TURBULENCE EFFECTS ON PRESSURE FLUCTUATIONS IN SEPARATED AND REATTACHING FLOWS II.PEAK PRESSURES AND SPECTRUM ANALYSIS

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1.INTRODUCTION

The previous paper presented and discussed the measured mean and fluctuating pressure streamwise distributions under a separation bubble. In this paper, peak pressure distributions and spectrum analysis of the fluctuating pressures are described.

The details of the experimental arrangements for this study were presented in the previous paper.

2.EXPERIMENTAL RESULTS

2.1 Streamwise Peak Pressure Distributions

Streamwise distributions of negative peak pressure coefficient,$C_{\check{p}}$ measured on the flat plate are shown in Fig.13. The peak pressure coefficients also show a dependence on both turbulence intensity and scale. In particular, the effect of turbulence scale on peak pressures becomes greater as turbulence intensity increases. It is interesting to note in Fig.13 that the magnitude of $C_{\check{p}}$ increases as L_x/D from 0.40 to 4.86. However, the values of $|C_{\check{p}}|$ have decreased at a scale ratio of 8.22. It can be found in Fig.13 that a 1.75:1 increase in turbulence scale is associated with a 24% increase in the maximum value of $|C_{\check{p}}|$. As shown in Fig.14, the magnitudes of $|C_{\check{p}}|$ on the streamwise surface of the rectangular cylinders also increase with increasing turbulence scale. A 7.4:1 increase in L_x/D is found to increase 38% and 86% in the maximum magnitude of $C_{\check{p}}$ for the cylinders with $H/D = 4$ and 2, respectively. Therefore, turbulence scale has more significant effect on $C_{\check{p}}$ measured on the cylinder with shorter afterbody length. The effect of turbulence scale on $C_{\check{p}}$ obtained on the square cylinder becomes more apparent at $L_x/D = 4.86$ for $I_u = 8.0\%$ as shown in Fig.15, and the values of $C_{\check{p}}$ measured in relatively smaller and larger turbulent flows ($L_x/D = 1.12$ and 8.22) are close to the peak pressure data obtained in smooth flow. Fig.16 shows the distributions of $C_{\check{p}}$ obtained on the four models tested for a given turbulent flow. As the afterbody length, H/D, decreases, the values of $C_{\check{p}}$ become more negative. As discussed above, an increase in turbulence intensity increases the magnitude of $C_{\check{p}}$. Therefore, an increase in the level of turbulence intensity causes the distribution of $C_{\check{p}}$ for a short model to be equivalent to that obtained with a longer model in low turbulence. This is consistent with the conclusion drawn by Courchesne and Laneville (1984) regarding drag coefficient of rectangular cylinders.

2.2 Peak Pressure Data

The minimum negative peak pressure coefficient, $C_{\check{p}Min}$, measured on the flat plate model as a function of turbulence intensity and scale, is presented in Fig17. Figures 18, 19, and 20 summarize the effect of the turbulence intensity and scale on the $C_{\check{p}Min}$ for rectangular cylinders with different afterbody lengths. The results obtained on the four models show that the magnitude of $C_{\check{p}Min}$ increases with increasing turbulence scale, and the scale effect becomes more pronounced at higher values of turbulence intensity. It is worth noting that turbulence intensities significantly greater than 15% are frequently encountered by buildings and structures in boundary layer wind flows. Moreover, peak pressure coefficients are widely used as design pressure coefficients on buildings. Therefore, it is important to correctly simulate free-stream turbulence scale to provide the largest magnitude of design pressures on buildings.

The cumulative distributions of $C_{\check{p}}$ measured at $X/D = 0.1$ on the cylinder with $H/D = 2$ are shown in Fig.21 and Fig.22. Fifty peaks were extracted from recorded 50 samples. Each sample contains 4096 collected pressure data and the point with the largest magnitude was chosen for calculation of $C_{\tilde{p}}$. The peak pressure coefficient are plotted as a function of the reduced variate,

$$\tilde{x} = -ln[-ln(i - 0.44)/(N + 0.12)] \quad (4)$$

where i is the rank order and N is the sample size (i.e. 50).

