflow through the openings is dominated by the wind. Here the external pressure on the plane of the windward opening in the case of a pressurized system, or leeward opening in an extraction system is strong enough to reverse the flow direction through the opening. The curves of the two equations meet tangentially at a point in which the pressure drop across the considered opening is zero, and in turn the rate of flow is zero.

The internal pressure of this type of building can also be expressed in the term of the pressurs coefficient (instead of the pressure difference) and equations (1) and (2) become respectively:-

$$CP_t = \frac{2 \Delta P_f}{\rho V_h^2} + \frac{\rho V_h^2}{32 \Delta P_f} (CP_w - CP_1)^2 + \tfrac{1}{2} (CP_w + CP_1) \quad ...(3)$$

$$CP_t = \tfrac{1}{2} (CP_w + CP_1) \pm \tfrac{1}{2} \left[\frac{-64 \Delta P_f^2}{\rho^2 V_h^4} - \frac{16 \Delta P_f}{V_h^2} (CP_w - CP_1)\right]^{-\frac{1}{2}} \quad ...(4)$$

Equations 1 to 4 may be used for extraction as well as pressurized ventilation systems.

In cases of unequal openings or the number of openings being more than two the solution for the internal pressure coefficient is obtained through the use of a computer calculation. The equation needing to be solved increases in degree with the increase in the number of openings.

Observed results obtained from the model, were plotted together with calculated rasults obtained from equations (1) and (2) these are shown in Figs. (3), (4) and (5). The three figures are for three different rates of air flow. Close agreement can be shown particulary in Fig. (3) and (4) small differences between calculated and observed results are shown in Fig. (5). However with making allowance for loss of energy of the flow passing through the opening close agreement was obtained as shown in Fig. (6).

THE RESISTANCE TO THE FAN DUE TO WIND EFFECT:

In the experimental measurements, since the extraction rate Q_f by the fan was kept constant during the measurements of the internal pressure ΔP_t, it was expected that, with the additional increase of wind speed V_h, the internal pressure would be lower than the original pressure set up by the fan ΔP_f. This would be due to the increase of the fan total pressure required to overcome the effect of wind working to drive the air out of the building through the leeward opening. However, an unexpected phenomenon was noticed during the measurements. The internal pressure reading increased with the increase of wind speed from the lower limit of speed used, and reached a maximum at a certain wind speed. It started to decrease after this point to a lower value than ΔP_f as shown in Fig. (3) and (4). In Fig. (5) the original pressure ΔP_f was small (i.e. Q_f was small) and the phenomenon could not be realized clearly.

There are two points to be noticed in Figs. (3) and (4),

i) The phenomenon mentioned above and the point of maximum internal pressure both fall in the range of wind speed defined as low wind.

ii) The position of the point of maximum internal pressure is dependant on the original pressure ΔP_f set up by the fan.

Since the internal pressure in the range of low wind speed obeys equation (1), then to investigate this phenomenon and the wind resistance on the fan, the terms of the equation were considared in turn. Four situations of wind pressure coefficients at the plane of the openings in the building were analysed as follows:-

a) If the external wind pressure on the windwerd opening is equal to that on the leeward opening and both are positive.

b) If the external wind pressue coefficients are equal on both sides but both are negative.

c) If the external positive wind pressure coefficient on the windward opening is numerically equal to that negative pressure coefficient on the leeward opening.

d) If the external pressure on the windward opening is not equal to that on the leeward opening.

In equation (1) it can be seen that the internal pressure is the sum of three terms. ΔP_f is the original internal pressure set up within the building by the fan in still air (i.e., no wind effect). The term $\frac{1}{2} \rho V_h^2$ $(CP_w + CP_1)$ is the original pressure that would be set up within the building by the wind if the fan was not in use. The third term consists of terms of fan pressur and wind pressure.

Taking case (a) above, equation (1) in this case became:-

$$\Delta P_t = \Delta P_f + \frac{1}{4} \rho V_h^2 \ (CP_w + CP_1) \quad \text{..................} (5)$$

Where the other term of the equation (1) in this case is zero.

