

OMAE2015-42344

HYDRODYNAMIC FORCE MEASUREMENTS ON A CIRCULAR CYLINDER FITTED WITH PERIPHERAL CONTROL CYLINDERS: PRELIMINARY RESULTS ON THE DEVELOPMENT OF VIV SUPPRESSORS

Mariana Silva-Ortega

NDF Research Group
Dept. Naval Arch. & Ocean Eng.
University of São Paulo
São Paulo - SP, Brazil

Gustavo R. S. Assi*

NDF Research Group
Dept. Naval Arch. & Ocean Eng.
University of São Paulo
São Paulo - SP, Brazil

Murilo M. Cicolin

NDF Research Group
Dept. Naval Arch. & Ocean Eng.
University of São Paulo
São Paulo - SP, Brazil

ABSTRACT

Recent achievements in controlling the boundary layer by moving surfaces have been encouraging the development and investigation of passive suppressors of vortex-induced vibration. Within this context, the main purpose of the present work is to evaluate the suppression of vortex shedding of a plain cylinder surrounded by two, four and eight smaller control cylinders. Experiments have been carried out on a fixed circular cylinder to investigate the effect of the control cylinders over drag reduction. Control cylinders with diameter of $d/D = 0.06$ were tested, where D is the diameter of the main cylinder. The gap between the main cylinder and the control cylinders varied between $G/D = 0.05$ and 0.15 . Experiments with a plain cylinder in the Reynolds number range from 5,000 to 50,000 have been performed to serve as reference. It was found that a cylinder fitted with four control cylinders presented less drag and fluctuating lift than cylinders fitted with two or eight small cylinders.

Keywords: VIV suppression, drag reduction, rotating control cylinders.

NOMENCLATURE

ρ	Specific mass of water
d	Diameter of control cylinders
D	Diameter of main cylinder
G	Gap between main cylinder and control cylinders
L	Cylinder length
U	Flow speed
F_D	Drag force
F_L	Lift force
$\overline{C_D}$	Mean drag coefficient
$\hat{C}_L$	RMS of lift coefficient
Re	Reynolds number
St	Strouhal number

INTRODUCTION

Over the past decades, offshore oil exploration reached the so-called ultra-deep waters. Consequently, new solutions of floating platforms appeared to reach reservoirs further out of the coast. Spars, semi-submersibles, tension-leg, FPSO and monocolumns are examples of these floating units. Most of them have circular cross sections being susceptible to vortex-induced vibrations (VIV). The development of new suppressors for flow-induced vibrations (FIV) of offshore structures is a topic that became frequent in the literature in the past years. As previously discussed in Assi et al. [1–3], with the advancement of offshore oil exploration research on FIV suppressors was pushed to a new level. “The industry demands suppressors that are not

*Corresponding author: G.R.S. Assi (g.assi@usp.br). NDF – Fluids and Dynamics Research Group. Address: PNV Dept. Eng. Naval e Oceânica, Escola Politécnica da Universidade de São Paulo, Av. Prof Mello Moraes 2231, 05508-030, São Paulo - SP, Brazil.

only efficient for low mass-damping systems but also that could be installed under harsh environmental conditions; such is the case for offshore risers” [3].

Vortex shedding behind a bluff body can be altered, suppressed or controlled over a limited range of Reynolds numbers. Various flow-control techniques, which results in reduction of drag and unsteady forces, have been suggested and tested in simple geometries. Zdravkovich [4] presents control techniques that can be classified into three categories: surface protrusions, shrouds and near wake stabilizers. He also investigated the relative effectiveness of the various means of flow control by applying them to the same test model including multi-cylinder arrangements. In an effort to study a passive control device, Strykowski and Sreenivasan [5] have reported that the vortex shedding past a circular cylinder can be controlled over a limited range of Reynolds number by the proper placement of a smaller control cylinder close to the main cylinder. Mittal and Raghuvanshi [6] have verified this phenomenon using a numerical approach and observed that the control cylinder provides a local favourable pressure gradient in the wake region, thereby locally stabilizing the shear layer. Gad-el Hak and Bushnell [7] review various techniques that are employed for separation control, including the moving-surface boundary layer control (MSBC) in which rotating cylinders are employed to inject momentum into the already existing boundary layer.

