Proceedings of the ASME 2011 30th International Conference on Ocean, Offshore and Arctic Engineering
OMAE2011
June 19-24, 2011, Rotterdam, The Netherlands

OMAE2011-49522

THE EFFECT OF ROTATIONAL FRICTION ON THE STABILITY OF SHORT-TAILED FAIRINGS SUPPRESSING VORTEX-INDUCED VIBRATIONS

Gustavo R.S. Assi*
University of São Paulo, Brazil
Dept. Naval Arch. & Ocean Engineering – NDF Group

Peter W. Bearman
Imperial College London, UK
Department of Aeronautics

Michael A. Tognarelli
BP America Production Company, USA

Julia R.H. Rodrigues
University of São Paulo, Brazil
Dept. Mechanical Engineering – NDF Group

ABSTRACT

Experiments have been carried out on a free-to-rotate short-tail fairing fitted to a rigid length of circular cylinder to investigate the effect of rotational friction on the stability of this type of VIV suppressor. Measurements of the dynamic response are presented for models with low mass and damping which are free to respond in the cross-flow and streamwise directions. It is shown how VIV can be reduced if the fairing presents a rotational friction above a critical limit. In this configuration the fairing finds a stable position deflected from the flow direction and a steady lift force appears towards the side the fairing has deflected. The fluid-dynamic mechanism is very similar to that observed for a free-to-rotate splitter plate of equivalent length.

Keywords: *VIV suppression, drag reduction, short-tail fairing.*

INTRODUCTION

Various methods for suppressing vortex-induced vibrations (VIV) of bluff bodies have been investigated over the past decades. With the advancement of offshore oil exploration research on VIV suppressors was pushed to a new level. The industry demands suppressors that are not only efficient for low mass-damping systems but also that could be installed under harsh environmental conditions; such is the case for offshore risers.

Zdravkovich [1] and Every et al. [2] present comprehensive reviews of solutions varying from the simple attachment of ribbons to quite expensive devices such as helical strakes and fairings. In the present work we contribute to the understanding of the mechanism behind a type of free-to-rotate (f-t-r) device known as the short-tail fairing, more and more employed on offshore drilling risers.

Drilling risers are not in operation for as long as production risers, therefore fatigue damage is not as important a concern as the loads caused by strong currents. Therefore, besides suppressing flow-induced vibrations (FIV), suppressors must contribute to reduce drag consequently reducing pipe bend during drilling operation. It is well known ([3], [4]) that helical strakes (also widely employed by the offshore industry) suffer from two major problems: the first being that they increase drag and the second that their effectiveness reduces with decreases in the mass-damping parameter. Whereas a strake height of 10% of cylinder diameter is sufficient to suppress VIV in air at least double this amount is required in water, and this increase

*Corresponding author: g.assi@usp.br. 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.

in height is accompanied by a corresponding further increase in drag.

FREE-TO-ROTATE SUPPRESSORS

It is known that if vortex shedding from a fixed cylinder is eliminated, say by the use of a long splitter plate [5], then drag is reduced hence conceptually an effective VIV suppression device should be able to reduce drag rather than increase it. This simple idea was the motivation for the development of suppressors such as splitter plates and fairings that act primarily disrupting the vortex shedding mechanism on the near wake of bluff bodies.

Assi et al. [6] have shown that suppression of cross-flow and in-line VIV of a circular cylinder, with resulting drag coefficients less than that for a fixed plain cylinder, has been achieved using two-dimensional control plates in low mass-damping systems. A f-t-r splitter plate was also found to suppress VIV but instead of remaining aligned with the flow on the centreline of the wake the plate adopted a stable but deflected position when it was released. VIV was suppressed, throughout the range of reduced velocity investigated, and drag reduced below that of a plain cylinder. Cimbala and Garg [5] had also observed this bi-stable behaviour for a f-t-r cylinder fitted with a splitter plate.

