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Discussion

LDV Measurements Near a Vortex Shedding Strut Mounted in a Pipe[1]

Z. D. Husain.[2] Reported results reflect a very carefully conducted experiment, and data are precise, for which authors must be commended. Since these data were not addressing azimuthal effects of the circular pipe, results from similar experiments in a rectangular test-section could possibly resolve the question on the existence of any noticeable three-dimensional or azimuthal influence of this flow facility.

In "Apparatus and Techniques," the authors stated "Throughout most of the pipe, the nonlinearity of the position was smaller than the length of the measuring volume . . ." This statement is vague. Relatively large errors due to nonlinearity is expected near the wall, especially at $y/D \approx \pm 0.5$. Again, those locations are not of major concern to data presented here. Hence, defining regions of large errors in the probe-volume location could be expressed in terms of y/D.

Data over $y/D < 0$ were generated by assuming symmetry or antisymmetry (as the case may be), hence lines over that region should not be drawn with any data symbol. Plotting with symbols over the entire flow field tend to imply that actual data were obtained. Again, the same symbol is used for all x/D locations, hence symbols are not essential to the plot. Please refer to plots by Kovasznay (reference [1]) and Durgin and Karlson (reference [2]), where one-half of the plot does not have any data symbol because data were not actually acquired.

It is stated that to handle data uncertainty in both time and space due to randomness associated with high-Reynolds number flows, the velocity power-spectral density was obtained to measure different fluctuating-velocity components relating to vortices. Since conventional true-RMS meters do not distinguish between the random part from the periodic part, how did authors measure the random part of the turbulence intensity? The total turbulence intensity can be obtained from the velocity power spectrum. From Fig. 10, it appears that the total turbulence intensity u_T is the vector sum of the random and two periodic components. A statement relating to the actual data acquisition method of different fluctuating-velocity components would be helpful. Please note that spectral averaging does not resolve the uncertainty in space/time randomness.

Figure 9 is a presentation of typical plot of the power spectral density, but has no reference to locations in y/D. I presume that the probe volume is near the path of the vortex center, because the spectrum shows noticeably large peaks at the fundamental vortex shed-frequency. A velocity signal which is not exactly sinusoidal in the frequency domain, through Fourier decomposition will show peaks at higher harmonics of the fundamental. Authors state that the "worst" spectrum in Fig. 9 is at x/D of 0.63. The velocity signal at that x/D location is expected to have high energy at the fundamental mode in the frequency domain. Hence, randomness in strength, shape and size of the vortex along with space/time dependence will result in peaks at higher harmonics of the fundamental mode in the frequency domain. From the controlled excitation study of a circular jet, Zaman and Hussain [8] reported nonsinusoidal velocity signals in the time domain even when very repetitive vortex structures were shed at the exit of an axisummetric jet. Note that velocity signals behind a cylinder is also nonsinusoidal (reference [1]). Spectra of such velocity signals show peaks at higher harmonics (Zaman and Hassain). Hence, there is nothing wrong with the "worst" spectrum in Fig. 9. Velocity signals at locations away from the path of the vortex center is not an exact sinusoid. Figure 10 showing peaks at the first harmonic of the fundamental and associated with decrease in the fundamental at $y/D \approx 0$ and $y/D \approx 0.5$ is consistent with the flow phenomenon.

Figure 14 shows that with increasing x/D there is a continual decrease in u_1/U_b values and increase in u_2/U_b values. Note also that with increasing distances from the strut, alternately shed vortices effectively double the vortex-passage frequency, thereby in the frequency domain a noticeable peak is observed at the first harmonic of the fundamental. Similar velocity signals were reported by Kovasznay (reference [1], Fig. 12), and Zaman and Hussain.

Conditionally sampled data could provide further insight into the vortex structure in space and in time domain when sampled at different phases of their evolution.

Additional Reference

8 Zaman, K. B. M. Q., and Hussain, A. K. M. F., "Vortex Pairing in a Circular Jet Under Controlled Excitation. Part I. General Jet Response," *J. Fluid Mechanics*, Vol. 101, 1980, pp. 449–491.

Note: Definition reads $v_T = (\Sigma v_n{}^2 + v_n{}^2)^{1/2}$; second subscript on the right-hand side of the equation should be "t" and not "n".

Authors' Closure

We thank Dr. Z. D. Husain for his discussion. We will answer paragraph by paragraph the questions he raised.

The azimuthal dependence of the incoming flow in our facility has been tested by comparing two perpendicular profiles at $x/D = -0.71$. The profiles were both symmetric and agreed with each other within better than 0.5 percent except within 2mm of the wall, where the agreement was within 1 percent. This shows that our facility produces axisymmetric flow. Also, profiles of the longitudinal velocity were taken along horizontal diameters at $x/D = 0.63$, 0.83, and 3.13 with the splitter plate vertical. Then the strut was rotated 90 degrees, and the same profiles were taken along vertical diameters with the splitter plate horizontal. The

[1] By T. T. Yeh, B. Robertson, and W. M. Mattar, published in the June 1983 issue of the JOURNAL OF FLUIDS ENGINEERING, Vol. 105, No. 2, pp. 185–196.

[2] Corporate R&D, Daniel Industries Inc., Houston, Texas 77224.

corresponding profiles agreed within better than one percent, showing again that the upstream flow from our flow facility is axisymmetric.

The point closest to the wall for which the velocities were measured is at $y/D = 0.48$ and $z/D = 0$ (with the splitter plate horizontal). At this point the nonlinearity in y/D is about 0.008 and in z/D about 0.004. At other points where the velocities were measured, the nonlinearity in the position calibration was too small to be measured. The largest contribution to position uncertainty is the approximately 1.5 mm × 0.15 mm size of the measuring volume in the 52 mm diameter pipe.

