COMPUTATIONS OF DRAG FORCE ON CYLINDER IN OSCILLATORY VISCOUS FLOW, AND COMPARISON TO EXPERIMENTS

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Summary Computations of the force coefficients, particularly the drag, on a cylinder oscillating in viscous fluid show, for $\beta = 11240$ and Keulegan-Carpenter (K) number up to 4 (and Reynolds number up to 45000), strong agreement with a set of experiments by Otter [1] and strong disagreement with another set of experiments by Sarpkaya [2]; the simulations illustrate that flow separation causes the drag coefficient to depart from the classical Stokes-Wang solution. The scale results are particularly relevant to ocean basin model tests of offshore wind turbines. Moderate β and $K < 8.5$ show better agreement between simulations and experiments [2].

INTRODUCTION

Oscillating cylinders in calm viscous fluid, and fixed cylinders exposed to viscous oscillatory fluid flow, are relevant in industrial applications. Cylindrical columns are useful as support of e.g. offshore wind turbines, where the wetted part is exposed to the oscillatory wave induced motion. The flow physics and forces on the geometries currently receive high interest.

In the present contribution we consider the boundary layer and flow separation effects at the cylinder, and the induced forces. Free surface effects are discussed elsewhere. More specifically, we consider the forces on a long circular cylinder that performs lateral oscillations in a viscous fluid of infinite extent, which is calm at infinity. The cylinder velocity is $U(t) = U_m \sin(2\pi t/T)$ (t time, T period). Besides the practical importance, this is a fundamental problem where a convergent solution generally is lacking; this is true in the parameter range where flow separation occurs and the Reynolds number is high.

The flow and forces are governed by the Keulegan-Carpenter number ($K = U_m T/D$) and beta-number ($\beta = D^2/\nu T$) (D cylinder diameter, ν kinematic viscosity). The Reynolds number equals $Re = \beta K$. The time-dependent sectional in-line force is a sum of inertia and drag components by $F(t) = \frac{1}{4}\pi\rho D^2 C_m \dot{U} + \frac{1}{2}\rho D C_d |U|U$ where C_m denotes inertia coefficient, C_d drag coefficient and ρ density. Classical works obtain the inertia coefficient by $C_m = 1 + 4(\pi\beta)^{-1/2} + (\pi\beta)^{-3/2}$ and drag coefficient by $C_d = (3\pi^3/2K)[(\pi\beta)^{-1/2} + (\pi\beta)^{-1} - \frac{1}{4}(\pi\beta)^{-3/2}]$, both valid for $K << 1$ and $\beta >> 1$. This analytical solution is referred to as the classical Stokes-Wang solution [3,4].

COMPUTATIONS OF THE FORCE COEFFICIENTS

We solve the filtered Navier-Stokes equations by a Finite Volume method, developing an extention of the CDP 2.5.1-code [5]. The equations are fully resolved in the laminar range. In the turbulent range we apply Large Eddy Simulation with a Dynamic Smagorinsky model as closure.

The computational domain extends $(30D, 10D, 3(4)D)$ in (x, y, z), and is extended periodically in all directions (x along the oscillation direction; z the cylinder axis). The total number of grid cells is $0.8 - 1.1 \times 10^6$. In the radial direction the grid cell nearest to the cylinder is $\Delta r/D = 0.0005$, there are 128 points in the angular direction; in the vertical direction $\Delta z/D = 0.05$. The time step is T/1000. More details about the solution and integration procedures are found in [6].

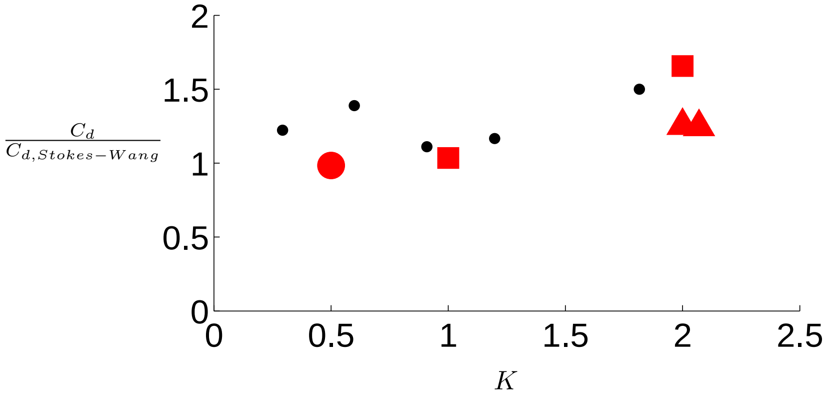

Figure 1. Drag coefficient C_d normalized by $C_{d,Stokes-Wang}$ obtained by Stokes-Wang solution vs. Keulegan-Carpenter number K. Measurements with $\beta = 61400$ by Otter (1990) (black small dots), computations by present method and $\beta = 61400$ (red filled circle), $\beta = 11240$ (red filled sq.), $\beta = 197,300$ (red filled triangle).

