

Mutual interference effects on the wind pressure distribution on two low-rise prismatic bodies

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In this paper, the wind pressure distribution on the various faces of two prismatic bodies with square cross-section and height to width ratio (h/b) of 1 and 3 are investigated. The mutual interference effects when the bodies are in tandem arrangement are considered. The pressure distribution is significantly altered when the interfering body (either $h/b = 1$ or 3) is in front.

Buildings can be usually considered as three-dimensional in nature as they have finite length to width ratios and height to width ratios. Further, they usually have sharp edges and are earth bound. Hence results of wind pressure distribution on prismatic bodies which act as scaled models can be used to obtain the wind loading on such structures. When a structure has a height to width ratio (h/b) of less than 3, it is considered as a low-rise structure and when (h/b) is greater than 3, as a high-rise structure¹. The distribution and magnitude of wind pressures on the various faces of a building can be expected to be strongly dependent on the approach flow conditions, building geometry and the relative dimensions. Another aspect, which would significantly influence the wind loading on any structure, is the 'interference' effects.

There are several investigations which deal with the measurement of wind loads on buildings exposed to different approach conditions. Several researchers¹⁻⁵ have investigated the wind pressure distribution on the various faces of three-dimensional prismatic bodies of different sizes and also exposed to different wind conditions. Meroney⁶ has reviewed the flow around simple rectangularly shaped bodies obtained from wind tunnel studies of mean surface pressure patterns and has suggested the need to accurately document the pressure measurements on the surface of buildings of different sizes exposed to different approach flow conditions.

As mentioned earlier, interference effects of one building located in the vicinity of another can be expected to significantly influence the wind pressure distribution. In practical situations, such

'interference' occurs quite commonly and its importance is highlighted by Kareem⁷. Gowda and Sitheeq^{8,9} have investigated the interference effects on the wind pressure distribution on a prismatic body with $h/b = 3$ exposed to mild and high shear velocity profiles. In another study, Gowda and Sitheeq¹⁰ have described the interference effects on two low-rise ($h/b = 1$) and two high rise ($h/b = 5$) bodies in tandem arrangement. Recently, Gowda *et al.*¹¹ have studied the influence of buildings of different heights ($h/b = 1$ and 5) arranged one behind the other.

The present investigation is a continuation of the above series of experiments to systematically understand and bring out the severity of interference effects on the wind loads on buildings. Here, bodies with square cross-section and height to width (h/b) ratio 1 and 3 are used. The sizes chosen belong to low-rise category and are relevant to practical building aerodynamics problems. Two cases have been considered:

1. When the body with $h/b = 1$ is the principal body (PB; provided with pressure taps) and body with $h/b = 3$ is the interfering body (IB; dummy body without pressure taps).
2. When the body with $h/b = 3$ is the PB and the other one ($h/b = 1$) is the IB.

In each case IB is located both in front and behind the PB and the gap between the two is varied systematically. The study is carried out for an approach velocity profile satisfying the $1/7^{th}$ power law, which corresponds to open country terrain.

Experimental Procedure

The measurements are carried out in the low-speed, straight-through, suction-type wind tunnel of our laboratory. The layout of the wind tunnel is shown in Fig.1. It is essentially the same as that used earlier. Air enters the test section after passing through a bell mouth entry, a honey comb, a settling chamber, with three screens and a smooth contraction (contraction ratio 9). The test section is 600 mm × 600 mm and 2125 mm long. This is followed by a transition and a diffuser with circular cross-section having 5° included angle. A fan, driven by a 27 kW DC motor, is fixed at the end of the diffuser.

A shear velocity profile, 500 mm in height ($\delta = 500$ mm; Fig. 2) satisfying a power law with an exponent

$n = 1/7$ is generated using the method suggested by Cowdrey¹². For this purpose a grid made of 10 mm smooth mild steel rod is made use of. This velocity profile of 500 mm thickness is first realised at a distance of 430 mm from the grid. The velocity profiles at several other down-stream distances from the grid are measured and found to satisfy the $1/7^{\text{th}}$ power law, i.e., the shape of the profile remains the same beyond 430 mm from the grid. The two-dimensionality of the flow field in the test section was examined by measuring the velocity profiles at two span-wise locations on either side of the centre (± 150 mm), at a station 950 mm from the grid. The two profiles are almost identical, indicating two-dimensionality in the region of interest of the present

