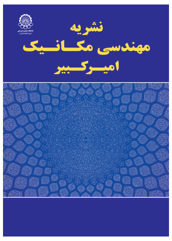

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Experimental Investigation of Flow Around a 3D Square Cylinder Using Five-hole Probe and Neural Networks Method

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ABSTRACT: In the present study, wake structure downstream a 3D square cylinder is investigated experimentally. Contours of mean velocity, total pressure, static pressure and vorticity are presented for the wake region. A five-hole probe is used for extracting required wake properties and determining the flow structure. A novel neural networks method is used for calibrating the five-hole probe. The calibration map obtained by this method is compared with the conventional linear and 5th order polynomial surface fit algorithms. Based on the statistical parameters of calibration data, it is concluded that the neural networks algorithm is more accurate and works faster than other methods. Finally, effect of cylinder's free end shape was investigated. Experimental results showed that by increasing the downstream distance from the cylinder, tip and base vortices are weakened, the height of wake region decreases while its width increases simultaneously. Downwash flow from free end of cylinder and upwash flow from the bottom wall decrease the width of the wake region near top and bottom of cylinder in comparison with the midheight region.

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1- Introduction

Clarification of flow behavior and its structure in wake of long cylinders have been focus of many research works. In addition, scientific aspect of physics of flow around finite square cylinder and its differences with the flow structure around two dimensional long cylinders require especial attention to this geometry. Flow around finite size cylinders has many applications in engineering and science such as predicting movement and settlement of pollutant particles nearby skyscrapers and high buildings, flow behavior around stacks, wind turbine, pipes of heat exchangers, cables, and heat transfer in electronic circuit boards. Formation of longitudinal and spanwise vortices influences flow field in rear of the finite square cylinder. Accurate experimental flow pattern prediction around and in the wake region of a finite size cylinders is the focus of current researches due to its interesting features and wide variety of applications. Moreover, the effect of free end geometry on the wake properties and flow structure has not been reported yet. Many instruments are normally employed to capture the flow features around cylinders including laser Doppler anemometer, PIV measurements, hot wire anemometry and seven-hole pressure probe. Vortex shedding from a finite cylinder in a cross flow extends up to a short distance from the tip [1]. Two vortical flows form in the back of the cylinder by rolling up spanwise vortices toward upstream of cylinder from its two sides. These vortices are known as tip vortex and base vortex. The tip vortex zone increases by increasing distance from the cylinder. Many researchers also observed the base vortices which originate from the upwash flow and have reverse rotating comparing to the tip vortices [1]. Krajnovic and Davidson [2] used Large Eddy Simulation (LES) to figure out flow structure around a finite circular cylinder. The wake formed is similar to Karman vortex shedding behind a two-dimensional cylinder, as the upwash and downwash flows are weakened in the zone close to midheight of the cylinder.

In this research, flow properties in the wake region of a finite size square cylinder is experimentally studied by employing a five-hole probe. A novel method of neural networks is used to calibrate the five-hole probe instrument. It is attempted to show that the time-averaged flows comprise of streamwise and spanwise vortices. Many researchers have investigated the wake properties of finite square cylinders, however, few of them used five-hole probe to figure out properties of flow field. The aim of the present study is to elaborate the wake properties and its features for flow past a finite square cylinder using a five-hole probe. Finally, the effect of cylinder's free end shape on the flow pattern in the wake region is investigated, as it has not been reported yet in the recent investigations.

2- Methodology

Five-hole probe is an instrument for measuring flow mean velocity, velocity components, total and static pressure in each point of flow. This probe is accurate for measuring angle of flow at probe location in the range of ±25 degrees for yaw and pitch angles.

2- 1- Artificial Neural Networks (ANN)

Artificial neural networks are capable to learn a pattern from experience and improve it. The significant privileges of neural networks are the capability of processing a large

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amount of data and also its ability to predict the model from training data.