Particle Image Velocimetry (PIV) measurements showed that on the side to which the plate deflected the separating shear layer from the cylinder appeared to attach to the tip of the plate and this had the effect of stabilising the near wake flow. Vortex shedding was visible downstream but this did not feed back to cause vibrations. An unwanted effect was that a steady transverse lift force developed on the cylinder towards the side to which the splitter plate deflected. This steady lift could be eliminated by using a pair of splitter plates arranged so that the shear layers that spring from both sides of the cylinder attach to the tips of the plates. The maximum suppression and drag reduction occurred with a pair of f-t-r parallel plates installed on the sides of the cylinder.

Assi et al. [6] also found that the level of rotational friction between the f-t-r plate and the cylinder plays a fundamentally important role, needing to be "high enough to hold the device in a stable position, while still allowing them to realign if the flow direction changes. Devices with rotational friction below a critical value oscillate themselves as the cylinder vibrates, sometimes increasing the amplitude of cylinder oscillation higher than that for a plain cylinder". All devices with rotational friction above the critical value appeared to suppress VIV and reduce drag. However, if the rotational resistance was above a limiting threshold the suppressors could not rotate and an undesired galloping response was initiated.

Based on previous investigations we believe that short-tail fairings and short splitter plates are able to suppress VIV based on the same fluid-dynamic mechanism. Short fairings are not a "fairing" in the strict sense of the term, i.e., they do not make a streamlined body. For this to happen the length of the fairing would have to be many times the diameter of the cylinder (as shown in [7], [8], [9]). In essence, we believe a short-tail fairing acts in the near wake with fully separated flow avoiding the interaction between the shear layers and delaying vortex shedding, therefore the same mechanism as the splitter plate.

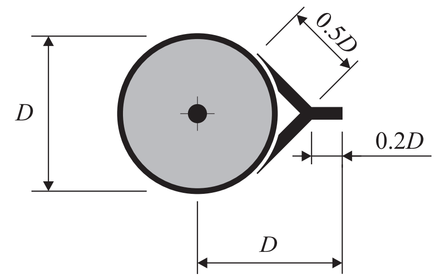


Figure 1. Free-to-rotate short-tail fairing. Geometry obtained from [11].

If this is true, we expect short fairings to find stable but deflected positions towards one of the sides of the cylinder instead of aligning itself with the flow. In the same manner as splitter plates, the stability of short fairings might also depend on a minimum level of rotational friction in order to suppress VIV. The effect of rotational friction on the stability of short-tail fairing is what this present study sets out to investigate.

FREE-TO-ROTATE SHORT-TAIL FAIRING

The suppression device tested was a triangular fairing with a flat tail piece, know as a short-tail fairing and shown in Figure 1. Similar devices are used by the offshore industry following its appearance as a commercial solution to reduce VIV [10].

The geometry adopted in this work was based on the proportions found in [11]. It consists of two perpendicular plates of $0.5D$ in length joined at the tip to a short $0.2D$-long tail plate. The characteristic length of the fairing is $0.5D$. Both front plates are kept at a small distance form the cylinder wall in order to allow the fairing to freely rotate about the centre of the cylinder. In the present investigation, the fairing was fabricated using aluminium plates and supported by two rotating arms at each end. Control of the rotational friction was achieved by adjusting a screw pushing a small brake plate between the rotating parts. The same system was employed by [6].

