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Contribution to Active and Passive Control of Flow around a Cylinder

M. Tahar Bouzaher

***Abstract*—**This numerical study aims to develop a coupled, passive and active control strategy of the flow around a cylinder of diameter D, and Re=4000. The strategy consists to put a cylindrical rod in front of a deforming cylinder. The quasi- elliptical deformation of cylinder follow a sinusoidal law in order to reduce the drag force. To analyze the evolution of unsteady vortices, the Large Eddy Simulation approach is used in this 2D simulation, carried out using ANSYS – Fluent. The movement of deformation is reproduced using an internal subroutine, introduced in the form of a User Defined Function UDF. Two diameters of the rod were tested for a rod placed at a distance L = 3 ×d, with an amplitudes of deformation A = 5%, A = 25% and A = 50% of the cylinder diameter, the frequency of deformation take the values fd = 1fn, 5fn and 8fn, which fn represents the naturel vortex shedding frequency. The results show substantial changes in the flow behavior and for a rod of 6mm (1% D) with amplitude A = 25%, and with a 2fn frequency, drag reduction of 60% was recorded.

***Keywords*—**CFD, Flow separation, control, Boundary layer, rod, Cylinder.

I. Introduction

SEVERAL studies considered the cylinder as the reference geometry for the study of external flows. In spite of the simplicity of this geometry, the flow involves all the phenomena of fluid mechanics as, the boundary layer separation, the vortex interaction, mass transfer, instability, chaos, turbulence ... etc.

Passive vortex generator is first developed by Taylor [1] in 1947 to eliminate boundary layer separation in the diffuser blower. The first systematic study of vortex generation and their effects on the boundary layer is performed by Schubauer and Spangenberg [2] in 1950. Vortex generators have been successfully applied to several aerospace applications, the main role of using this device is to promote inter action and to increase the transfer between kinetic energy rich zone and the zone of death fluid near wall. The review of Greenblatt et al. [3] summarized the flow separation control by periodic excitation in various forms. Mittal et al. [4] characterized the different frequencies scales present in a separated flow to understand the physical of the separation control by steady and pulsed vortex Generator Jets. Igarashi et al [5] use a rod as vortex generators to control the flow around a square cylinder for a Reynolds number of 3.2×10^4, the results shows a drag reduction of 50% with taking into account the drag of the cylindrical rod. For a Reynolds number located in the range $1.9 \times 10^4 \leq Re \leq 7.7 \times 10^4$ .The experimental study of Igarashi on the effect of the interaction between the wake of a cylindrical rod, and the boundary layer of a vertical disc indicated a drag redaction between 20% and 30% compared to the case without cylindrical rod. Hua Shan et al [6] carried out a numerical simulation of flow behind a pair of active vortex generators over a NACA0012 airfoil with 6° angle of attack; they have proved that it is possible to reduce the drag of 80%. Tsutsui et al. [7] set the cylindrical rod to a circular cylinder in order to reduce drag force; they have found with the ratio $d\ /\ D\ =\ 0.25$ a drag reduction about (63%) where d and D present respectively the rod and the cylinder diameter. The aim of this work is to study the flow separation control using a coupled, passive and active control strategy. The study focuses on estimating of the characteristic aerodynamics and the efficiency of this strategy in drag reduction.

M. T. Bouzaher is a Research Associate at the Department of Mechanical Engineering of the University of Biskra, 07000, Algeria (e-mail: mohamedbouzaher@yahoo.fr).

II. Geometry Characteristics and Mesh Generation

We thought to cut the cylinder into two equal and symmetrical parts. Then we had to translate one of the two parties in the direction of flow in order to have the general shape of an ellipse, so it is an elongation in the direction of the flow diameter (large axis of the ellipse) through this process we can generate a sinusoidal pulsation on the moving part of cylinder.