Since ΔP_f in the extraction system is negative (with respect to ambient pressure) therefore, it can be seen in equation (5) that the introduction of wind increases the internal pressure ΔP_t to greater than the original pressure ΔP_f. The increase in this case is represented by the term $\frac{1}{4} \rho V_h^2$ $(CP_w + CP_1)$ and this increases with windspeed. This case reduces the resistance which the fan has to overcome by a value equal to this term.

If with the same building a pressurized ventilation system were used, the pressure ΔP_f would be positive and, therefore, ΔP_t would increase by the same amount as in the case of the extraction system. The pressure which the fan has to resist would increase by a value equal to the same term $1/4 \rho V_h^2 (CP_w+CP_l)$. This term is then the new resistance R_t to the fan due to the effect of wind. In order for the designed rate of air flow to be obtained, therefore, the fan total pressure should be modified to balance the new resistance.

In case (b) where the wind pressure coefficients at both openings are equal and negetive, the internal pressure is expressed also by equation (5). As in case (a), the term $1/4 \rho V_h^2 (CP_w+CP_l)$ repressents the resistance R_t to the fan due to wind effect.

In case (c) in which the positive wind pressure coefficient on the windward opening is numerically equal to the negative coefficient on the leeward opening, equation (1) becomes:-

$$\Delta P_t = \Delta P_f + \frac{\rho^2 V_h^4}{64 \Delta P_f} (CP_w - CP_l)^2 \quad \text{.................(6)}$$

The other term included in equation (1) has become zero in this case. The internal pressure ΔP_t decreasese with the increase of wind speed if the system is one of extraction. It is the contrary in the case of a pressurization system where ΔP_t increases with the increase of wind speed. The change in ΔP_t is equal to the second term of equation (6). This represents the resistance R_t in this case. Since both terms included in equation (6) have the same sign as ΔP_f, then the resistance on the fan will increase due to wind whether the ventilation is by extraction or pressurization.

In case (d) where the pressure coefficients are dissimilar the internal pressure is that of equation (1). The increase in the internal pressure over ΔP_f due to wind affect is expressed as :-

$$R_t = 1/4 \rho V_h^2 (CP_w+CP_l) + \frac{\rho^2 V_h^4}{64 \Delta P_f} (CP_w-CP_l)^2 \quad \text{........(7)}$$

Where R_t is again the resistance on the fan due to wind effect.

Now consider the case of a building with two equal openings but ventilated naturally by wind. There are two cases in which the internal pressure comes to zero (with respect to the free stream static pressure),

i) If the outside wind condition is calm.

ii) If the positive wind pressure coefficient on the inlet is numerically equal to the negative wind pressure coefficient on the outlet.

In case (i) there will be no air passing through the buildind (with the assumption of isothermal conditions), but in case (ii) air will flow through the building. If the fan is introduced in case (i) the internal pressure is ΔP_f. But if the fan is introduced to case (ii) then although the datum internal pressure is similar to that in (i) of still air, the internal pressure will not be ΔP_f. It is equal to that of equation (6).

From these comparisons, it was concluded that the second term of equation (6) is a force working to drive the air out of the building. If this force is designated R_d then.

$$R_d = \frac{\rho^2 V_h^4}{64 \Delta P_f} (CP_w - CP_l)^2 \quad \ldots\ldots\ldots\ldots\ldots (8)$$

It is increased with the increase of wind speed and decreased with the increase of the original pressure ΔP_f set up by the fan. It is of course equal to zero in still air.

If in a building the coefficients of pressure $CP_w = CP_l$ the force R_d is then equal to zero. Since the internal pressure is expressed by equation (5) then it can be concluded that the second term in this equation (i.e., $1/4 \rho V_h 2 (CP_w + CP_l)$) represents a new pressure datum replacing the zero datum of the case of still air.

It becomes clear that, the three terms included in equation (1) are the original pressures ΔP_f set up by the fan, internal static pressure $R_s = 1/4 \rho V_h 2 (CP_w + CP_l)$ (being the new datum set up in the building) and a force R_d working to move the air to outside in the direction of the wind. Since R_s and R_d represent a pressure set up on the fan due to wind effect, then the total resistance R_t due to wind is expressed as:-

$$R_t = R_s + R_d \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

The phenomenon appearing in Figs. 2 and 3, which was noticed during measurements of the internal pressure are explained. When the speed of wind was low, the resistance R_d which takes the same sign as the original pressure ΔP_f was small compared with the positive pressure R_s producing the new datum. In this case the internal pressure increased, but when wind speed rose to a level at which the resistance R_d become higher than the positive pressure R_s then the internal pressure was decreased.

