EXPERIMENTAL INVESTIGATION OF THE FLOW PAST A LOW-RISE BUILDING

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ABSTRACT

It is now well documented that large suction pressures develop along the leading edges of the building when the wind is incident at oblique angles due to the formation of corner vortices. It is not uncommon for these large suction pressures to cause localized destruction, which may even result in the total failure of roofs. The present paper gives the results from experiments conducted on 1:100 scale models of Texas Tech University (TTU) test building in different flow conditions. The results show that a separation and re-circulation region exists on rooftop along with vortex near ground. The formation of corner vortices was also noted when the wind was incident at oblique angles. There is an enormous influence of rounding of roof edges on the flow and pressure characteristics in all the flow conditions studied. It was also noted that different magnitude of rounding is affecting the pressures differently.

Keywords: *Suction pressures, building, failure, roofs, rounding, flow conditions.*

الملخص

من المعلوم أن ضغوط الأمتصاص العالية تتكون عند الحافات الأمامية في المباني عندما تهب الرياح بزوايا مائلة بسبب تشكل الدوامات عند الزوايا. ومن المعروف أن ضغوط الأمتصاص العليا يسبب ضررا موضعيا وقد ينتج عنه في نهاية الأمر تدهور كامل في السقف. وورقة البحث هذه تبين النتائج التي تم الحصول عليها من التجارب التي تم أجراؤها على نماذج المباني في جامعة تكساس للتكنولوجيا بمقياس رسم ١: ١٠٠ وتحت ظروف مرور هواء مختلفة.

وقد بينت النتائج أن مناطق الفصل وأعادة الدوران عند أعلى أسقف المباني وكذلك مع الدوامات بالقرب من سطح الأرض. ولوحظ أيضا تشكل الدوامات عند الزوايا عند وقوع الرياح على الزوايا المائلة وهنالك أثر هائل يتضح في دائرية أطراف الأسقف على خواص أنسياب الهواء في كل حالات دفع الهواء التي تمت دراستها وكذلك لوحظ أن التدوير الكبير المتفاوت في أطراف الأسقف يؤثر في الضغوط بشكل متفاوت أيضا.

1. INTRODUCTION

The information regarding wind-induced pressures on buildings is usually derived from wind-tunnel tests. The TTU Wind Engineering Research Field Laboratory (WERFL) is a low-rise building (13.7m x 9.1m x 4m) currently providing full-scale data for wind tunnel comparative studies.

It is now well established that large suction pressures develop on the roof when the wind is incident at oblique angles. These are generated due to the formation of corner vortices on the roof, because of flow separation from the leading edges. These vortices cause the severe suction pressure, which results in local damage to the roof. It is also important to define both the location and magnitude of these worst suctions, especially at oblique angles.

Several investigations have been carried out in the past to investigate the pressure experienced by the roofs of low-rise buildings including the pioneering work by Jensen and Frank, 1965. This work was carried out in both field and also in wind-tunnel to obtain mean and rms pressure values. An investigation by Kind, 1986, tried to discuss the experimental data together with some previous works on low-rise buildings taking into consideration the worst suctions experienced by roofs.

In recent year, with the advent of research facility at TTU [Levitan and Mehta, 1992 and 1993], systematic measurements of roof corner pressures have been carried out for low-rise buildings and the results were compared with the wind-tunnel experiments [Mehta et al. 1992; Tieleman 1993; Biekiewicz et al. 1992]. Some of the load reduction studies were also conducted in scale models to reduce wind loads either by changing the roof edge design or by using cylinders and screens on rooftop. These studies claim some success in reducing the wind loads at edges of isolated low-rise buildings [Surry and Lin, 1995; Cocharan et al. 1995].

Though considerable work has been reported on the suction pressures on the rooftop, it appears that most of them employed only a limited number of pressure taps. There has also been mostly a single case of simulated boundary layer flow, which has been used. In the present study, different flow conditions were chosen to carry out this study.

