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Pressure Distribution on a Roof in Presence of the Moving Surface Boundary-layer Control

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***Abstract*:** The paper studies effect of momentum injection, accomplished through circular cylindrical rotating elements, on the pressure distribution at the roof of a model house. Extensive wind tunnel tests, complemented by flow visualization, suggest that such Moving Surface Boundary-layer Control (MSBC) effectively delays separation and significantly increases the pressure, both on leeward and windward surfaces. This would assist in protection of the roof against wind storms and snow accumulation.

***Keywords*:** wind-induced roof pressure, boundary-layer control.

1. Introduction

Wind effects on buildings have been a subject of considerable interest for quite sometime. Over the years, a vast body of literature has evolved aimed at both high-rise as well as low-rise structures. So far as the low-rise buildings are concerned, perhaps one of the early major studies is due to Eaton and Mayne (1975). They provided extensive results through field measurements of roof pressure for a set of prototype structures. More recently, Morisaki et al. (1994) conducted wind tunnel tests on a model of a house to assess forces on roof-tiles. Uematsu and Isyumov (1997) have presented information on wind pressure acting on the 4:12 pitched roof of a low-rise building based on extensive wind tunnel tests. Snow accumulation and its load on roofs as well as its drift have also received some attention (Uematsu et al., 1991; Taylor, 1985; Baskaran and Kashef, 1996). Stathopoulos and Zhou (1993) have discussed a numerical approach to this class of problems. However, the control of separating boundary-layer to affect roof-pressure and snow accumulation has received virtually no attention.

Ever since the introduction of the boundary-layer concept, there has been a constant challenge faced by scientists and engineers to minimize its adverse effect. Suction, blowing, vortex generators, turbulence promoters, etc. have been studied at length and used in practice with a varying degree of success. A systematic study aimed at Moving Surface Boundary-layer Control (MSBC) has received attention only recently. Modi (1997) has reviewed the MSBC contributions aimed at increasing lift and delaying of stall in aeronautical applications, reduction in drag of bluff bodies including that of highway trucks, and suppression of vortex resonance as well as galloping instabilities encountered in industrial aerodynamic problems. With this as background, the present paper studies effect of the MSBC on the pressure distribution at the roof of a house. This has direct implications concerning safety of the roof (and tiles) during high wind condition, as well as accumulation of snow in winter.

2. Test Procedures

A scale model of a house with gabled roof of 45° pitch was constructed (Fig. 1). It was provided with 36 pressure taps at the central station as indicated. The house was provided with three circular cylinders, located at three corners, and each can be driven independently at a desired speed to inject momentum into the boundary-layer. The important parameter in the study is the ratio U_C / U, where U_C = surface velocity of the cylinder and U = uniform free stream velocity. Boundary-layer associated with the incoming wind is not an important parameter in the study.