In the case of high wind, the low wind speed equation (i.e., equations 2 and 4) cannot be applied in two of the four situations of the external wind pressure coefficients stated previously. In cases (a) and (b) the flow would not reverse direction through any of the openings under any circumstances of wind speed for any of the ventilation systems. The fan in these cases dominates the direction through the openings. The situation is different in cases (c) and (d).

In case (c), equation (2) of the high wind case becomes:-

$$\Delta P_t = \pm \tfrac{1}{2} \left[-16 \Delta P_f 2 - 4 \Delta P_f \rho V_h^2 (CP_w - CP_l) \right]^{\frac{1}{2}} \quad \ldots\ldots\ldots\ldots (10)$$

Where the first term in the equation (2) is zero. The resistance R_d in this case therefore is:-

$$R_d = \pm \tfrac{1}{2} \left[-16 \Delta P_f 2 - 4 \Delta P_f \rho V_h^2 (CP_w - CP_l) \right]^{\frac{1}{2}} - P_f \ldots (11$$

The sign is dependent on the system of ventilation, being negative in the case of extraction. The force R_d in this case represents also the force R_t on the fan.

In case (d) of wind pressure coefficient, the resistance R_t expressed as:-

$$R_t = \left[\frac{\rho V_h^2}{4} (CP_w + CP_1) \pm \left[-16\ \Delta P_f^2 - 4\ \Delta P_f\ \rho V_h^2 (CP_w - CP_1)\right]^{\frac{1}{2}}\right] - \Delta P_f \quad \ldots\ldots(12)$$

In cases of buildings with more than two openings or with unequal openings the problem of obtaining the resistance R_t becomes complicated. The degree of equations needed to be solved for R_t increases with the increase in the number of openings in the building.

The observed R_t obtained from the model used, as $R_t = \Delta P_t - \Delta P_f$ was plotted against the speed of wind $\bar{V}_h$ as shown in Figs. (7), (8) and (9). The computed results for the same model using equation 7 and 12 were also plotted in the same figures. It can be seen that, there is close agreement between the results plotted.

The back pressure caused by the wind on the fan can be taken in addition. This pressure can be computed for any wind speed if the wind pressure coefficient at the position of the fan in the building is known. This can be obtained through wind-tunnel tests.

SUMMARY AND CONCLUSIONS:

A model building with two equal openings was used in a boundary wind-tunnel for study of the effect of wind on a fan ventilated building.

Results obtained from the model were compared with computed results using mathematical equations expressing the internal pressure and resistance set up on the fan due to wind effect.

From the analysis made it can be concluded that the effect of wind is a result of two actions which in turn produce the resistance R_t:

i) Wind sets up a static pressure R_s representing the new datum replacing the zero datum from which the fan was working in the case of still air (the ambient pressure is a datum). This pressure is a function of the wind pressure coefficients at the plane of the openings and wind speed. It increases with the increase of wind speed. For cases of buildings with two equal openings it is expressed as $1/4\ \rho V_h^2\ (CP_w + CP_1)$ both for cases of extraction and of pressurization ventilation systems for any wind speed.

ii) Wind sets up a force R_d working to drive the air out of the building in the direction of wind. This force is dependent on the pressure ΔP_f, wind pressure coefficients at the plane of the openings and wind speed. It increases with the increase of wind speed and wind pressure coefficients and decreases with the increase of ΔP_f. For cases of two equal openings this force is expressed by equations 8 and 11 for low and high wind cases respectively. They may be equally used with pressurized as well as extraction systems.

The force R_d is working against the fan whether the system is extraction or pressurization. But the pressure R_s may assist or oppose the fan according to the type of the system and wind pressure coefficients at the openings.

The R_s, R_d and in turn R_t are also functions of the energy losses through the openings.