2. EXPERIMENTAL DETAILS

The experiments were carried out in the research wind tunnel of King Fahd University of Petroleum & Minerals (KFUPM). This wind tunnel is open-return type and has a working rectangular test section of 1.1 m x 0.8 m and length of approximately 4.0 m. The models were fabricated to 1:100 scale in plexiglass. Different types of flow conditions chosen include smooth flow (turbulence less than 0.1%), nominal boundary layer turbulent flow (turbulence 4%), and barrier generated boundary layer flow. The velocity profiles and turbulence intensity profiles at the test section for different flow conditions are given in Figure 1. It is believed that this investigation will enable to study the influence of the nature of flow on suction pressures, corner vortices, turbulence levels, etc.

The wind velocity at model height was about 10 m/s and 8.5 m/s for smooth and turbulent flows, respectively. The mean pressure coefficients were evaluated considering these velocities at the model height using the following equation:

$$C_p = \frac{(P - P_\infty)}{\frac{1}{2}\rho V_\infty^2}$$

Where:

C_p = Mean coefficient of pressure
p = Local static pressure
P_∞ = Free stream static pressure
V_∞ = Wind velocity at model height of 40 mm, and
ρ = The density of air.

Laser-light illumination technique and smoke-wire techniques were used at normal and oblique incidences to observe the flow over the roof. The model surface was provided with 108 pressure holes of 0.8 mm diameter. High precision Betz-type manometers were used to record pressure levels. The hot-wire measurements were carried out using a plain hot-wire, DISA Type 55P11. This was calibrated at every run to ensure reliable data acquisition. Different edge radii of the models have been considered, like *R*=0 (sharp edge), 5 mm, 8 mm and 10 mm, to find out the influence of rounding of roof edges.

3. EXPERIMENTAL RESULTS

The mean pressure coefficient plots, Figures 2, 3 and 4, reveal the variation of pressures over the roof for different flow conditions at an incidence of α=45˚. It can be noted from the pressure plots that for a sharp edge model, the maximum value of mean suction occurs at point close to the roof corner on a hole corresponding to # 50205 on TTU test building and a considerable reduction of about 75% in severe suction pressure was noted when the edges were rounded to a radius of *R*=10 mm. This pressure value noted matched with what was reported in Ref. [Kawaii and Nashimura, 1996] for a sharp edge model. At an incidence of 25° the area of severe suction shifts to one side as can be noted from Figure 5. It is seen that the magnitude of rounding influences the magnitude of change in the suction pressures for this incidence also. A pressure behavior different from α=45˚ appeared because of change of incidence. The effect of reduction in suction pressures due to rounding gradually decreases when moving downstream along the model edge and almost vanishes around 50% of the model length and further proceeding towards the end shows a mild but an opposite effect of rounding for the case of α=45˚.

Top

The flow was visualized using laser light at two stations on the model top surface. Figure 6 shows the section of the flow at 15-20% from the leading edge corner whereas Figure 7 shows the section of the flow at station 2, which was at about 50% of the distance of the leading edge. The video film when played slow shows that corner vortices do exist on the top surface of the sharp edge model due to shear layer separation and rolling and these vortices grow downstream. A similar observation was also reported by Biekiewicz et al. 1992, on a sharp edge cubical model. These vortices cannot be considered of the same shape as what usually observed on sharp edged low aspect ratio delta wings [Stahl et al. 1992]. For smooth flow conditions there seem to exist concentrated vortices close to leading edges, but it was difficult to catch the vortex formed in turbulent flows. The still pictures did not reveal easily the vortex formation whereas flow visualization using video recording with a slow running motion shows that corner vortices also exist for this type of flow, but with a difference that a large scale turbulent region exist just above a well defined concentrated vortex. When round edge model with radius R=5 mm was placed in the same flow conditions at α=45˚, the flow separation looks to be very much delayed and a clear vortex formation could not be detected at station 1 (Figure 6). A very thin size weak vortex looks to form at this size of rounding. The effect due to weak vortex formation can be noted from pressure plots where a considerable reduction in pressures appeared. This change can be attributed to the rounding of roof edges.

For an incidence of 90° there is a clear separation of the flow from sharp windward edge and formation of bigger bubble when compared to round edge model (Figure 8). Part of the flow, which is incident on the front wall, goes downwards and forms a vortex near ground and is not affected even when edges are rounded.

A plain hot-wire was placed above a hole close to leading edge corresponding to hole # 50205 of TTU test building. The intention here was to find out the difference in longitudinal velocity fluctuations and turbulent intensities between a sharp edge model and a round edge model at some important location. The hot-wire transverse above this hole shows that rms velocity fluctuations and intensity of turbulence drop considerably between sharp edge and round edge model in the region close to the surface (Figure 9). This change in turbulence level and rms velocity fluctuations should have a possible influence on the pressure fluctuations also.