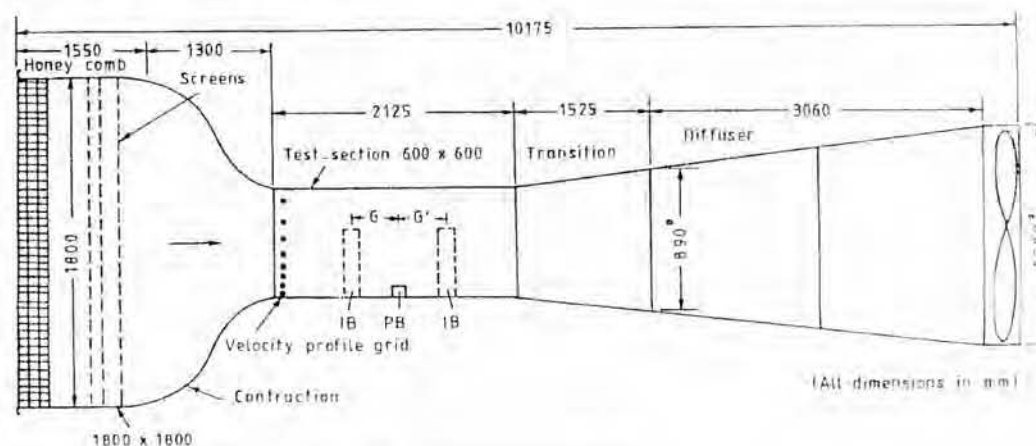


Fig. 1—Experimental set-up

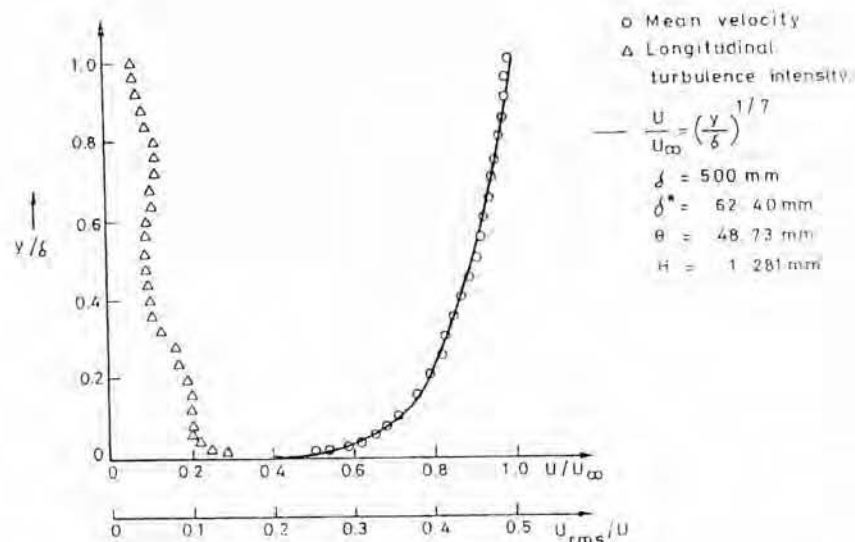


Fig. 2—Mean velocity and longitudinal turbulence intensity profiles in the wind tunnel

investigation. Fig. 2 shows the mean velocity profile measured along a vertical line in the central plane of the tunnel at the location where the principal body is placed. The characteristic parameters of the boundary layer are also given in the figure. For the measurement of the mean velocity, a standard pitot-static tube with a tip diameter of 3 mm was used. A linearised hot wire anemometry system (DISA 56 C01 with other accessories) operated in the constant-temperature mode was used to obtain the turbulent quantities.

All the models used in the present study are made out of 10 mm thick plexiglas sheets. Models have square cross-section (60 mm×60 mm) with sharp edges. The principal bodies (either $h/b = 1$ or 3) have surface pressure taps (1 mm diameter) along the centre line on all sides (except the bottom) at intervals of 5 mm. The model is hollow to facilitate the connection for pressure taps. The interfering bodies (either $h/b = 1$ or 3) are dummy bodies without any pressure taps. The models are fixed rigidly at various positions on the tunnel floor so that they do not vibrate in any way and also there is proper sealing at the bottom where the models are fixed. The principal body is turned at 90° intervals to measure the pressure distributions on the various faces. The pressure taps are connected through PVC tubings to the various ports of a scanning box (FC091; make: Furness Controls, UK) which are in turn connected to a digital micromanometer (FC012) with an accuracy of 0.01 mm water column.

During measurements, the tunnel wall-static pressure at a point 200 mm behind the grid is continuously monitored using a Betz manometer. As mentioned in the introduction, for the study of interference effects, two cases are considered when (i) the body with $h/b = 1$ is the principal body (PB) and the body with $h/b = 3$ is the interfering body (IB) (ii) the body with $h/b = 3$ is the PB and the other ($h/b = 1$) is the IB, in tandem arrangement. In each case IB is located both upstream and downstream of the PB and the spacing ratio (G/b when IB is in front; G'/b when IB is at the rear; Fig.1) is varied systematically. The blockage ratio, defined as the frontal area of the model to the cross-section of the tunnel section, is 3% for the taller model. Since tandem arrangement is used in this investigation, the blockage is not expected to be higher in cases with interference. No correction, however, has been made for blockage. All the tests are carried out at a tunnel free-stream

velocity of 17.5 m/s. At this velocity, the Reynolds number, referred to the width of the body, is 7×10^4 . For the type of the bodies tested, there is hardly any influence of the Reynolds number³ since the positions of the separation lines are fixed and the results presented are applicable to practical situations. The pressures are measured along the centre line on all faces of the body and the variation of the pressure coefficient is determined. Pressure measurements on the principal body without any interference are also carried out. As mentioned earlier, the $1/7^{th}$ power law velocity profile was achieved at a distance of 430 mm from the grid rods. Keeping this in view, the PB is located at a distance of 950 mm from the grid so that, even for the highest value of G/b , viz. 8, the interfering body is located further than 430 mm from the grid and is in the region where $1/7^{th}$ power law profile is valid. The maximum uncertainty with 20:1 odds in the values of C_p is estimated (using standard methods) to be 1.4 %.