It was suggested by Holmes (1984) that this plotting method provides a good approximation to an unbaised plotting formula for the Type I extreme-value distribution. $C_{\tilde{p}}$ can be expressed as following:

$$C_{\tilde{p}} = U_c + (1/a)\tilde{x} \quad (5)$$

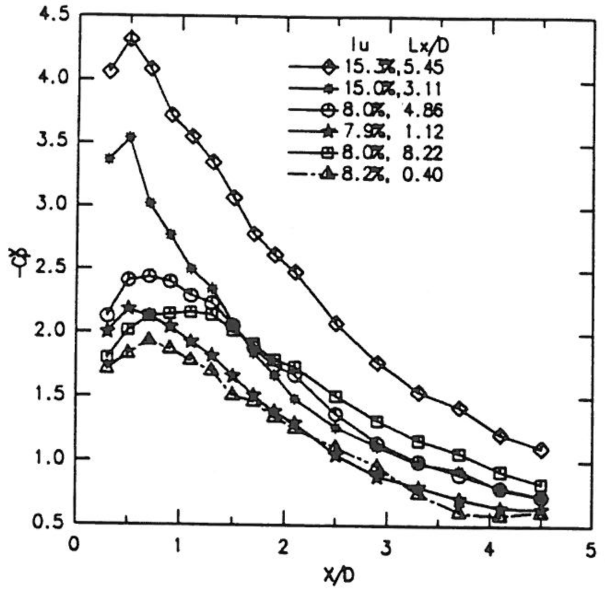

Figure 13. Negative Peak Pressure Coefficient Distributions On The Flat Plate

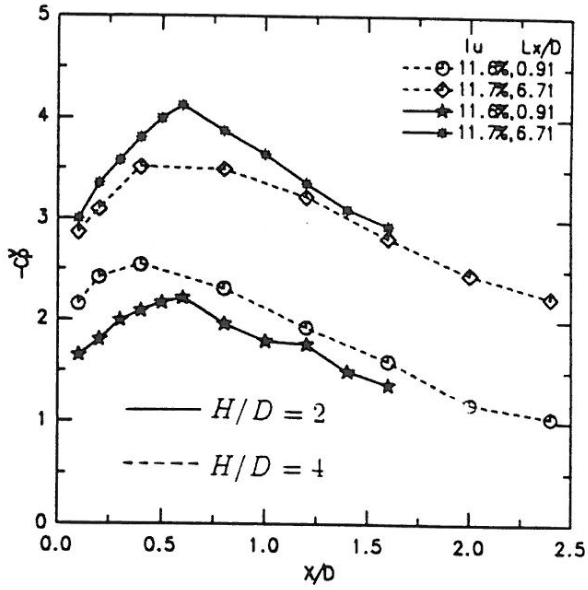

Figure 14. Negative Peak Pressure Coefficient Distributions On The Cylinders With H/D=2,4

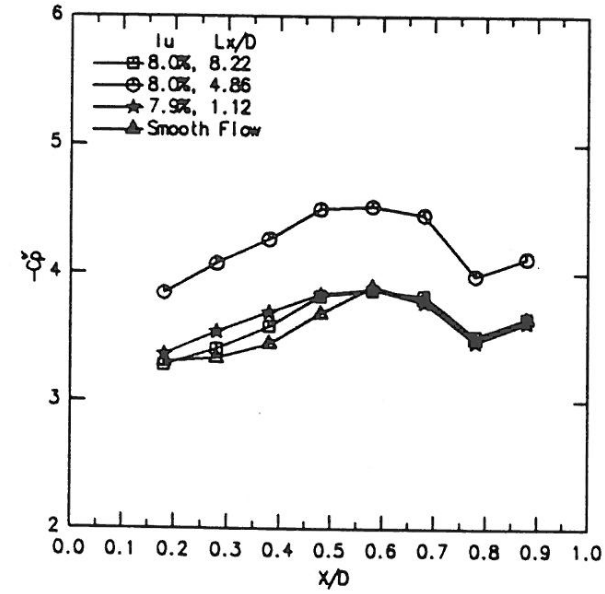

Figure 15. Distributions of Peak Pressure Coefficient On The Square Cylinder In Turbulent and Smooth Flows

