Performance of Wide-Angle Two-Dimensional Diffusers with Area Suction (2nd Report)

Performance of Wide-Angle Two-Dimensional Diffusers with Area Suction (2nd Report)†

Eisho YAMAZATO*

Experiments have been made with area suction used for boundary-layer control in two-dimensional diffusers with divergence angles of 90° and 180° (Sudden enlargement) and an area ratio of 4 : 1 and an aspect ratio of 4 : 1.

These experiments, conducted with various extents of porous area and with suction quantities, indicated that the flow separation was not eliminated and no greater improvement of the performance was obtained by the use of area suction for both 90° and 180° diffusers. It is also found that the suction effect tends to be constant for the various extents of porous area from the diffuser entrance.

I. Introduction

In the flow channels or fluid machineries, we are often confronted with the problem of diffuser which will efficiently convert the dynamic pressure into static pressure. In general, a diffuser flow with small divergence angle results in a smooth flow with high pressure recovery efficiency, low energy loss, and good exit velocity profiles. On the other hand, in the wide angle diffusers, a flow almost always results in unsteady flow with large pulsations and separation. This flow separation creates undesirable effects on the diffuser performance. In order to improve the diffuser performance, a method of boundary-layer control by suction or blowing through slots has been employed by some investigators.[1)~4)] The results of some of these tests showed that the flow losses in diffusers are effectively improved by the boundary-layer control introduced into the diffuser flow.

In a previous work, tests were made with area suction used for boundary-layer control in two-dimensional diffusers with divergence angles of 30° and 60° and showed that the area suction was effective to improve the diffuser performance although the flow separation was not exactly eliminated.

This paper is continuation of previous work,[5)] and discussed on the performance characteristics of wide-angle diffusers with divergence angle of 90° and 180° (Sudden enlargement).

Nomenclature

A: cross-sectional area of duct
b : width of approaching duct
L : length of diffuser wall
p : static pressure
Q : main flow rate
q : suction flow rate
U : velocity outside of boundary layer
u : local x-direction velocity in boundary layer
$\bar{u}$: average velocity in a cross section
v : suction velocity
x : longitudinal distance along the centerline from the entrance
y : vertical distance from divergence wall
2θ : total divergence angle

† Received Oct. 31, 1969.
* Dept. of Mech. Eng., Univ. of the Ryukyus

c_p : pressure coefficient
η_p : pressure recovery efficiency
ζ: loss coefficient
ρ: density of air

Subscripts
1 : inlet section
2 : outlet section where recovery will finish
s : suction chamber

2. Pressure recovery efficiency and loss coefficient

In evaluating the performance of a diffuser with boundary-layer control, it is necessary to modify the conventional concept of a diffuser efficiency to account for the power required to effect boundary-layer control. The following equations are developed in the previous paper for the purpose and used in reducing the date.

$$\eta_p = p_2 - p_1 / \Big[\frac{1}{2}\rho \bar{u}_1^2 \Big\{ 1-\frac{q}{Q}\Big)^2 \Big(\frac{A_1}{A_2}\Big)^2 \Big\} + \frac{q}{Q}\Big(p_2 - p_s + \frac{1}{2}\rho \bar{u}_2^2 \Big)\Big] \qquad \text{(1)}$$

$$\zeta = \frac{\frac{1}{2}\rho \bar{u}_1^2 \Big\{ 1 - \Big(1-\frac{q}{Q}\Big)^2 \Big(\frac{A_1}{A_2}\Big)^2 \Big\} + \frac{q}{Q}\Big(p_2 - p_s + \frac{1}{2}\rho \bar{u}_2^2\Big) - (p_2 - p_1)}{\frac{1}{2}\rho \bar{u}_1^2 \Big(1-\frac{A_1}{A_2}\Big)^2} \qquad \text{(2)}$$