Results and Discussion

The results are presented in terms of the pressure coefficient (C_p) which is defined as

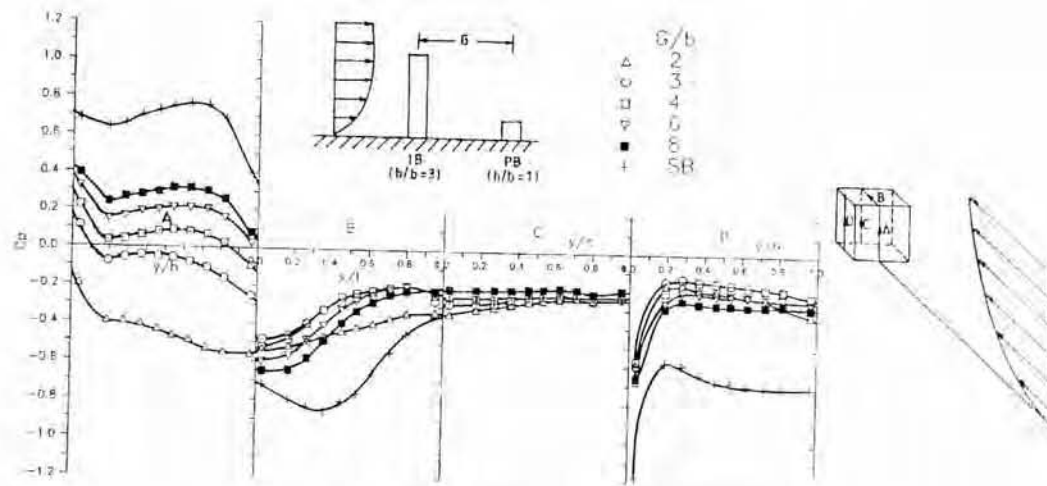
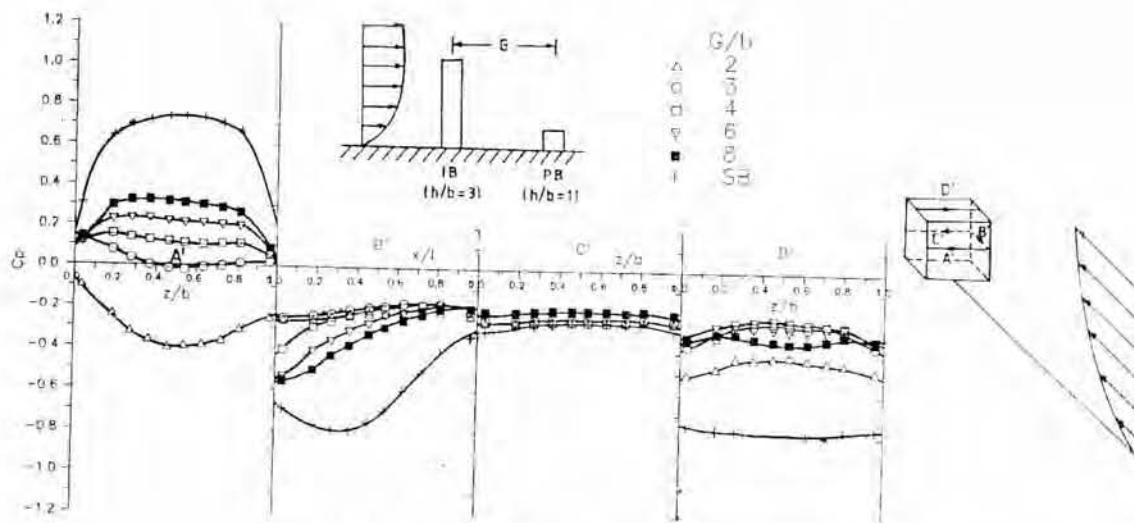
$$C_p = \frac{P_b - P_f}{\frac{1}{2} \rho U_h^2}$$

where P_b is the pressure at any point on the body, P_f is the free stream reference static pressure betz reading, U_h is the velocity in the undisturbed flow (i.e., without the presence of the bodies) at the principal body height and $\frac{1}{2} \rho U_h^2$ is the dynamic pressure in the undisturbed flow. To bring out the effects of interference, measurements with single body were also carried out. It is to be noted that the bodies are placed such that one of their faces is normal to the flow. The co-ordinate used are x, y, z ; x is measured along the flow direction, y is normal to the flow in the vertical direction and z is along the binormal to the flow in the horizontal direction.