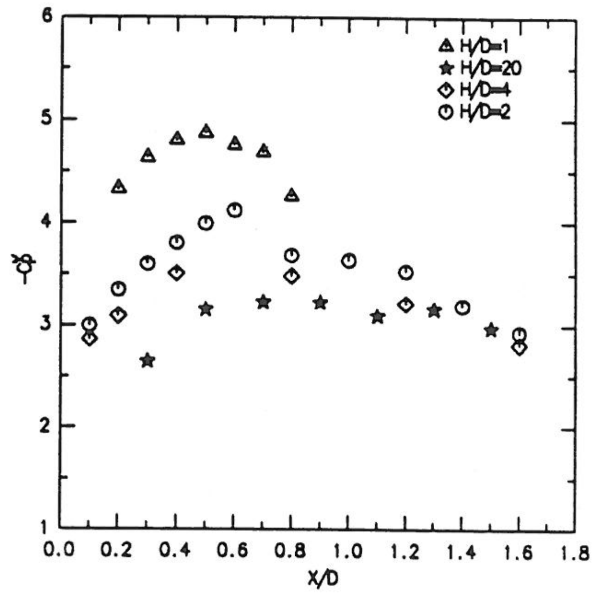

Figure 16. Distributions Of Peak Pressure Coefficient On The Four Cylinders In Turbulent Flows(Iu=12%,Lx/D=6.7)

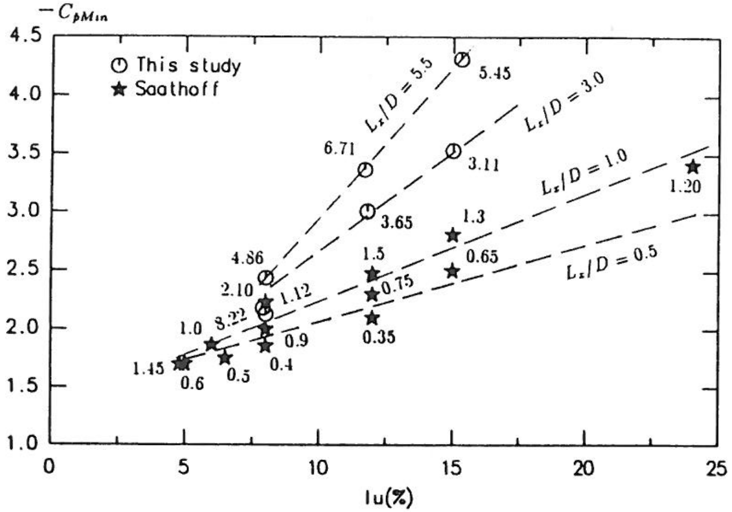

Figure 17. Minimum Negative Pressure Coefficients On The Flat Plate(Values of Lx/D Are Shown Next to Each Data Point)

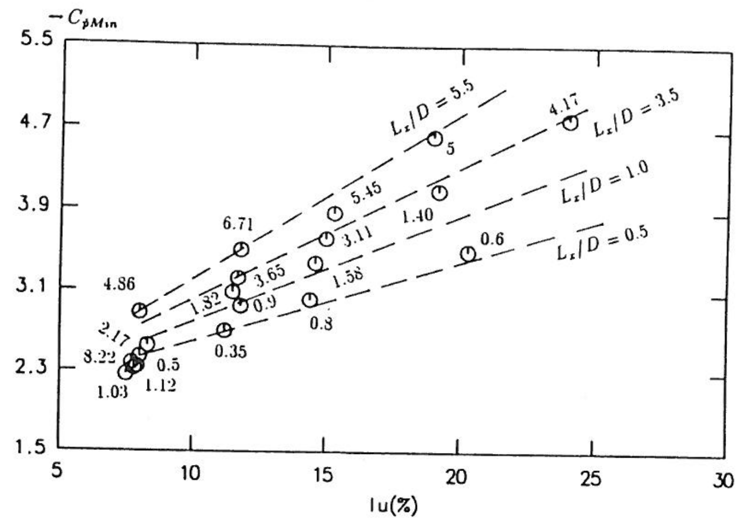

Figure 18. Minimum Negative Peak Pressure Coefficients On The Cylinder With H/D=4(Values of Lx/D Are Shown Next to Each Data Point).

