Experimental Investigation of the Frequency Spectra of Vortex Shedding from a Triangular Bluff Body at Different Flow Angles

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ABSTRACT

The base of the vortex flowmeter is the linear relationship $Q = Kf$ (K is a constant and f is vortex shedding frequency). Therefore, the accuracy of the flow meter is only a function of the vortex shedding frequency measurement accuracy. To determine the frequency measurement accuracy, it is necessary to investigate its frequency spectrum. In this research, vortex shedding and its frequency spectrum downstream of an equilateral triangular model of 10 mm side have been investigated experimentally in a closed-type wind tunnel using a hot-wire anemometer. The vortex shedding frequency spectra were fitted using the normal Gauss distribution, and based on the expected confidence level, the accuracy of the frequency measurement was evaluated and its changes were quantified using the standard deviation of the normal distribution. Results show for Re >1200, the Strouhal number variation is independent of the Re number, and it is only a function of the flow angle. Also, for a 95% confidence level, the maximum frequency measurement error for the triangular model is 1.53% for $\alpha = 60°$ and 2.46% for $\alpha = 0°$. The standard deviation of the frequency spectra has an increasing trend streamwise, however, it is constant spanwise outside the wake region. When the flow angle is in the range of $18° < \alpha < 23°$, the measurement error increases to about 9%.

KEYWORDS

Hot-wire anemometer, Strouhal number, Triangular model, Vortex flowmeter, Vortex shedding frequency spectrum

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1. Introduction

Vortex shedding from bluff bodies, which causes the vibration of the body or the bodies in its downstream, is an important fluid flow phenomenon. This phenomenon is the basis of the working of vortex shedding flowmeters [1].

The Strouhal number ($St = {}^{fd}\!/_{U}$) is used to study the vortex shedding phenomenon, where d is the bluff body characteristic length, U is the free stream velocity and f is the vortex shedding frequency. Also, the frequency spectrum near the vortex shedding frequency should be studied. Knowing the vortex shedding frequency spectrum, the uncertainty in measuring the vortex shedding frequency can be determined.

Various researchers have investigated the vortex shedding from bluff bodies, especially the triangle shape. The reported research is mainly numerical for $\mathrm{Re} < 200$ and experimental and numerical for Re>200. Kumar and Dalal [2] performed a numerical investigation of the vortex shedding from an equilateral triangle with the triangle vertex facing the flow for $80 < \mathrm{Re} < 200$ and blockage ratios of 0.083 to 0.33. They found that the critical Reynolds increases with an increase in blockage ratio: the critical Reynolds number is about 40 at a blockage ratio of 0.083, and it is about 64 at a blockage ratio of 0.33. Derakhshandeh and Mahboob [3] studied numerically the flow downstream of an equilateral triangle for $\mathrm{Re} < 200$. They showed that the critical Reynolds number for a triangle model with the triangle vertex facing the flow is about 38.04. Luo et al. [4] studied the flow downstream of the triangle, square, and trapezoidal bluff models using wind and water tunnels. Their results indicate that the Strouhal number depends on the flow angle related to the model, reaching its maximum at a flow angle of 22°.

In experimental work, Ardekani et al. [5] investigated the vortex shedding from a triangular model for use in a vortex flowmeter and/or for calibration of hot-wire anemometer at low velocities. They used a wind tunnel and a hot-wire probe to study the airflow distribution, flow turbulence, and vortex shedding from an equilateral triangular model of 10 mm side. They showed that the variation of the Strouhal number with the flow angle is significant. They also showed that the flow angle has negligible effects on the velocity distribution and the flow turbulence intensity.

This paper presents the experimental study of the vortex shedding and its frequency spectrum from a triangular model at different flow angles and Reynolds numbers. Also, the vortex shedding downstream of the model, and its frequency spectrum streamwise and spanwise, were studied.

2. Experimental Method

All the experiments were done using the wind tunnel at the Mechanical Engineering Department, Iranian Research Organization for Science and Technology (IROST). A single-sensor hot-wire probe was used to measure the vortex shedding frequency. A traverse mechanism was used to place the probe at any desired position in the wind tunnel. Data was acquired and transferred to a computer for further processing using an A/D card. The two-dimensional experimental model was an equilateral triangle of 10 mm side and 150 mm length. A rotating mechanism was used to rotate the model through different angles. In this research, the flow downstream of the model was studied for different flow angles and $1200 < \mathrm{Re} < 15000$.