From equ. (1) and (2), the relations between η_p and ζ are expressed by:

$$\eta_p = 1 - \zeta \; \frac{\frac{1}{2}\rho \bar{u}_1^2 \Big(1-\frac{A_1}{A_2}\Big)^2}{\frac{1}{2}\rho \bar{u}_1^2 \Big\{ 1 - \Big(1-\frac{q}{Q}\Big)^2 \Big(\frac{A_1}{A_2}\Big)^2 \Big\} + \frac{q}{Q}\Big(p_2 - p_s + \frac{1}{2}\eta \bar{u}_2^2\Big)} \qquad \text{(3)}$$

$$\zeta = \frac{(1-\eta_p)\Big[\frac{1}{2}\rho \bar{u}_1^2 \Big\{ 1 - \Big(1-\frac{q}{Q}\Big) \Big(\frac{A_1}{A_2}\Big)^2 \Big\} + \frac{q}{Q}\Big(p_2 - p_s + \frac{1}{2}\rho \bar{u}_2^2\Big)\Big]}{\frac{1}{2}\rho \bar{u}_1^2 \Big(1-\frac{A_1}{A_2}\Big)^2} \qquad \text{(4)}$$

3. Experimental apparatus and procedure

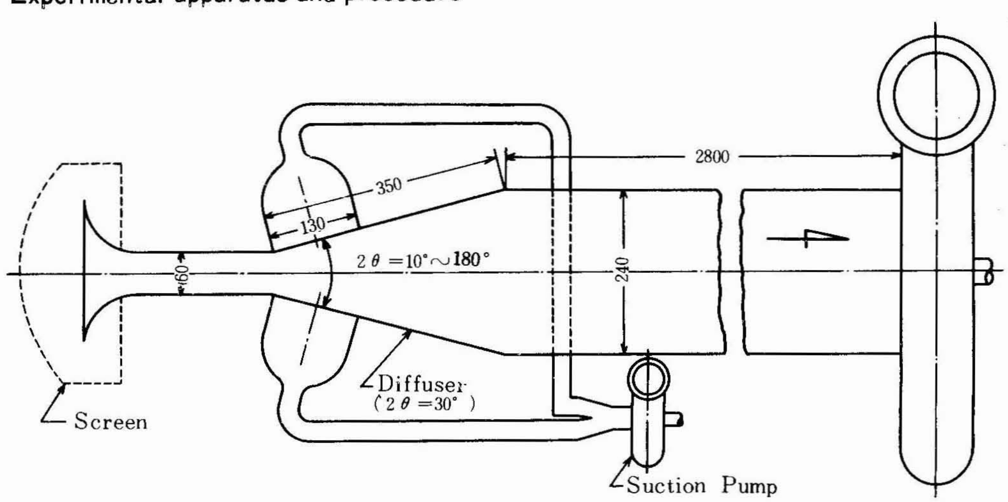

Fig. 1. Schematic view of test apparatus

The experimental apparatus is schematically shown in Fig. 1. The apparatus is formed by the combination of the approaching duct of 60 mm width and 600mm length, the diffuser with throat aspect ratio of 4:1, and the downstream duct of 240 mm width and 2,800 mm length.

The two diffusers tasted have divergence angle of 90°and 180° and an area ratio of 4:1 and an aspect ratio of 4:1. Details of the porous section of the diffusers are shown in Fig. 2. The porous section is made of fine wire screen attached to wooden

