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Investigations into the Cylinder Flow Stabilities with a Thin Film Attachment

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Abstract : The wakes of a cylindrical body have been investigated. The cylindrical body was attached with a thin film. The film is made of silicon with configurations of 50mm(W) x 150mm(L) x 0.3mm(T). The cylinder wakes have been measured with PIV experiments under the conditions with and without the thin film. The diameter of the installed cylinder body is 30mm and the Reynolds numbers are 2730, 6160 and 9750 with the diameter. The measurement system consists of an Ar-ion laser(6W), a high speed camera(1024 x 992 pixel, 500fps) and a host computer. FFT analyses have been carried out using the velocity vectors obtained by PIV measurements at the point X/D=1.52 and Z/D=0.52. For understanding the three-dimensional flow structures, a new Volumetric PTV(particle tracking velocimetry) has been constructed, in which the same four high-resolution cameras have been used. It has been verified that the flexible film suppresses or damps the vortices separated from the cylinder body, which makes the cylinder's wakes stable. With increase of Re numbers the intensity of the dominant frequency of the wakes become smaller.
Key words : Stabilization, Cylinder Wake, Thin Film, 2D-PIV, Volumetric PTV

1. Introduction

The VIV(vortex induced vibration) affects the dynamics of riser tubes bringing oil from the seabed to the surface, as well as civil engineering structures such as bridges, chimneys, and buildings, further for offshore and ocean structures' applications. The range of problems caused by vortex- induced vibration has led to a large number of experimental and computational studies on the subject, including several review articles [1, 2, 3, 4, 5]

In studies of vortex-induced vibration, the case of an elastically mounted rigid cylinder, constrained to move transverse to an incoming flow, is often used as a paradigm for understanding more diverse experimental arrangements [6]. Williamson and Roshko [7] studied the vortex wake patterns for a cylinder, forced to translate in a sinusoidal trajectory, over a wide variation of amplitudes (A/D up to 5.0) and wavelengths (l/D up to 15.0). They defined a whole set of different regimes for vortex wake modes, in the plane of {l/D, A/D}, where a descriptive terminology for each mode was introduced. Each periodic vortex wake pattern comprises single vortices (S) and vortex pairs (P), giving patterns such as the 2S, 2P and P+S modes.

Donald Rockwell's group at Lehigh University [8] were the first to measure vorticity dynamics using PIV on the problem of controlled cylinder vibration. The first

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vorticity measurements for free vibrations, by Govardhan and Williamson [9], confirmed that the initial and lower branches correspond to the 2S and 2P vortex wake modes respectively.

In the mean while, there are several studies in controlling the wake behind a circular cylinder. Fujisawa [10] used a small cylinder for controlling the wake of the main cylinder. Sakamoto et. al [11] used a fine flat film to suppress of the forces acting on the cylinder. Fuchiwaki et al. [12] used an elastic airfoil to control the wake generated its behind. Gomes and Lienhart [13] carried out an experiment using PIV technique to check the fluid-structure interaction problems on the cylinder wake behind which a thin film was attached. Their measurements were carried out using two-dimensional PIV.

In this study, the control characteristics of a thin film which is attached behind a circular cylinder are investigated using a 2D-PIV and a Volume PTV.

2. Experiments

Figure 1 shows the overall experimental setup. A cylinder (D=30mm) is installed inside of the circulating water channel(1100mm x 300mm x 300mm). A thin film (silicon) of which size it 0.3t x 500mm x 150mm has been attached onto the body of the cylinder as shown in Figure 1. The tested Reynolds numbers are 2730, 6160 and 9750. In order to investigate the flow characteristics of the flow, a PIV system has been used. The system consists of an Ar-ion laser (5W, continuous) for visualizations of the flow field, a high speed camera (1024 x 992 pixel, 500fps) and a host computer. FFT analysis has been carried out using the measured velocity vectors obtained by PIV. The sampling position for the acquisition of the velocity vector is at X=1.52D and Y=-0.52D from the center position of the system as shown in Figure 2.