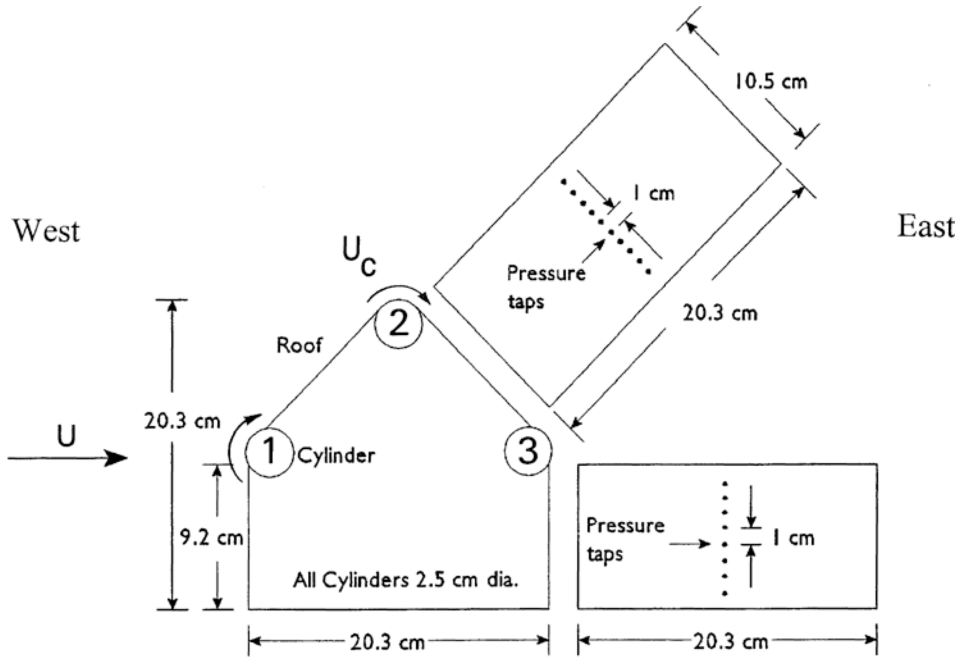


Fig. 1. A schematic diagram of the house model, with a 45° roof, used in the test-program. The model was provided with 36 pressure taps at the central station.

The model with rotating cylindrical elements providing the MSBC was tested in a low speed, low turbulence, return-type, wind tunnel at a subcritcial Reynolds number of around 3×10^5 (based on the free stream velocity and projected height). The pressure measurement procedure is well established in any aerodynamics laboratory. The tests were conducted over a wide range of U_C / U (0 – 4), several surface roughness, and yaw inclination (α = 0 – 90°). It should be pointed out that during the test-program, only cylinder 1 and cylinder 2 were used. The third cylinder is provided to tackle wide variation in the wind direction, say from west to east. For the easterly wind, one would use cylinders 2 and 3 with counterclockwise rotation.

The wind tunnel test-program was complemented by a flow visualization study carried out in a closed circuit water channel. It used slit-lighting in conjunction with polyvinyl chloride particles as tracers. Long exposure photography captured pathlines.

The amount of information obtained through a planned variation of $(U_C / U)_1$, $(U_C / U)_2$, α, and the cylinder roughness is rather extensive. Here some typical results are presented to establish trends.

3. Results and Discussion

Reference pressure distribution on the roof is presented in Fig. 2. The trend is as expected. From the stagnation on the front face in the vicinity of taps 5-7, the flow accelerates, separates at the apex of the roof (around pressure taps 18, 19; near cylinder 2) and the negative wake pressure is essentially uniform at around $C_P \approx -0.65$. The effect of momentum injection through rotation of cylinder 2 is shown in Fig. 3. There is a remarkable increase in the wake pressure which is desirable; however, the windward face of the roof experiences suction effect and hence shows reduction in the pressure. Rotation of cylinder 1 increases the pressure on both windward and leeward faces of the roof, however, the rise is essentially through an increase in the pressure head (Fig. 4). The results clearly suggest a need for suitable combination of cylinder rotations to overcome suction effect on the windward side of the roof. As shown in Fig. 5, momentum injection corresponding to $(U_C/U)_1 = 6$ and $(U_C/U)_2 = 4$ is quite successful in significantly increasing the pressure on the entire roof, and particularly on the leeward face. From the mechanical consideration, it would be desirable to achieve similar performance at lower values of U_C/U.

Next, it was decided to explore the effect of cylinder surface roughness. The results for three different surfaces are presented in Fig. 6. It is apparent that the spline configuration appears to be quite promising.