4. CONCLUSION

The suction pressures on top of the roof are affected by rounding of roof edges to a considerable magnitude in different flow conditions. When the flow is incident at an oblique angle of 45°, two areas of low pressure develop adjacent to the leading edges. However, for an incidence angle of 25° the area of severe suction shifted to one side of the building model.

Top

Flow visualization shows that corner vortices do exist at α=45˚ and 25° on the top surface of the sharp edge model in both the smooth and turbulent flow conditions; whereas for round edge model that is for *R*=5 mm, a very thin and a weak vortex looks to form. The rms. velocity fluctuations in the vortices when plotted as turbulence intensity, shows a considerable drop between a sharp edge and a round edge model for all the flow conditions considered. For an angle of 90° there is a clear separation and re-circulation of flow from the frontal edge of the model.

ACKNOWLEDGMENTS

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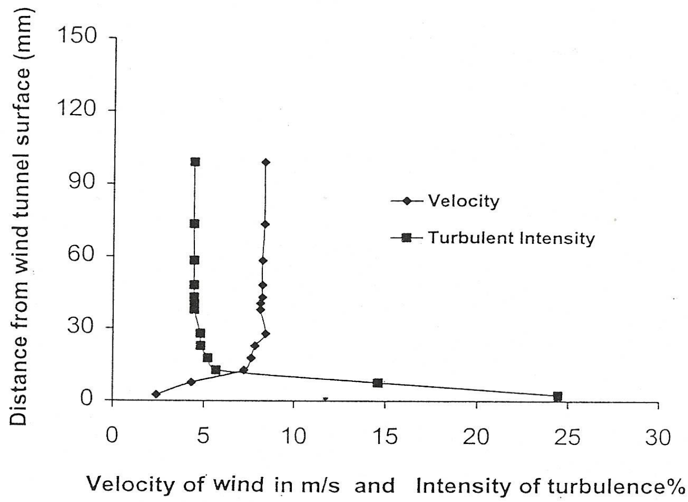
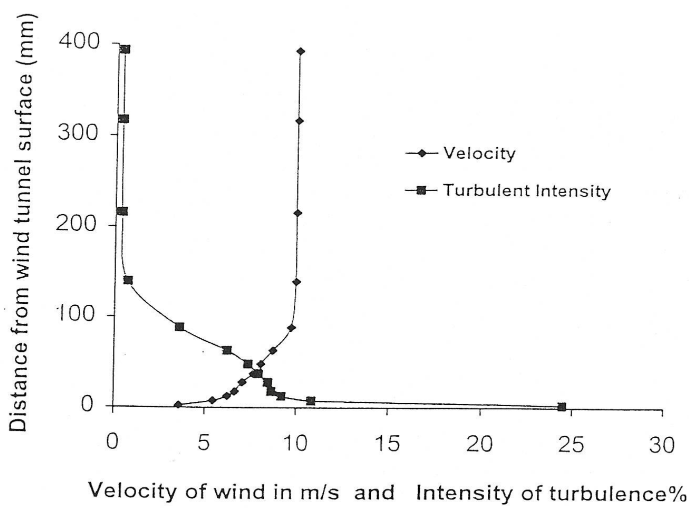


(a) Nominal boundary layer turbulent flow (4% turbulence).



(b) Barrier generated boundary layer flow.

Figure (1). Velocity and turbulent intensity profiles in different flow conditions.