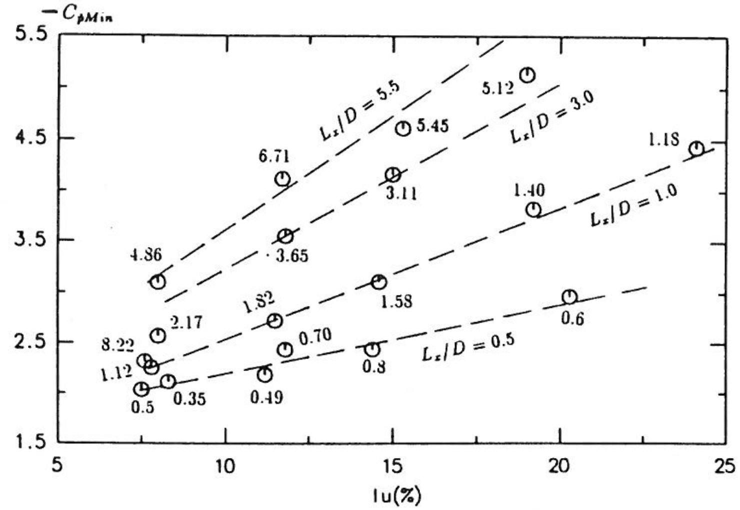

Figure 19. Minimum Negative Peak Pressure Coefficients On The Cylinder With H/D=2(Values of Lx/D Are Shown Next to Each Data Point).

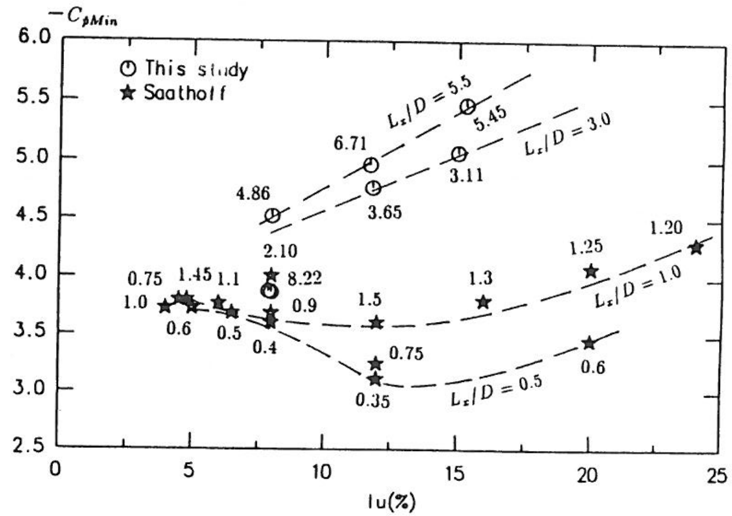

Figure 20. Minimum Negative Peak Pressure Coefficients On The Square Cylinder(Values of Lx/D Are Shown Next to Each Data Point)

It can be seen that the effect of turbulence scale on peak pressure data in the two Figures. As shown in Fig.21, an increase in L_x/D by a factor of two increases the value of U_c by approximately 20% while the values of $-(1/a)$ are approximately same for turbulence flows having different scale ratios but with about the same turbulence intensity. Figure 22 also demonstrates the significant effect of turbulence scale on the extreme value distribution of pressure coefficients. The data obtained in highly turbulent flows have approximately the same slope, but there is a difference between the slopes of data measured in turbulent flows and those obtained in smooth flow indicating that peak pressure fluctuations are caused by different processes.

Fig.23 shows $C_{\check{p}Min}$ as a function of L_x/D for $I_u = 8.0\%$ measured on the four models. It can be seen that as the afterbody length ratio,H/D is increased, the values of $C_{\check{p}Min}$ become progressively less negative, in particular in larger turbulent scale flows. It is interesting to note that as L_x/D increases the values of $C_{\check{p}Min}$ become more negative, however, with further increasing the scale ratio up to 8.22, the effect of turbulence scale on minimum peak pressures is not significant and the magnitudes of $C_{\check{p}Min}$ decrease.