Case (i) Body (PB) with $h/b = 1$

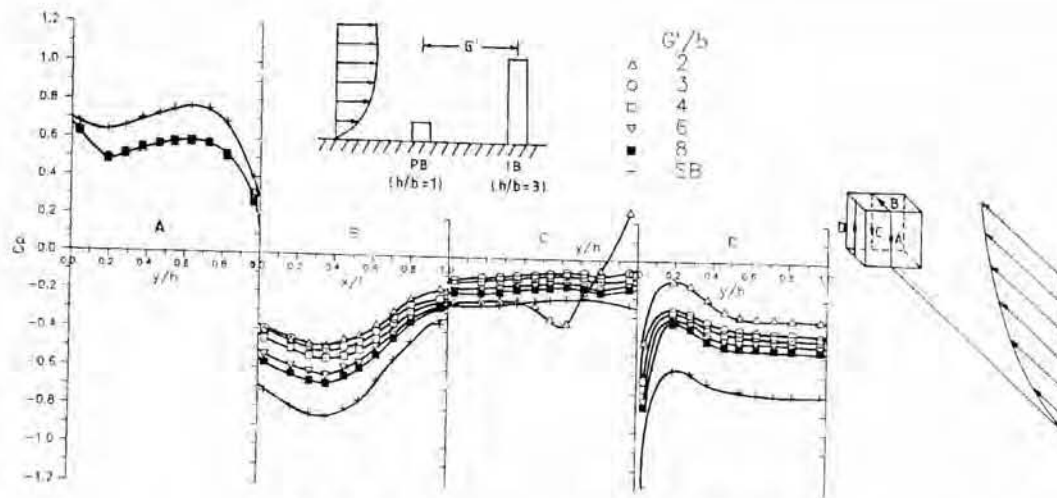
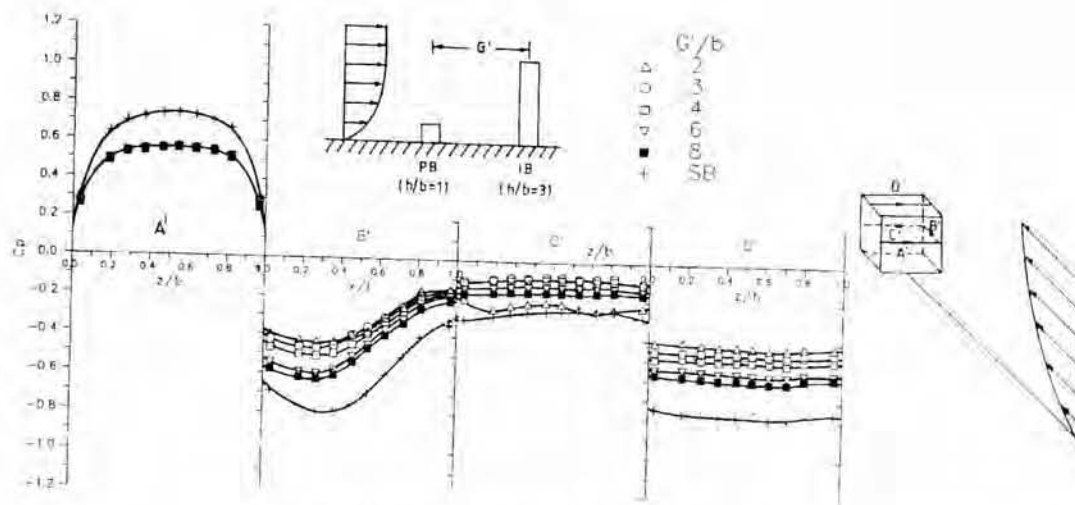
(a) IB in front of PB

The C_p distribution on various faces of PB due to the presence of IB at various upstream positions is shown in Figs 3a and 3b. It is observed that when the two bodies are close to each other ($G/b = 2$), the C_p on the front face (Figs.3a-A and 3b-A') is negative in

Fig. 3a—Interference effects; PB: $h/b = 1$; IB: $h/b = 3$ Fig. 3b—Interference effects; PB: $h/b = 1$; IB: $h/b = 3$

both vertical and horizontal directions i.e., y and z directions. C_p values are negative in y direction (Fig. 3a-A) for $G/b = 3$ also. The pressure distribution tends towards the no-interference values as the gap ratio increases. But even at $G/b = 8$, the pressure coefficient is only half of that for the single body case in magnitude in both y and z directions. On the top surface (roof) for $G/b = 2$, the C_p values in both x and z directions are less negative than those for the no-interference case (Figs 3a-B and 3b-D'). As the distance between the two bodies increases, gradients reappear as for the no-interference case. Interference effects on the rear face are marginal in both y and z directions (Figs 3a-C and 3b-C') at all G/b ratios. It is

interesting to note that at $G/b = 2$, if the C_p distributions on both rear and front faces are considered, the resultant force indicates the possibility of a negative drag or thrust force. There is considerable influence on the side surface also due to interference (Figs 3a-D and 3b-B'). In the vertical direction (Fig. 3a-D) the trend in C_p distribution is similar to that of the no-interference case. But in x direction (Fig. 3b-B'), almost constant pressure distribution for $G/b = 2$ and 3 is seen. Even with further increase in the gap ratio (G/b), the C_p values over a considerable portion of the side surface remain different from the no-interference values.