Top

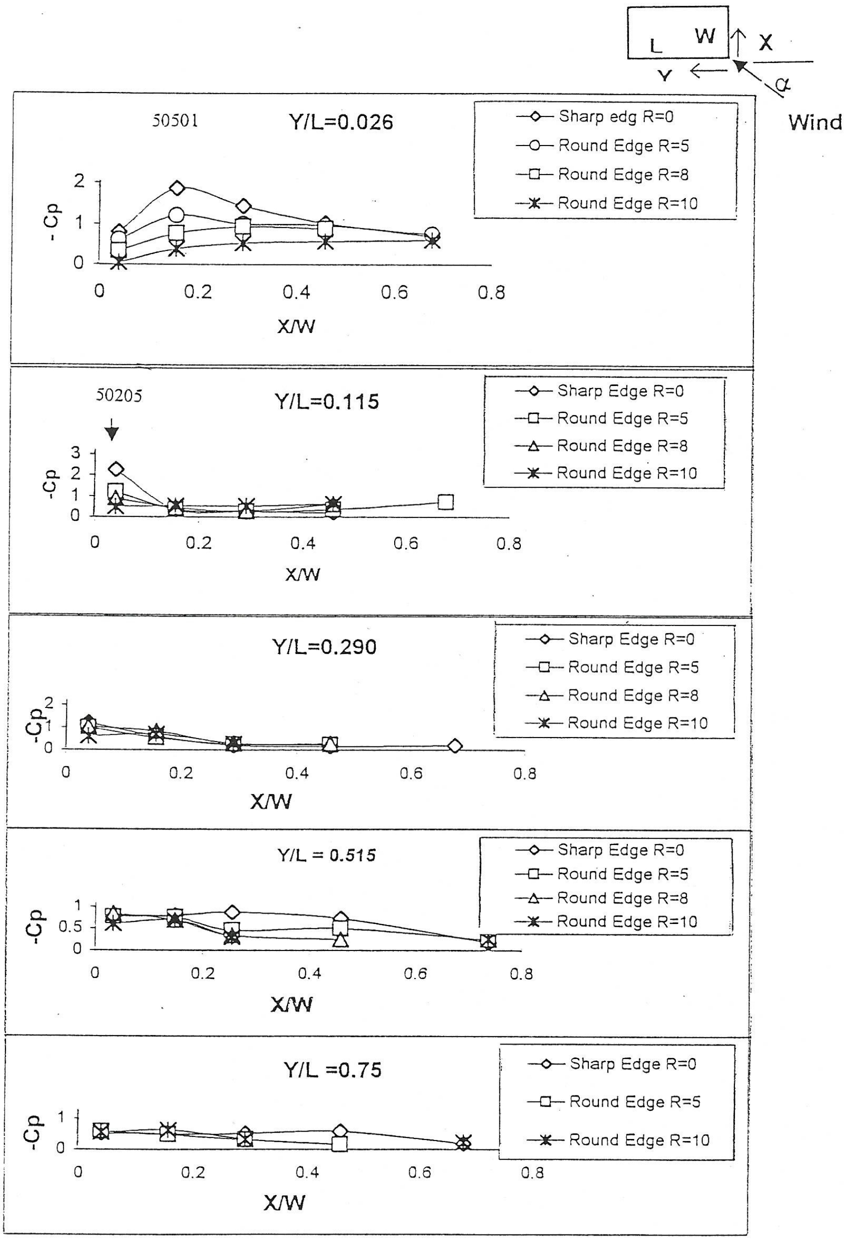


Figure 2. Mean pressure distribution on top surface of sharp edge and round edge models, α=45°, smooth flow.