2.3 Spectrum Analysis

Pressure spectra measured at $X/D = 0.1$ on the four models are displayed in Fig.24 for a turbulent flow and the turbulence spectrum is also presented. A high-amplitude spike in pressure spectrum corresponding to the Strouhal frequency in a narrow band is evident in the case of the square cylinder, which illustrates that pressure fluctuations near the leading edge of a square cylinder at this turbulence level are dominated by vortex shedding at the Strouhal frequency. The pressure spectra obtained on the flat plate and rectangular cylinders with $H/D = 2$ and 4 have a similar distribution with the longitudinal velocity spectra except in the high-frequency range where the decay is fast. This implies that longitudinal turbulence is responsible for the majority of pressure fluctuations near the leading edge of rectangular cylinders with $H/D = 2$ or larger.

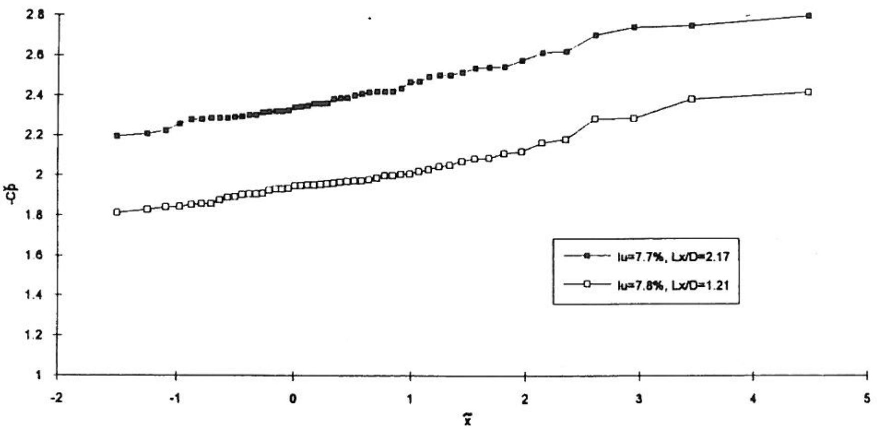

Figure 21. Cumulative distributions of peak pressure coefficents

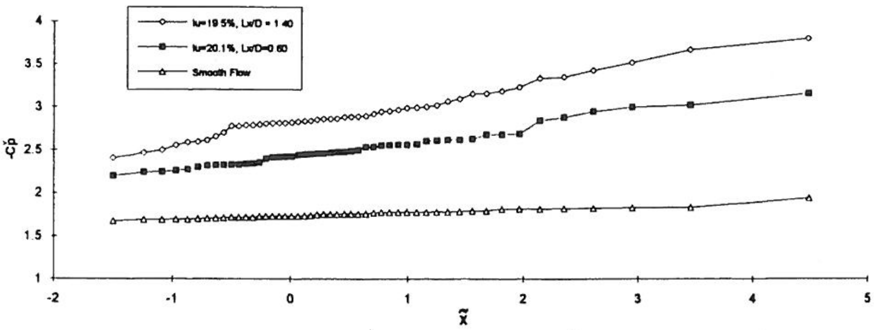

Figure 22 Cumulative distributions of peak pressure coefficents

2.4 Lateral Pressure Correlation

Fig.25 shows the lateral cross-correlation of fluctuating pressures near separation (at $X/D = 0.2$) measured on the cylinder with $H/D = 4$. It can be seen that the turbulence scale dominates the distribution of lateral cross-correlation of fluctuating pressures. An increase in turbulence scale causes the cross-correlation to increase progressively. The results obtained on the other three models also draw the same conclusion. The effect of depth/thickness ratio on the lateral pressure correlation can be seen in Fig.26 by comparing the data measured at the same turbulence configurations for the models tested with different afterbody lengths. The spanwise correlation measured on the bluff 2:1 section is higher than that obtained on the slender 4:1 section.