We agree it would have been better to plot symbols only where data were actually taken.

To determine the magnitudes of the periodic velocity components, we measured the area under the corresponding peak in the power spectrum as described on page 192. The level of random signal subtracted was determined by averaging 5 data points on each side of the 21 points and interpolating linearly between the two averages.

The spectra of Fig. 9 were taken at $y/D = 0.096$ ($y = 5$mm) and $z/D = 0$ for all three values of x/D listed. The 3rd harmonic of the velocity signal was smaller than about 1 percent of the larger of the 1st or 2nd harmonics at all points where data were taken. We chose the word "worst" only to express this point, not to suggest that anything was wrong. Harmonics higher than the third were too small to be measured. We agree that periodic signals in general exhibit higher harmonics. We would certainty have observed them in our experiment if they were larger than the turbulence at that frequency. To a good approximation, the only components that are there are just the mean, the fundamental, the second harmonic, and broadband turbulence.

As noted on page 194, vortices passing on both sides of the centerline cause a maximum in the second harmonic u_2 of the longitudinal velocity but a zero value for the second harmonic v_2 of the transverse velocity on the centerline. By second harmonic, we mean the component at twice the frequency of the first harmonic or fundamental.

Interference Between Two Circular Cylinders of Finite Height Vertically Immersed in a Turbulent Layer[1]

M. M. Zdravkovich.[2] The authors are to be complimented for an excellent and detailed pressure measurement on one of two interferring cylinders at $R_e = 1.55 \times 10^4$. The height to diameter ratio of both cylinders was only 3 and the thickness of the turbulent boundary layer along the wall on which the cylinders were attached was 0.86 of the cylinder height. At the base of the cylinders near the ground, the turbulent boundary layer presumably rolled down and formed a strong horse-shoe eddy. At the free-end, the flow was deflected upwards on the upstream side and pressure coefficient could not reach the value of one. The extent of these two regions probably overlapped for short $h/d = 3$ and it *should* have resulted in a complete suppression of eddy shedding in the wakes of both cylinders. This inference seems to be supported by the measured values of the base pressure coefficient, C_{p180} being in the range -0.3 to -0.6. These are considerably above the values of -1.2 to -1.4 found behind the nominally two-dimensional cylinder at the same Reynolds number. The overall drag coefficient of 0.65 is almost half of that produced by the nominally two-dimensional cylinder. However, the authors did not mention eddy shedding and my first question is whether they found that the eddy shedding was suppressed for all arrangements tested.

If my inference about the suppressed eddy shedding is correct then the authors demonstration of a qualitative similarity of the interference effects between the short finite cylinders and nominally two-dimensional ones gives a new insight into the phenomena involved. The biased jet in side-by-side arrangements reappeared between the short cylinders despite the absence of eddy shedding and presence of the strong horse-shoe eddy and end-effects. The bistable nature of that phenomenon was demonstrated in Fig. 10, but single values for C_D and C_L were plotted in Figs. 13 and 14. There must have been intermittent occasions when the monitored cylinder experienced the jet-switch and produced different pressure distribution. My second question to the authors concerns the effect of bistable jet swich on the overall C_L and C_D.

There is another flow instability in slightly staggered arrangements when the strong gap flow between the cylinders may suddenly cease and result in a discontinuous change of C_L. This gap flow switch was a prominent feature of the interference between the two nominally two-dimensional cylinders. The authors chain-dot line $C_{L\max}$ in Fig. 13 is located in the region where the gap flow instability should be expected. The question is whether similar gap flow switch was observed by the authors.

The tandem arrangements displayed a typical change in pressure distribution on the upstream side as seen in Fig. 8(*a*) for $s/d = 3$ and 4. This always produced discontinuous jump in C_D (reference [10]). This jump, however, is not shown in Fig. 14 and the authors comment's will be helpful.

The effect of Reynolds number was not mentioned in the paper. The beautiful flow visualization photographs shown in Fig. 10 were obtained at R_e about 620. The flow pattern should not be expected to be identical for $R_e = 1.55 \times 10^4$ at which pressure distributions were measured. The difference of two flows is caused not only by the laminar boundary layer along the wall, as stated by the authors, but also due to long laminar free-shear layers separated from the cylinders. The transition in free shear layers at $R_e = 1.55 \times 10^4$ is expected to be not further than 0.5D from the separation. The simulation of turbulent boundary layers on both cylinders in reference [11], was done with the aim of simulating post-critical flow regime. However, despite the strong Reynolds number effect an extremely valuable qualitative insight can be gained from Fig. 10. May I ask the authors what was the height of the smoke-wire relative to the height of the cylinders and could they show some photographis for $y/h = 0.11$ and $y/h = 0.89$? The first will reveal three-dimensional flow due to the horse-shoe eddy (as in reference [14]), while the second equally intriguing one will show three-dimensional flow around the free end.

Finally the inferred double flow structure by the discusser along the height of the short cylinders can be proved or disproved by presenting equilift and equidrag lines for local sections. The horse-shoe flow structure will strongly affect local C_D and C_L at $y/H = 0.11$ while the free-end effect will dominate local C_L and C_D at $y/H = 0.89$. The present Figs. 13 and 14 hide these two separate effects.

Additional Reference

14 Taniguchi, S., Sakamoto, H., and Arie, M., "Flow Around a Circular Cylinder of Finite Height Placed Vertical in Turbulent Boundary Layers," *Bull. J.S.M.E.*, Vol. 24, No. 187, 1981, pp. 37–44.

[1] By Taniguchi, S., Sakamoto, H., and Arie, M., published in the December 1982 issue of the ASME Journal of Fluids Engineering, Vol. 104, No. 4, pp. 529–536.

[2] University of Salford, Salford, U.K. Mem. ASME.