Top

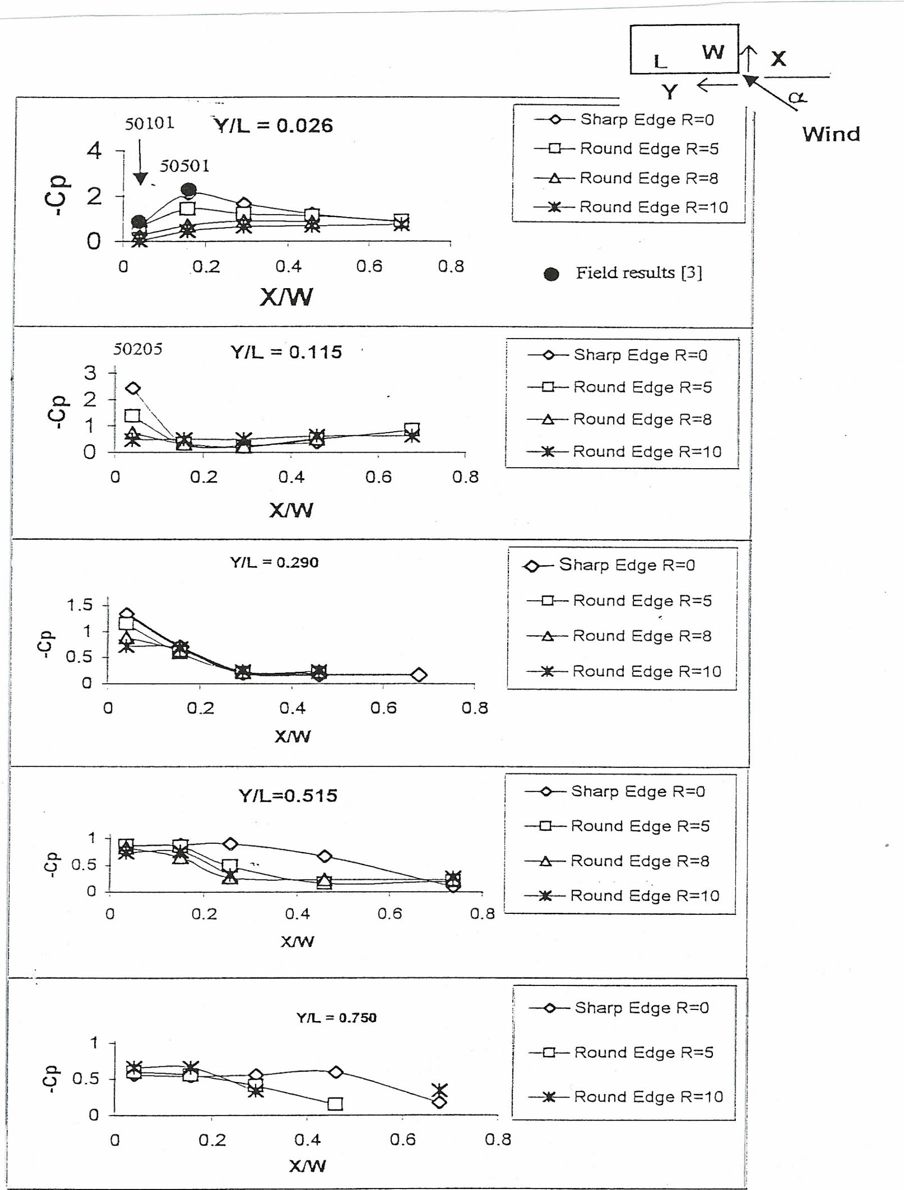


Figure 3. Mean pressure distribution on top surface of sharp edge and round edge models, α=45°, nominal boundary layer turbulent flow (4% turbulence).