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Drag coefficient with $K = O(1)$

Present drag coefficient calculations with $K = O(1)$ and $197 < \beta < 61400$ agree with the classical Stokes-Wang solution, and also agree with the experiments by Otter [1], in this range. Note particularly the drag coefficient with $K = 2$ and 2.07 and $\beta = 300$ and 197, respectively, where the computational C_d is 25 percent higher than $C_{d,Stokes-Wang}$, and is unchanged before and after the Honji-instability occurs in the computations.

Drag coefficient with $2 < K < 8$ and comparison to results by Otter and Sarpkaya

In a rather large range of the Keulegan-Carpenter number, present computations are rather far from the experiments by Sarpkaya [2] when β is 11240 (figure 2a). Present calculations with $\beta = 11240$ agree very favorably with the experiments by Otter [1], using $\beta = 61400$. The results in figure 2a are particularly relevant to ocean laboratory tests of offshore wind turbines, with scale 1:50000, and also to full scale applications. With $K < 3$ results show that the drag force is negligible in comparison to the inertia force. For larger K and β high, flow separation contributes with an essential drag force. In the small scale range, with $\beta = 1035$ (figure 2b) C_d is comparatively higher. Computational C_d amounts to 1.6 and in Sarpkaya's experiments to 1.85, for $K = 8.5, \beta = 1035$, with a relative discrepancy of 15 per cent (figure 2b).

The instantaneous flow separation and details of the velocity field in the center plane are illustrated for $\beta = 11240$ and $K = 3$ (figure 3).

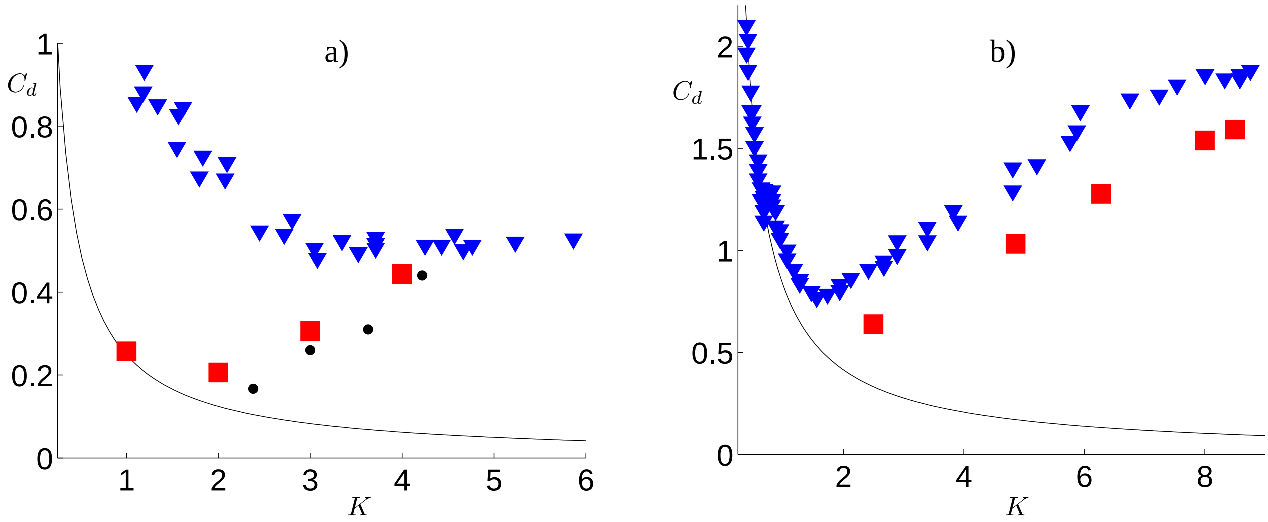

Figure 2. Drag coefficient C_d vs. Keulegan-Carpenter number K. a) Measurements with $\beta = 61400$ by Otter (1990) (black small dots), measurements with $\beta = 11240$ by Sarpkaya (1986) (blue filled triangle), computations by present method and $\beta = 11240$ (red filled sq.), Stokes-Wang solution (solid line). b) Same but $\beta = 1035$.

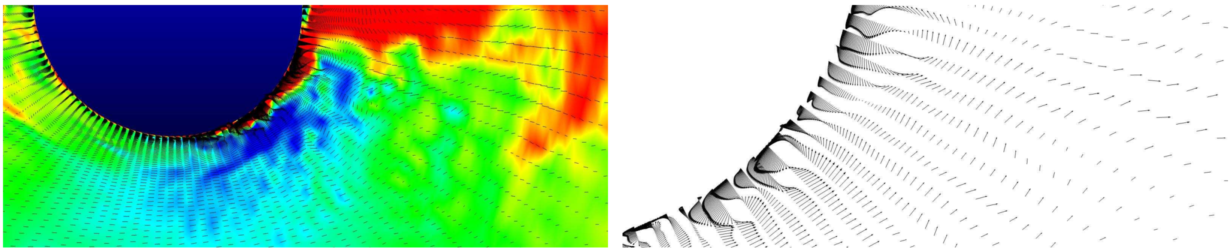

Figure 3. Flow separation (left) and velocity field (right) close to the cylinder boundary, in mid $z = const.$ plane, at $t/T = 10.4567$, for $\beta = 11240$, $K = 3$. Colors in left panel indicate the angular velocity component where red means negative velocity and blue and green positive.

References

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