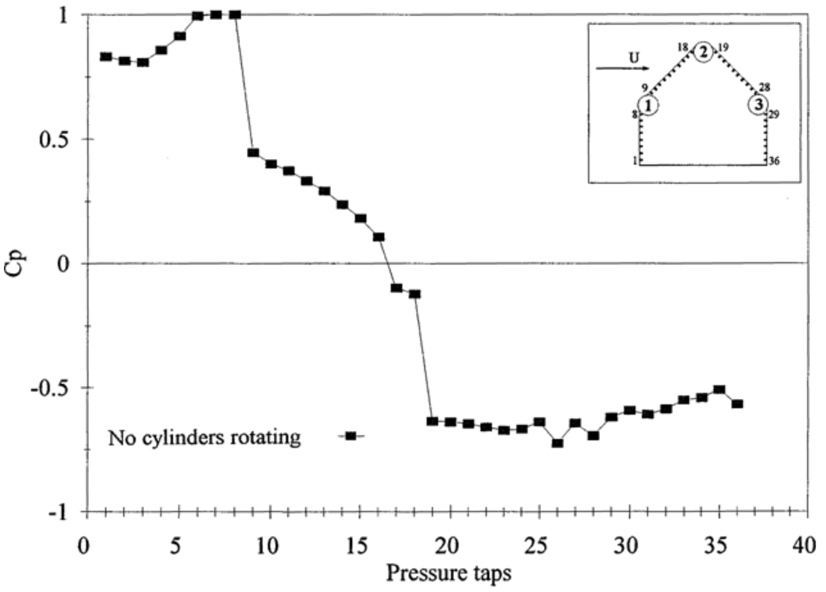


Fig. 2. Reference pressure distribution on the surface of the house model in absence of the momentum injection.

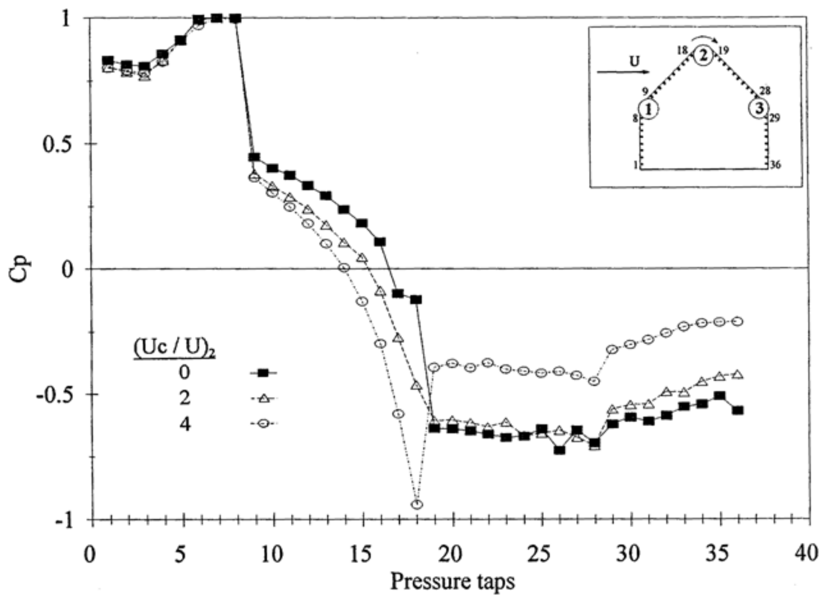


Fig. 3. Effect of the second cylinder rotation is to create suction on the upstream side which is undesirable. However, the downstream portion of the roof shows an increase in pressure.

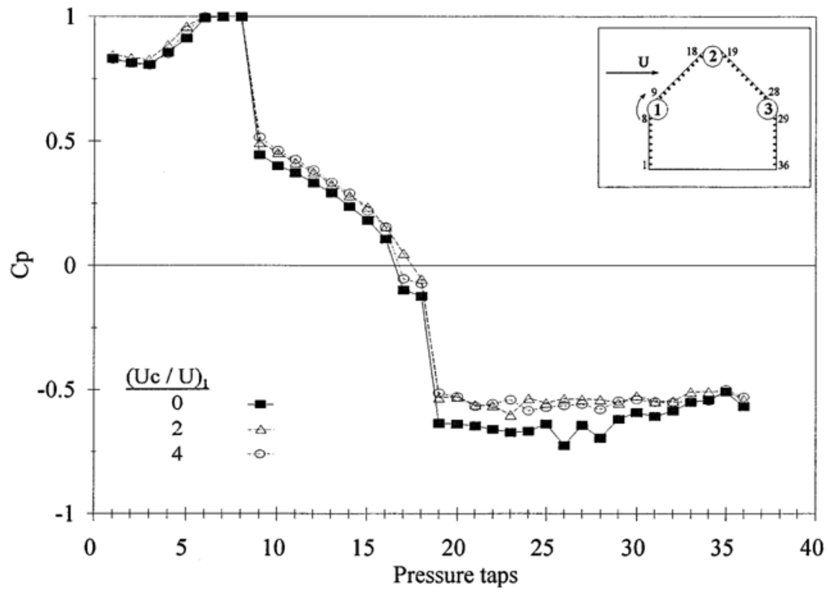


Fig. 4. Rotation of the cylinder 1 increases the pressure throughout which is desirable. However, the rise is essentially through the increase in the pressure head.