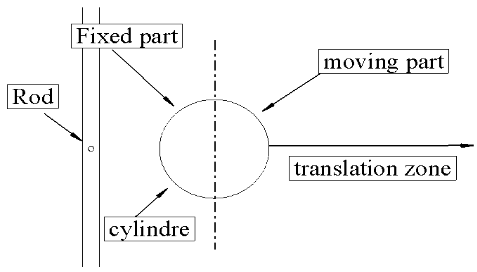

Fig. 1 Rod-cylinder geometrical characteristics

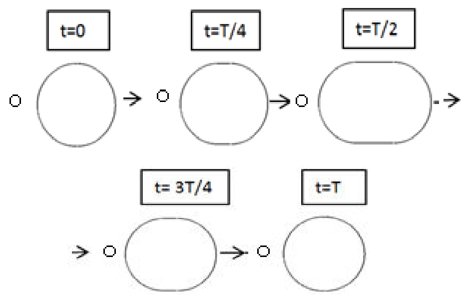

Fig. 2 Cylinder cycle of deformation

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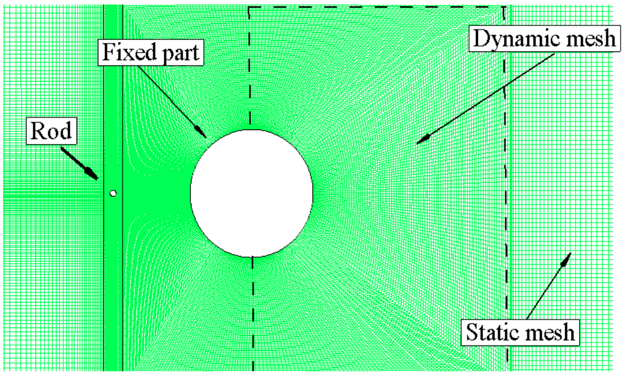

Fig. 3 Description of the grid

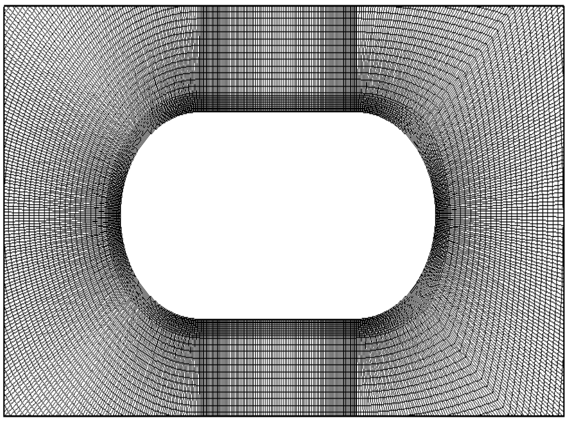

Fig. 4 Grid after deformation

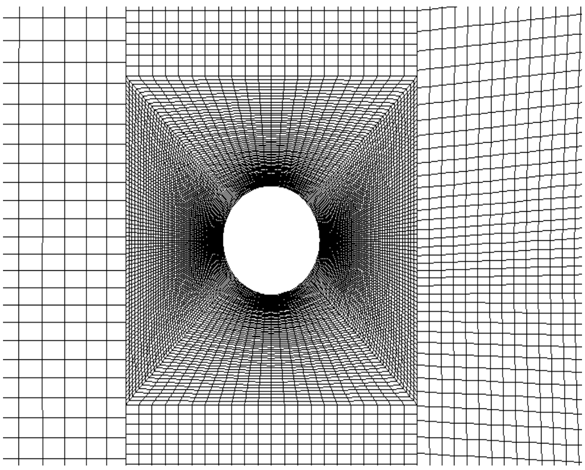

Fig. 5 Grid around the rod

The total drag and lift coefficients are defined, respectively, as:

$$C_{DT}(t) = C_{DCYlinder} + C_{DRod} = \frac{F_{1X}(t)}{\left(\frac{1}{2}\right)\rho\left(U(t)\right)^2 D\, sin\alpha} + \frac{F_{2X}(t)}{(1/2)\rho(U(t))^2 d}$$

$$C_{LT}(t) = C_{LCYlinder} + C_{LRod} = \frac{F_{1y}(t)}{\left(\frac{1}{2}\right)\rho\left(U(t)\right)^2 D\, cos\alpha} + \frac{F_{2y}(t)}{(1/2)\rho(U(t))^2 d}$$

where, $F_{1X}(t)$ and $F_{2X}(t)$ represent, respectively, the instantaneous total force in the x-direction (longitudinal) apply in the cylinder and in the rod, $F_{1y}(t)$ and $F_{2y}(t)$ represent, respectively, the instantaneous total force in the normal (transversal) direction apply in the cylinder and in the rod, t, the time, D the cylinder diameter , and d the rod diameter.