EXPERIMENTAL ARRANGEMENT

Experiments have been carried out on various devices fitted to a rigid length of cylinder free to respond in two degrees of freedom (2-dof). The investigation was carried out in a recirculating water channel in the Department of Aeronautics, Imperial College, London, with a test section 0.6m wide, 0.7m

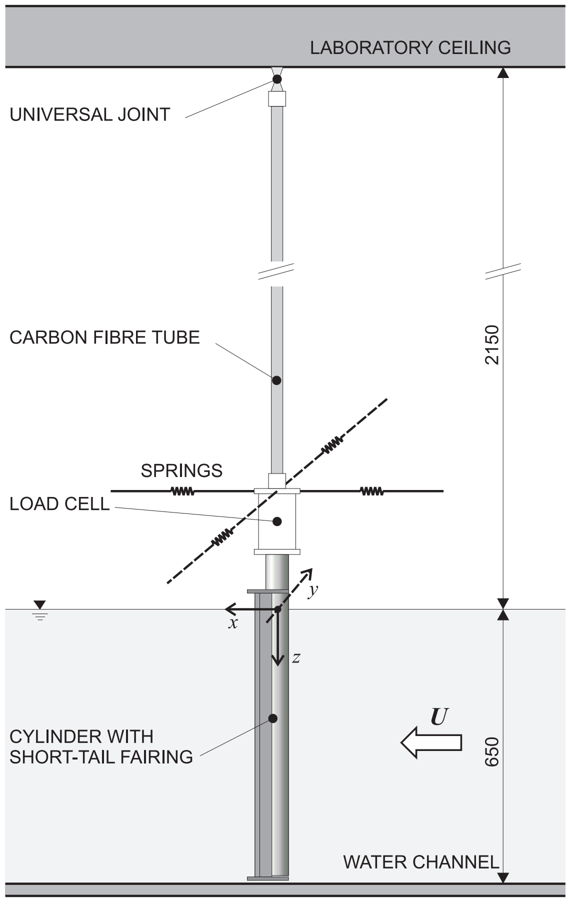


Figure 2. Experimental setup: short-tail fairing model mounted on the 2-dof rig in the test section of the water channel.

deep and 8.0m long. The flow speed, U, is continuously variable and good quality flow can be obtained up to at least 0.6m/s. The cylinder model was constructed from 50mm diameter Perspex tube, giving a maximum Reynolds number of approximately 30,000, based on cylinder diameter D.

Models were mounted on a very low damping rig that allowed the cylinder to freely respond in both cross-flow and streamwise directions (Figure 2). The cylinder model was mounted at the lower end of a long carbon fibre tube which formed the arm of a rigid pendulum. The top end of the arm was connected to a universal joint fixed at the ceiling of the laboratory so that the cylinder model was free to oscillate in any direction in a pendulum motion.

Two independent optical sensors were employed to measure displacements in the x- and y-directions at the mid-length of the model. It should be noted that for a displacement equal to 1 diameter the inclination angle of the cylinder was only just over 1 degree from the vertical. Two pairs of springs were installed in the x- and y-axes to set the natural frequencies in both directions of motion allowing different natural frequencies to be set for each direction. Although the cylinder was initially aligned in the vertical position, in flowing water the mean drag displaces the cylinder from its original location. To counteract this effect, the in-line pair of springs was attached to a frame that could be moved back and forth in the direction of the flow. For each flow speed there was a position of the frame that maintained the mean position of the cylinder in the vertical direction. By using two pairs of springs perpendicular to each other, the assembly has nonlinear spring constants in the transverse and in-line directions. Movement in the transverse direction will cause a lateral spring deflection in the in-line direction and vice versa. This nonlinearity is minimised by making the springs as long as possible, hence the in-line springs were installed at the end of 4m-long wires, fixed at the extremities of the frame.