The numerical simulations performed by Mittal [8] showed promising results in the use of MSBC to control the flow around a static cylinder and smooth reduction of drag and lift forces. Korkischko [9] performed an experiment employing MSBC to suppress VIV of an isolated cylinder mounted on an elastic base with one degree of freedom in the transverse direction. Hence, MSBC has already been tested as a means to suppress vortex shedding of static cylinders as well as VIV of oscillating bodies. The smaller control rotating cylinders inject angular momentum in the boundary layer of the main cylinder leading to vortex suppression and consequently drag decrease as well as reduction of the transverse velocity fluctuations in the wake.

EXPERIMENTAL ARRANGEMENT

Experiments have been carried out in the Circulating Water Channel of NDF (Fluids and Dynamics Research Group) at the University of São Paulo, Brazil. The NDF-USP water channel has an open test section which is 0.7m wide, 0.9m deep and 7.5m long. Good quality flow can be achieved up to 1.0m/s with turbulence intensity less than 3%. This laboratory has been especially designed for experiments with flow-induced vibrations and more details about the facilities are described in Assi et al. [10].

Models were mounted on a one-degree-of-freedom rig developed by Assi [1] and employed in several VIV experiments.

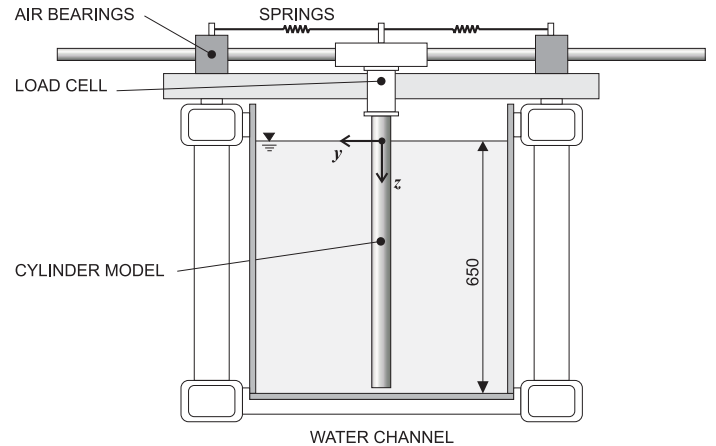


FIGURE 1. Experimental setup: cylinder with parallel plates mounted on the two-degree-of-freedom rig in the test section of the NDF-USP water channel.

TABLE 1. Geometrical parameters.

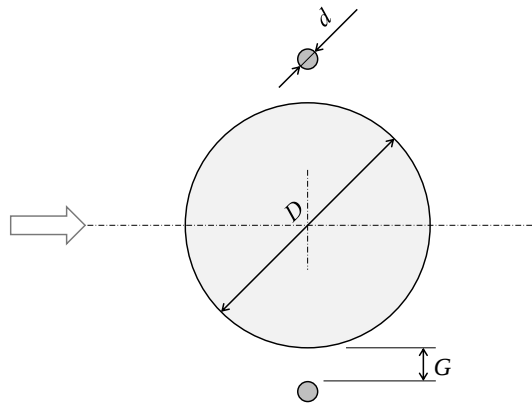
Number of control cylinders		2, 4, 8
Diameter of control cylinders	d/D	0.06
Gap between cylinders	G/D	0.05, 0.10, 0.15

In the present study, however, the rig was employed only to hold the main cylinder fixed in a static position. Future experiments will employ the same rig to allow the system to freely respond with vibrations. A specially built load cell was attached between the cylinder and the support system to deduce the instantaneous and time-averaged hydrodynamic forces on the cylinder model. An illustration of the experimental setup is presented in apparatus is Figure 1.

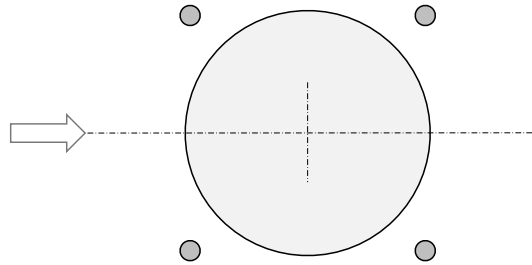
A rigid section of circular cylinder was made of a perspex tube and mounted on a rig fixed to the water channel. Two, four or eight identical control cylinders were made of perspex rods and supported by the extremities of the main cylinder. They were installed parallel to the main cylinder spanning the whole length of the model. In this present investigation the control cylinders were not rotating, but simply acting as static structures with to the main cylinder.

