A Critical Review of the Intrinsic Nature of VIV

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This is a concise and comprehensive review of the progress made during the past two decades on vortex-induced vibration (VIV) of mostly circular cylindrical structures in uniform flow. The critical elements of the evolution of the ideas, theoretical insights, experimental methods, and numerical models are traced systematically; the strengths and weaknesses of the current state of the understanding of the complex fluid/structure interaction are discussed in some detail. Finally, suggestions for the future objectives of VIV research are presented.

Von Kármán once wrote: "Problems never have final and universal solutions, and only a constant inquisitive attitude toward science and a ceaseless and swift adaptation to new developments can maintain the security of this nation." During the past century, a great deal of work has been done on flow-induced vibrations and fluidelastic instability. The number of contributions and incremental publishing has increased exponentially. Clearly, to move forward and to shape the art and science of flow-induced vibrations in the new century, the existing theoretical, experimental, numerical and empirical evidence must be periodically re-energized and marshaled for new discoveries and applications. This requires a comprehensive review, at least every 25 years.

The difficulties experienced in describing the nature, identifying the occurrence, and predicting the characteristics of vortex induced vibrations of bluff bodies and galloping (to a lesser extent), have been reviewed by Parkinson (1974), Sarpkaya (1979), Griffin and Ramberg (1982), Bearman (1984), Parkinson (1989), Pantazopoulos (1994), Sarpkaya (1995), and in books by Chen (1987), Blevins (1990), Naudascher and Rockwell (1993), Sumer and Fredsoe (1997), and Au-Yang (2001) and, less formally, in practically every doctoral thesis, as part of the obligatory “previous studies” section.

Flow-induced vibrations occur in many engineering situations, such as bridges, stacks, transmission lines, offshore structures, heat exchangers, marine cables, flexible risers in petroleum production, and other hydrodynamic and hydroacoustic applications. This review is not a flat chronology of scientific/engineering developments in VIV and does not make an effort to refer to everything that has ever been published, but one that seeks to provide an intimate feeling of physical reality or physical insight. It makes no promises that are either excessively pessimistic or unreasonably reassuring. It encourages cross stimulation between relatively idealized physical and numerical experiments and far more complex technological applications (often found in books and numerous conference proceedings).

Much progress has been made during the past decade, both numerically and experimentally, towards the understanding of the kinematics (vice dynamics) of VIV, albeit in the low-Reynolds number regime. The fundamental reason for the foregoing is that VIV is not a small perturbation superimposed on a mean steady motion. It is an inherently nonlinear, self-governed or self-regulated, multi-degree-of-freedom phenomenon. It presents unsteady flow characteristics manifested by the existence of large-scale structures, sandwiched between two equally unsteady shear layers.

A phenomenon as robust as the vortex shedding gives rise to forces as unpredictable as the lift force whose power can be fully appreciated only when one tries to eliminate VIV without *excising* the after body. There is much that is known and understood and much that remains in the empirical/descriptive realm of knowledge. Industrial applications highlight our inability to predict the dynamic response of fluid-structure interactions. They continue to require the input of the in-phase and out-of-phase components of the transverse force, in-line drag, correlation lengths, damping coefficients, relative roughness, shear, waves, and currents, among other governing and influencing parameters, and thus the input of relatively large safety factors.

As in the case of many other fluid flows, stability and turbulence, often with large coherent structures, unknown integral length scales, and motion-dependent coherence lengths remain as major obstacles to the understanding of the physics and to the numerical simulation of the dynamics as well as the kinematics of flow structures in the shear layers and the near-wake of cylinders and cables. There does not appear to exist one or two parameters into which we can lump our inability to account for the effects of all the individually non-quantifiable influencing parameters. The most obvious candidates are those that exhibit large scatter in every experiment, e.g. the fluctuating lift (its spectra and r.m.s. value), a measure of the turbulence distribution of the ambient flow (intensity and the integral length scales), and some measure of pressure fluctuations on the body.

In summary, the discussion of the intrinsic nature of VIV, the role of added mass, the decomposition of time-dependent force, the linear and non-linear equations of motion, the free and forced oscillations, the numerical simulations, and the hopes for suppression are followed by recommendations for future directions. It is concluded that partly the prediction and thereby the avoidance of VIV and partly the application of more ingenious means and passive devices may be the road to the future. After all, the lift will always be there with or without the VIV and the pure circular cylinder will always be the preferred shape with or without shape modifications.