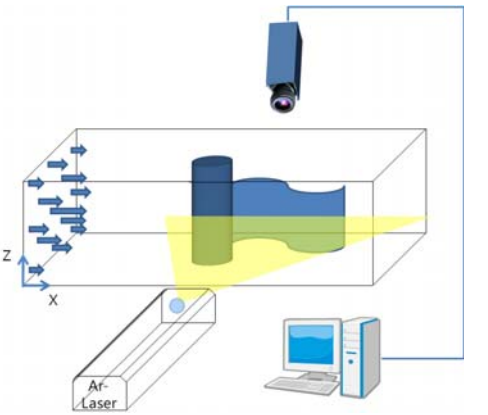


Figure 1: Experimental setup.

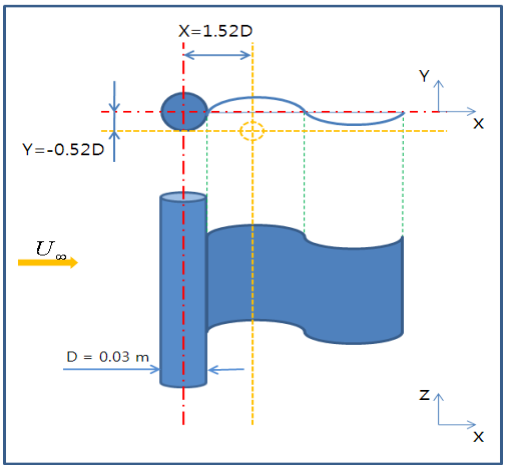


Figure 2: Coordinate relations for vector sampling.

2.1 FFT analyses with 2D-PIV Measurements

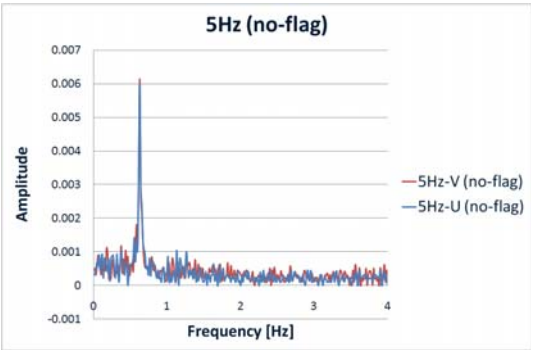
Table 1: Comparison with frequency f and f_{exp}.

Re_D	St	f u_∞ (=St*/D)	f_{exD} (no-flag)	f_{exD} (flag)
2730	0.21	0.6	0.63	0.64
6160	0.204	1.4	1.45	1.87
9750	0.199	2.2	2.22	2.18

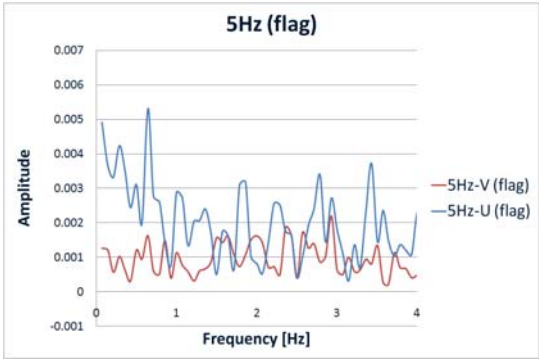
Table 1 shows the comparison results on the frequencies measured by Rousan and Wu[14], Williamson[15] and Rey[16] with our experimental results. The frequency f in the table has been calculated from the Re_D and St in their reports. f_{exp}

shows the frequency obtained in this experiment. Here, 'no-flag' means that the thin film has not been attached and 'flag' means the contrary. It can be seen that there is no significant difference in f values except at the Reynolds number Re_D=6160 when the thin film has been attached. This implies that the shedding frequency of vortex at this condition is being controlled by the thin film.

Figure 3 shows the FFT results at Re_D=2730 when the thin film is not attached (no-flag) and the attached (flag). The U-components at the case of having the flag show different profiles from those at the case of without the flag. That is, there is no significant frequency in V-component when the flag has been attached.