The main circular cylinder and the control cylinders models are made of rigid acrylic with a smooth surface. The main cylinder external diameter is $D = 100\text{mm}$ and the immersed length $l = 700\text{mm}$, giving an aspect ratio of $l/D = 7$. The mass parameter is $m^* = 1.09$, which is the ratio between the structural mass and the mass of displaced fluid.

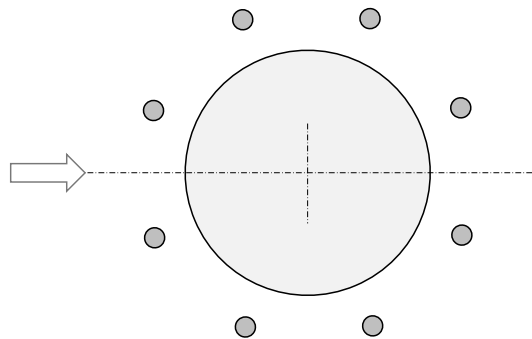
Figure 2 presents three configurations of models varying the number of control cylinders. Two, four, or eight smaller cylinders with diameter $d = 6\text{mm}$ were fitted about the centre



(a) Two control cylinders



(b) Four control cylinders



(c) Eight control cylinders

FIGURE 2. Geometrical parameters for three configurations of control cylinders.

of the main cylinder. The gap between the main cylinder and the control cylinders was set to $G/D = 0.05, 0.10$ and 0.15 , measured from wall to wall. Table 1 summarises the geometrical parameters considered in the present investigation, adding up to 9 different experimental configurations. In addition, preliminary tests have been performed with a plain cylinder to serve as reference for comparison.

The only flow variable changed during the course of the experiments was the flow velocity U , which alters the Reynolds number between 5,000 and 50,000.

RESULTS AND DISCUSSION

The moving surface boundary-layer control (MSBC) is usually employed with the objective of reducing the drag of bluff bodies. Korkischko (2012) demonstrated the efficiency of the MSBC for the mean drag for the circular cylinder with two control cylinders. Figure 3 shows the mean drag coefficient for statically mounted cylinders. The $\overline{C_D}$ value for each configuration is the average of the mean drag calculated at the 15 equally spaced velocities in the range between $Re = 5,000$ and 50,000 with the next equation.

$$\overline{C_D} = \frac{\overline{F_D}}{\frac{1}{2}\rho U^2 DL} \quad (1)$$

Firstly, one can note that the addition of static control cylinders increases the mean drag coefficient, compared to the plain cylinder, for all the cases with 2 control cylinders from $Re = 8,000$ to $Re = 50,000$ and only for two cases with 8 control cylinders ($G/D = 0.05$ and $G/D = 0.15$) until $Re = 15,000$. Besides at $Re = 5,000$ to 50,000 the configuration of 4 control cylinders at different gaps the mean drag coefficient is lower than that observed for an isolated cylinder, the lowest value being $\overline{C_D} = 0.75$ for the gap $G/D = 0.05$. Likewise, for each configuration with 8 control cylinders the values of the mean drag coefficient slightly decrease from $Re = 15,000$ to 50,000.

Similarly to the previous section the rms of the lift coefficient was calculated by

$$\hat{C}_L = \frac{\hat{F}_L}{\frac{1}{2}\rho U^2 DL}, \quad (2)$$

where $\hat{F}_L$ is the rms of measured lift.

The measured values of $\hat{C}_L$ are shown in Figure 4 for the various values of gap for each configuration of 2, 4 and 8 control cylinders. The rms lift coefficient obtained at $Re = 5,000$ in most of the cases is higher than that observed for a plain cylinder.