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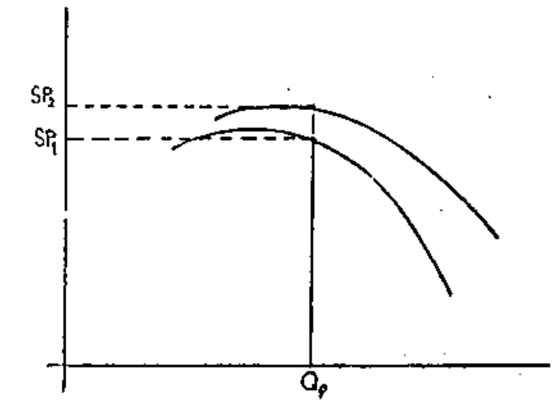

Fig (1) Volume-pressure curve of fan.

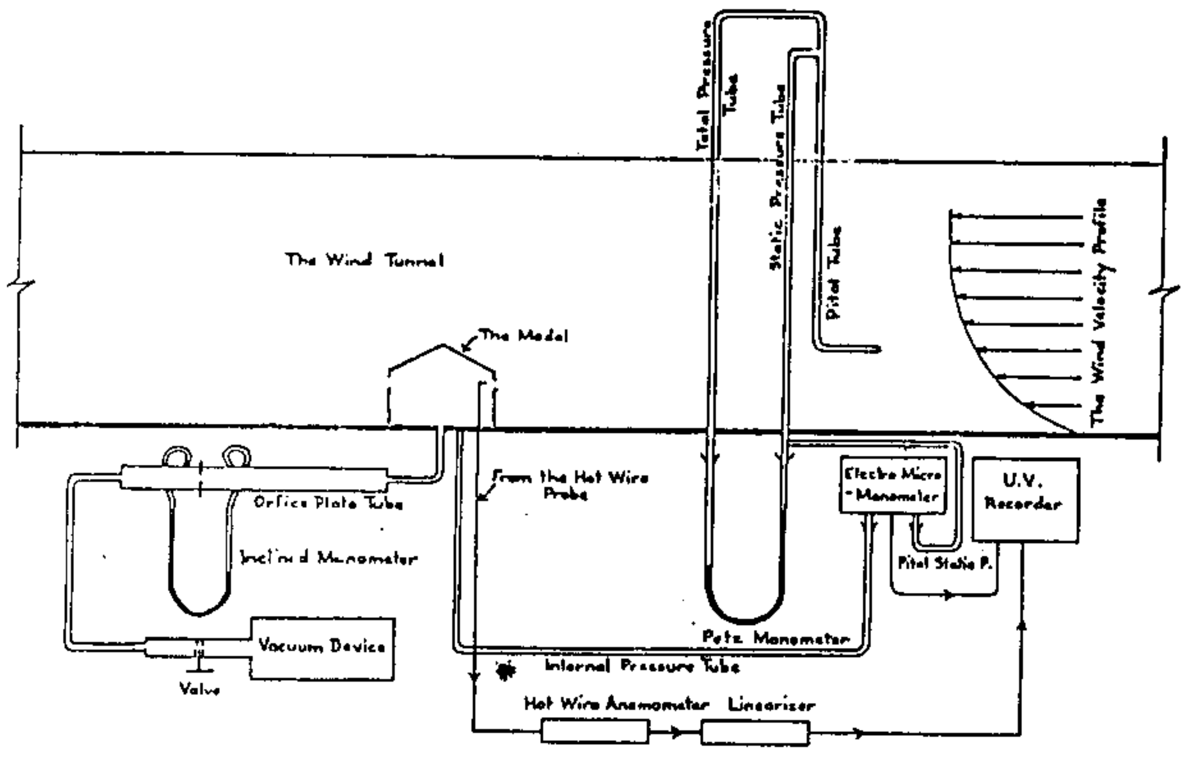

Fig. (2) Schematic diagram of the model in the wind tunnel and instrumentation arrangement for measuring the internal pressure and inlet velocity.

