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PIV experiments on vortex induced vibrating cylinders at high Reynolds numbers

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Problem focus. The recent paper by Sarpkaya (2003) gives state-of-the-art description of the intrinsic nature of vortex induced vibrations (VIV) and lists a number of conclusions and recommendations for further studies of the phenomenon. The difficulties in numerical simulations of VIV at high Reynolds numbers are mentioned as particular challenges for future studies. The difficulties arise because of the turbulent character of the fluid motion close to the cylinder boundary and within the shear layers behind the cylinder. Sarpkaya noted that the numerical simulations are to be guided by flow-visualization experiments on high Reynolds number using non-intrusive techniques like PIV (Particle Image Velocimetry). Desired PIV measurements include: effect of the ambient turbulence on separation excursions and VIV, the evolution of the instability of unsteady shear layers emanating from the cylinder, effects in the body proximity, effects of the ambient turbulence on shear layer instability.

Predictions of the loads and motion of long pipelines and cables in the ocean, and motions of risers that connect floating production units on the ocean surface to wells on the sea floor, represent a continuous practical challenge for industries operating offshore. The needs within practice request better theoretical and experimental understanding of VIV and motivates for continuous efforts in developing improved simulation tools. These should be capable for use and accurate predictions of vortex induced vibrations and loads at high Reynolds numbers.

With this motivation we carry out PIV measurements for Reynolds numbers primarily in the range around 100.000. Smaller values of Re down to about 4000 are also investigated. A rigid (horizontal) cylinder of diameter 0.08 m, mounted to springs, is moved with constant speed in a water tank of dimensions (25 m, 0.5 m, 1 m) (length, width, depth). The cylinder is allowed to vibrate in the cross-flow and in-line directions. During each experiment, we record vertical and horizontal forces using gauges at the ends of the cylinder, as well as recording the flow field in sections parallel to the side walls of the tank. The field of views (FOV) in use are typically of size 2d x 2d and d x d, where d denotes the diameter of the cylinder. While the big FOV gives the more global fluid motion behind the cylinder, the close up d x d FOV is useful to extract details in the flow. The local turbulence distribution, the eddy dissipation rate, the Reynolds stresses, and thus the various terms contributing to the turbulent kinetic energy budget (TKEB), are extracted from the PIV measurements. The PIV measurements enable a detailed study of the flow separation occurring at the shoulders of the cylinder. The movement of the separation point is extracted.

The Digital PIV system consists of dual pulsed lasers, a high speed camera with resolution 1k x 1k, storing to computer a sequence of 100 double images per second in the examples below, with subsequent data analysis by the MatPIV program developed in our laboratory.

Results. An ensemble-average of the velocity field, of size 2d x 2d, is performed at constant phases during one cycle of the transverse lift force, thus separating the phase-locked motion from the random turbulent motion. In these tests the cylinder has constant forward motion with speed U, is restrained from vibrations, and Re=24.000. A control box moving with the cylinder has 28 by 41 velocity arrows (horizontal by vertical). This field is decomposed into an (ensemble) averaged part plus a fluctuation, i.e. $(u, v) = (<u>, <v>) + (u', v')$. (Velocities (u, v, w) and coordinates (x, y, z) denote components along the far-field stream, across and along the cylinder contour, respectively.) In figure 1, 75% of the forward speed U is subtracted from the mean velocity field, such as to exhibit the classical flow topology in the near-wake, consisting of a newly formed vortex center at (-0.7,0.2) and saddle point at (-1,-0.6). The position of the separation areas on both shoulders is clearly asymmetric. The two-dimensional normal Reynolds stresses $< u' >^2$ and $< v' >^2$ show peak values of about 10% of U at x=-1,y=0. For $< u' >^2$ a corresponding peak value occurs in the lower shear layer emanating from the separation at the cylinder boundary. On the contrary, the shearing Reynolds stress $< u'v' >$ concentrates away from the centerline, with a maximum close to the saddle point defined above. The sign indicates a flux of x-momentum from the free-stream into the near wake.

