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PIV measurements of near wake behind a sinusoidal cylinder

W. Zhang*, Daichin** and S. J. Lee***

Abstract

The near wake behind a sinusoidal cylinder at Re=5200 has been investigated using DPIV system. The velocity fields, streamlines and vorticity contours of the mean flow were compared at the nodal, saddle and middle planes with those of a right circular cylinder. For the sinusoidal cylinder, the vortex core moves downstream and the vortex formation region is expanded in streamwise direction while suppressed in transverse direction at the nodal plane. At the saddle and the middle plane the vortex spread in both streamwise and transverse directions, forming the maximum vortex region at the saddle plane.

Key words: Sinusoidal Cylinder, Near Wake, PIV

1. Introduction

The flow around a smooth circular cylinder has been well-studied by many researchers, as can be seen from the comprehensive reviews of Williamson (1996) and Rockwell (2001). PIV system has been employed to investigate flow structure such as streamlines and vorticity around a circular cylinder (Lin et al. 1996; Chyu & Rockwell 1996). Recently, cylinders with wavy geometry are receiving greater interest to reduce drag force and decrease vortex-induced-vibration (VIV) by introducing some form of three-dimensional disturbance to the normally two-dimensional bluff body. For instance, Ahmed & Khan (1993) examined the flow behind a wavy-cylinder using flow visualization, total pressure surveys and LDV measurements. They mentioned about the topology of the boundary layer separation line and its relationship with the three-dimensional development of the turbulent structures of the wake. Lam et al. (2003) measured three velocity components of the near wake of a wavy cylinder using LDV system. They found that the drag reduction and suppression of vibration was attributed to the long vortex formation length of the wavy cylinder. Owen and Bearman (2001) found the suppression of vortex shedding and drag reduction up to 47% for the cylinder with a sinuous axis. However, there is little detailed investigation on modification of flow structure of the near wake behind a wavy cylinder.

In this study, we investigated the flow field of the near wake behind a sinusoidal cylinder using DPIV measurements. For comparison, a smooth circular cylinder case at the same Reynolds number was also investigated. Discussions are focused on the ensemble-averaged mean flow field and the mechanism of the cross-flow behind a sinusoidal cylinder.

2. Experimental apparatus and methods

The present experiments were carried out in a recirculation water channel. The free-stream velocity U_0 was 0.38m/s and the corresponding Reynolds number based on U_0 and the smooth cylinder diameter 20mm was about 5200. The geometry of the sinusoidal cylinder tested can be described by the following equation:

$$D = D_m + A\sin(2\pi \cdot z / \lambda)$$

Where D_m=20 mm, A / D_m=0.2 and λ / D_m=2.0.

The axial location with maximum diameter is called as "node" and that with minimum diameter is termed as "saddle". The terminology and schematics of the sinusoidal cylinder are shown in Fig. 1. The sinusoidal cylinder installed perpendicular to free stream is about 300mm long and it spans the width of the water channel.

Vestosint® 1118 particles having a mean diameter of 37 μm were seeded in the flow, which were illuminated by a thin light sheet formed from a dual-head 25 mJ/pulse Nd:YAG laser. To avoid light scattering, the cylinder surface was coated with black paint. Particle images were captured by a high-resolution CCD camera (2048×2048 pixels) at the frame rate of 4f/s. The laser and CCD camera were synchronized by a delay generator. The single-frame cross-correlation method was used to get instantaneous velocity field with interrogation window of 64× 64 pixels. The spatial distribution of turbulence statistics was ensemble averaged from 400 instantaneous velocity fields.

3. Mean flow field results

The mean velocity field and streamline distribution at three sagittal planes, namely the nodal, saddle and middle planes, are shown in Fig. 2. It can be seen that the size of vortices formed behind the cylinder shows significant difference. Compared with the vortex formation region X/D_m=1.0 for the smooth cylinder, in all measurement planes behind the sinusoidal cylinder the vortex formation region is elongated to between X/D_m=1.0 and X/D_m=2.0. Especially in the saddle plane, this length is nearly closed to X/D_m=2.0. In addition, velocity recovers almost at about X/D_m=3.0 behind the smooth cylinder, while for the cases of the sinusoidal cylinder, velocity recovery occurs at further downstream location. In the saddle plane, the velocity recovery is delayed largely up to X/D_m=5.0. This indicates

* Dept.of Mech.Eng., POSTECH, weizhang@postech.ac.kr
**Dept.of Mech.Eng., POSTECH, daichin@postech.ac.kr
***Dept.of Mech.Eng., POSTECH, sjlee@postech.ac.kr

that the vortices formed behind the sinusoidal cylinder elongated and velocity recovery is delayed, compared with the smooth cylinder. It is also important to note that the wake structure varies periodically along the spanwise direction.

