Proceedings of the ASME 2017 36th International Conference on Ocean, Offshore and Arctic Engineering
OMAE2017
June 25-30, 2017, Trondheim, Norway

OMAE2017-61235

THE INFLUENCE OF DAMPING ON THE VIV SUPPRESSION OF A CIRCULAR CYLINDER FITTED WITH FLEXIBLE SHROUDS

Murilo M. Cicolin
NDF, Dept. Mechanical Eng., EPUSP
University of São Paulo, São Paulo, Brazil
E-mail: mmcicolin@usp.br

Gustavo R. S. Assi
NDF, Dept. Naval Arch. & Ocean Eng., EPUSP
University of São Paulo, São Paulo, Brazil
E-mail: g.assi@usp.br

ABSTRACT

Experiments have been carried out with a circular cylinder fitted with four different models of flexible shrouds with variable values of structural damping. Shroud models were derived from the geometry of the suppressor called "ventilated trousers". VIV responses are presented in a range of reduced velocities from 2 to 15 and Reynolds number from 2,000 to 25,000. Influence of structural and hydrodynamic damping is considered and, since the meshes generate more hydrodynamic damping than a bare cylinder, this effect on VIV suppression is analyzed. With the minimal structural damping, the VT mesh reduced about 55% of the amplitude peak of bare cylinder, while the thick-sparse, thin-sparse and thin-dense meshes reduced about 50%, 45% and 50%, respectively. For the case with similar levels of total damping (structural plus hydrodynamic) the same models reduced about 50%, 25%, 40% and 50%, respectively. The results show that the effect of increasing the structural damping has an important role in the VIV suppression of the thick-sparse mesh. For the other models, this effect is less significant.

NOMENCLATURE

D Cylinder external diameter
d Characteristic diameter of bobbin
p Mesh perimeter
w Mesh width
m^* Mass ratio
f_N Natural frequency measured in water
$f_N{}^{air}$ Natural frequency measured in air
U Flow speed
$\hat{y}$ Cross-flow amplitude of vibration
ζ_{air} Damping ratio measured in air
ζ_{water} Damping ratio measured in still water

INTRODUCTION

The phenomenon of vortex-induced vibration (VIV) is particularly harmful to submarine structures, such as risers employed for drilling and oil extraction. The most usual way to attenuate the effects of VIV is the installation of suppressors like strakes and fairings along the riser. Recently, a type of VIV suppressor reappeared in the scientific-technological scene with novel geometric modifications. Patented by Brown in 2010 [1] it has since been called the *Ventilated Trousers*, or simply VT. Essentially, the VT is a development of the idea of wrapping the drilling riser in a type of flexible shroud, able to deform with the flow and mitigate the body response to hydrodynamic loads. The VT could be thought of as a combinations of or inspired by previous solutions as rope nets, canvas sleeves and perforated shrouds.

Starting from the patented geometry of the VT, three other flexible shrouds were tested, as illustrated in figure 3. The new geometries had simplified bobbins made of cylindrical tubes, illustrated in Figure 2. The length of the small tubes was 5d, equal to the length of the VT bobbin, thus covering the entire length of a cell of the mesh. Three meshes were built with different distributions of tubes. The first, called the thick-sparse mesh in figure 3(b), had the same distribution of the VT with tubes of diameter 3d in every other cell. The second, thin-sparse mesh, had the same distribution of VT and thick-sparse mesh, but their bobbins have diameter of d. The third, called the thin-dense mesh, had tubes of diameter d fitted in every cells of the mesh as seen in figure 3(d). The dimensions of the models can be found on the Table 1 for a reference cylinder's diameter $D = 50$mm.

Full-scale tests on a 0.53m diameter riser in the range of $Re = 1.2 \times 10^6$ have been performed by King et al. [2] and reported a 90% reduction in peak amplitude of vibration. Laboratory-scale tests performed by Cicolin et al. [3, 4] with elastic mounted cylinders reported a reduction of about 60%, in conditions of low mass and damping. In these later works, significant reduction was observed for a whole family of flexible shrouds.