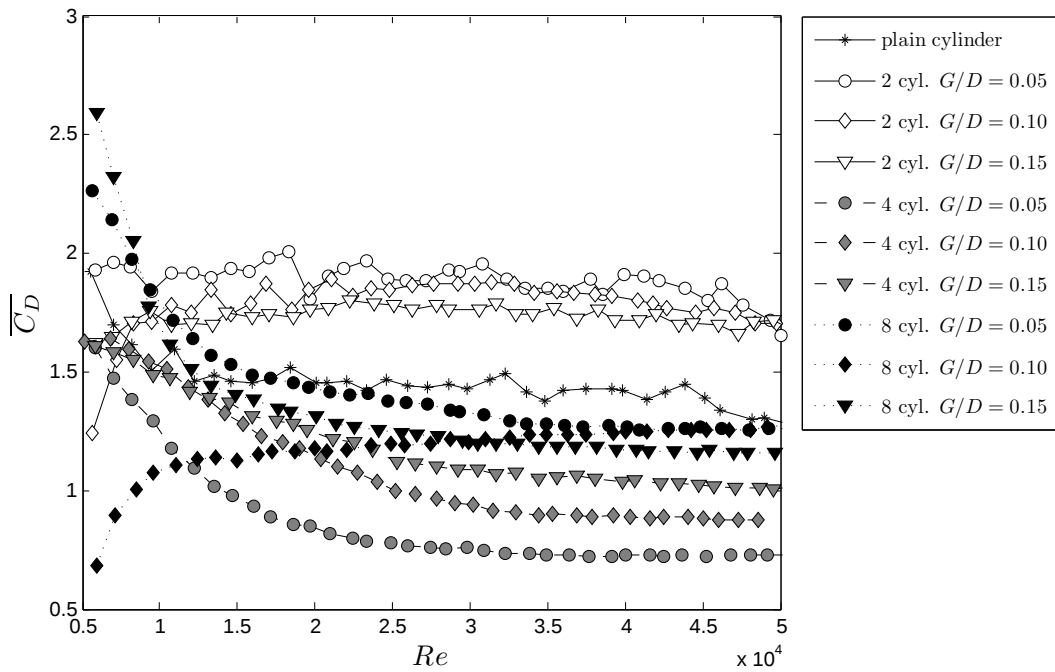


FIGURE 3. Mean drag coefficient versus Re for sets of control cylinders with $d/D = 0.06$ and varying gap.

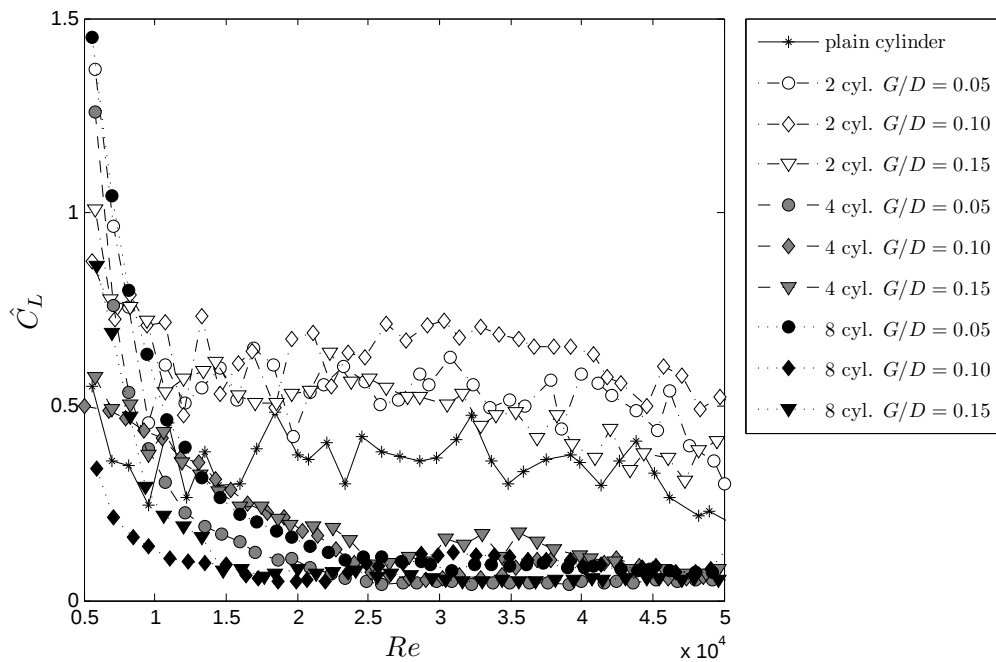


FIGURE 4. RMS of lift coefficient versus Re for sets of control cylinders with $d/D = 0.06$ and varying gap.