Radial Basis Function (RBF) is the one of most popular ANNs which enable proper generalization, amelioration of input perturbations and ability of online learning. RBF networks are neural networks methods which are based on localize basis functions and iterative function approximation. In calibration process, neural network is applied for prediction of the parameters twice. Initially, the five-hole probe is installed within the wind tunnel and its pitch and yaw angles are varied and the static and total pressure coefficients as well as pitch and yaw pressure coefficients are calculated. At the first implementation of neural network, the pitch and yaw pressure coefficients obtained in the wind tunnel calibration are selected as the input parameters for learning the neural network, introducing the pitch and yaw angles from calibration in the wind tunnel as the output parameters. After proper learning neural network, the obtained pitch coefficients and yaw coefficients from measuring data in the experiment are fed into the neural network. The predicted outputs are the pitch and yaw angles of the flow that passed the five-hole probe. At the second step, pitch and yaw angles of calibration at the wind tunnel are fed as the input parameters and the total and static pressure coefficients will be as output parameters of learning neural network. After suitable learning neural network, the calculated pitch and yaw angles of first step are imported to the neural network. The generated outputs are the total and static pressure coefficients of flow that passed the five-hole probe. Finally, from the measured total and static pressure coefficients, three components of the local velocity vectors can be calculated.

3- Results and Discussion

The vorticity contours calculated by measuring the three velocity components have been displayed at some *Y-Z* (*X*-constant) planes for $0.0<Y/D<7$ and $-3.5<Z/D<3.5$. The chosen *X*-constant planes are *X/D*=5, 7.5,10. It is seen from Fig. 1 that near the free end of the cylinder, two counter-rotating vortices are formed that are known as tip vortices. Moreover, two weaker counter-rotating vortices are also formed under midheight of the cylinder close to the ground plane which are known as base vortices (Fig. 1 (a-c)). The base vortices and tip vortices are formed by rotating spanwise vortex shedding phenomenon toward downstream of the cylinder. The tip vortices encounter with free shear flow from top of the cylinder causing a downwash flow. As it is obvious in Fig. 1 (a-c), the tip and base vortices strength are decreased with increasing distance from the cylinder.

Fig. 2 represents non-dimensional total pressure contours in *X*-constant planes for flat and elliptical free end square cylinders. It is seen that the wake height and width is considerably reduced by changing the cylinder tip from flat tip to the elliptical one. Moreover, the minimum total pressure is also reduced within the wake of the elliptical free end cylinder in comparison with the cylinder with the flat free end.