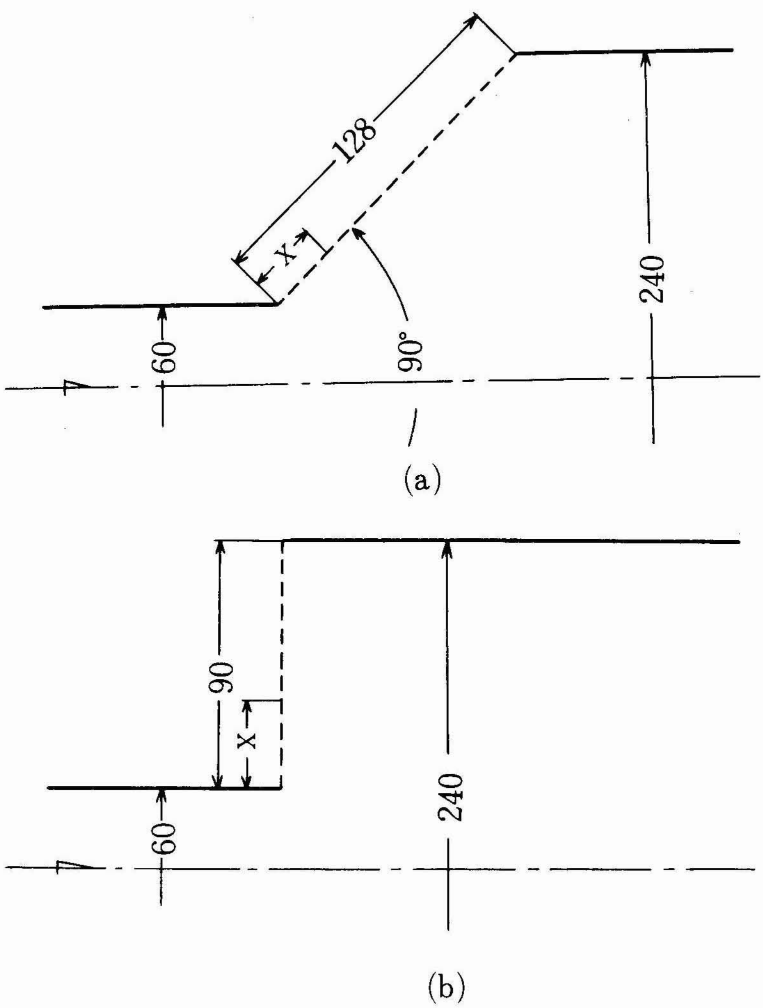

Fig. 2. Diffuser details

frames. The extent of porous area is controlled by covering a portion of the porous area with a nonporous tape.

The main air flow through a screen and curved wall entrance section is introduced by a driving fan at the downstream exit. Tests are conducted using a 90° and a 180° diffusers with various extents of porous area and suction flow rate under constant inlet velocity of about 35 m/s. The main air flow rate and suction flow rate are determined from their velocity profiles which are measured by traversing the pitot tube in the approaching duct and suction tube.

The forty-four static pressure taps are installed along the center line of the parrallel plates, and the longitudinal static pressure are measured by a multitube manometer.

4. Experimental results

4.1. Static pressure distributions

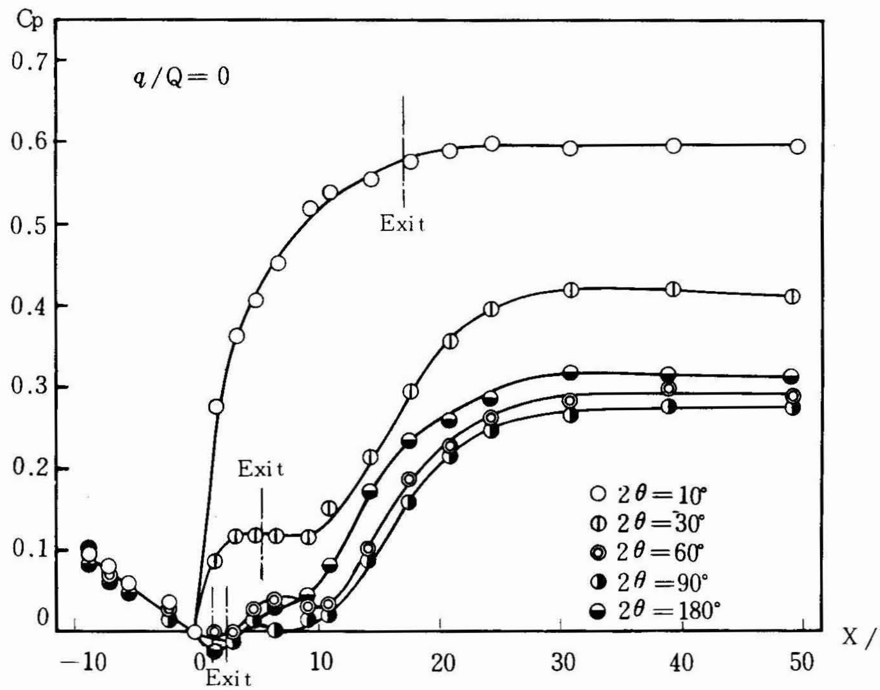

Fig. 3. Variation of static pressure coefficients with divergence angle for diffusers without area suction.

