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Pulsating flow around a stationary cylinder: An experimental study

A. DOUNI & D. S. MATHIOULAKIS
School of Mechanical Engineering, Fluids Section
National Technical University of Athens
Heroon Polytechniou 9 St., Zografos 15773, Athens
GREECE
mathew@fluid.mech.ntua.gr

Abstract:- This experimental work refers to the study of the velocity field around a stationary cylinder exposed to an oscillatory flow of a zero mean flow rate. The experiments were conducted in an oscillating water tank, having the shape of the reversed Greek letter Π. A cylinder was mounted on the tank in such a way that its axis is close to the tank's axis of oscillation and it is normal to the flow main direction. Varying the frequency of oscillation, the flow field was studied for low Keulegan-Carpenter and Stokes numbers upon which the examined problem depends. Employing Particle Image Velocimetry, the velocity field on the mid span plane of the cylinder was measured for various time instants within a period. Detailed recording of the phenomenon revealed information concerning the birth and destruction of vortical structures which are prominent in this type of flow.

Key-Words: - vortical structures, pulsating flow, PIV, circular cylinder

1 Introduction

Pulsating flow around a stationary cylinder is met in many engineering applications, particularly in off-shore structures exposed to ocean waves. The velocity field in this case depends on the so called Keulegan-Carpenter (KC) number which is the inverse of the Strouhal number, and on the Stokes number (β) which is a combination of the Reynolds number and KC. If U is the maximum velocity of the incoming pulsating free stream, T its period, D the diameter of the cylinder, and ν the kinematic fluid viscosity, the above numbers are defined as follows: $KC=UT/D$ and $\beta=Re/KC=D^2/T\nu$. Previous experimental and theoretical studies [1-5] have shown the complex character of the flow field, mainly characterized by vortical structures the number and paths of which are a function of the above non dimensional numbers. As it is mentioned in [3] an increase of KC by 7 increases the number of the shed vortices by one, increasing at the same time the frequency of the applied forces upon the cylinder. It is characteristic that the shed vortices do not follow trajectories parallel to the free stream, having an inclination with respect to the main stream at angles dependent mainly on KC. This behaviour results in forces (drag and lift) the magnitude and sign of which vary in a not easily predictable way. The previous experimental works on this subject have focused both on the qualitative and quantitative flow analysis using flow visualization and force measurements. However, it seems that there is still a lack of knowledge with regard to the detailed picture of the flow field.

In the context of this work the velocity field was measured for low Keulegan-Carpenter (close to 13) and Stokes numbers (12 to 23) using PIV.

2 Experimental procedure

The experiments were carried out in an oscillating water tank having the shape of the inverted Greek letter Π (Fig.1).

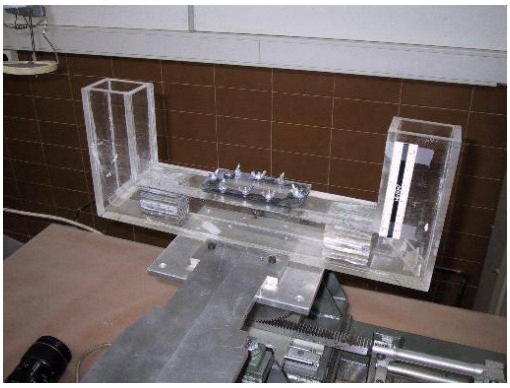

Fig.1 Water tank and the oscillation mechanism

A plexiglas made circular tube of an external diameter 10mm and a length of 40mm (Fig.2) is installed at the base of the tank with its long axis being close and parallel to the tank's axis of rotation. The cross section of the water tank was rectangular

($60x40mm^2$) with the longer dimension perpendicular to the long axis of the tube.

Fig.2 Circular cylinder

The circular tube, playing the role of the circular cylinder, was filled with water in order to minimize light scattering when applying PIV. The tank was mounted on a rocking mechanism producing a pulsating flow of controllable frequency and free surface amplitude (Fig.1). The displacement of the tank's water free surface was measured by two submerged electrodes the analog output of which was stored in a PC.

An Argon Ion Laser (300mW) provided the light sheet for the illumination of the area around the cylinder at its mid span cross section. Hollow glass spheres (10μm mean diameter) were used as tracers and a CCD camera (25 frames /sec) was recording their motion, oscillating with the tank and the cylinder. Therefore, the frame of reference was attached to the cylinder, the translation of which was nevertheless very small due to its proximity (2cm) to the axis of rotation. The images stored in a PC were analyzed by software developed by the authors based on cross correlation technique.

3 Results and Discussion

Three periods of oscillation were examined, namely T=8s, 6s and 4.4s and the corresponding amplitude of the free water surface was 18 ± 0.5 mm. The above correspond to a KC number close to 13 and the following β numbers: 12.5, 16.67 and 22.72, respectively. In order to obtain more details about the flow characteristics, the camera was focused only on one half of the flow field (Fig.3).