The present work is motivated purely by the scientific interest on the topic. Our objective is to shed some light on the hydrodynamic and fluidelastic mechanisms underlying the VIV suppression by this kind of device. In previous works [3, 4] it was shown that the family of meshes are able to reduce the VIV while increasing hydrodynamic damping. Since there is a strong and direct relationship between the amplitude of response and damping [5, 6], we now intend to investigate the actual influence of hydrodynamic damping in the mechanism of VIV suppression by flexible shrouds.

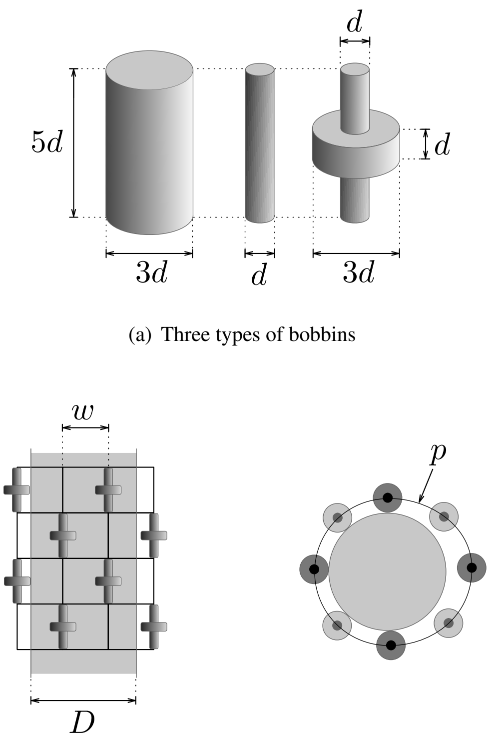
EXPERIMENTAL ARRANGEMENT

Experiments have been carried out in the recirculating water channel of the NDF Fluids and Dynamics Research Group at the University of São Paulo, Brazil. The test section is 7.5m long, 0.7m wide and 0.9m high and good quality flow with a turbulence intensity below 3% is achieved for flow speeds up to 1m/s. For a detailed description of the facilities, please refer to [7].

A section of a rigid circular cylinder made of acrylic tube has been installed on an elastic rig (the same employed by [3, 8]). A cross-view of the cylinder and the rig installed on the test section of the channel is illustrated in Figure1(a) and helps in describing the operation of the system. The support system is firmly installed on the channel structure and the sliding cylindrical guides are free to move in the transverse direction, defined by the y-axis. Air bearings are intended to avoid the friction between the guides and the system and then minimize the system's structural damping. An optical sensor was employed to measure displacements in the y direction. One pair of springs was installed in the y axes to set the natural frequency of motion in the cross-flow direction.

The moving part of the rig is connected to an arm immersed in viscous liquid. This device is intended to generate additional structural damping for the system, since viscous damping is produced by the movement of the arm in the still fluid. Altering the quantity of fluid allows to set different values of damping parameter.

Four different models of suppressors based on flexible shrouds have been assembled. The first is a typical VT model, built according to the description by Brown [1]. The main properties of the model are the bobbin size (d), the mesh width (w) and mesh perimeter (p). The scale of the bobbins in relation to the cylinder is given by the ratio of diameters $d/D = 0.11$, as defined in Figure 2.