Values of $\hat{C}_L$ for 4 and 8 control cylinders at different gaps reduce for increasing Re when compared to the isolated cylinder. Unlike the previous section the lowest value of $\hat{C}_L = 0.2$ is for the configuration with 8 control cylinders with $G/D = 0.15$. The configuration of 2 control cylinders at the different gaps results in an increase of $\hat{C}_L$.

CONCLUSION

In the present work, the effect of the gap between the main cylinder and the configuration of 2, 4 and 8 control cylinders was investigated. The range of Reynolds number was from 5,000 to 50,000 and the control cylinders were fixed. All the cases were compared to the hydrodynamic forces of an isolated cylinder.

The suppression effectiveness and drag efficiency must be directly related to the configuration and gap of the control cylinders. For $d/D = 0.06$, the configuration of 4 cylinders with $G/D = 0.05$ produced less drag and less unsteady lift acting on the body.

It was found that the gap is an important parameter in the design of MSBC. A value of $G/D = 0.05$ in each configuration has been found to be the best solution for all tested cases, presenting the lowest values of $\overline{C_D}$ and $\hat{C}_L$.

Results presented here are for static control cylinders fitted about a fixed main cylinder. These are part of an ongoing research project to develop new VIV suppressors. Nevertheless, mean and RMS values of hydrodynamic forces measured in static models might offer an insight into the dynamics of the system when susceptible to vibrations. Future work in this topic will consider the rotation of the control cylinders that correspond to a tangential velocity with the geometric parameters, diameter ratio and cylinder gap.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support of FAPESP (São Paulo State Research Foundation) through the research grant 2011/00205-6. MSO is in receipt of an MSc scholarship from CAPES Brazilian Ministry of Education. GRSA is grateful to CNPq (308916/2012-3).

REFERENCES

- [1] Assi, G.R.S., Bearman, P.W and Kitney, N **2009** Low drag solutions for suppressing vortex-induced vibration of circular cylinders. *J. Fluids and Structures* 25, 666-675.
- [2] Assi, G.R.S., Bearman, P.W., Kitney, N., Tognarelli, M.A. **2010** Suppression of wake-induced vibration of tandem cylinders with free-to-rotate control plates. *J. Fluids and Structures*, 26, 1045-1057.
- [3] Assi, G.R.S., Bearman, P.W., Rodrigues, Tognarelli, M., J.R.H. **2011** The effect of rotational friction on the stability of short-tailed fairings suppressing vortex-induced vibrations. *In the proceedings of OMAE2011, 30th International Conference on Ocean, Offshore and Arctic Engineering*, Rotterdam, The Netherlands.
- [4] Zdravkovich, M.M. **1981** Review and classification of various aerodynamic and hydrodynamic means for suppressing vortex shedding. *J. Wind Eng. and Ind. Aerodynamics*, 7(2), 145-189.
- [5] Strykowski, P.J., Sreenivasan, K.R. **1990** On the formation and suppression of vortex shedding at low Reynolds numbers. *Journal of Fluid Mechanics*, 218, 71-107.
- [6] Mittal, S., Raghuvanshi, A. **2001** Control of vortex shedding behind circular cylinder for flow at low Reynolds numbers. *International Journal for Numerical Methods in Fluids*, 35, 421-447.
- [7] Gad-el-Hak, M. **2000** Flow control: Passive, Active, and Reactive Flow Management. *Cambridge University Press*, London, United Kingdom.
- [8] Mittal, S. **2001** Control of flow past bluff bodies using rotating control cylinders. *Journal of Fluids and Structures*, 15, 291-326.
- [9] Korkischko, I., Meneghini, J.R. **2012** Suppression of vortex-induced vibration using moving surface boundary-layer control. *Journal of Fluid and Structures*, 34, 259-270.
- [10] Assi, G.R.S., Meneghini, J.R., Aranha, J.A.P., Bearman, P.W., Casaprima, E. **2006** Experimental investigation of flow-induced vibration interference between two circular cylinders. *J. Fluids and Structures*, 22, 819-827.