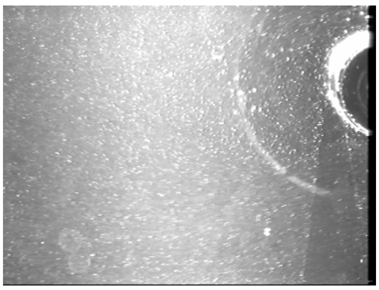

Fig.3 The illuminated flow field

Below, the velocity vectors measured through PIV are shown for various time instants within a cycle, along with the time record of the free surface displacement. Each time instant is characterized by a letter and a number which are also shown on the graph of the free surface displacement.

3.1 Period T=8sec

The free surface displacement x(t) is shown below (Fig.4). The extreme values of this graph correspond to the instants at which the flow direction reverses. Also, when x is reduced, the flow direction is from right to left and the illuminated flow field is in the wake of the cylinder.

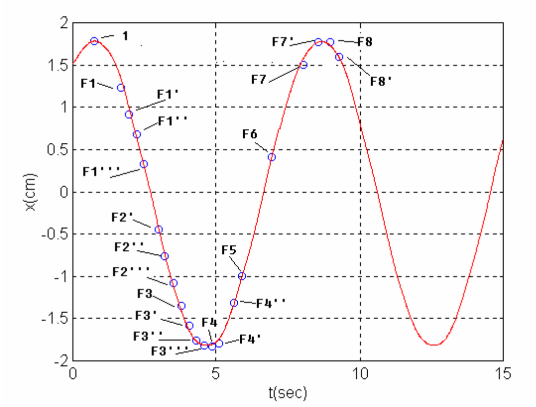

Fig.4 Free surface displacement versus time

Since the flow separates from the surface of the cylinder forming discrete vortices, when the flow direction reverses, the oncoming flow is perturbed due to the presence of these vortices, thus creating a complex flow picture downstream of the cylinder. In Fig.5 (t=F1') as well as in the subsequent figures the cylinder's half is located at the upper right corner. At this particular time instant that the flow starts accelerating, there are no vortices in the cylinder's

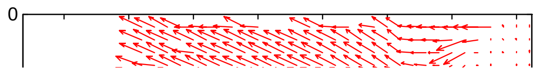

Fig.5 t=F1'

wake. However, we notice that far from the cylinder the velocity vectors are parallel mainly to two directions. More particularly, below the cylinder the flow is parallel to the solid walls of the tank whereas in the rest the velocity vectors point upwards.

This picture is common more or less for all the examined cases except during the flow reversal at which the velocity vectors at the bottom are not any more parallel to the tank's walls. Further acceleration of the flow caused the formation of a counter clockwise vortex just downstream and close to the surface of the cylinder (Fig.6, t=F2').

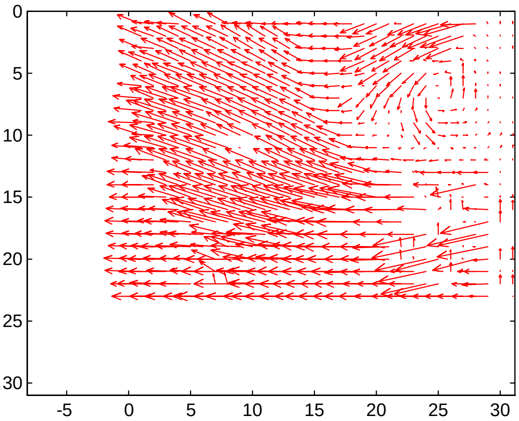

Fig.6 t=F2'

The presence of this vortex causes a curvature to the streamlines, inducing another vortex of smaller circulation at a later instant. This vortex is well shaped at the end of this half cycle, the center of which is two cylinder diameters downstream of the main vortex (Fig.7, t=F3'''). It is also noteworthy that the centers of these vortices are on a line inclined with respect to the flow main direction. Similar observations using flow visualization have been made in [6] for the examined KC and β numbers.

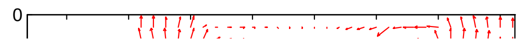

Fig.7 t=F3'''

After the flow changes direction, the strength of the vortices is reduced progressively and finally they extinct at the middle of this cycle (Fig.8, t=F6).

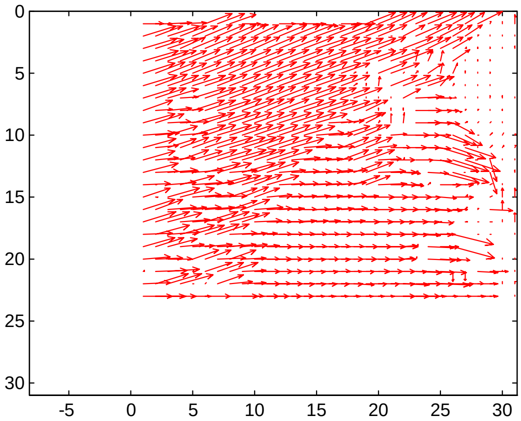

Fig.8 t=F6

3.2 Period T=6sec

Reducing the period of the flow, the flow picture remains more or less the same except that the strength of the vortices becomes stronger. In other words, it seems that increasing Stokes number and keeping KC constant this flow phenomenon becomes more intense. This is shown in Fig.9, a little before the end of the half cycle, showing a well shaped vortex downstream of the cylinder, and in Fig.10, two well shaped vortices exist in the beginning of the next half cycle. The corresponding graph of the free surface displacement is shown in Fig.11.