Top

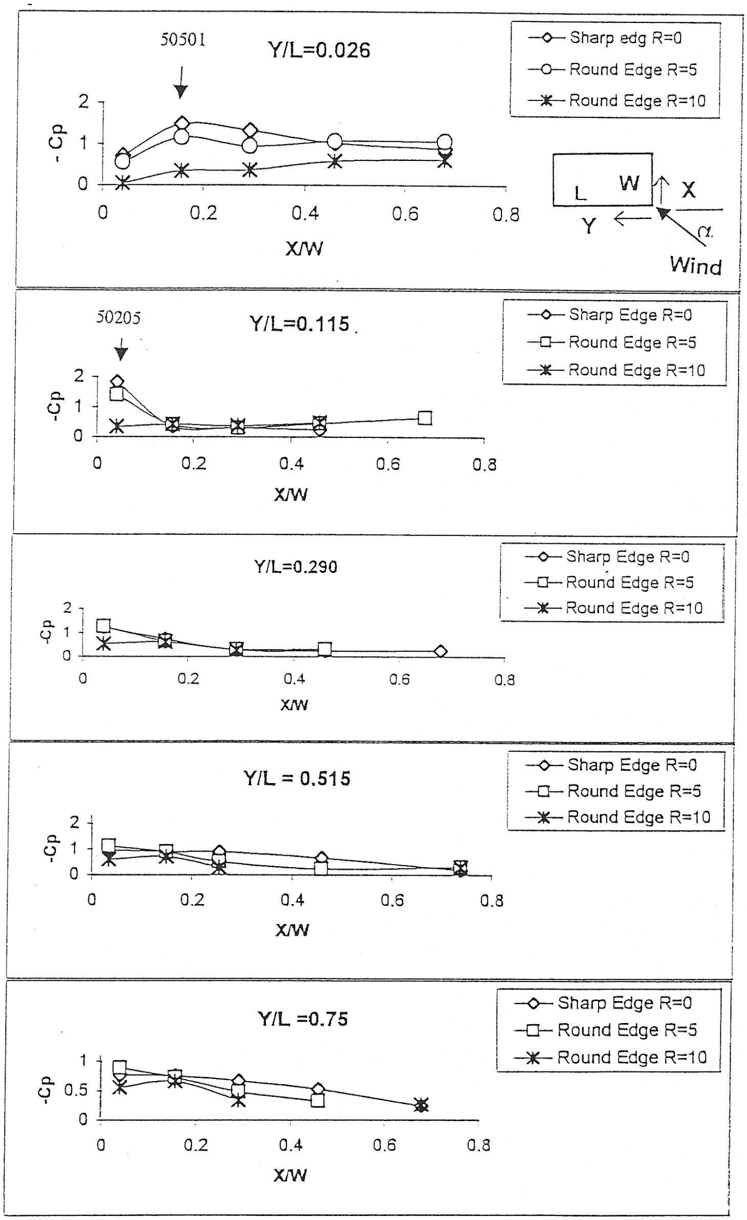


Figure 4. Mean pressure distribution on top surface of sharp and round edge models, α=45°, boundary layer flow generated using barrier.

Top

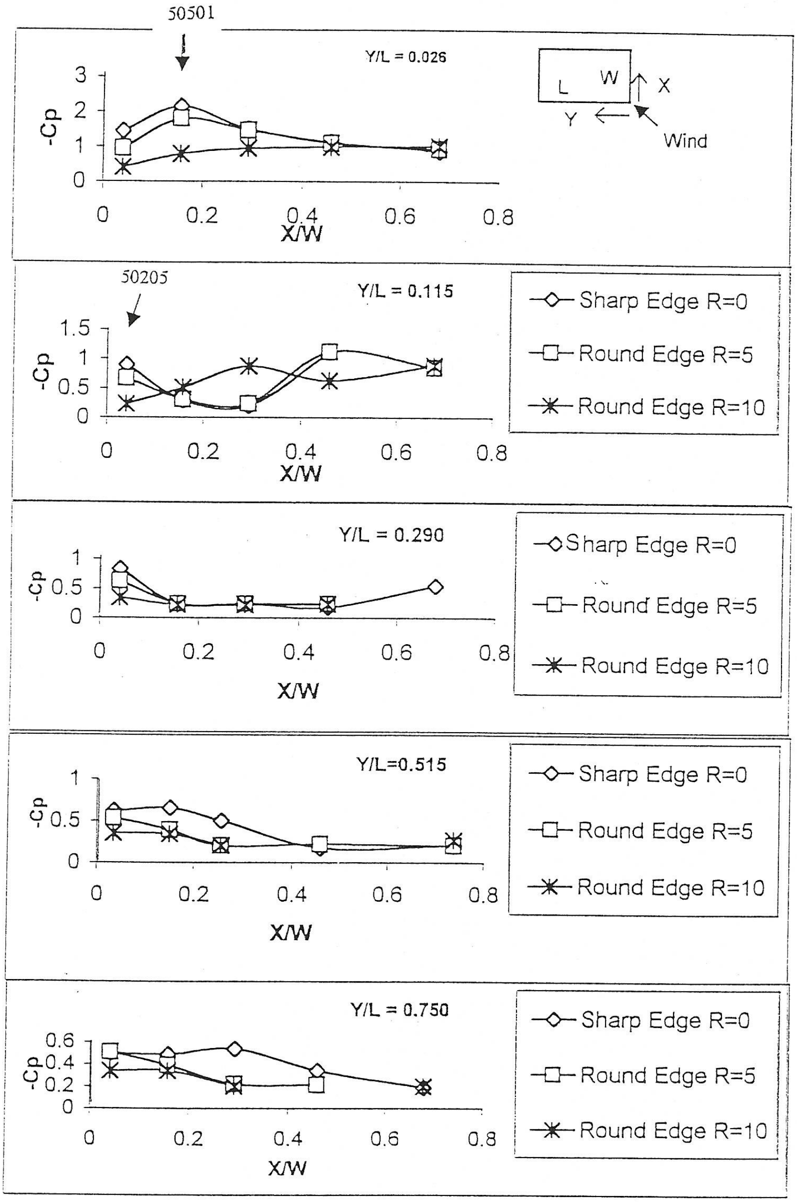
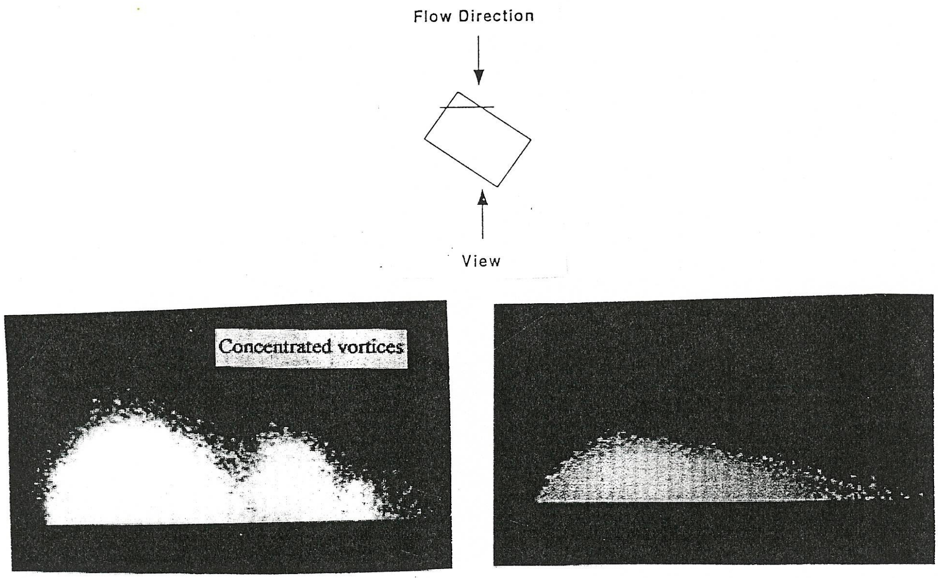