(a) Three types of bobbins

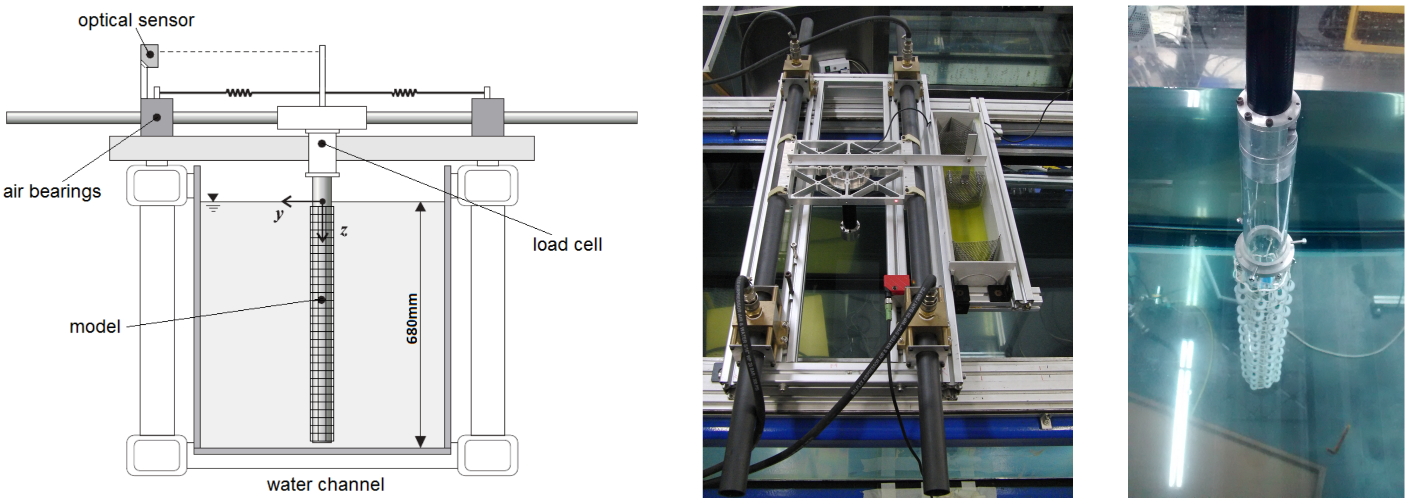
(b) Mesh

(c) Net perimeter

FIGURE 2: Geometric properties and dimensions.

The three other meshes were based on modified bobbin geometries and distribution. These new meshes were made fitting small sections of straight cylinders with varying diameter on a flexible net, resulting in a *thick-sparse mesh*, *thin-sparse mesh* and *thin-dense mesh*, as showed in Figure 3 and Table 1. Mesh width $w = 5d$ and perimeter $p = 4.64D$ were the same for all meshes. Further details about the models building process are described in [9].

Tests have been carried out with fixed models and models free to oscillate in one degree of freedom in the cross-flow direction for various reduced velocities between $U/f_N D = 3$ and 15. Reynolds number was varied between $Re = 5,000$ and 25,000 by changing the flow speed (U) in the water channel. The VIV response, represented by the normalized amplitude of displacement ($\hat{y}/D$) has been measured for all suppressors for the range of reduced velocities as well as for a bare cylinder employed as a reference. A load cell attached to the rig measured instantaneous



(a) Cross-view of the test section.

(b) elastic rig

(c) VT model attached to the rig

FIGURE 1: Illustration of the experimental apparatus

TABLE 1: Model properties

Model	d (mm)	d_{ext} (mm)	w (mm)	p (mm)
VT mesh	5.8	17.4	29	232
Thick-sparse mesh	5.8	17.4	29	232
Thin-sparse mesh	5.8	5.8	29	232
Thin-dense mesh	5.8	5.8	29	232

lift and drag acting on the models. (Though this paper will not discuss the hydrodynamic loads.)