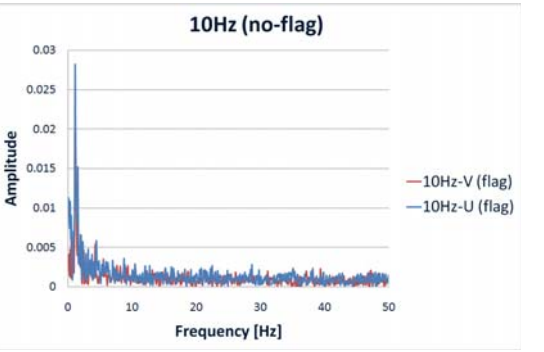


(a) without the thin film

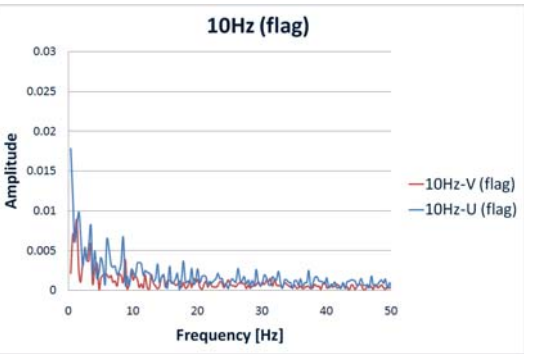


(b) with the thin film

Figure 3: FFT analysis results on the PIV data at Re_D=2730.



(a) without the thin film



(b) with the thin film

Figure 4: FFT analysis results on the PIV data at Re_D=6160.

This means that the flag controls the vortices at the downstream of the wake. Further, the frequency of the u-components shows smooth profiles. This implies that the flag plays a role of suppressing the high frequencies of the vortices.

Figure 4 shows the FFT results at Re_D=6160 for the two cases without the flag and with the flag, too. There is no significant difference in V-components between the two cases. But, the amplitude of the U-component in the case of having flag has been significantly reduced than the case of no-flag. On top of it, the frequency itself has been increased higher than in the case of no-flag. This implies that the flag plays a significant role in controlling the vortices shed from

the cylinder at this Re_D=6160. The fact that the dominant frequency at the case of having the flag has been shifted to higher one indicates that the vortices generated behind the cylinder would have been broken due to the flag's motion. This phenomenon can be explained by Figure 5. In Figure 5, the red colored point show the location of data sampling. This figures show that the flag's state and the flow around it. With time increasing, the flag is going downward toward the red point. This means that the curved flag plays as an obstacle against the vortices coming from upstream, and eventually these vortices become broken due to this convex surface(see at T=+0.49sec in Figure 6, circle area).

Figure 6 shows the FFT results at ReD=9750 for the two cases. The amplitude of V-component in the case of having flag has been largely reduced than in the case of no-flag. The amplitude of U-component has been also reduced than that of the case in no-flag. However, there is no difference in the dominant frequencies between the two cases.

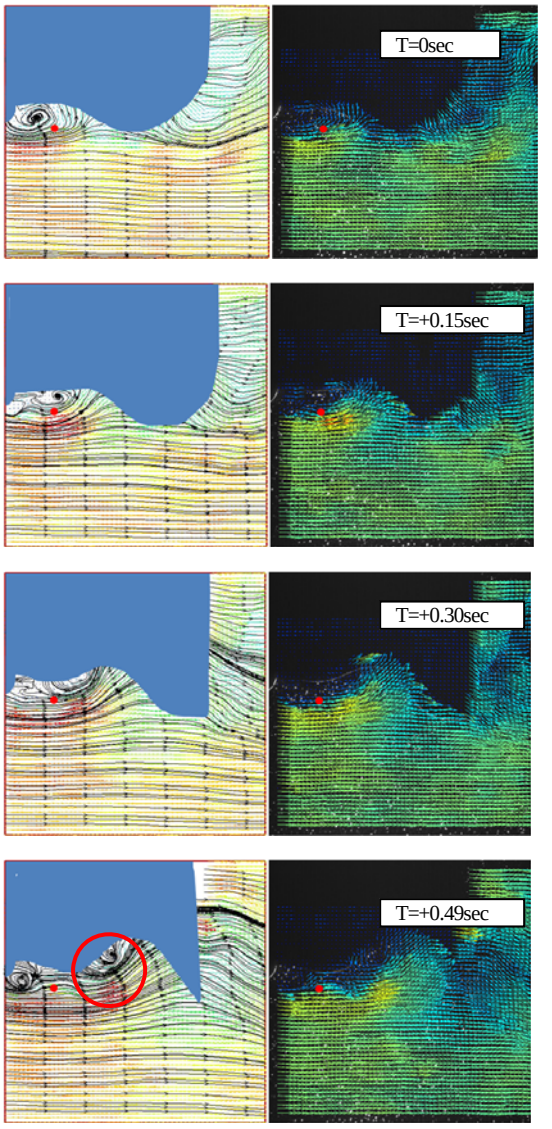
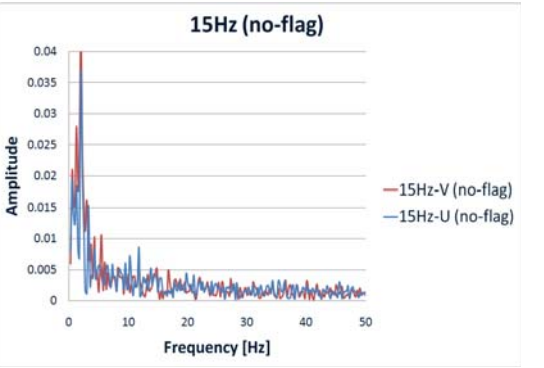
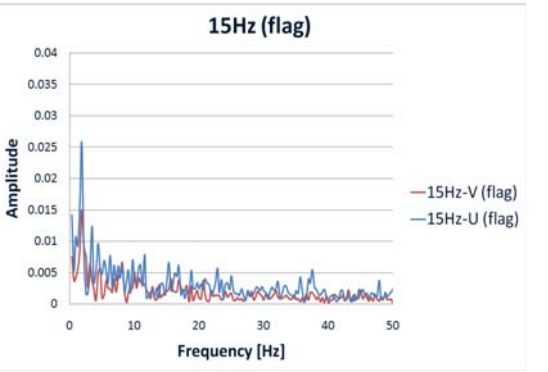