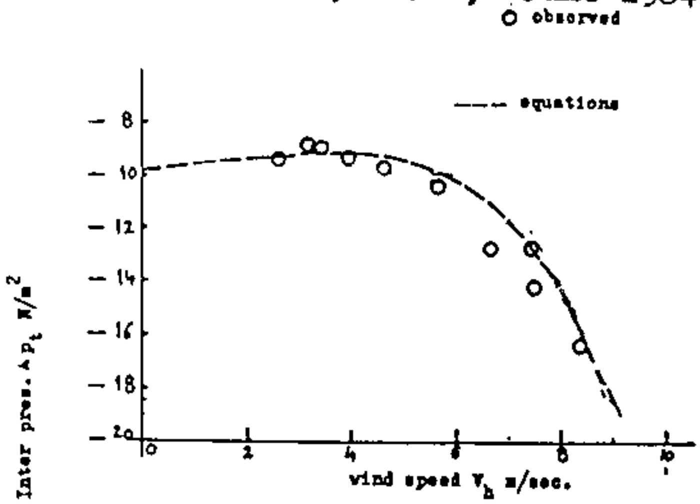

Fig.(3) Computed and observed internal pressure
(Δp_f = -9.81 N/m^2)

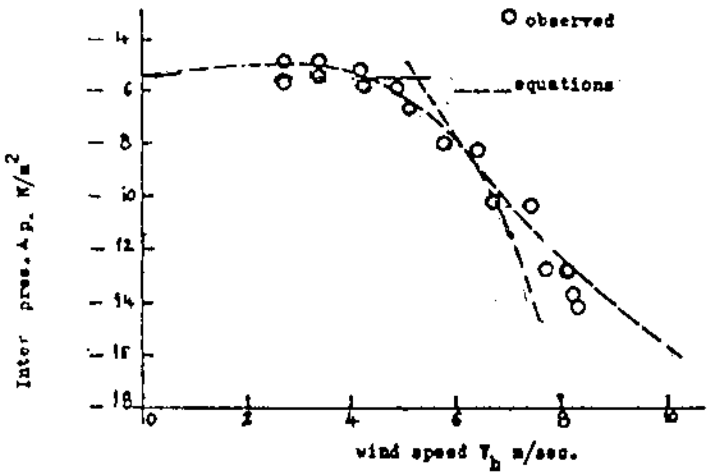

Fig.(4) Computer and observed internal pressure
(Δp_f = -5.39 N/m^2)

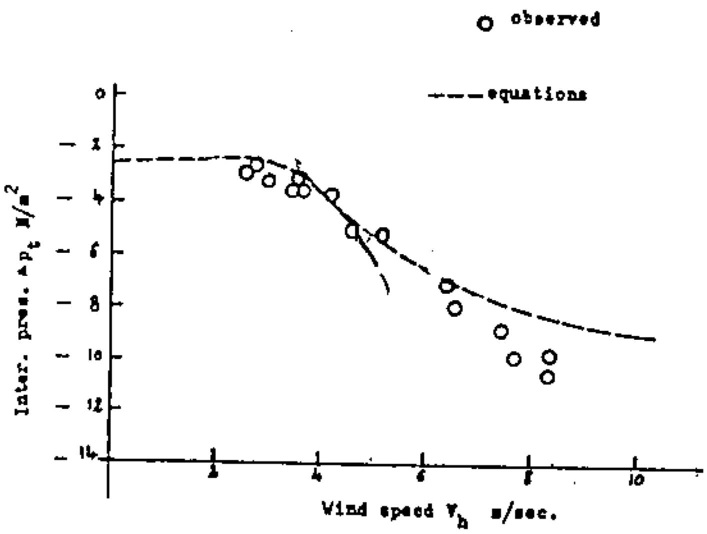

Fig.(5) Computed and observed internal pressures
(Δp_f = -2.5 N/m^2)

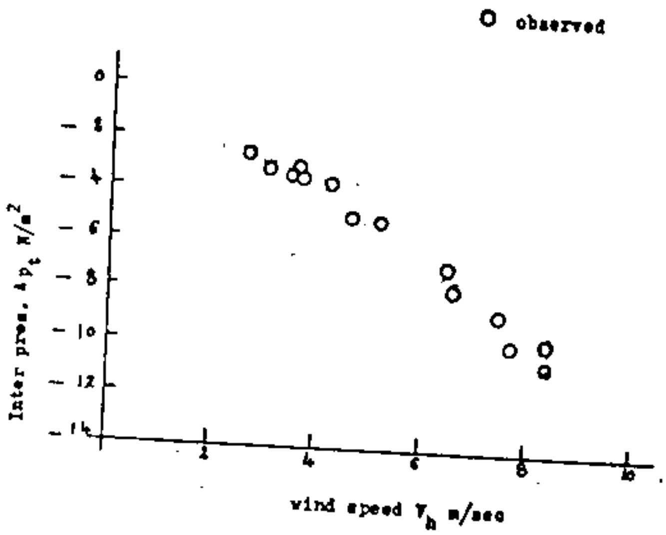

Fig. (6) Computed and observed internal pressures
Δp_f = -2.5 N/m^2)

