

**A NUMERICAL STUDY ON THE RECTI-LINEAR OSCILLATIONS  
OF A CIRCULAR CYLINDER IN CROSS-FLOW:  
FLOW PATTERNS AND LOADING**

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The problem of unsteady, laminar flow past a circular cylinder which performs recti-linear oscillations at an arbitrary angle with respect to the oncoming uniform flow is investigated numerically for the first time. Not only do these oscillations have practical consequences relating to the design of engineering structures, but from a fundamental standpoint the forced oscillations of cylinders at an arbitrary angle with respect to the oncoming uniform flow form an important and relatively unexplored class of oscillatory flows. The flow is incompressible and two-dimensional, and the cylinder oscillations are harmonic.

The investigation is based on the solution of unsteady Navier-Stokes equations together with the mass conservation equation in the case of viscous fluids. The method of solution is based on the use of truncated Fourier series representations for the stream function and vorticity in the angular polar coordinate. A non-inertial coordinate transformation is used so that the grid mesh remains fixed relative to the accelerating cylinder. The Navier-Stokes equations are reduced to ordinary differential equations in the spatial variable and these sets of equations are solved by using finite difference methods, but with the boundary vorticity calculated using integral conditions rather than local finite-difference approximations.

The cylinder motion starts suddenly from rest at time  $t = 0$ . Immediately following the start of the cylinder motion, a very thin boundary-layer develops over the cylinder surface and grows with time. Accordingly, we divide the solution time into two distinct zones. First zone begins following the start of fluid motion and continues until the boundary-layer becomes thick enough to use physical coordinates. In this zone, we use boundary-layer coordinates, which are appropriate to the flow field structure, in order to obtain an accurate numerical solution. The spacing of the grid points used in this zone are such that they are spaced closer together near the surface and further apart at large distances. In addition, the adopted grid mesh continually grows in time to properly accommodate the vortex shedding process and boundary-layer development of the flow. The second zone starts following the first one and continues until the termination of calculations. The change from boundary layer coordinates to physical coordinates is made when boundary layer thickens which also ensures that the same grid points can be used in boundary-layer and actual physical space. In this way the numerical solution procedure can be started with good accuracy and continued with comparable accuracy until a periodic vortex-shedding regime is established.