Fig. 3 show the static pressure distributions along the flow for the 10°, 30°, 60°, 90° and 180° diffusers without area suction. As shown in the figure the static pressure in a 10° diffuser is almost recoveried near the diffuser exit. In the wide-angle diffuser ($2\theta=30°\sim180°$), however, the static pressure recovery is not observed in the diffuser, and the pressure is gradually increased near the distance of $x/b_0=10$ from the diffuser entrance. It should be noted that there exists a certain region where the pressure distribution is uniform. It is understood that the flow is separated from the diverging walls in this region. This flow separation is also clarified by the flow picture in the previous study.[6] In Fig. 3, it should be pointed out that the static pressure coefficient of the 180° diffuser is larger than that of the 60° and 90° diffusers.

The effect of suction flow rate on the longitudinal static pressure distributions along the flow of 90° diffuser is shown in Fig. 4 for several extents of porous area.

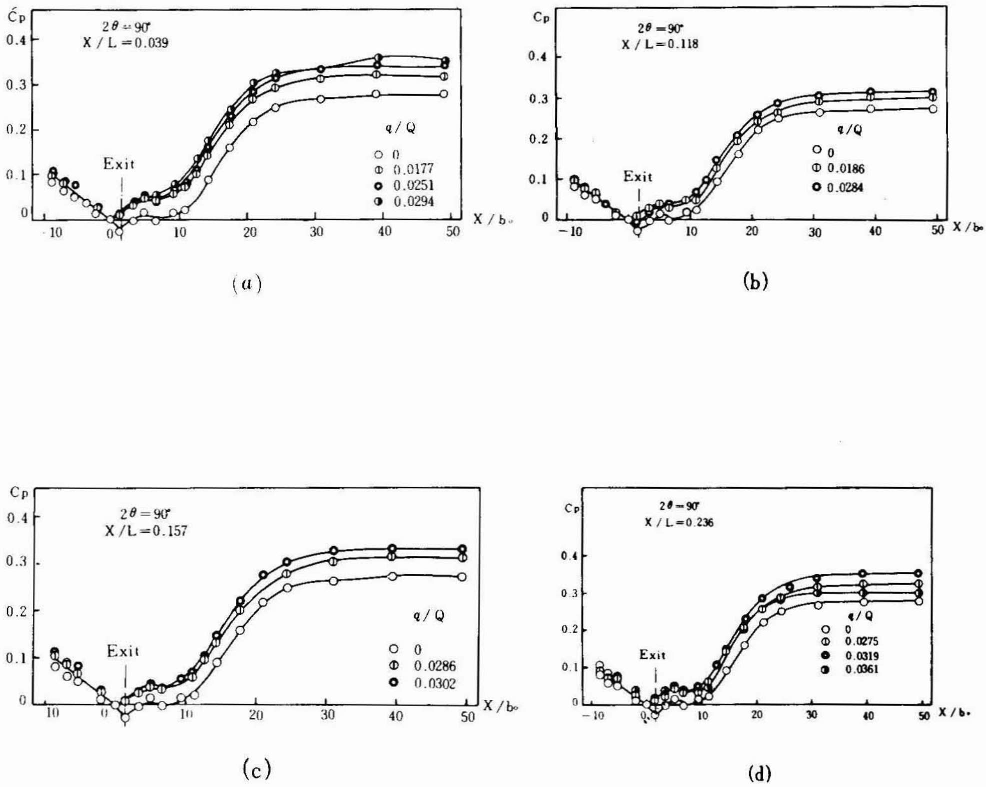

Fig. 4. Effect of area suction on the longitudinal static pressure coefficients along the 90° diffuser.