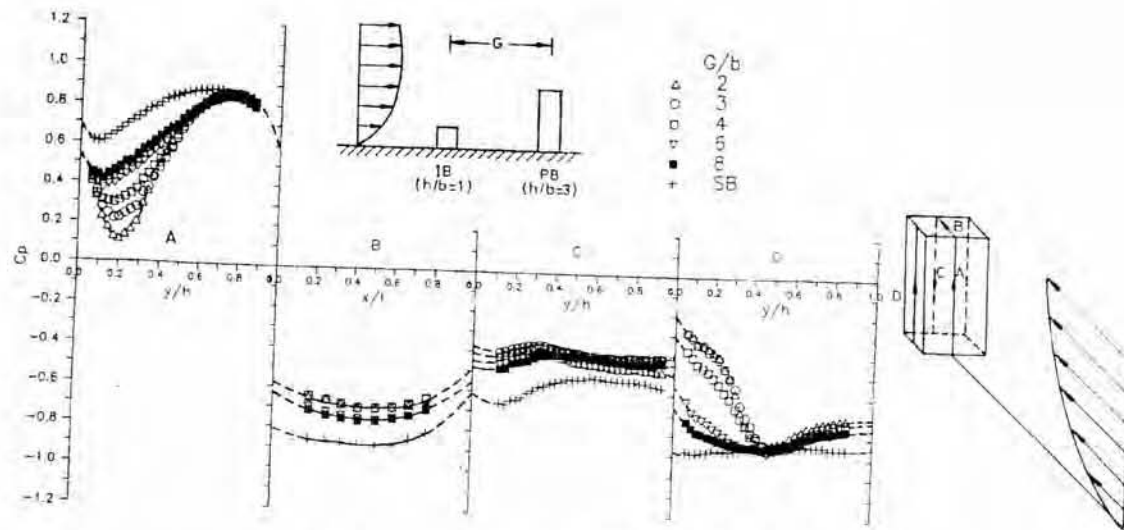
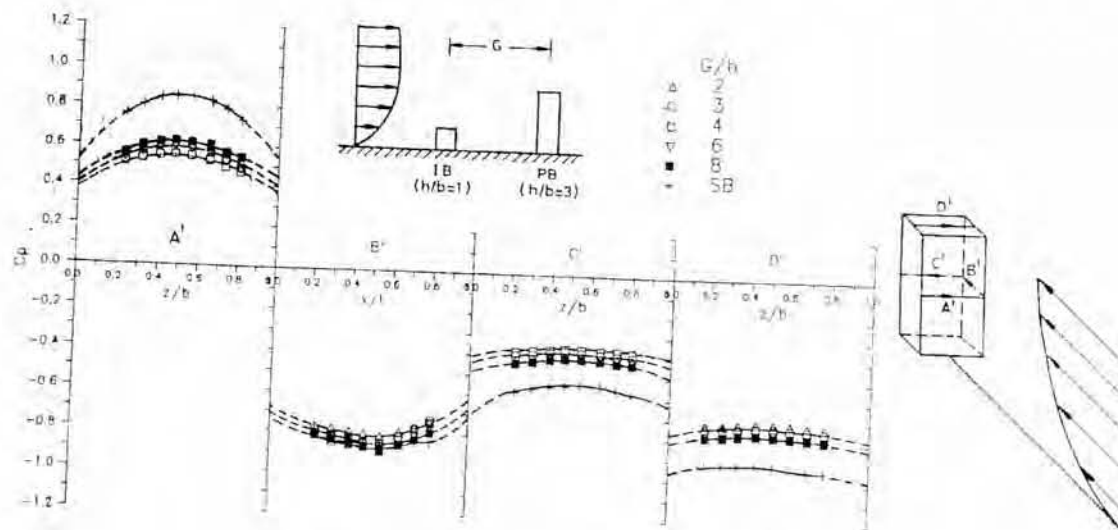
Fig. 4a—Interference effects; PB: $h/b = 1$; IB: $h/b = 3$ Fig. 4b—Interference effects; PB: $h/b = 1$; IB: $h/b = 3$ **(b) IB behind PB**

Figs 4a and 4b show the interference effects on the various faces of the PB when the IB is placed at various distances behind it. The results indicate that there is no changes in C_p with gap on the front face (Figs 4a-A and 4b-A'). The influence is appreciable on other faces. At $G'/b=2$ pressure rises steeply near the base on the rear face (Fig. 4a-C) suggesting that the flow may be deflected on to the face of the PB due to the IB. As G'/b increases, the C_p distribution on the surface tends towards that for the single body case. On the side surface (Figs 4a-D and 4b-B') the pattern in C_p distribution is similar to that for the no-interference case in y and z directions. On the roof,

(Figs.4a-B and 4b-D'), there is a pressure increase resulting in lower suction pressure for $G'/b=2$. As G'/b increases, C_p distribution gradually tends towards the single body case in both y and z directions.

Case (ii) Body (PB) with $h/b = 3$ **(a) IB In front of PB**

The C_p distribution on all faces of PB when IB is at various distances in front of it is given in Figs 5a and 5b. On the front face (Fig. 5a-A), it is observed that due to interference, there is a decrease in the C_p distribution at lower y/h values ($y/h < 0.5$). The C_p values remain almost unchanged at various G'/b