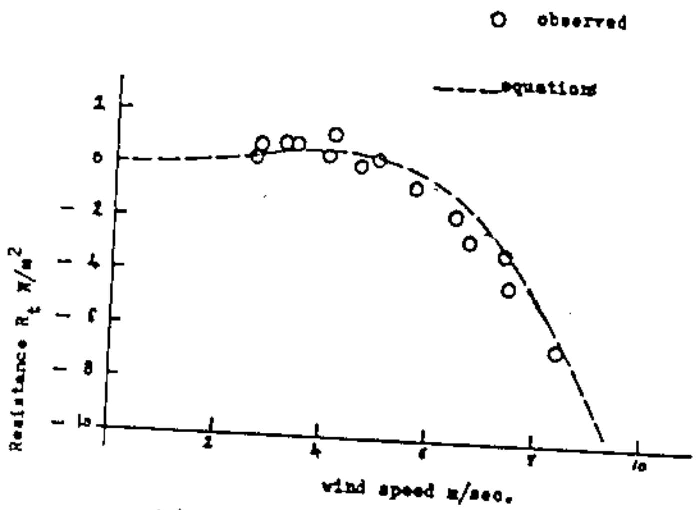

Fig.(7) The variation of the resistance R_t with wind speed.

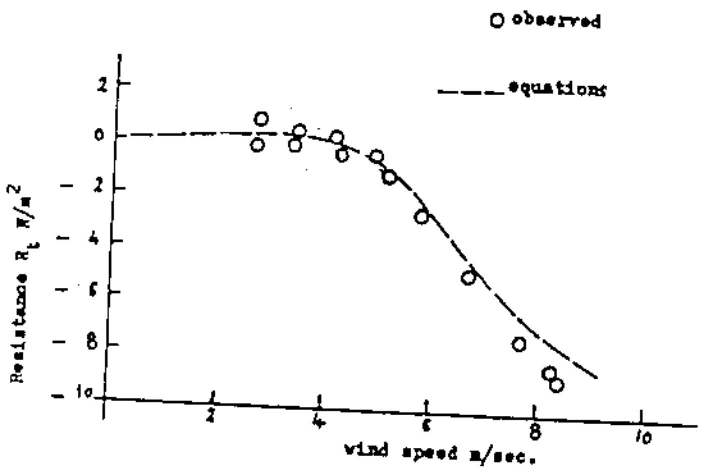

Fig.(8) The variation of the resistance R_t with wind speed.

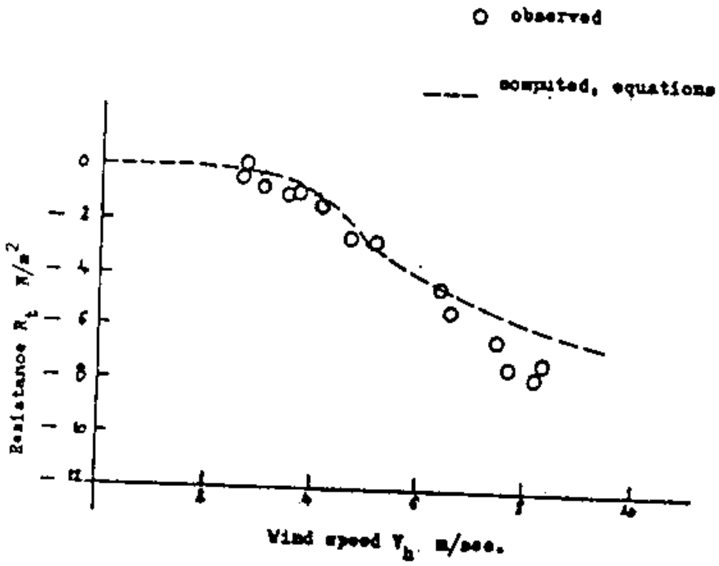

Fig. (9) The variation of the resistance R_t with the wind speed.