3.CONCLUSION

From the experimental results presented in the previous and this papers the following conclusions can be drawn.

Mean pressure distributions are strongly dependent on free-stream turbulence intensity but not significantly affected by turbulence scale over a range of turbulence scale ratio for $L_x/D < 4.9$ for a blunt flat plate and $L_x/D < 2.1$ for rectangular cylinders with $H/D = 2$ and 4. However, the measured mean pressure coefficients on the square cylinder model are apparently changing with turbulence scale in all the ranges of turbulence scale tested. Fluctuating pressures and negative peak pressure coefficients are increased with both increasing turbulence intensity and scale, as noted previously. However, with further increase in L_x/D (e.g. $L_x/D = 8.22$, $I_u = 8.0\%$), the magnitudes of C_{σ_p} and $C_{\breve{p}}$ were found to be smaller than those measured at the same turbulence intensity but with lower scale ratios. An increase in the level of turbulence intensity causes the distribution of $C_{\breve{p}}$ for a short model to be equivalent to that obtained with a longer model in low turbulence. As the afterbody length ratio,H/D is increased, the values of $C_{\breve{p}Min}$ become progressively less negative. But as L_x/D is increased to a larger value (e.g. $L_x/D = 8.22$), the values of $|C_{\breve{p}Min}|$ decrease. The magnitude of $C_{\breve{p}Min}$ increases with increasing turbulence scale for the range of $L_x/D < 6.75$ and the scale effect becomes more pronounced at higher values of turbulence intensity. Spectrum analysis shows that longitudinal turbulence is responsible for the majority of pressure fluctuations near the leading edge of rectangular cylinders with $H/D = 2$ or larger while pressure fluctuations on a square cylinder are dominated by vortex shedding at the Strouhal frequency. The lateral cross-correlation of fluctuating pressures near separation are significantly affected by turbulence scale. An increase in L_x/D causes the spanwise correlation to become greater. The spanwise correlation measured on the bluff section ($H/D = 2$) is higher than that obtained on the slender section ($H/D = 4$).

It has been shown that not only turbulence intensity and but also turbulence scale have significant effects on the standard deviation fluctuating pressures and magnitude of the very low peak pressures. Therefore, it is necessary to correctly model both turbulence intensity and scale to predict the highest value of design pressures on buildings and structures.

4.ACKNOWLEDGEMENT

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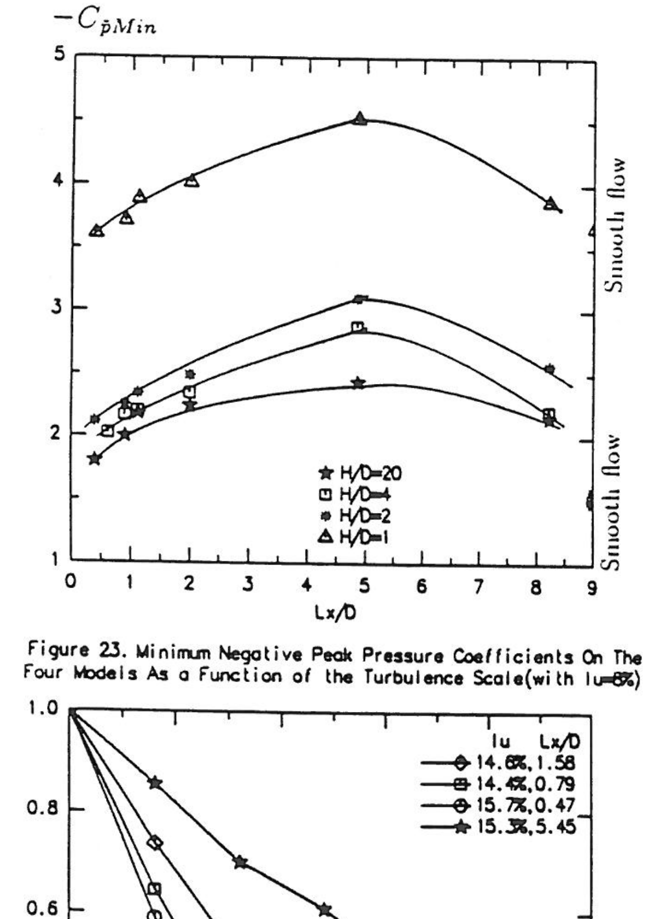