The vorticity contours of the near wake behind the sinusoidal cylinder and smooth cylinder are compared in Fig.3. Two vortices shed from the sinusoidal cylinder are elongated toward the streamwise direction. The location of vortex core having the maximum vorticity value moves downstream. In the nodal plane, the vortex formation is expanded in streamwise direction while largely suppressed in transverse direction. However, in the saddle and middle planes the vortex expands along both streamwise and transverse directions. It should be also noticed that the size of vortex formation region reaches maximum in the saddle plane.

From these results, we can see that the flow structure in various cross flow planes has pronounced variation along the span of the sinusoidal cylinder. This confirms that the near wake behind the sinusoidal cylinder is typically three-dimensional and momentum exchange occurs in spanwise direction, greatly influencing on the flow characteristics.

4. Conclusion

The near wake behind a sinusoidal cylinder at Re=5200 was investigated experimentally. Mean velocity fields, streamlines and vorticity distribution are compared with those of a smooth cylinder. The near wake behind the sinusoidal cylinder is confirmed to be typically three-dimensional and shows significant spanwise variation of flow structures. Compared with a smooth cylinder, the vortex formation region expands in streamwise direction, particularly forming the maximum vortex region in the saddle plane. Further study on the near wake along the spanwise direction is needed to provide full three-dimensional flow structure.

Acknowledgements

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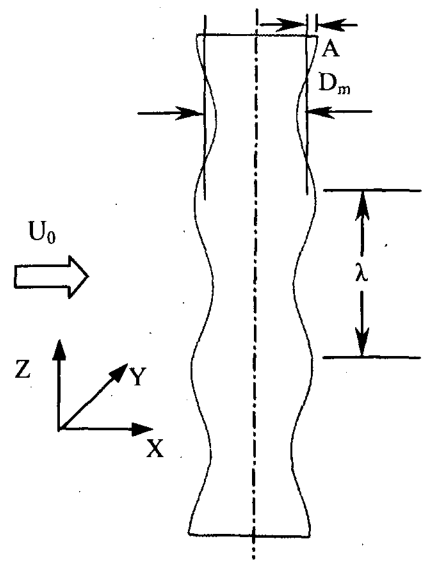
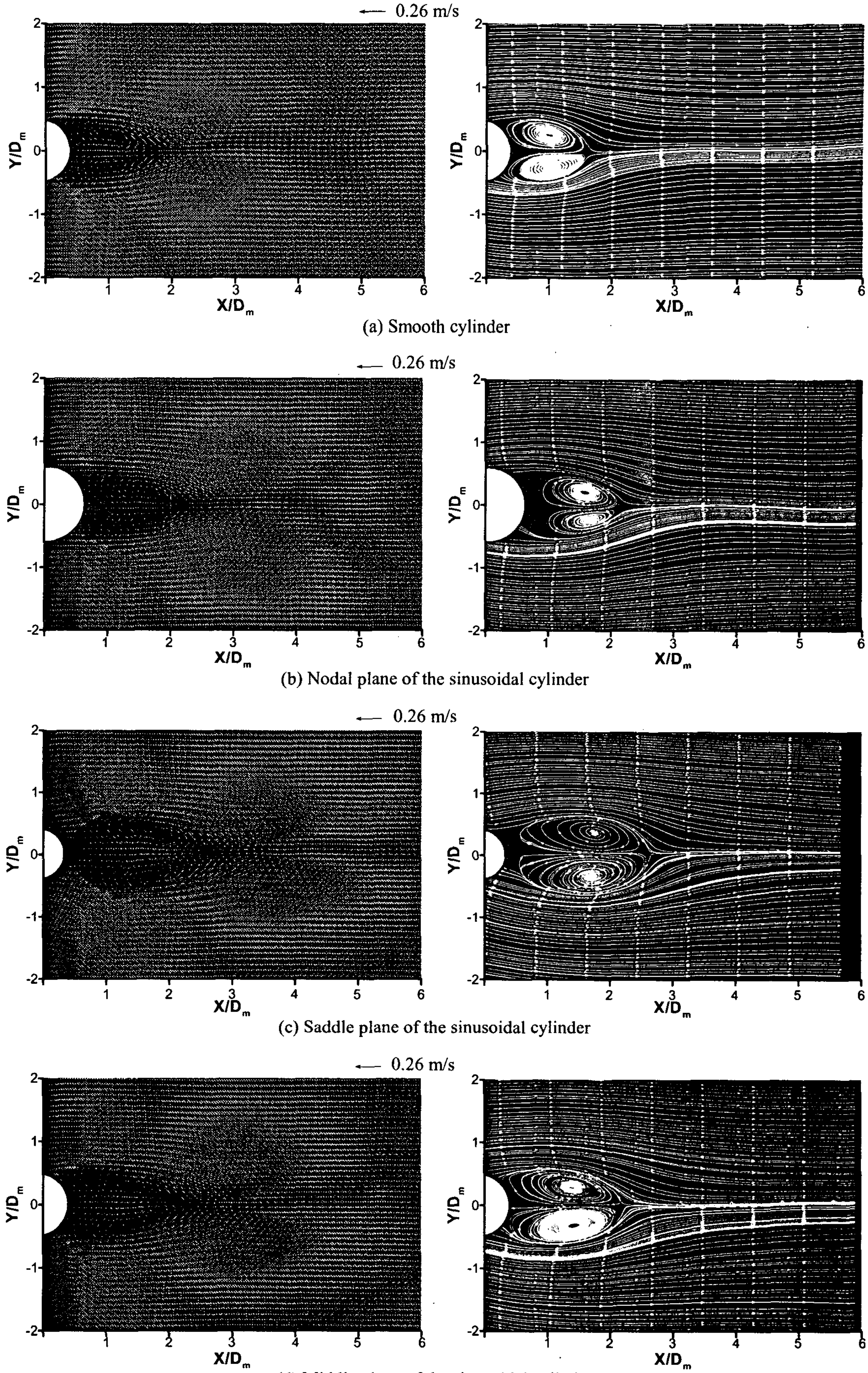