The instantaneous total force defined as

$$F(t) = F_P(t) + F_S(t)$$

where $F_P(t), F_S(t)$ represent, respectively, the generated pressure force and wall shear force.

A. Mesh Independence

To study the simulation results mesh independent, many cases were simulated with several mesh concentrations. The drag evolution in function of cells number was given in Fig. 6 the number of cells used in all cases was between 0.15 and 0.25 million. Generally, we require a larger number of cells to realize mesh witch is able to give a good estimation of aerodynamics forces and flow characteristics.

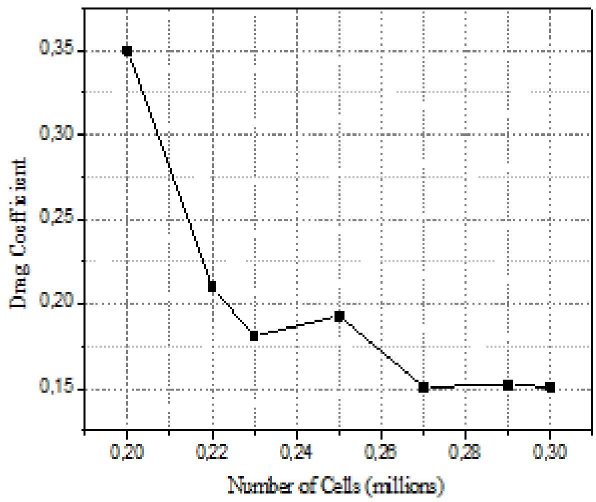

Fig. 6 Drag coefficient versus number of mesh volumes

III. Results

For a better prediction of aerodynamic coefficients, we realized a grid with C topology, for both the natural and the controlled case. Indeed, the grid of a topology C is relatively easy to implement for a cylinder. To avoid a prohibitive number of cells we choose to generate a grid using the interface conditions.

A. Amplitude of Deformation Effect

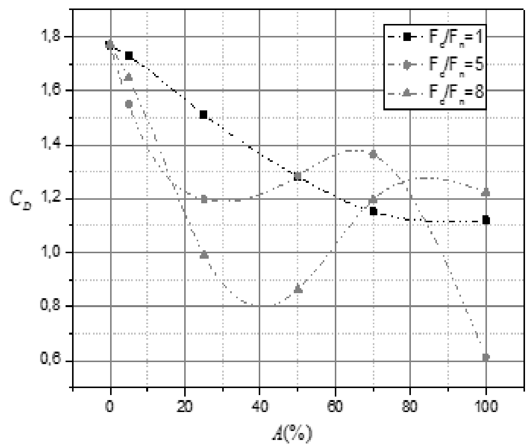

Fig. 7 Drag coefficient versus amplitude

The curves of the drag coefficient illustrated in Fig. 7 show a decrease in the drag for the three considered frequencies, $Fd = 1Fn$, $5Fn$, $8Fn$ relative to the nominal value (without control). This drag reduction reaches high values for high deformation amplitudes (A 50%), for all frequencies. It is noted that for the average frequency control= $5FN$, the drag decreases to 30% and with a deformation amplitude up to 70% we noted a reduction of 65%. For the frequency $Fd = 1Fn$, the drag decreases and then stabilizes around a value of37%

B. Frequency of Deformation Effect

To see the influence of the frequency of deformation on the mean values of CD we varied the ratio of the frequency (Fd / Fn) between 0.2 and 10 for the deformation amplitudes 25%