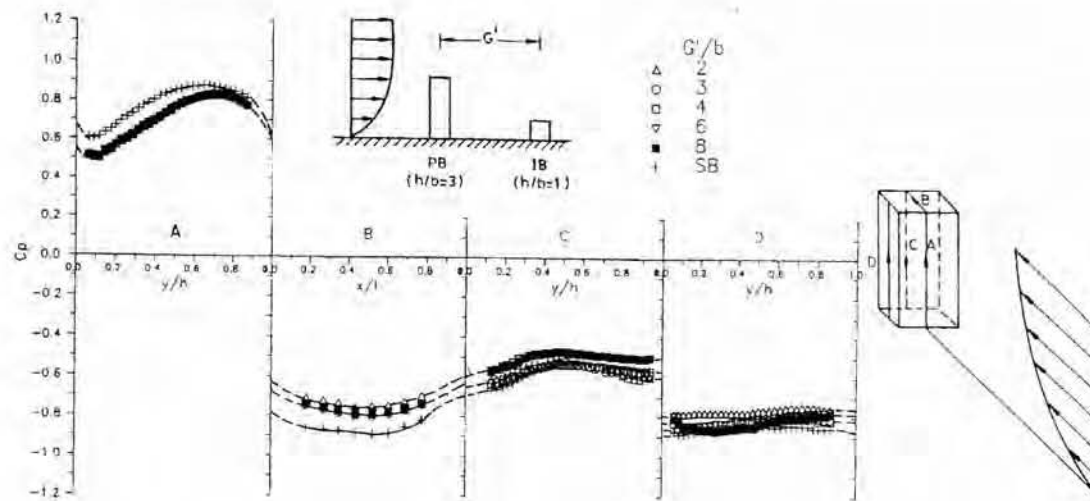
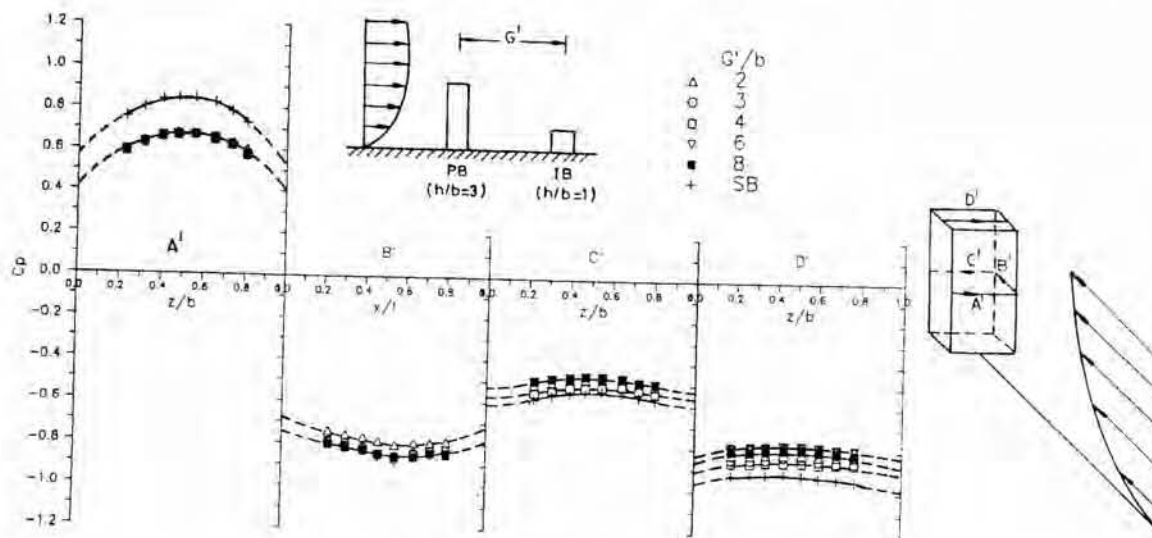
Fig. 5a—Interference effects; PB: $h/b = 3$, IB: $h/b = 1$ Fig. 5b—Interference effects; PB: $h/b = 3$; IB: $h/b = 1$

values for the remaining height of the body. As G/b increases, C_p values increase and tend towards the no-interference case. It is seen that there is only a little effect due to interference on the C_p in the z direction as seen from Fig. 5b-A'. On the roof (Figs 5a-B and 5b-D') the suction pressures reduce considerably for $G/b = 2$ and 3. As the gap ratio (G/b) increases the suction pressure also increases. On the side surface (Fig. 5a-D), there is a steep gradient at lower values of G/b (2 and 3) up to y/h of 0.4 and a mild gradient beyond that. As G/b increases, the gradient becomes mild on both the top and bottom parts of the side face, tending towards the no-interference case. The interference effects on the rear and roof faces though

present are only marginal compared to other faces (Figs 5a-C and 5b-C').

(b) IB behind PB

The pressure distribution on all faces of the PB due to the presence of IB of $h/b=1$ at various downstream positions is shown in Figs 6a and 6b. Though there is almost no effect of G'/b on the variation of pressure distribution on the front face of the PB (Figs 6a-A and 6b-A') the values of C_p with interference are slightly lower than those without the interference. On the roof there is a reduction in the suction pressure at low values of G'/b (Figs 6a-B and 6b-D'). As the gap ratio (G'/b) increases, there is a slight change in

Fig. 6a—Interference effects; PB: $h/b = 3$; IB: $h/b = 1$ Fig. 6b—Interference effects; PB: $h/b = 3$; IB: $h/b = 1$

suction pressure but it is still less, compared to the single body case. The C_p distribution on the rear and the side surface in y direction is slightly affected by the IB when it is very near the PB (Figs 6a-C and 6a-D); however as G'/b increases the C_p distribution tends towards the no-interference case. But in the z direction it remains almost unaffected at various values of G'/b (Figs 6b-C' and 6b-B').