3. Results and Discussion

Results show that for Re>1200, the Strouhal number is independent of the Reynolds number. However, the Strouhal number varies with the flow angle (α). Also, the minimum Strouhal number is 0.135 at α = 60°, and the maximum value is 0.23 for $\alpha = 20°, 100°$. Additionally, the standard deviation at $\alpha = 60°$ equals 0.765, which is lower than other angles. Hence, the placement of the triangular model at $\alpha = 60°$ is more suitable for flowmetry applications.

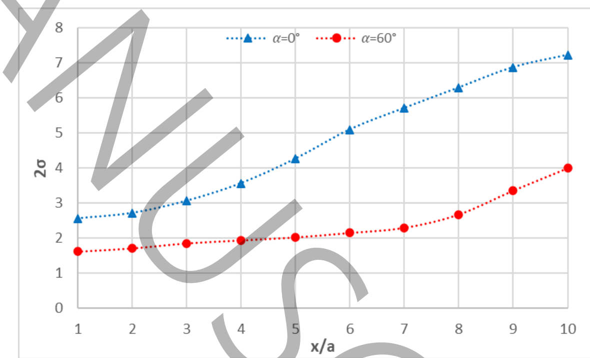

Figure 1: Value of 2σ downstream of the model in the longitudinal direction for 0° and 60° flow angles and $Re = 6700$

According figure 1 the vortex shedding frequency amplitude is small near the model and it initially increases with distance from the model and then decreases with further distance. The results show that with an increase in distance in the longitudinal direction the standard deviation increases. Therefore, the probe should be placed at a closer longitudinal distance from the model to reduce the vortex frequency measurement error.

Other results show that at $\frac{x}{a} = 2$, and in the range $-0.35 < \frac{y}{a} < 0.35$, the vortex shedding does not occur. Also, the amplitude of the vortex shedding frequency is higher in the wake region and it reduces with distance from this region and approaches zero. There are no appreciable variations at $-3 < \frac{y}{a} < -0.35$ and $0.35 < \frac{y}{a} < 3$.(see fig 2)

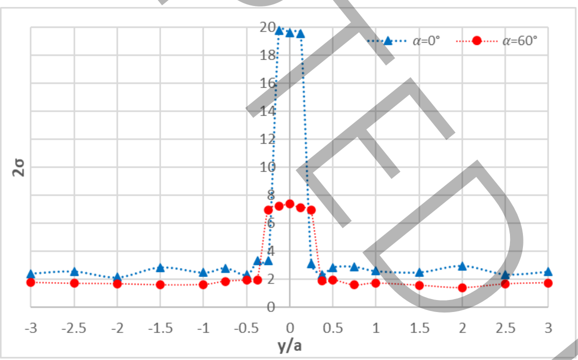

Figure 2: Value of 2σ downstream of the model in the lateral direction for 0°and 60° flow angles and $Re = 6700$

The last result shows that the standard deviation value and the amplitude of the vortex shedding frequency are different at different flow angles. For $\alpha = 20°$to $23°$, the 2σ value equals 9%. Therefore, the placement of the model at these angles is not suitable for vortex flowmetry.

4. Conclusions

The following conclusions can be mentioned:

Considering a 95% confidence level, at $\alpha = 60°$, the maximum error in measuring vortex shedding frequency is 1.53%, and for $\alpha = 0°$ the error equals 2.46%.

The wake region downstream of the model affects the standard deviation of the spectrum of the vortex shedding frequency. With an increase from the model along the longitudinal direction, up to $\frac{x}{a} = 4$, the standard deviation shows no significant variation, showing an increase thereafter.

The variation of the standard deviation of the vortex shedding frequency spectrum is negligible in the lateral direction (perpendicular to the flow direction). However, the variations increase in the separation region.

5. REFERENCES

[1] M. Ardekani, Air flow measurement in experimental fluid mechanics, Iranian Research Organization on Science and Technology, Iran, (2014). (in persian)

[2] A. Kumar De, A. Dalal, Numerical study of laminar forced convection fluid flow and heat transfer from a triangular cylinder placed in a channel, Journal of Heat transfer, 129(5) (2007).646-656.

[3] J. Derakhshandeh, M.M. Alam, A review of bluff body wakes, Ocean Engineering, 182 (2019) 475-488.

[4] S. Luo, M.G. Yazdani, Y. Chew, T. Lee, Effects of incidence and afterbody shape on flow past bluff cylinders, Journal of wind engineering and industrial aerodynamics, 53(3) (1994) 375-399.

[5] E. Ardekani, A. Teymourtash, M.A. Ardakani, Experimental Investigation on Flow Downstream of a Triangular Bluff Body at Different Angles, Amirkabir Journal of Mechanical Engineering, 53(1 (Special Issue)) (2021) 427-436. (in persian)