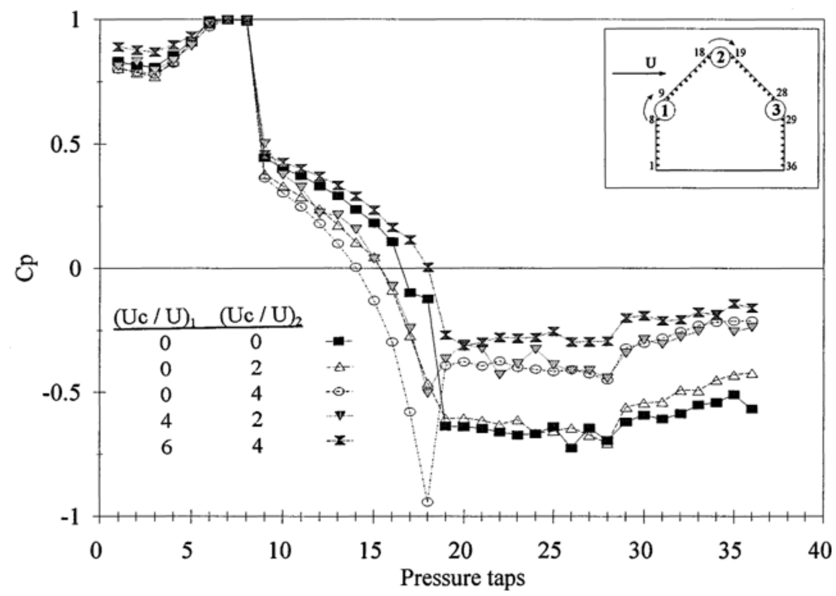


Fig. 5. Effect of simultaneous rotation of cylinders one and two on the pressure distribution at the roof. Note, the appropriate combinations of speeds can provide favourable results.

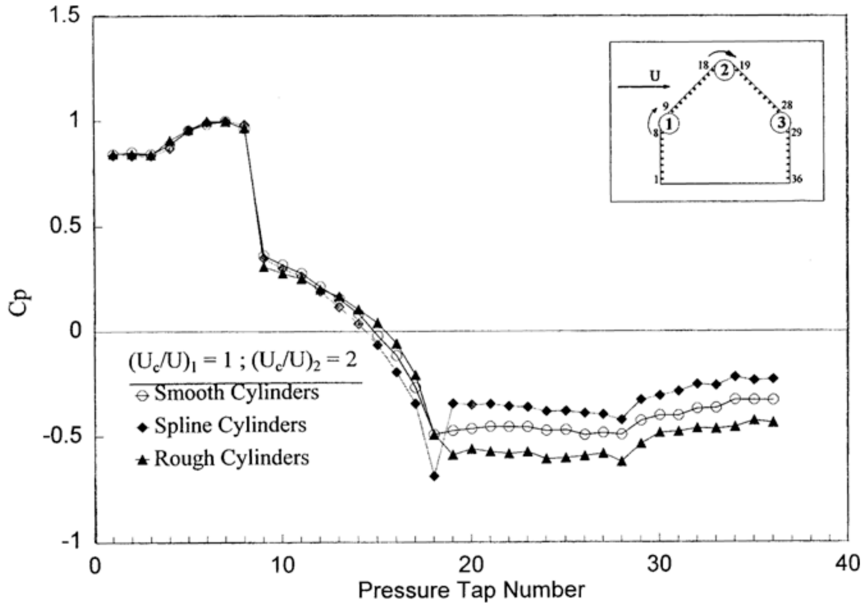
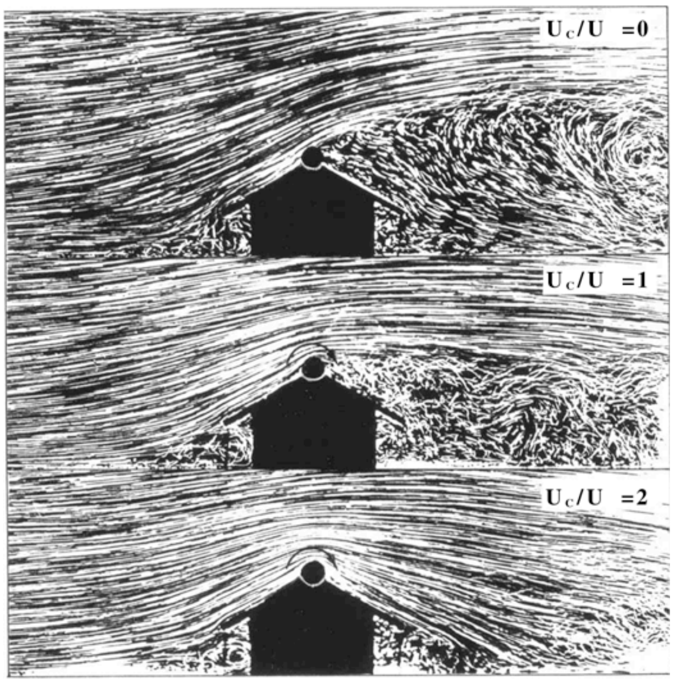