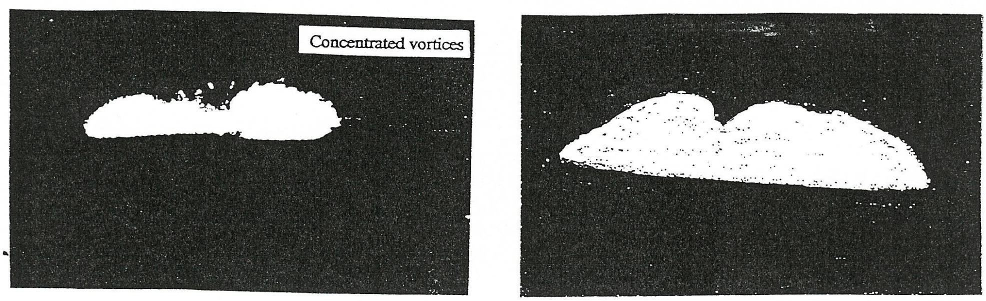
Figure 5. Mean pressure distribution on top surface of sharp and round edge models, α=25°, nominal boundary layer flow (turbulence 4%).

Top



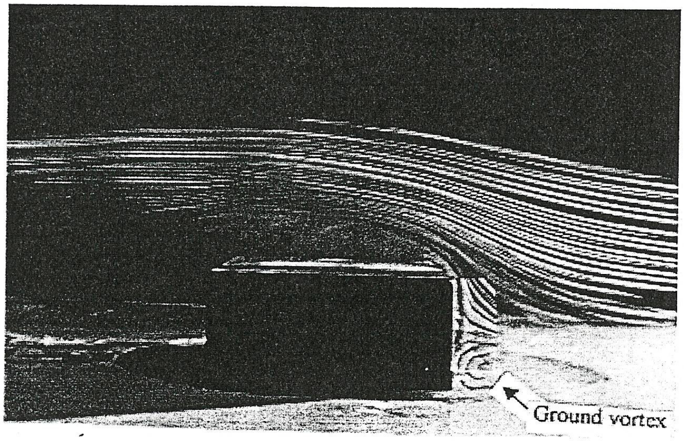
(a) Sharp edge model. (b) Round edge model, R=5 mm

Figure 6. Flow visualization, top surface, using laser light sheet illumination technique, α=45°, Station 1 (smooth flow).