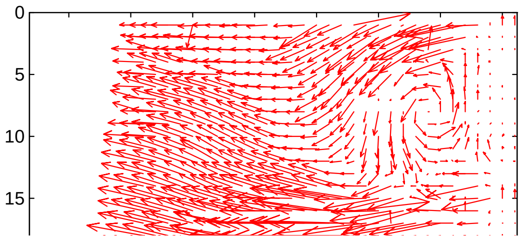

Fig.9 t=G7

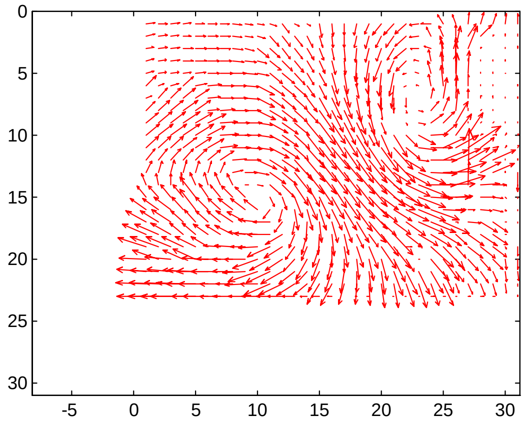

Fig. 10 t=G8’

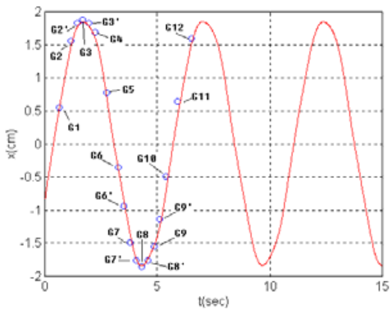

Fig.11 Free surface displacement versus time

We notice that the line connecting the two vortices is again inclined with respect to the flow main direction and in this case this angle is greater.

3.3 Period T=4.4 sec

In this case the strength of the vortices is higher compared to the previous ones as well as the curvature of the streamlines. Moreover, at some instants three dimensional flow structures appeared in contrast to the previous cases. Characteristic flow pictures are shown in Fig.12 (t=H2’) and Fig.13 (t=H3). The graph of the free surface displacement is shown in Fig.14.

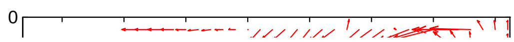

Fig.12 t=H2’

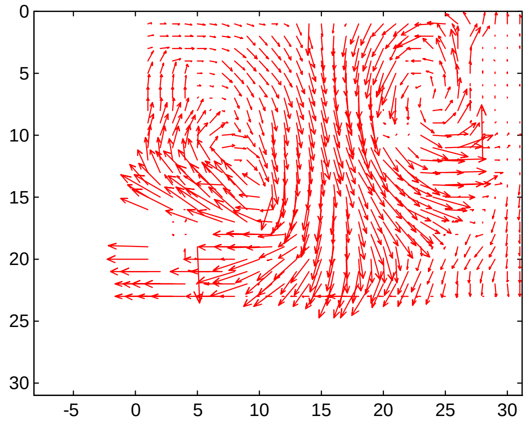

Fig.13 t=H3

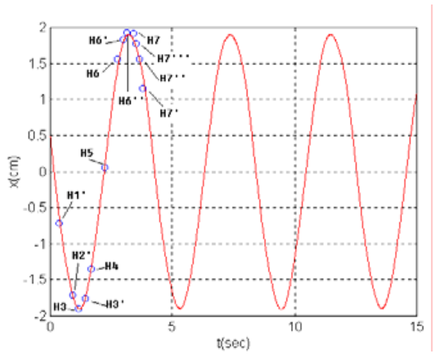

Fig.14 Free surface displacement versus time

4 Conclusions

The flow field around a stationary cylinder exposed to an oscillatory flow was examined experimentally for low Keulegan-Carpenter (13) and Stokes numbers (12-23). During flow acceleration, a vortex is formed in the near wake of the cylinder and at the end of this half cycle another weaker vortex of opposite rotation is induced further downstream. The centres of these vortices are on a line inclined with respect to the main flow direction at an angle which increases with increasing Stokes number. When the flow reverses, the vortices survive till the middle of this half cycle being essentially stationary. In general, while KC is kept constant the flow picture does not change, whereas increasing Stokes number the flow becomes more intense in a sense that the vortex circulation increases as well as the curvature of the streamlines

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