The tentative physical explanation for the observed features mentioned above is as follows. For the case when the body with $h/b = 1$ is the PB and the IB ($h/b = 3$) is in front, the shear layers that separate from the upstream IB interact with the PB. When G'/b is small ($=2$), the PB would be completely enveloped by

those shear layers and probably this is the reason for the uniformly negative pressures that occur on all the faces of the PB. As G'/b increases (e.g., at $G'/b = 3$), there will be reattachment of the separated shear layers from the upstream body on to the top of the downstream body which would alter the pressure distribution on the roof. With further increase in G'/b , these shear layers would reattach on to the front face of the rear body or on the ground plane in front of the PB. This reattachment process can be expected to be influenced by two factors (i) the turbulence in the approach flow and (ii) the presence of the PB itself which might alter the shape of the shear layers separating from the IB. The process appears to be

quite complex and because of this reason it is difficult at present to explain exactly the pressure gradients seen on the roof (Fig. 3a-B).

For the case when the IB is at the rear of the PB, the wake behind the later, particularly when the former is very close ($G'/b=2$ and 3) is considerably affected. Due to the presence of the IB a strong pressure gradient near the ground plane can be expected, which would push the vertical flow behind the shorter body to its sides. The marked changes in the pressure distribution observed at the lower values of G'/b on all faces (excepting the front face) in Figs. 4a and 4b, could be attributed to this. The change is particularly striking on the rear face at $G'/b=2$, (Fig. 4a-C). As the distance increases beyond $G'/b=3$, the reattachment of the flow behind the PB can be expected to take place in a fashion very similar to that for the single body case, with only marginal influence of the IB.

When the body with $h/b=3$ is the PB, the interference due to the IB kept ahead of PB is concentrated closer to the ground plane on the front

face (Fig. 5a-A). The horse-shoe vortex system in the front of the PB and the general flow field around would be affected by the shorter body in front, resulting in the changes in pressure distribution seen for $y/h<0.5$ (Fig. 5a-A). When the IB is at the rear, there is no significant effect on C_p on the front face. It is interesting to note that the C_p distribution on the roof of the PB and its rear are affected by interference. This might be due to the influence of the IB on the shear layers separating from the top of the tall body.

Maximum Values of C_p

The maximum values of C_p (i.e., $C_{p_{max}}$) is of interest from the point of view of loads on the faces. $C_{p_{max}}$ values on the various faces for the two cases considered are shown in Figs 7 and 8. Considering the case shown in Fig. 7, it is observed that appreciable difference occurs on the front face (Fig. 7a), when IB is located in front of PB. Roof is affected marginally at various G/b or G'/b ratios. There is some interference effects on the front face