Figure 23. Minimum Negative Peak Pressure Coefficients On The Four Models As a Function of the Turbulence Scale(with Iu=8%)

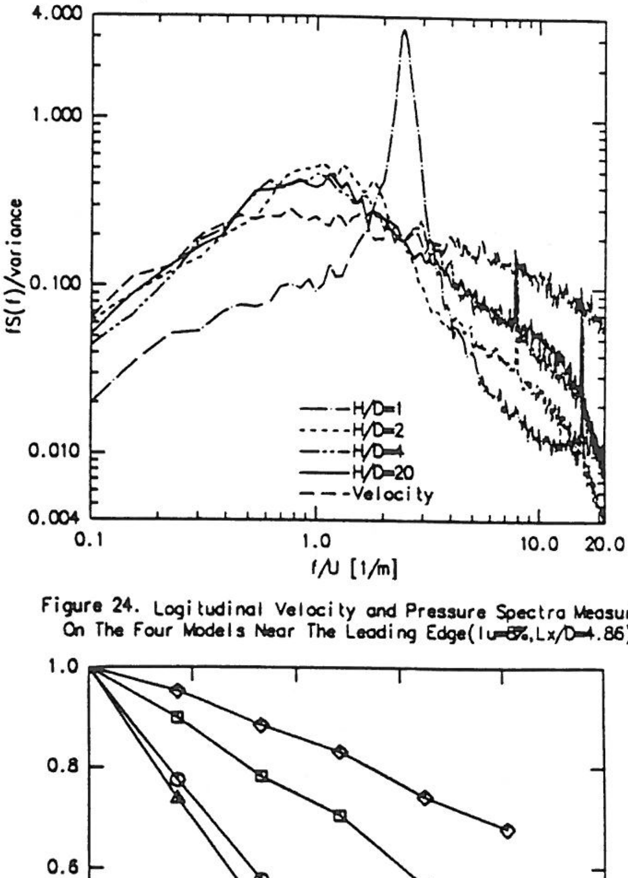

Figure 24. Logitudinal Velocity and Pressure Spectra Measurd On The Four Models Near The Leading Edge(Iu=8%,Lx/D=4.86)

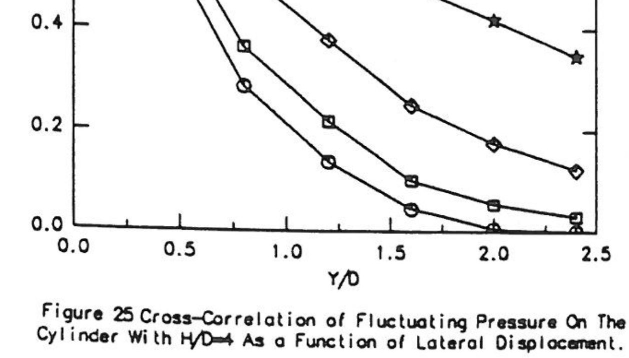

Figure 25 Cross-Correlation of Fluctuating Pressure On The Cylinder With H/D=4 As a Function of Lateral Displacement.

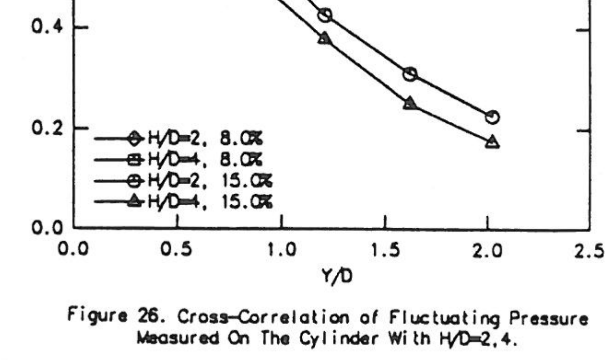

Figure 26. Cross-Correlation of Fluctuating Pressure Measured On The Cylinder With H/D=2,4.