As shown in figure, increasing the suction flow rate, increases the pressure coefficient, but there also exists a certain region where the pressure distribution is uniform. It is also seen in the figure that the extents of porous area have a negligible effect on diffuser performance for the 90° diffuser.

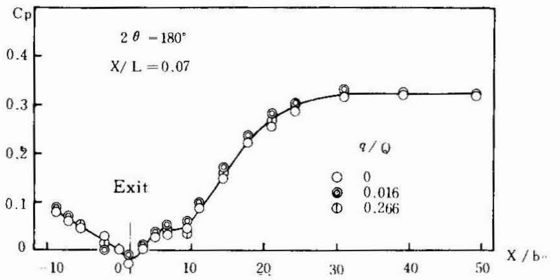

Fig. 5. Effect of area suction on the longitudinal static pressure coefficients along the 180° diffuser.

Fig. 5 show the effect of suction flow rate on the longitudinal static pressure distributions along the flow of 180° diffuser. As shown in the figure, no improvement on the pressure coefficient is attained for the extent of porous area.

Therefore, it can be said that the suction effect tends to be constant for various extents of porous area for the 90° and 180° diffusers.

4.2. Diffuser performance

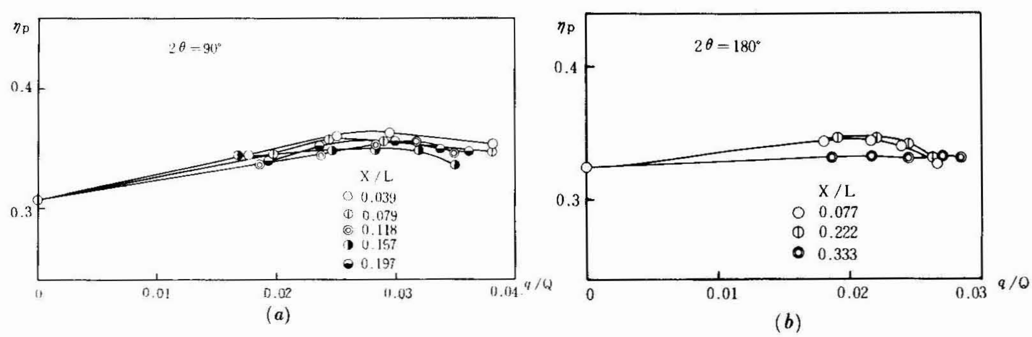

Fig. 6. Variation of pressure efficiency with suction flow rate for various extents of porous area

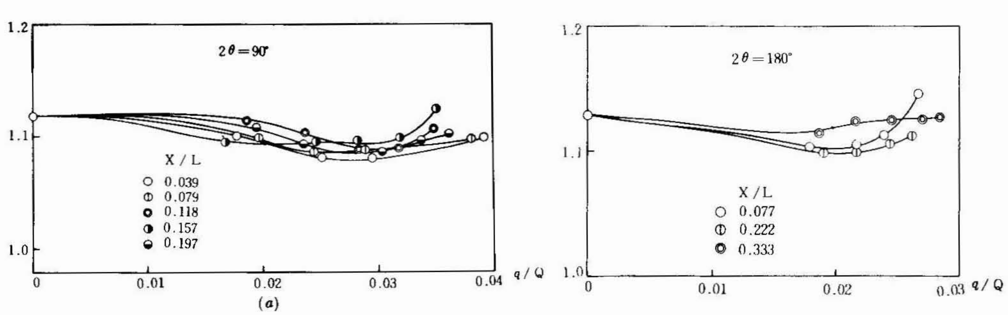

Fig. 7. Variation of loss coefficients with suction flow rate for various extents of porous area

In Fig. 6 and 7, the pressure recovery efficiency and loss coefficients are plotted against suction flow rates for various extents of porous area. For the 90° diffuser, with increase of the suction quantity, the efficiency gradually increased until the suction flow rate is about 3%. However, no greater improvement of the performance is obtained.