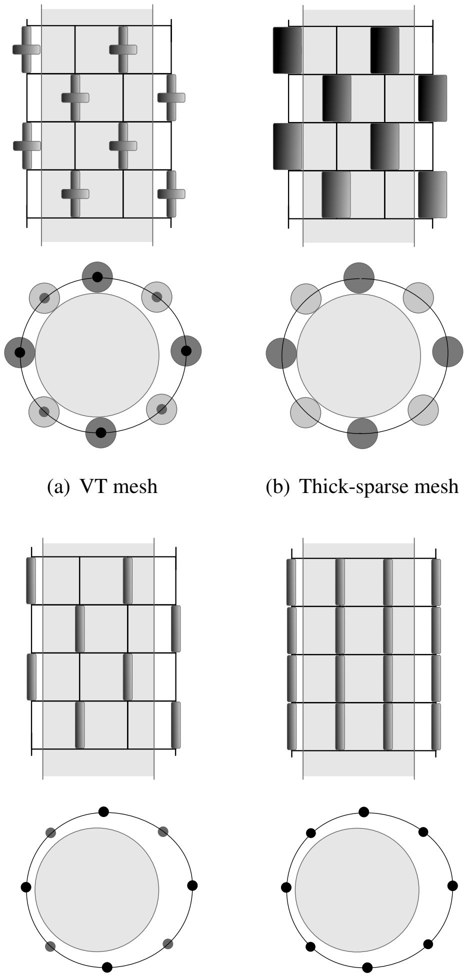
The focus of the paper is to investigate how the effect of damping influences the whole VIV response of a system with flexible shrouds. In order to simplify the problem, the damping is divided in two terms: structural and hydrodynamic damping. The former is obtained by decay tests in air. These tests are performed by measuring the response of the system free to vibrate immersed in air (that is in the empty water channel). The structural damping ratio ζ_{air} is defined as a fraction of the critical damping. The same procedure is used for decay tests in water, but in this case the model is immersed in still water, and gave the coefficient of total damping ζ_{water}, which is the sum of the structural and the hydrodynamic terms. Previous tests showed that the hydrodynamic damping induced by the meshes is several times higher than that induced by the bare cylinder. So, in order to investigate the importance of damping in the whole VIV suppression, we input an amount of structural damping to a bare cylinder mimicking the level of hydrodynamic damping naturally achieved by the shrouds in still water. Hence we are able to compare the responses of the models with similar levels of total damping (structural plus hydrodynamic).

RESULTS AND DISCUSSION

Four experimental campaigns were carried out with the goal of comparing the VIV response of each model with that of a bare cylinder. In each case, it was firstly measured the VIV response with the minimal structural damping possible. Next, the structural damping was altered in order to set the total damping of the bare cylinder equal to the total damping of the shroud model without extra damping. Then, the VIV response was measured for both bare cylinder and shrouded model.

The values of natural frequency in air (${f_N}^{air}$), natural frequency in water (f_N) and reduced mass (m^*) are practically invariable for all measurements, as presented in Table 2. The values of the structural damping (ζ_{air}) and total damping (ζ_{water}) are presented in the respective plot along the Figures 4-7 by the combined parameter $m^*\zeta$, which is most usual for predicting the peak response [6, 10].

Figure 4 shows the comparison between the VT mesh and bare cylinder. At the minimal level of structural damping ($m^*\zeta_{air} \approx 0.01$), the bare cylinder presents a typical VIV response, with a peak close to 0.8 around reduced velocity 5, which is in accordance to other results in the literature [6, 10]. The VT mesh, for the same level of damping, shows a peak close to 0.35,



(a) VT mesh (b) Thick-sparse mesh (c) Thin-sparse mesh (d) Thin-dense mesh

FIGURE 3: Different configurations of flexible shrouds.

which has also been observed previously [3].

Since the hydrodynamic damping of the VT mesh is higher than that of the bare cylinder, the structural damping was increased up to the level when the combined parameter $m^*\zeta_{water}$ of the bare cylinder reached that of the VT mesh. For this new level of damping, the bare cylinder reached a peak of response close to $\hat{y}/D = 0.7$, approximately 12% lower than that found with lower damping, but significantly higher than the peak found for the VT mesh. The peak of the VT mesh for the new level of damping decreases approximately by 20% to $\hat{y}/D \approx 0.28$.

Considering the bare cylinder and the VT mesh with similar values of $m^*\zeta_{air}$, the bare cylinder presents $\hat{y}/D \approx 0.7$, more than twice as that for the VT mesh ($\hat{y}/D \approx 0.35$). It indicates that not only damping, but other hydrodynamic effects contribute to the efficacy of the VT mesh on suppressing VIV.