Fig. 6. Efficiency of the momentum injection as affected by the cylinder surface roughness.



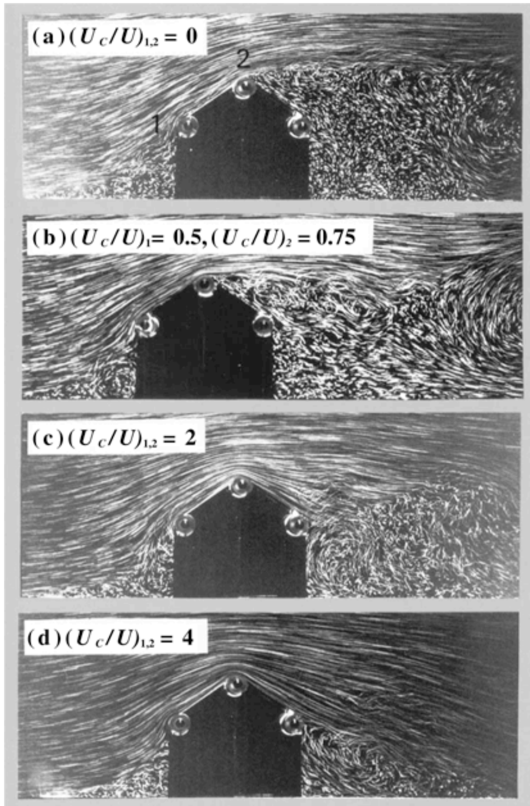


Fig. 7. Flow visualization study showing effectiveness of the momentum injection through a rotating cylinder at the apex (cylinder 2). Note, for U_C / U = 2, the boundary-layer separation on the roof is avoided.

Fig. 8. Boundary-layer control through momentum injection using cylinders 1 and 2.

The flow visualization study dramatically showed effectiveness of the momentum injection in keeping the boundary-layer attached with one cylinder at the apex as well as with the two cylinders on the windward side (Figs. 7, 8).

Application of the concept to a real-life prototype house is rather straightforward, as the MSBC is essentially a semi-passive procedure, i.e. it involves only little expenditure of energy. The cylinders can be hollow, and hence light. The energy losses are primarily associated with the bearing friction. In fact, NASA has built and successfully tested the concept on an airplane called OV-10A. So application to a house is relatively simple.

4. Concluding Remarks

The momentum injection through rotating cylinders can be used to advantage in suppressing the boundary-layer separation on the roof. This, in turn, raises the roof pressure and thus helps in protecting it against wind storms as well as snow accumulation. The flow visualization study substantiates this observation quite remarkably.

Acknowledgment

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