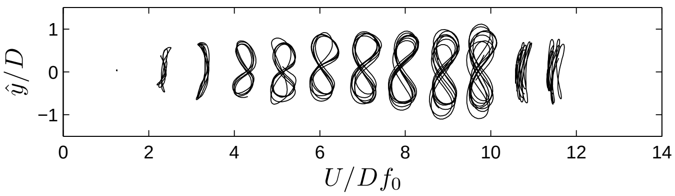
It is known that during the cycle of vortex shedding from bluff bodies the fluctuation of drag has double the frequency of the fluctuation of lift. Hence a particularly severe vibration might be expected to occur if the hydrodynamic forces in both directions could be in resonance with both in-line and transverse natural frequencies at the same time. For this reason, we set the in-line natural frequency (f_{x0}) to be close to twice the transverse (f_{y0} or simply f_0) by adjusting the stiffness of both pairs of springs. The structural damping of the 2-dof rig was $\zeta = 0.3\%$, as a fraction of critical damping, approximately the same for both principal directions of motion. A load cell was attached between the cylinder and the support system to deduce the instantaneous and time-averaged hydrodynamic forces on the cylinder model. In order to obtain the dynamic forces acting, the inertia force (cylinder structural mass times acceleration) was subtracted from the forces recorded by the load cell. The mass ratio (m^*, defined as vibrating mass divided by the displaced mass of water) was kept to the lowest possible value.

Measurements were made using a fixed set of springs and the reduced velocity range covered was from 1.5 to 13, where reduced velocity ($U = D/f_0$) is defined using the cylinder natural frequency of oscillation in the cross-flow direction measured in air. The only flow variable changed during the course of the experiments was the flow velocity U, which, as for full-scale risers, alters both the reduced velocity and the Reynolds number. Throughout the study, cylinder displacement amplitudes ($\hat{x}/D$ for streamwise and $\hat{y}/D$ for cross-flow) were found by measuring the root mean square value of response and multiplying by the square root of 2 (the so called harmonic amplitude). This is likely to give an underestimation of maximum response but was judged to be perfectly acceptable for assessing the effectiveness of VIV suppression devices. Displacements are nondimensionalised by dividing by the plain cylinder diameter D.

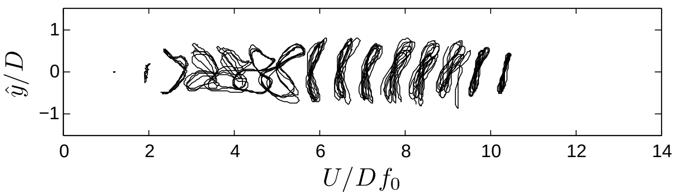
Preliminary tests have been performed with a plain cylinder to serve as reference for comparison. Table 1 presents the structural parameters for the arrangements of cylinder and suppression device tested.

Table 1. Structural properties.

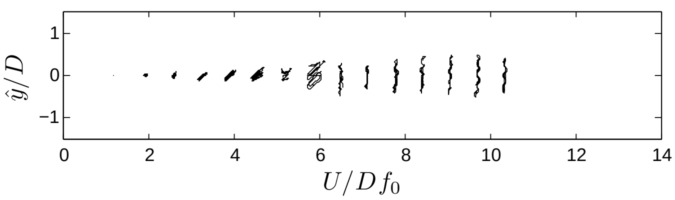
	m^*	ζ	$m^*\zeta$	f_{x0}/f_{y0}
Plain cylinder	1.6	0.3%	0.0047	1.93
Short-tail fairing	1.7	0.3%	0.0051	1.90



(a) Plain cylinder

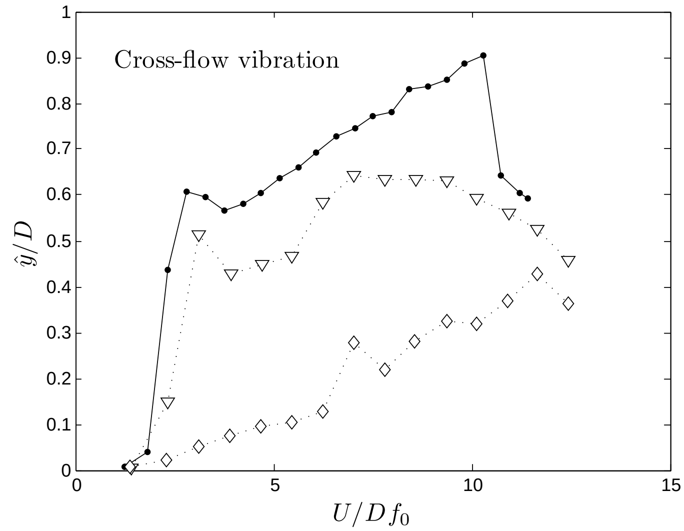


(b) Short-tail fairing: low friction ($\tau_f = 0.009$Nm/m)