Fig.1. Schematics of the sinusoidal cylinder



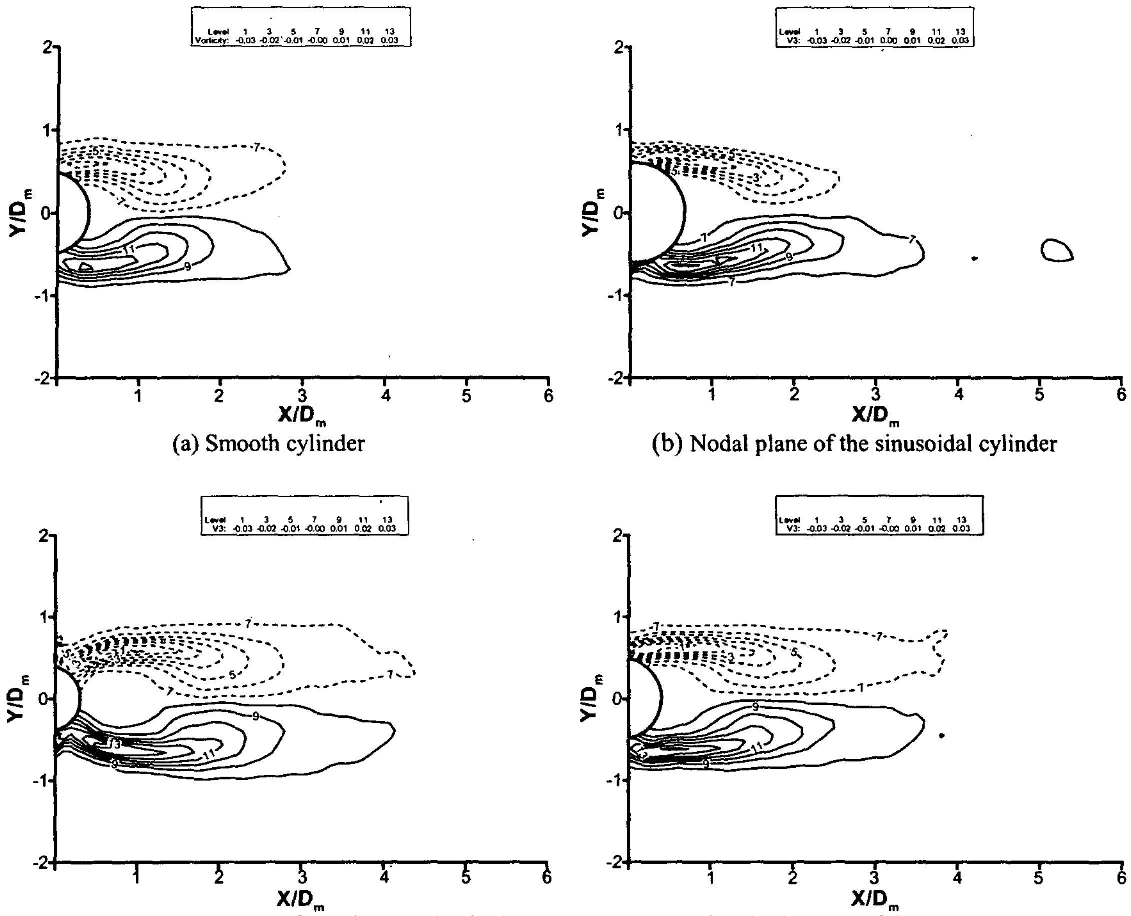
(a) Smooth cylinder

(b) Nodal plane of the sinusoidal cylinder

(c) Saddle plane of the sinusoidal cylinder

(d) Middle plane of the sinusoidal cylinder

Fig. 2. Velocity field and streamlines in sagittal planes



(a) Smooth cylinder

(b) Nodal plane of the sinusoidal cylinder

(c) Saddle plane of the sinusoidal cylinder

(d) Middle plane of the sinusoidal cylinder

Fig. 3. Camparison of vorticity contours