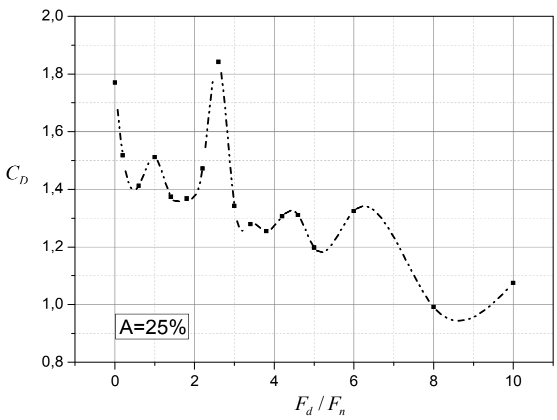

Fig. 8 Drag coefficient versus frequency

The variation of drag coefficient for the case of deformation, A = 25%, has a tendency to fluctuate by increasing the frequency control. The minimum value of CD is recorded for a Fd/ Fn ratio =8 corresponding to a drag reduction of 44%.

IV. Flow Visualization

The instantaneous fields of vorticity which show creation, the development and the detachment of the flow vortices for a one-period (T), are given on Fig. 9. It was noted that the zone of recirculation does not exist downstream the cylinder in fact, the wake of the rod and the cylinder deformation allowing the formation of small structures around the cylinder surface.

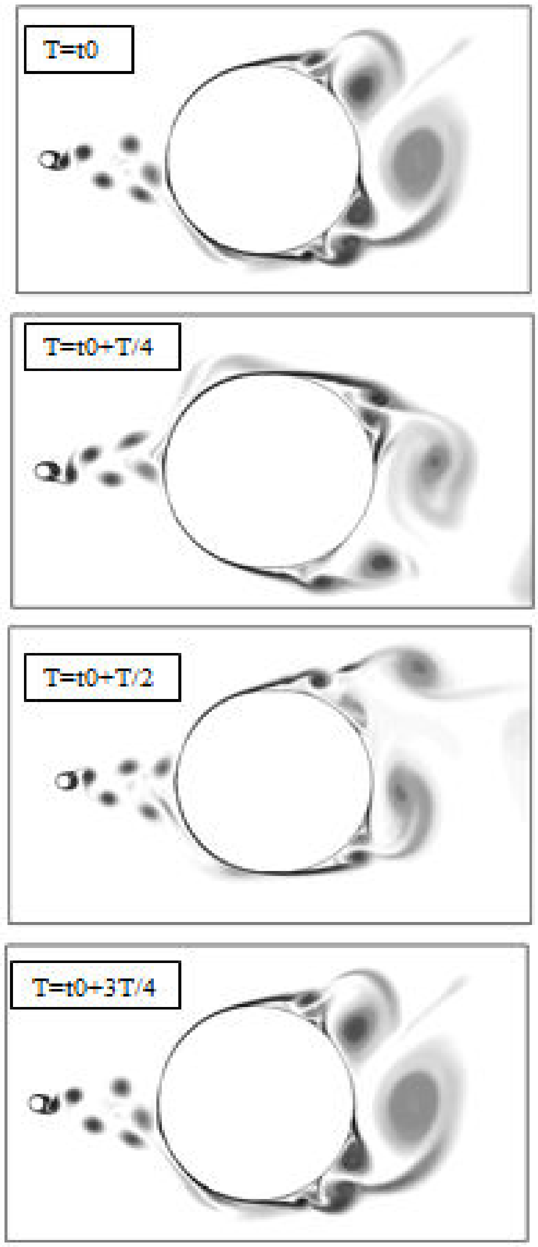

Fig. 9 Vorticity field for the case $Fd = 1.Fn\ A = 5\%$

V. Conclusion

In this study we try to develop a coupled, passive and active control strategy of the flow around a cylinder, it consists to put a cylindrical rod in front of a deforming cylinder with a quasi-elliptical deformation law in order to reduce the drag force.

Analyzes of unsteady vortices indicate an important modifications in the flow behavior. Our results show that for the optimal case a maximum drag reduction of 65% was registered.

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