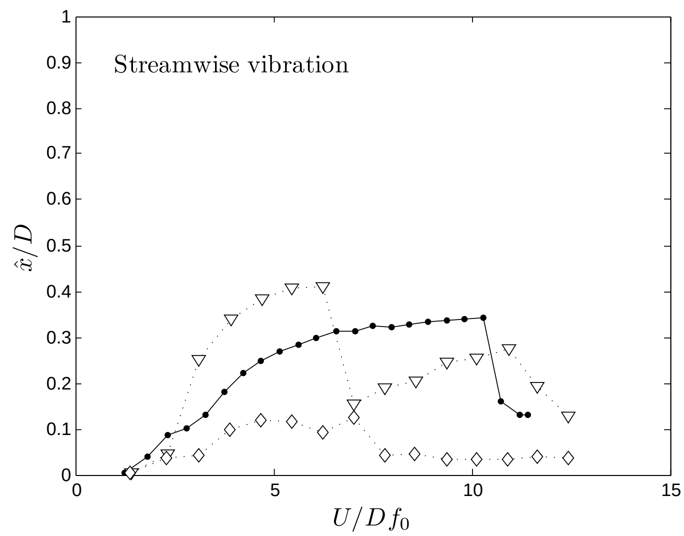


(c) Short-tail fairing: high friction ($\tau_f = 0.035$Nm/m)

Figure 3. VIV trajectories of motion for a plain cylinder (a) and a short-tail fairing below (b) and above (c) critical friction.



(a) Cross-flow amplitude of vibration



(b) Streamwise amplitude of vibration

Figure 4. Cross-flow (a) and streamwise (b) VIV response of a plain cylinder and a short-tail fairing with high and low friction. Please refer to Fig. 5 for key.

RESULTS AND DISCUSSION

Preliminary experiments performed with a plain cylinder (previously presented in [6]) will serve as reference for the discussion that follows. Figure 3(a) shows trajectories of a few cycles along selected values of reduced velocity. A distinct 8-shape motion is observed for a wide range of reduced velocity in agreement with other results found in the literature. Figure 4 presents the same 2-dof response projected in the cross-flow ($\hat{y}/D$) and streamwise ($\hat{x}/D$) directions, revealing a different behaviour from the typical VIV response in 1-dof cross-flow. Initial, upper and lower branches are not clearly identified but instead 2-dof vibrations build up in the form of a single branch during the synchronisation range.

In order to investigate the rotation stability of f-t-r short-tail fairings we prepared models with two values of rotational friction τ_f. A low friction ($\tau_f = 0.009$Nm/m) and a high friction ($\tau_f = 0.035$Nm/m) cases were chosen based on the results obtained for a splitter plate presented in [6]. τ_f is measured in torque per unit length.

Similar to what was observed for a splitter plate in [6], the short-tail fairing with low friction ($\tau_f = 0.009$Nm/m) was unable to find a stable position about the centre of the cylinder, instead it oscillated from side to side as the cylinder responded with VIV. The trajectory of motion also resembles a deformed 8-shape (Figure 3(b)) and amplitude of vibration is almost as high as those observed for a plain cylinder. Figure 4 shows that cross-flow and streamwise displacements are as high as those