TABLE 2: Experimental properties

Model	${f_N}^{air}$(Hz)	f_N(Hz)	m^*
bare cylinder	0.67	0.57	2.36
VT mesh	0.67	0.55	2.48
Thick-sparse mesh	0.66	0.51	2.50
Thin-sparse mesh	0.67	0.56	2.41
Thin-dense mesh	0.67	0.55	2.43

Figure 5 presents results for the thick-sparse mesh model compared to the bare cylinder. This model produced the highest hydrodynamic damping, about five times that of the bare cylinder. For the minimal structural damping condition, the thick-sparse mesh shows a typical VIV response, its resonance starts around reduced velocity of 5 and the synchronization range finishes round reduced velocity 12. It reaches a peak$\hat{y}/D \approx 0.4$ approximately half of the peak of bare cylinder $\hat{y}/D \approx 0.8$. Adding the level of structural damping, the bare cylinder decreases its peak to $\hat{y}/D \approx 0.55$, while the thick-sparse mesh decreases it to $\hat{y}/D \approx 0.3$, which means a reductions of 30% for both models. The plots for the bare cylinder and meshes with similar values of $m^*\zeta_{water} \approx 0.26$ are rather close. In this case the model reduced only about 25% of the cylinder's peak amplitude of vibration. It indicates that the hydrodynamic damping has a strong role in the suppression.

The responses of the thin-sparse mesh compared with that of the bare cylinder are presented in Figure 6. For the case with minimal structural damping, the mesh's peak of response of $\hat{y}/D \approx 0.45$ is approximately 55% that of the bare cylinder ($\hat{y}/D \approx 0.8$). For the case with extra structural damping, the bare cylinder's peak decreases to $\hat{y}/D \approx 0.7$ while the mesh's peak reaches $\hat{y}/D \approx 0.4$, a reduction close to 10% for both. When comparing the bare cylinder and thin-sparse mesh for the case with similar values of $m^*\zeta_{water}$, the bare cylinder shows higher value, and the difference between them during the whole synchronization range is several times higher than the reduction due to the increasing damping parameter.

The results for the thin-dense mesh, shown in Figure 7, points to the same direction. For the case with minimal damping, thin-dense mesh has a peak of $\hat{y}/D \approx 0.4$. For the case with extra structural damping, the peak sustain values of $\hat{y}/D \approx 0.4$, which indicates that damping has a weaker influence on its behavior. Besides that, both cases do not present a typical synchronization range. Cicolin et al. [3, 4] has observed that the thin meshes develop a mechanism similar to a sail, extracting energy from the flow.

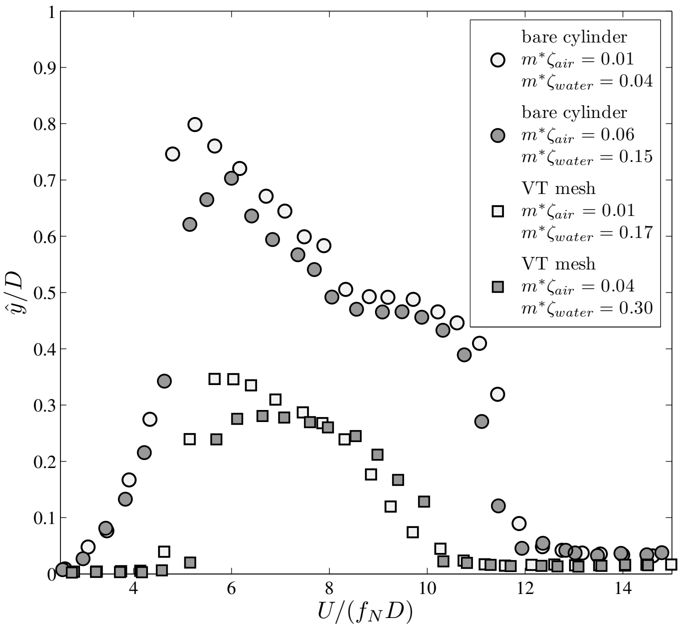


FIGURE 4: VIV response of the bare cylinder and the VT mesh.