Figure 5: Instantaneous vector fields with the thin film.



(a) without the thin film



(b) with the thin film

Figure 6: FFT analysis results on the PIV data at Re_D=9750.

2.2 Investigation of Flow structures with Volumetric PTV Measurements

In order to investigate the role of vortices in three-dimensional, a new volumetric measurement technique has been constructed. Figure 7 shows an experimental setup for this. Four cameras (1024 x 992 pixel, 500fps) were used for capturing instantaneous flow motions. Small particles (d=0.1mm) were used as tracers for PTV (particle tracking velocimetry). The Reynolds number for this test is 4800. For flow visualizations, the same Ar-ion laser (5W, continuous) used in the 2D-PIV in the previous section was used. Since image data from the four cameras are quite big, two host computers were used, and they were synchronized by a house made control system. In order to get the three-dimensional motion of those particle seeded in the channel, 3D-PTV algorithm[17] developed by the author has been revised. Generally, a process called 'camera calibration' should be carried out for the four cameras in advance before using them as the sensors for image capturing. Detailed calibration method is well explained in the reference[17].

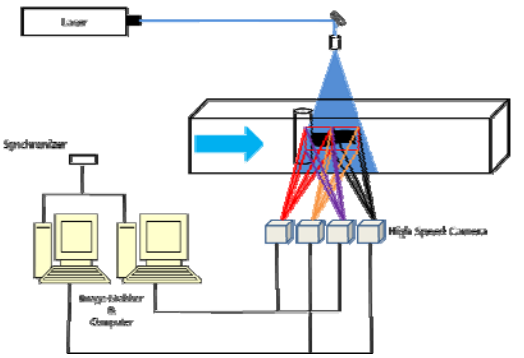


Figure 7: Experimental setup for Volumetric PTV measurements.

2.2.1 Measurement Principle

Figure 8 shows the overall tracking procedure of the Volumetric PTV. Vector tracking algorithm is made as follows. (1) Obtain the 2-dimensional vectors for each camera within a certain displacement.

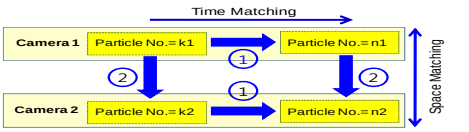


Figure 8: Overall procedure for vector acquisitions.

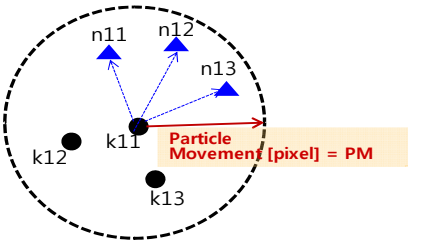


Figure 9: Definition of particle movement [PM].