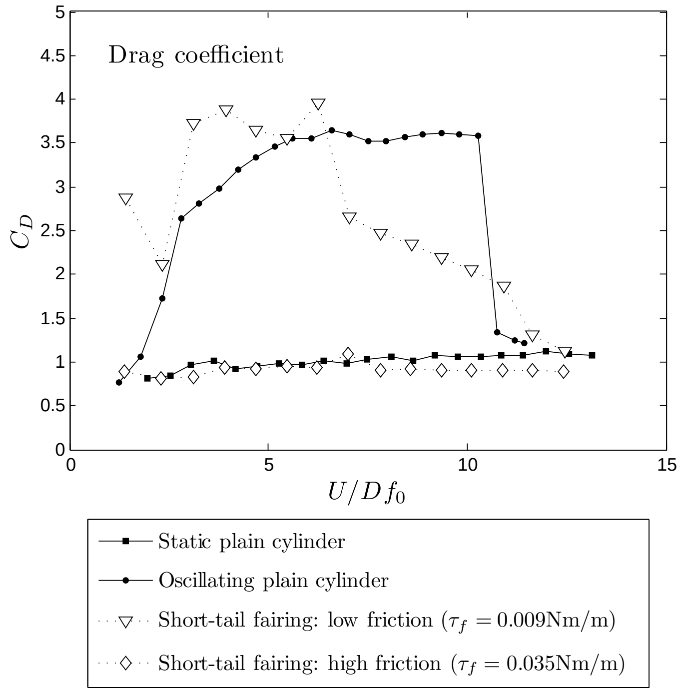


Figure 5. Mean drag coefficient of a plain cylinder and a short-tail fairing under VIV compared with drag coefficient of a static cylinder.

measured for the plain cylinder, confirming that significant VIV suppression was not achieved in this case.

In contrast, the short-tail fairing with high friction ($\tau_f =$ 0.035Nm/m) presented a distinct behaviour. The device was able to find a stable position about the axis of the cylinder and, similar to what was observed for the splitter plate in [6], VIV was reduced. This position was on a deflected angle from the centreline of the wake. In this configuration the short-tail fairing was successful in suppressing VIV considerably, as shown by the motion trajectories in Figure 3(c). Figure 4 shows that the maximum amplitude of vibration was $\hat{y}/D = 0.45$ in the cross-flow and $\hat{x}/D = 0.15$ in the streamwise directions within the synchronisation range.Significant vibrations might still appear because the fairing is not long enough to delay the vortex shedding sufficiently downstream of the body and vortices are feeding back and exciting the cylinder.

As far as drag reduction is concerned, Figure 5 shows that a short-tail faring with low rotational friction presented drag coefficient higher than a plain cylinder under VIV for at least half of the synchronisation range. On the other hand once the fairing was able to stabilise with high friction the level of drag dropped to values comparable to a static plain cylinder. This device did not show such a considerable drag reduction as other studied in [6], but an average 6% reduction if we consider the whole range of *Re* covered in this experiment.

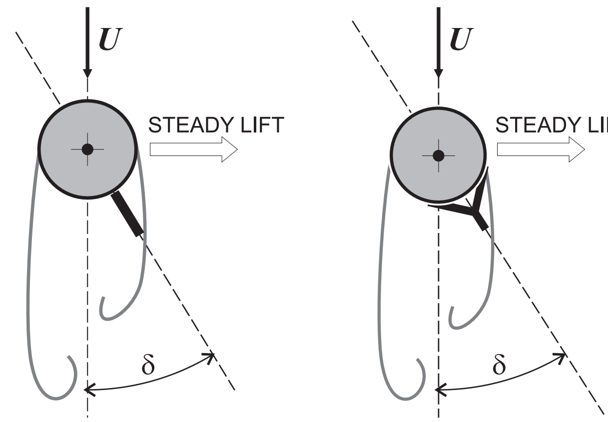


Figure 6. Deflected but stable position of a $0.5D$ splitter plate and a short-tail fairing. A steady lift force is generated towards the side the suppressor is deflected.