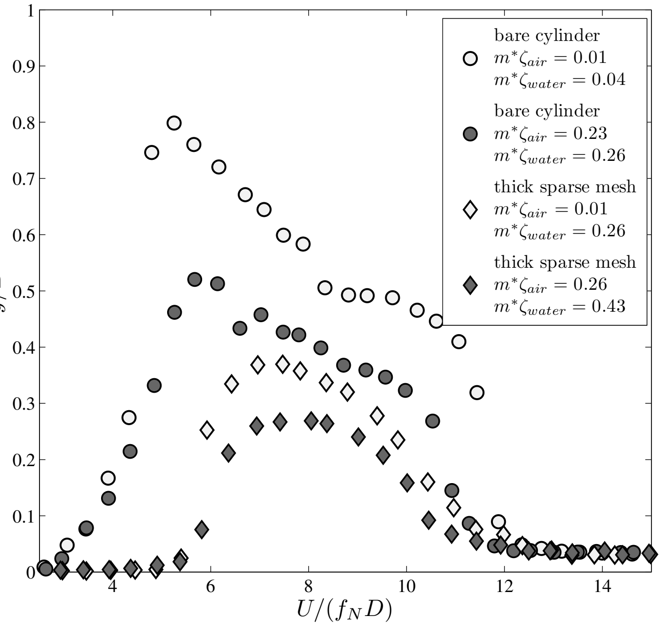


FIGURE 5: VIV response of the bare cylinder and the thick-sparse mesh.

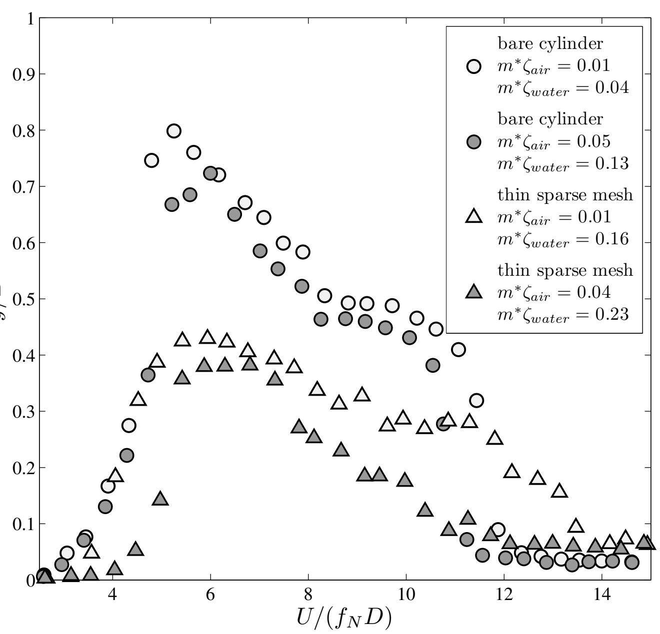


FIGURE 6: VIV response of the bare cylinder and the thin-sparse mesh.

CONCLUSIONS

In the present work we have investigated the VIV response of a circular cylinder fitted with four suppressors of the flexible shrouds family for different levels of structural damping, mimicking the level of hydrodynamic damping naturally achieved by the shrouds in still water. The main goal was to compare the response of a bare cylinder and the shrouded models with similar level of total damping.

The VT mesh reduced almost 55% of the peak response found for a bare cylinder with an increase of about 4 times the reference damping. When submitted to a level of damping similar to that of the bare cylinder, the VT mesh still reduces about 50% of the peak response.

The thin-sparse mesh and the thin-dense mesh presented similar behaviors. They reduced about 40% of the response amplitude of the bare cylinder for the case with minimal structural damping. For the case with a similar level of damping they still reduced more than 30%.

Therefore we conclude that the effect due to an increase in the structural damping is not the main responsible for the suppression achieved by the following shrouded models: VT, thin-sparse and dense meshes.

On the other hand, the thin-sparse mesh increased the hydrodynamic damping to a level more than six times that achieved by the bare cylinder. In the case with minimal structural damping, the model reduced more than 50% of the amplitude peak found for the bare cylinder. For a similar level of total damping, the model reduced less than 30%.