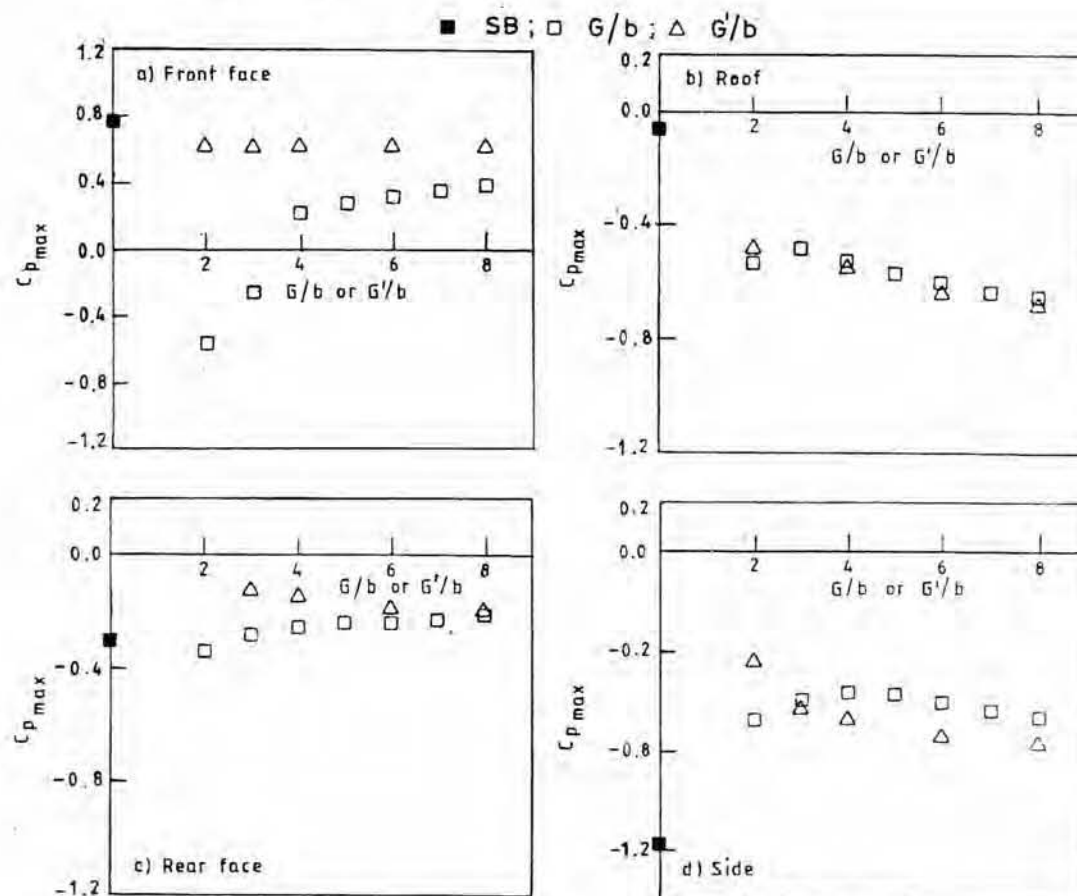


Fig. 7—Values of $C_{p_{max}}$ on various faces: PB: $h/b=1$; IB: $h/b=3$

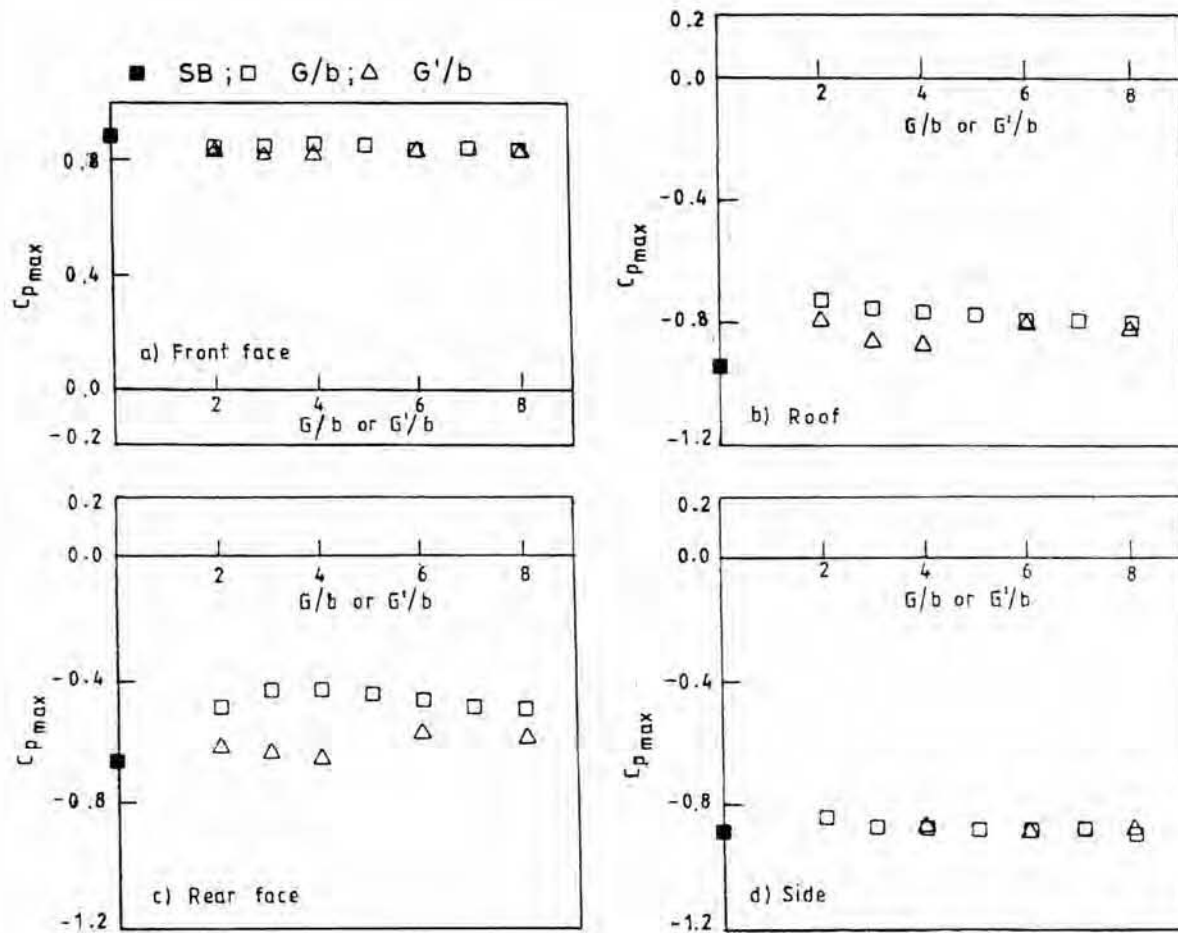


Fig. 8—Values of $C_{p_{max}}$ on various faces: PB: $h/b = 3$; IB: $h/b = 1$

(Fig. 7a) when IB is at rear of the PB. Interestingly the $C_{p_{max}}$ values on the side surface show considerable difference for this condition (Fig. 7d) even at $G/b = 8$. As far as the rear face is concerned, interference effects are small (Fig. 7c) at various G/b or G'/b ratios.

Considering case shown in Fig. 8, there is only marginal influence on $C_{p_{max}}$ values on all the faces except on the rear face, both when IB is in front or behind the PB.

Conclusions

From the results presented, the following conclusions are drawn:

- 1 Due to the shielding effect of the front body there is the beneficial influence seen in the reduction of the suction pressure compared to the single body case on the roof, sides and the rear, when the two bodies are close to each other. The magnitude of reduction depends on both h/b and G/b values.

The body with $h/b = 1$ can experience a negative drag force when it is in close proximity ($G/b = 2$ and 3).

- 2 When the body is in front, the pressure on the front face of the body ($h/b = 1$) becomes fully negative for small gap between the bodies. The interference effects persists even at large gaps between the bodies.
- 3 When the interfering body is behind the principal body, the pressure distribution on the front face for both bodies ($h/b = 1$ and 3) remain almost same at all G/b ratios tested. But appreciable differences occur on other faces.

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