Technical Notes

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Experimental Study of Turbulent Flow near a Suction Tube

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Introduction

FLUID dynamics and heat and mass transfer effects in turbulent boundary-layer flows with suction through a porous surface (wall suction or surface suction) have been studied extensively.[1-3] However, when the mass of fluid in a duct is withdrawn through a suction tube set on the centerline of the duct and parallel to the duct flow (tube suction), the change of turbulence mechanism near a suction tube inlet has not been studied yet.

In this study, we measure the turbulence intensities of the duct flow near a suction tube, which was set on the centerline of the duct and parallel to the flow in the duct, by using X-array hot-wire anemometers. The objective of this Note is to describe the flow of air near the inlet of a suction tube, in order to contribute basic data to various engineering operations.

Experimental Apparatus and Procedure

The experimental setup is illustrated in Fig. 1. We used the square duct (47 cm × 67 cm). The air was circulated in the duct by the blower as shown in this figure. The suction tube was located on the centerline of the duct. The tube diameter D and the tube length l are 15 mm and 150 mm, respectively. The air was withdrawn from the tube by the vacuum pump. The suction rates, VR (the ratio of the mean suction velocity averaged over the cross section of the suction tube to the averaged centerline velocity of the duct at the far upstream from the suction tube inlet), could be varied between 0 and 5.0. The Reynolds number based on the tube diameter was between 8300 and 41,500 and the Reynolds number based on the duct diameter was 276,000. The averaged centerline velocity of the duct was kept at 8.3 m/s for these tests.

The turbulence measurements were made by using KANOMAX constant-temperature hot-wire anemometers with type 29-1141 X-array hot-wire probes. The probe was a platinum-coated tungsten wire, 5-μm in diam, 1-mm long, and had a cold resistance of 4-7 ohm. The wires were calibrated before and after every run in a 5×5 cm exhaust plane of a nozzle where the turbulence level was about 0.5%. To correct the effects on hot-wire output due to difference between ambient and calibration temperatures, the mean temperature was continuously measured with a thermometer. All results in this report have been corrected for the ambient temperature changes where applicable. The frequency response of the anemometers was found to be such that the 3-dB down point was over 25 KHz, which was much higher than the highest frequency of interest.

Results and Discussion

The typical profiles of axial components $\sqrt{\overline{u_z'^2}}$ of rms turbulence velocity for various suction rates are shown in Fig. 2, where U_0, R, $\bar{r}$, and $\bar{z}$ are the axial time-averaged velocity in the main stream, the suction tube radius, the normalized radial r/R, and the normalized axial distance z/R from the suction tube inlet to the upstream, respectively. Examination of the plots in this figure reveals that the relative turbulence intensity near the suction tube inlet decrease and the region where the turbulence intensity is lowered spreads with the

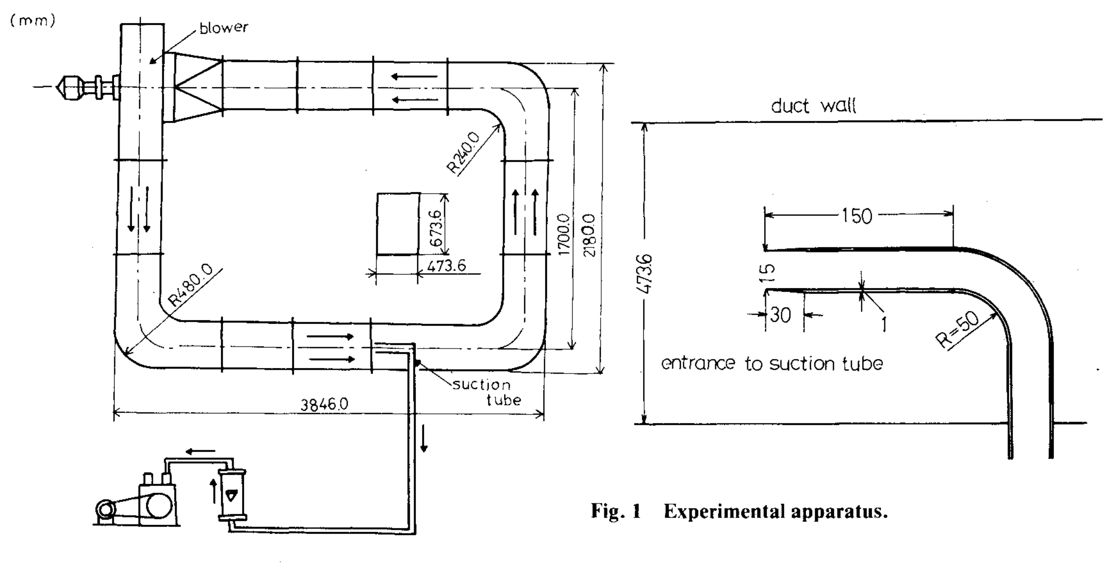

Fig. 1 Experimental apparatus.