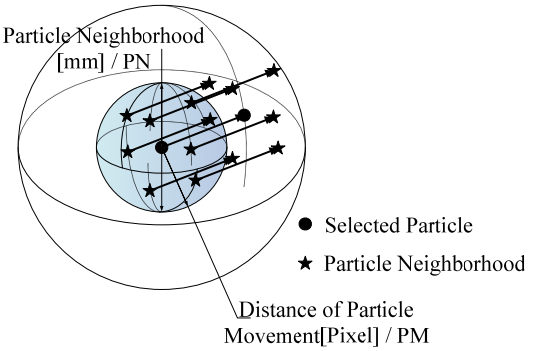


Figure 10: Definition of particle neighbourhood [PN].

Here, PM(particle movement) has been set to a certain pixel value according to the flow speed. This procedure is called as time matching. (2) Find candidate of particle pairs on the image of camera 2. Here, Epipolar line has been used to find the candidate particles on the image of the camera 2 and to save calculation time. For the particle 'n1' and 'n2', the same procedure for finding the candidates is made. Once the candidate (k2) of the particle image of the camera 2 for the initial point (k1) are found, the terminal point of

the 2D vector is automatically decided since the 2D vectors had been already obtained. If the candidate for particle 'n1' is found within the Epipolar search area, the particle set of (k1, n1, k2, n2) is sorted into the candidate group. (3) For the whole particles in the images of the camera 1 and the camera 2(Figure 9), the candidate group database is constructed. (4) For the candidate group database, a particle neighborhood value [PN] is set to a certain value [mm]. Within this PN (Figure 10), a vector fitness [VF] is calculated using Eq. (1). u_i indicates the whole vectors within PN except the target vector itself and u_o represents the mean value of the whole vectors within PN except the target vector itself. (5) Lastly, a sigmoid-like hybrid fitness function (Figure 11) defined as equation Eq. (2) is used for sorting out the most probable candidate from the candidate group database. Using PN and PM values implies to find a coherency of the neighborhood particles. It has been shown that the optimal parameters are PM=8 pixel, PN=5mm and VF=0.3. More detailed explanation for the measurement algorithm is to be referred to the paper done by Doh et al. [18]. For the camera calibration for three-dimensional reconstruction is to be referred to the reference [17].

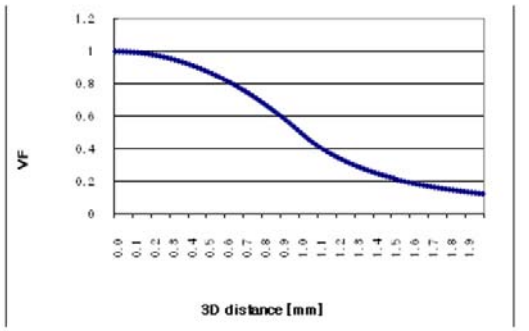


Figure 11: Hybrid fitness function used for sorting the most probable candidate from the candidate group database.

$$Vector\ Fitness[VF]= \frac{\sum |u_i - u_o|}{\sum u_i} \quad (1)$$

$$f(x) = \begin{cases} -0.5x^2 + 1, & at \quad (0 \le x \le 1) \\ 0.5x^{-2}, & at \quad (x \ge 1) \end{cases} \quad (2)$$

2.2.2 Measurement Results

Figure 12 shows the measurement volume behind the cylinder wake. The front volume has been measured by the first camera and the third camera from the left in Figure 7. And the rear volume has been measured by the second camera and the fourth camera. The whole volume size is 150mm(L) x 60mm(H) x 15mm(T).

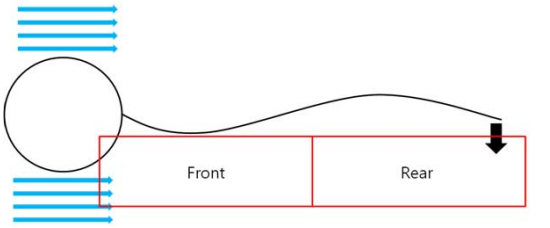
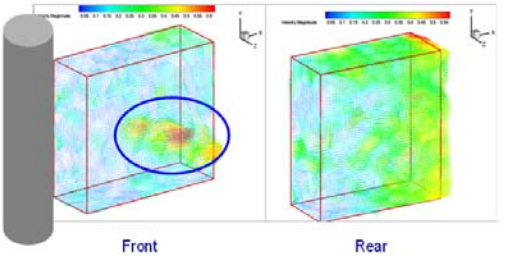
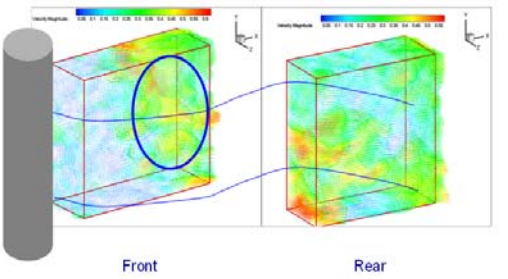


