

Paper 34.6

Vortex lock-on phenomena due to pulsating flow in tube arrays

by

E. Konstantinidis, D. Castiglia, G. Papadakis, S. Balabani and G. Bergeles[†]

Experimental and Computational Laboratory for the Analysis of Turbulence

Department of Mechanical Engineering, King's College London, Strand, WC2R 2LS, U.K.

[†]Laboratory of Aerodynamics

National Technical University of Athens, Zografou Campus, Athens 157 10, Greece

ABSTRACT

This paper describes an experimental and numerical investigation on the effects of imposed pulsations on the cross-flow over tube arrays in the subcritical regime. Three different arrays were considered, namely inline, staggered and asymmetric with the same streamwise and transverse spacing-to-diameter ratios of 2.1 and 3.6 respectively. A laser-Doppler anemometer was employed for velocity measurements and laser-sheet visualisation was used to reveal the underlying unsteady flow patterns. Simulation of the flow was carried out by solving the Navier-Stokes equations on an orthogonal curvilinear grid and using the Smagorinsky model for scales smaller than the grid size. The time-dependent simulation was performed in two dimensions in order to constrain the computational time while providing data for the entire flow field.

Spectral analysis of the time-resolved velocity data showed that the flow exhibits periodic phenomena that depend strongly on the tube arrangement. Visualisation of the flow indicated that these phenomena are associated with vortex shedding. The observed Strouhal numbers (St) were 0.14 for the in-line and 0.24 and 0.33 for the staggered arrays, whereas for the asymmetric array it was not possible to ascertain a specific value as the shedding period displayed random fluctuations. Pulsing the flow resulted in vortex shedding lock-on. When the non-dimensional pulsation frequency (F) was near twice the unforced Strouhal number, shedding occurred at the sub-harmonic of the pulsation frequency, i.e. $St = 0.5F$. A second mode of lock-on was observed when F was near the unforced St with $St = F$. Modification of the vortex shedding characteristics due to lock-on resulted in changes of the time-mean velocity and turbulence characteristics. The amplitude of velocity fluctuations increased with lock-on due to an increase in the amplitude of the organised velocity fluctuations associated with vortex shedding. Numerical predictions were compared with experimental data for the in-line and asymmetric arrays and despite some discrepancies, the results showed better agreement than simulations with standard turbulence models for this complex flow. The effects of imposed pulsation on the velocity characteristics were similar as in the experiment. However, the 2-D simulation of the flow imposes a severe constraint; the effects of the three-dimensional mechanism for the dissipation of vorticity and turbulence production cannot be accounted for in the simulations.

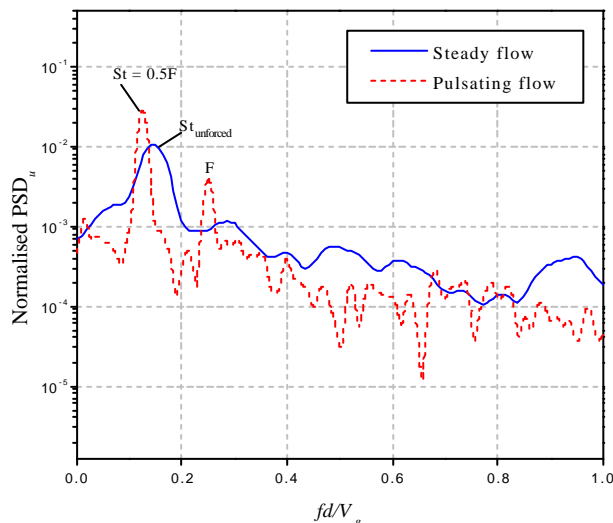


Figure: Typical lock-on of the vortex shedding from a cylinder in the fifth row of an in-line array at the sub-harmonic pulsation frequency.