In the 180° diffuser, the variations are well within the experimental scater so that the pressure recovery efficiency are almost identical. This is in agreement with the result in the previous study using suction slots.

In Fig. 8, the optimum extent of porous area, the maximum efficiencies η_{pmax} and the optimum suction flow rate $(q/Q)_{opt}$ for η_{pmax} are plotted against the various extents of porous area. As discussed before, evident suction effect can not be seen for the 90° diffuser. For the 180° diffuser, however, no improvement on the efficiency is available for each width or porous section.

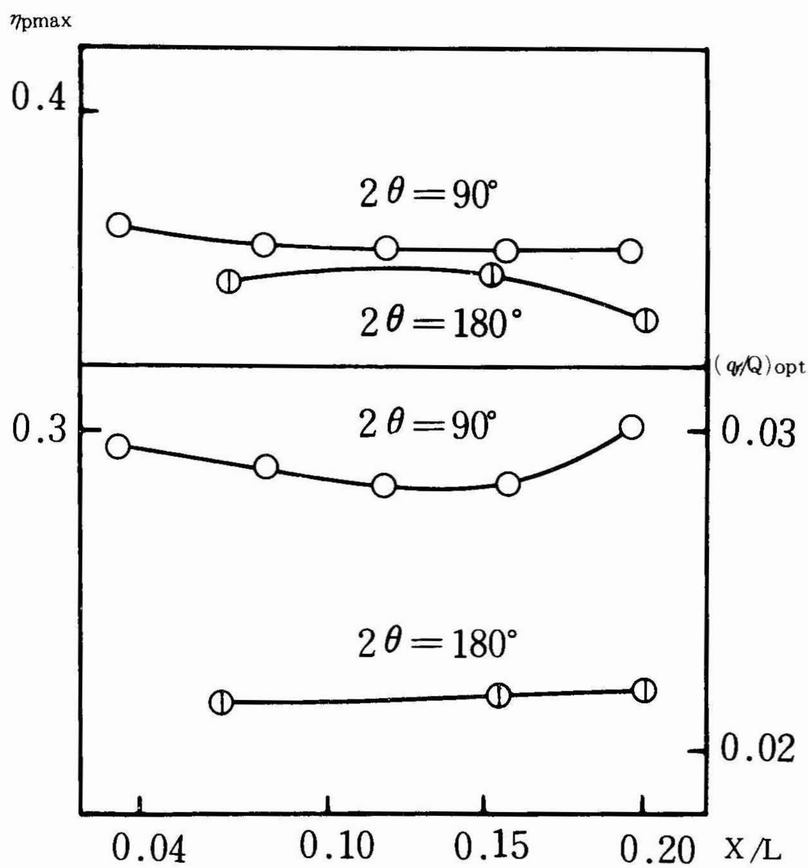

Fig. 8. Effect of extents of porous area on maximum pressure efficiency and suction flow rate to give maximum pressure efficiency.

5. Conclusions

Experiments were made with area suction applied to two-dimensional diffusers with divergence angle of 90° and 180° under constant inlet velocity of about 35 m/s.

The following are the main results of the present investigation:

1. In general, the diffuser performance is improved by the use of area suction near the entrance. However, greater improvement as in the 30° and 60° diffusers was not obtained.
2. The suction effect tends to be constant for the various extents of porous area from the diffuser entrance.

References

1) J. Ackeret, *VDI-Z*, **70**(1926), 1153.
2) L. B. Gratzer and R.H. Smith, *Rep. No. 300, Aero. Lab.*, Univ. of Washington,(1948).
3) C. A. Halzhauser and L. P. Hall, *NACA TN* 3793, (1956).
4) Y. Furuya, T. Sato, and T. Kushida, *Bulletin of JSME*, **9**-33(1966),131.
5) E. Yamazato, *Bulletin of Sience & Eng. Div., Eng. No. 2*, Univ. of the Ryukyus,(1969),1.
6) Y. Furuya et al, *Trans. of JSME*, **35**-274(1969), 1249.