Figure 12: Measurement volume for the Volumetric PTV.

Figure 13(a) shows instantaneous velocity vector distribution in volume at time T=T1 and Figure 13(b) shows the one at T=T2. The time difference between the two results is 1/200sec. In Figure 13(a), there is a strong local vortex at the region (see the ellipse colored blue) at the boundary between the front and the rear volumes. But, this vortical structures at the time T=T1 + 1/200 [sec] spread over the whole spanwise direction. This implies that the thin film controls the vortices shed from the cylinder widely over the whole region. This might have been occurred by the vortices' merging or breaking. Figure 14 (a) and Figure 14 (b) show the spatial distributions of the three-dimensional velocity vector at five cross sections along the spanwise. Cleary, the local vortical structures at

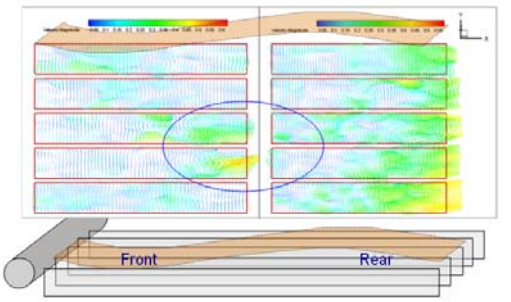


(a) T=T1

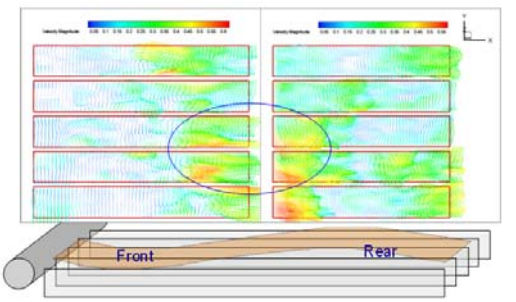


(b) T=T1 + 1/200 [sec]

Figure 13: Volumetric velocity vector distribution obtained by the Volumetric PTV.



(a) T=T1



(b) T=T1 + 1/200 [sec]

Figure 14: Cross sectional distribution of the three-dimensional velocity vectors of Figure 13.

time T1 are seen at the center section, while these structures become spread over the whole spanwise region. This implies that the momentum affecting the cylinder is controlled by these vortices, eventually implying the cylinder's stabilizations.

3. Conclusions

The purpose of the study is to investigate the role of vortices controlled by a thin film which has been attached to the rear part of a circular cylinder. To do this, two measurements have been carried out, one with 2D-PIV system and the other one with a newly constructed volumetric PTV system. Followings are several key results from the experiments.

There are big changes in U-component when the flag has been attached to the cylinder. The amplitudes of U-component were always reduced at all Reynolds numbers, and the reduction degree of the amplitude of U-component at Re_D=6160 was larger than any other cases. Further, the dominant frequency at at Re_D=6160 became increased while those at other Reynolds numbers showed no changes with that in the case of no-flag.

Especially, U-component at Re_D=2730 became smoothed, which can not be seen at other Reynolds numbers. This implies that the vortices behind the cylinder at this Reynolds number become merged. On the contrary, the most dominant frequency of U-component at Re_D=6160 with the flag became shifted to a higher frequency region. This implies that the vortices shed from the cylinder become broken state but not the merging state at Re_D=2730.

For V-components, the frequency at Re_D=2730 became smoothed while other two cases were not. And the amplitude of V-component Re_D=6160 and Re_D=9750 became largely suppressed by the flag, which implies that a possible oscillation made by the vortices around the cylinder become reduced or

stable. This implies that the thin film plays a role of stabilizations for the cylinder.

Acknowledgments

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