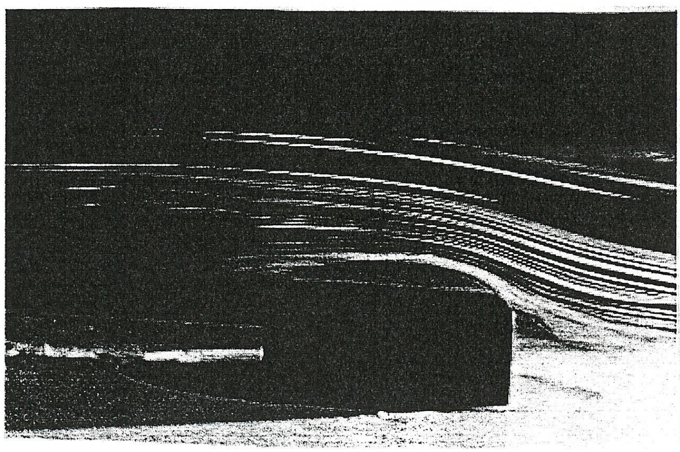


(a) Sharp edge model. (b) Round edge model, R=5 mm

Figure 7. Flow visualization, top surface, using laser light sheet illumination technique, α=45°, Station 2 (smooth flow).

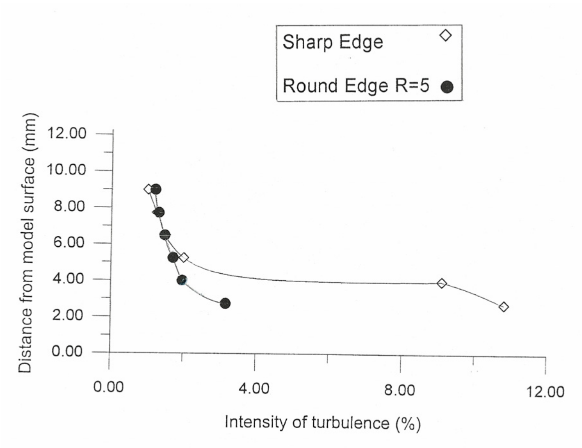


(a) Sharp edge model.

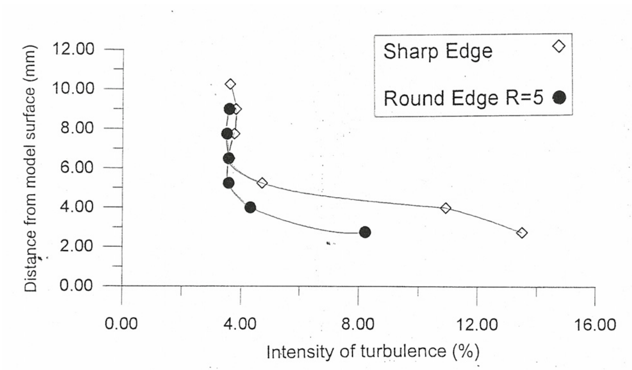


(b) Round edge model, R= 10 mm.

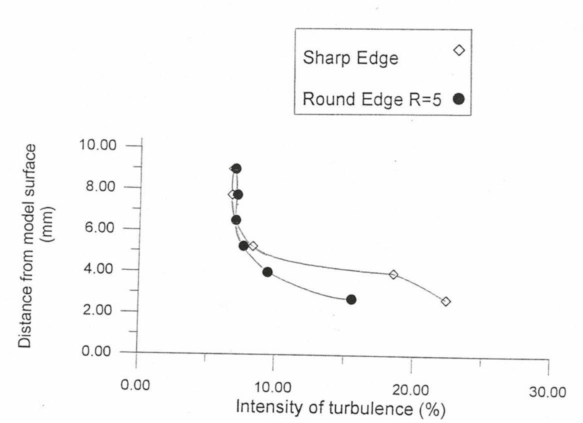
Figure 8. Flow visualization using smoke-wire technique, α=90° (smooth flow condition).



(a) Smooth flow.



(b) Nominal boundary layer turbulent flow (4% turbulence).



(c) Barrier generated boundary layer flow.

Figure 9. Turbulence in vortices (top surface) corresponding closely to hole # 50205, α=45°.