An angle of deflection δ around 25 degrees was adopted by the short-tail fairing and was very close to that found for a $0.5D$-long splitter plate by [6], as illustrated in Figure 6. PIV measurements of the near wake (not presented in this paper) show that the fluid-dynamic mechanism that held the fairing in the stable position was caused by the reattachment of the shear layer on the side the device had deflected. This suggests that, likewise the splitter plate, a short-tail fairing requires a deflected position in order to stabilise and disrupt the communication between the shear layers, consequently delaying vortex shedding and suppressing VIV.

Just like the single splitter plate, the fairing also generates a mean lift force towards the side to which it is deflected. In practise, long risers are fitted with a series of fairings mounted along the span of the pipe. We believe that some fairings might randomly deflect to one side whereas others find a stable position at the opposite side, in a way that the resultant lift force generated on the entire riser is neutralised. This prediction was not verified in our experiments but we believe on-site observations would help to clarify this point.

CONCLUSION

After this study we can say that we have a better understanding of the principle behind the way short-tail fairings work to reduce VIV. It appears that the short-tail fairing behave in a similar manner to a single splitter plate of length $0.5D$. Although the critical value of rotational friction τ_f has not been determined for a short-tail fairing, our results suggests that a critical value exists between the low and high friction cases presented here.

It seems likely that different suppressors might have different stability boundaries for rotational resistance, but there is clearly a range of τ_f within which VIV suppression would be achieved with short-tail fairings. As with all circular cylinder flows, undoubtedly Reynolds number plays a role and hence some caution may need to be exercised in extrapolating the results presented here to full-scale risers. However, the underlying flow physics is not expected to change and the devices described in this study are likely to be effective at suppressing VIV when applied to full-scale risers.

Short-tail fairings with a characteristic length of $0.5D$ proved to reduce amplitude levels (at the expense of a mean transverse force) but were not as efficient as other longer suppressors reported in [6]. Rather than reducing drag for the entire range of reduced velocities tested, the fairing increased it for certain velocities. As a result, the average drag has a similar level to that of a plain fixed cylinder, offering a slight reduction of 6% throughout the *Re* range.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support of the Engineering and Physical Sciences Research Council, BP Exploration Operating Company and BP America Production Company. GRSA is grateful to the Brazilian Ministry of Education (CAPES) for a PhD scholarship. JRHR is grateful to FAPESP for an undergraduation research grant.

REFERENCES

[1] 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.

[2] Every, M.J., King, R., Weaver, D.S. **1982** Vortex-excited vibrations of cylinders and cables and their suppression. *Ocean Engineering*, 9(2), 135-157.

[3] Korkischko, I., Meneghini, J., Casaprima, E., Franciss, R., **2007** An experimental investigation of the flow around isolated and tandem straked cylinders. In proceedings of BBVIV5 5th Conf. on Bluff Body Wakes and Vortex-Induced Vibrations, Costa do Suipe, Brazil, 2007

[4] 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.

[5] Cimbala, J.M., Garg, S., **1991** Flow in the wake of a freely rotatable cylinder with splitter plate. *AIAA Journal* 29, 1001-1003.

[6] 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, 1-10.

[7] Henderson, J.F., Some towing problems with faired cables. *Ocean Engineering* 5(2), 105-125.

[8] Wingham, P.J. **1983** Comparative steady state deep towing performance of bare and faired cable systems. *Ocean Engineering* 10(1), 1-32.

[9] Packwood, A.R. **1990** Performance of segmented swept and unswept cable fairings at low reynolds numbers. *Ocean Engineering* 17(4), 393-407.

[10] D.W.Allen and D.L.Henning **1995** Small fixed teardrop fairings for vortex induced vibration suppression. United States Patent number 5,410,979 - May 2, 1995.

[11] J.P. Pontaza and H.C. Chen **2006** Numerical simulations of circular cylinders outfitted with vortex-induced vibrations suppressors. In the proceedings of ISOPE Int. Soc. Offshore and Polar Eng., 2006.