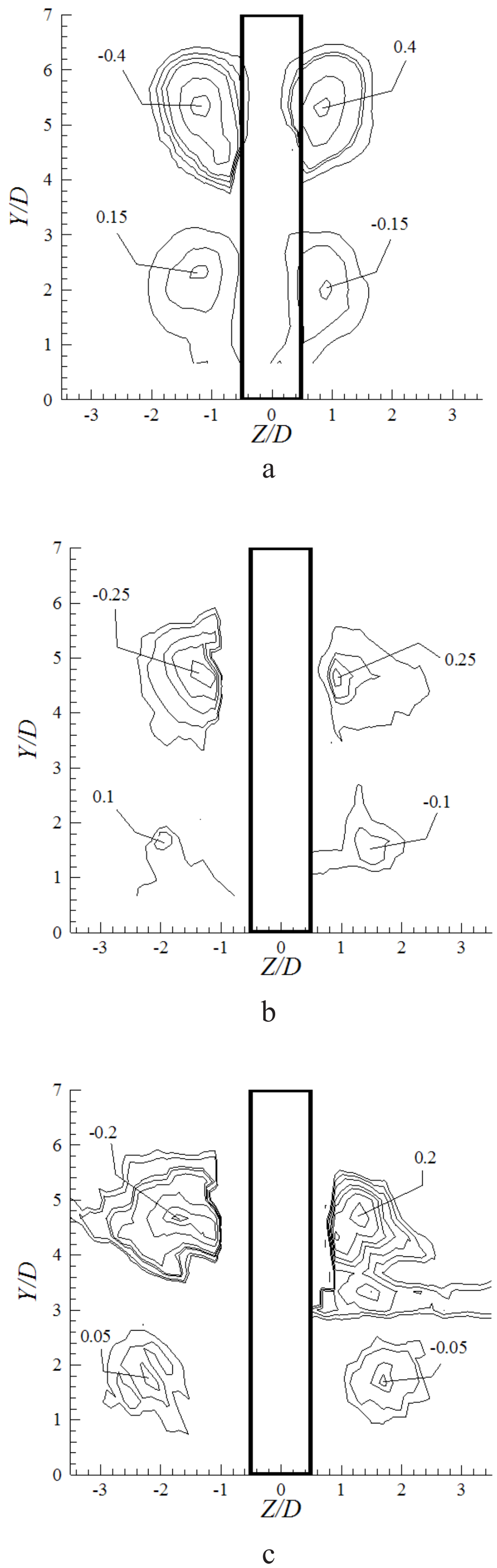
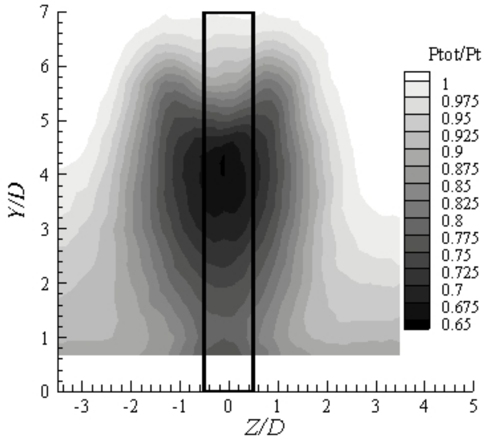
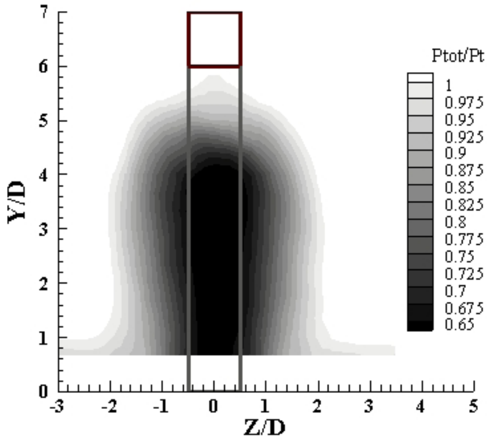


Figure 1. Tip vortices and base vortices in ω_x contours (a) *X/D*=5 (b) *X/D*=7.5 (c) *X/D*=10 ;vorticity contour increment 0.05, minimum vorticity contour -0.4 and maximum vorticity contour + 0.4



a



b

Figure 2. Non-dimensional total pressure at *X/D*=5: (a) flat free end; (b) elliptical free end

4- Conclusions

Flow structure and the wake properties of a surface-mounted finite cylinder have been experimentally investigated by employing a five-hole probe. The flow structure around free end of a 3D cylinder is markedly different from that of a 2D cylinder. The 3D wake structure seems to be induced from an interaction between the ambient fluids entrained from both sides of the cylinder and the separated shear flow descending from the free end. The size of the wake bubble formed above the flat-tip cylinder is largely reduced by shaping of the tip geometry to the elliptical shape. The shear layer separating from the plain tip descends faster as the flow proceeds toward the downstream, compared to the other tips tested. A counter-rotating longitudinal vortex pair is formed in the wake region just behind the cylinder tip. These two longitudinal vortices have almost the same size and are nearly symmetric with respect to the central plane of the wake. Moreover, two weaker counter-rotating vortices are also formed under midheight of the cylinder close to the ground plane.

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