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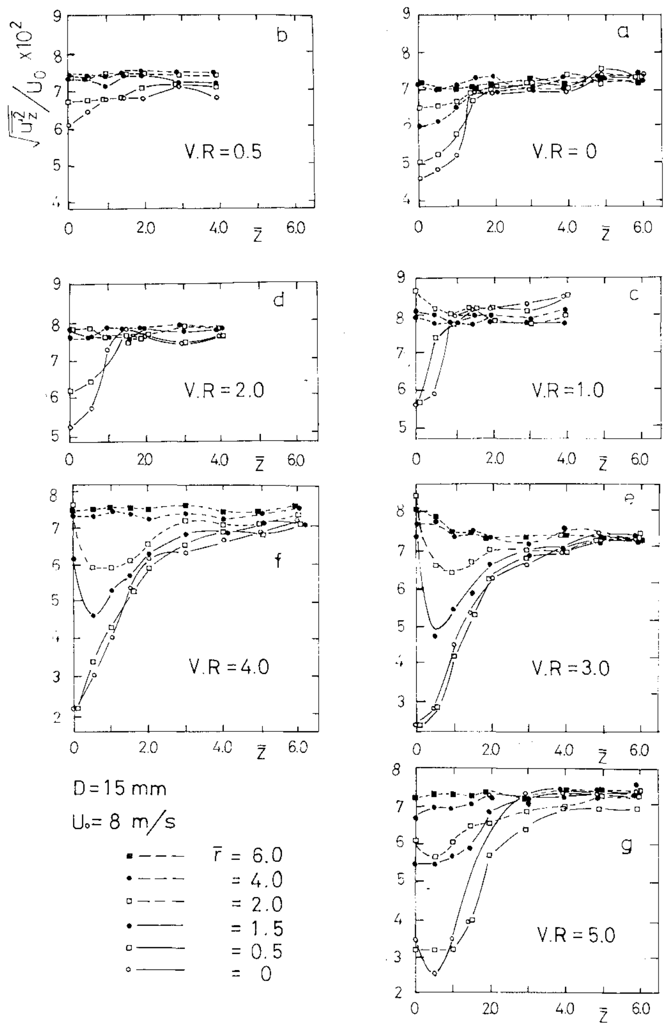

Fig. 2 Profiles of axial component of rms turbulent velocity.

increasing suction rate VR, except the case of $VR=0$ and 5. When the flow is accelerated, namely $\partial U/\partial z>0$, $-\overline{u_z'^2}\,\partial U/\partial z$ in the turbulence-energy equation is negative, where U is the axial component of the time-averaged velocity. Hence, it accelerates a decrease in the turbulence energy. On the other hand, the turbulence energy has a tendency to increase when $\partial U/\partial z<0$. Hence, in an accelerated flow in space, there is a tendency for a relative turbulence intensity to decrease, and in a decelerated flow in space, the turbulence intensity tends to increase. When $VR=0$, $\partial U/\partial z<0$. However, the turbulence intensity clearly lowered near the tube inlet as in Fig. 2a. In the case of $VR=0$, the air velocity in the suction tube is zero and the Reynolds number based on the suction velocity becomes zero. Therefore, the turbulence is naturally laminarized near the tube inlet. Similar effects also act on the flow when $VR=0.5$. Comparing Fig. 2f ($VR=4$) with Fig. 2g ($VR=5$), the relative turbulence intensity in Fig. 2f is much lower than that of Fig. 2g. This is because the Reynolds number based on the suction velocity of $VR=5$ becomes larger than that of $VR=4$ and it overcomes the laminarizing effect of accelerated flow by the suction. Hence, there are four effects in the flowfield near the suction tube: 1) the acceleration of the flow by the suction which decreases the relative turbulence intensity, 2) the deceleration of the flow by the suction which increases the relative turbulence intensity, 3) the reduction of the Reynolds number by the low-speed suction which decreases the relative turbulence intensity, and 4) the increase of the Reynolds number by the high-speed suction which increases the relative turbulence intensity.

$\sqrt{\overline{u_z'^2}}/U_0$ should approach the same value independent of VR at large z; however, the experimental values of $\sqrt{\overline{u_z'^2}}/U_0$ at large z in Fig. 2 vary from about 7 to about 8 for various VR. It seems that the variation is due to the experimental errors. Hence, the data include about $\pm 7\%$ error.

The results of radial component $\sqrt{\overline{u_r'^2}}$ of rms turbulent velocity, whose indication was omitted for the sake of simplicity, were similar to those of the axial component. The axial and radial relative turbulent intensities at the centerline of the duct were about 7% and 5%, respectively. These values are higher than previously reported values,[4] which were about 3% and 2.5%, respectively, over the same duct Reynolds number range because the air was circulated in the duct shown in Fig. 1.

References

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