Production. The turbulence production is estimated from $\mathcal{P} = - < u_i' u_j' > S_{ij}$ where $S_{ij} = \frac{1}{2}(\frac{\partial <u_i>}{\partial x_j} + \frac{\partial <u_j>}{\partial x_i})$. In the present examples it suffices to approximate the production by $\mathcal{P} = - < u'u' > \frac{\partial <u>}{\partial x} - < u'v' > \frac{\partial <u>}{\partial y}$, since $< v > \; << \; < u >$ and $\frac{\partial}{\partial x} << \frac{\partial}{\partial y}$. The turbulence production is remarkably concentrated at the saddle point, which highlights the crucial role of these singularities in the physics of such flows: turbulence levels close to the cylinder are the same as found by Cantwell and Coles (1983) in the far field.

Motion of the separation point. A detailed analysis of the normal and tangential velocity components along the cylinder contour shows that flow separation occurs at about 15 degrees from the shoulder of the cylinder, on its lee side. The flow separation is moved about 10 degrees towards the lower (upper) shoulder when the downward (upward) lift is at maximum.

Forces are recorded, fitting with published results by Norberg (2003).

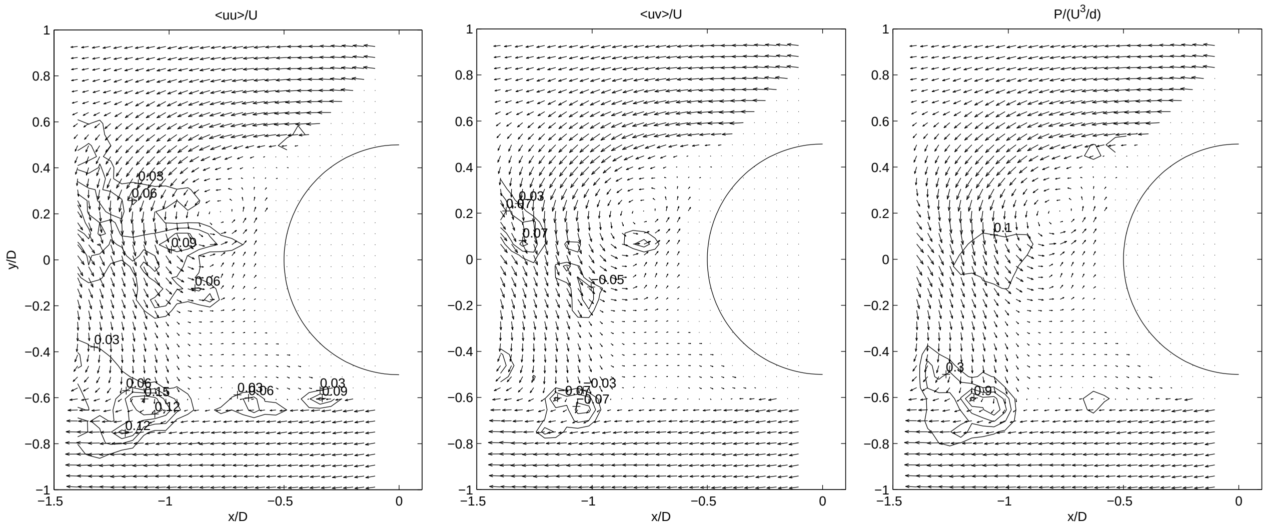

Figure 1: Mean velocity fields at constant phase (75% of U subtracted). Superimposed are the $< u'u' >$ normal Re stress (left), the shearing Reynolds stress (center) and the turbulent production (right).

References

T. Sarpkaya. A critical review of the intrinsic nature of vortex induced vibrations. NPS-ME–03-002. Naval Postgraduate School, Monterey, California, 2003, 111 pp.

B. Cantwell & D. Coles. An experimental study of entrainment and transport in the turbulent near wake of a circular cylinder. J. Fluid Mech. 136, 1983.

C. Norberg. Fluctuating lift on a circular cylinder: review and new measurements. J. Fluid and Structures 17, 2003.

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