Engineering Notes

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Turbulent Flow over a Step with Nonzero Angle of Inclination of the Plates

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Introduction

TURBULENT flow over a backward-facing step is a very complicated problem in the field of fluid mechanics. It involves separation, reattachment, and redevelopment of turbulent shear flow. Many investigators have published their results related to this problem.[1,2] As to the knowledge of the authors, all the models previously used consist of two horizontal plates with zero-angle of inclination to the undisturbed stream. The purpose of this Note is to present some results of turbulent flow over a backward facing step with nonzero angle of inclination of the plates. It was found that both the step height and the angles of inclinations played an important role on the pressure distribution and the length of reattachment point from the step.

Results and Discussion

The experiments were carried out in an open low speed wind tunnel with a test section of 30×30 cm. The freestream velocity and ambient temperature were 15.68 m/sec and 300°K, respectively. The length of the model was 213 cm; it consisted of three essential portions, namely the leading plate, the step piece, and the trailing plate. The leading and trailing plates were made of plywood with formica lining on the top surfaces in an attempt to make a hydraulically smooth surface. Three step pieces were made with different step heights (1 cm, 2 cm, and 3 cm). The three portions were hinged together for easy adjustment of the angle of incidence of the plates. The angles were adjusted by lead-screws. Pressure holes with 0.5 mm diameter were drilled on the center line of the plates. Pressure distributions for different profiles of the model were recorded by an inclined mometer bank. These different profiles were the combination of three different step heights ($h = 1$, 2, and 3 cm), three different angles of incidence of the leading plate ($\alpha = 0°, 2°$, and $4°$), and five different angles of inclination for the trailing plate ($\beta = -4°$, $-2°, 0°, 2°$, and $4°$). Typical pressure distribution curves for $h = 2$ cm, were shown in Figs. 1 and 2. Figure 1 shows the results of zero angle of incidence of the leading plate. The curves are almost horizontal upstream of the step showing that the pressure is constant. In all these curves there is a slight drop in pressure just downstream of the step, followed by a rather rapid increase of pressure indicating the reattachment of the separated flow. When $\beta = 0$, the pressure on the trailing plate resumes a new constant value asymptotically. When $\beta < 0$ the gradient of pressure coefficient is positive showing that it is diverging, whereas for $\beta < 0$ the gradient is negative. In these results the distance x is measured along the surface from the step face. The surface pressure p is being written in the terms of pressure coefficient

$$C_p = \left(\frac{P - P_0}{\frac{1}{2} \rho U_0^2} \right) \tag{1}$$

where P_0 and U_0 are the static pressure and mean velocity, respectively, at the location 29 cm upstream from the step face and 8 cm above the surface, and ρ is the density of air. Figure 2 shows the results for $\alpha = 4°$. For any value of β the gradient of C_p upstream of the step is less than zero, indicating the flow is accelerating due to the converging effect. In this region, the difference of C_p is small showing that the inclination of the trailing plate has little effect on the pressure distribution upstream of the step. During the tests, trip wire

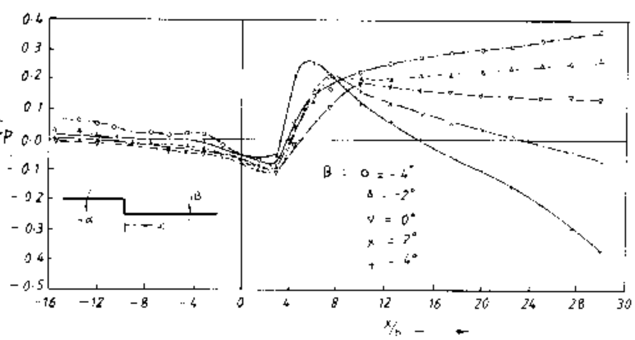

Fig. 1 Variation of pressure coefficient for $h = 2$ cm, $U = 15.68$ m/sec, $\alpha = 0$.

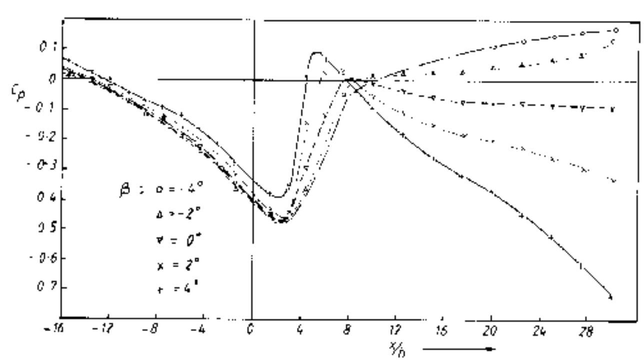

Fig. 2 Variation of pressure coefficient for $h = 2$ cm, $U = 15.68$ m/sec, $\alpha = 4$.

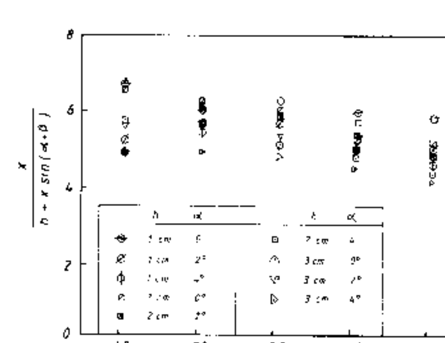

Fig. 3 Variation of reattachment point with α, β, and h.

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with 1.5 mm diam was placed perpendicular to the flow at a distance of 35 cm upstream of the step.

Tuft method was employed to locate the region of reattachment. Three rows of tuft were placed near the center line of the plate. This region is determined from the last tuft which is curved in the reverse direction to the point where all tuft were directed forward. The middle point in this region is assumed to be the reattachment point. The reattachment point ranged from $x/h=4$ to 14 for all the combinations of α, β, and h, where x is the distance from the reattachment point to the step. Figure 3 shows the reattachment point with x being normalized by $h+x\sin(\alpha-\beta)$ instead of h. If the following mean value is chosen

$$\left(\frac{x}{h+x\sin(\alpha-\beta)}\right)=5.4 \tag{2}$$

the maximum error involved in the measured result from the value predicted by Eq. (2) is less than 25%.

References

[1] Abbott, D. E. and Kline, S. J., "Experimental Investigation of Subsonic Turbulent Flow over Single and Double Backward Facing Steps," *Journal of Basic Enginerring: Transactions of the ASME*, Series D., Vol. 84, Sept. 1962m, pp. 317-325.

[2] Tani, I., Iuchi, M., and Komoda, H., "Experimental Investigation of Flow Separation Associated with a Step or a Groove," Aeronautical Research Institute, University of Tokyo, Rept. No. 364, April 1961.