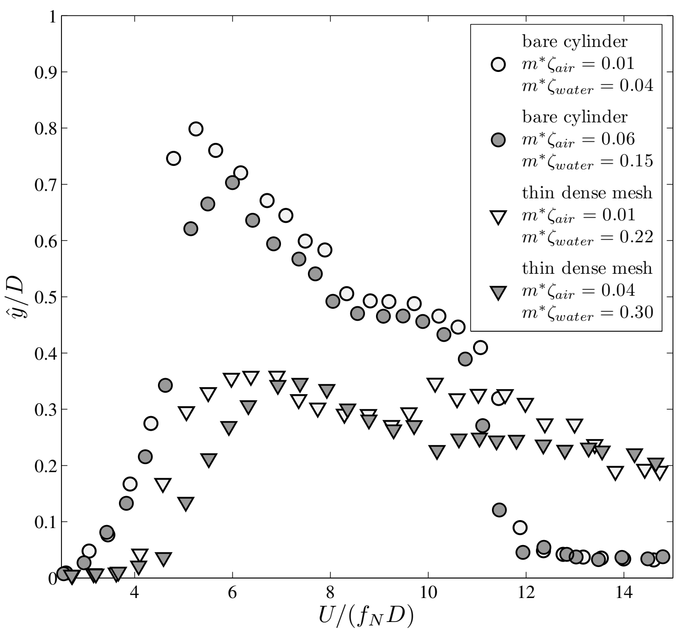


FIGURE 7: VIV response of the bare cylinder and the thin-dense mesh.

We conclude that, in spite of other hydrodynamic mechanisms, the damping increasing effect has a significant role on the suppression achieved by this specific model.

Future works should concentrate on different hydrodynamic mechanisms that are able to explain the suppression achieved by the models. Novel tests should concentrate one PIV (particle-image velocimetry) measurements of the wake and measurements of sectional lift forces.

ACKNOWLEDGEMENTS

MMC is thankful to the support of Brazilian Ministry of Education (CAPES). GRS Assi is grateful to FAPESP (2011/00205-6, 2014/50279-4), CNPq (306917/2015-7) and the Brazilian Navy.

REFERENCES

[1] Brown, A.J., Device and Method for Suppressing Vortex Induced Vibration. *United States Patent Application Publication* , **2010**.

[2] Brown, A.J., King, R., Tests with Flexible Quasi-Fairing to reduce Riser Drag, Suppress VIV and Limit Drilling Down-Time, *Offshore Technology Conference (OTC 2008)*, 19161, **2008**

[3] Cicolin, M.M., Freire, C.M., Assi, G.R.S, "Suppression of the Vortex-Induced Vibration of a Circular Cylinder with Permeable Meshes", *Proceedings of the 4th Joint US-European Fluids Engineering Summer Meeting (FEDSM 2014)*, 22149, Chicago, USA, **2014**

[4] Cicolin, M.M., Freire, C.M., Assi, G.R.S; "VIV Response and Drag Measurements of Circular Cylinders Fitted with Permeable Meshes", *Proceedings of the 34th International Conference on Ocean, Offshore and Arctic Engineering (OMAE 2015)*, 42278, St. John's, Canada, **2015**.

[5] Griffin, O.M.; "Vortex-excited cross-flow Vibration of a Single Cylindrical tube", *ASME Journal of Pressure Vessel Technology*, 102, p.158-166, **1980**.

[6] Govardhan, R., Williamson, C.H.K.;"Defining the Modified Griffin Plot in Vortex-Induced Vibration: Revealing the Effect of Reynolds Number Using Controlled Damping", *Journal of Fluid Mechanics* 561, p. 147–180, **2006**

[7] Assi,G. R. S., Meneghini,J.R., Aranha,J.A.P., Bearman,P.W., Casaprima,E.;"Experimental investigation of flow-induced vibration interference between two circular cylinders", *Journal of Fluids and Structures* 22, p.819-827, **2006**.

[8] Assi, G. R. S., Bearman, P. W., Kitney, N.; "Low Drag Solutions for Suppressing Vortex-Induced Vibration of Circular Cylinders", *Journal of Fluids and Structures*, 25, p.666-675, **2009**.

[9] Cicolin, M.M.; "Suppression of the vortex-induced vibration of circular cylinders with permeable meshes"; *MSc Thesis, Escola Politécnica, University of São Paulo, Available in Portuguese from www.teses.usp.br*, **2015**.

[10] Williamson, C.H.K., Govardhan, R.; "Vortex-Induced Vibrations", *Annual Review of Fluid Mechanics* 36, p.413-455, **2004**.