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Secondary Flow Phenomenon at Elbow Ducting of The Closed-Circuit Subsonic Wind Tunnel: An Experimental Study

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Abstract. The installation of elbow ducting in closed-loop wind tunnel installation will cause a pressure drop. Pressure drop was caused by flow separation and secondary flow phenomenon in the elbow ducting. The test section used in this experimental study was an octagonal elbow 90º with radius ratio (r_m/D_h) = 0.6. Diameter hydraulic (D_h) elbow of 806 mm. In this study, the Reynolds number is measured based on the free flow velocity (U_∞) inlet section, that is $Re_{Dh} = 4.63x10^5$. The experimental results showed the pressure drop is $\Delta C_p = 1.46$ for $Re = 4.63x10^5$. This difference in pressure value between the outer and inner (ΔC_p) of the elbow ducting was caused by secondary flow. The secondary flow was observed through a horizontal velocity profile where at $x_i/D_h = 1.35$, fluid flow was accelerated on the inner wall and decelerated on the outer wall of the ducting elbow. Then, at $x_i/D_h = 1.63$ to $x_i/D_h = 2.01$, there are gradual shifts of the velocity profile where the fluid flow is accelerated toward the outer wall.

Keyword: elbow ducting, closed-loop wind tunnel, pressure drop, secondary flow.

1. Introduction

The first wind tunnel was created in 1871 by Francis Wenham and John Browning with the aim of simulating flight in the atmosphere. Then the wind tunnel was used as an experimental research tool to analyse the effect of the airflow moving around the objects.

Nowadays, wind tunnel technology is developing very rapidly with various types depending on experimental needs. There are two types of wind tunnel design, that are open-circuit and closed-circuit. The open-circuit type has components such as fans, test sections, diffusers, and contractions. The closed-circuit type has several components such as a nozzle, test section, diffuser, fan, corner, honeycomb, and settling chambers [1]. In terms of efficiency, closed-circuit wind tunnels have higher efficiency than open-circuit due to the open-circuit design requires a large power consumption. In a closed-circuit design, airflow will continue to circulate throughout the closed channel. Apart from efficiency consideration, another advantage of the closed-circuit design is easy to control airflow quality through corner turning (elbow ducting) and screens (honeycomb) [2].

In a closed-circuit wind tunnel design, there is a corner turning or 90 elbows ducting that is used to deflect the airflow so that it continues to circulate in the ducts of the wind tunnel. Pressure drops are due to changes in a flow direction like fluid flow in elbows. These pressure drops are mainly caused by secondary flow (see Figure 1) and flow separation phenomena in elbow ducting [3, 4, 5, 6, 7]. The elbow ducting in the wind tunnel installation causes the pressure drop as well. Four elbows in closed-circuit wind tunnels contribute more than 50% of the total pressure drop that occurred [8].

This study intends to observe the secondary flow phenomenon experimentally so that the best way to reduce secondary flow can be provided in the future. Thus, the performance of closed-circuit wind tunnels can be utilized optimally.

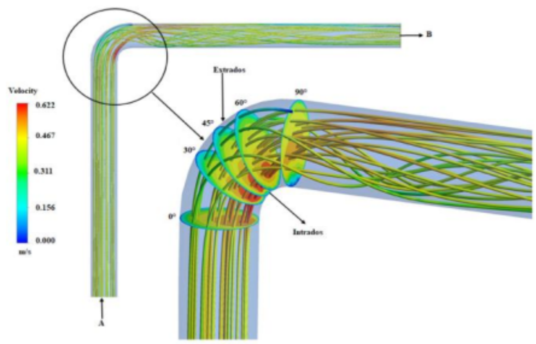
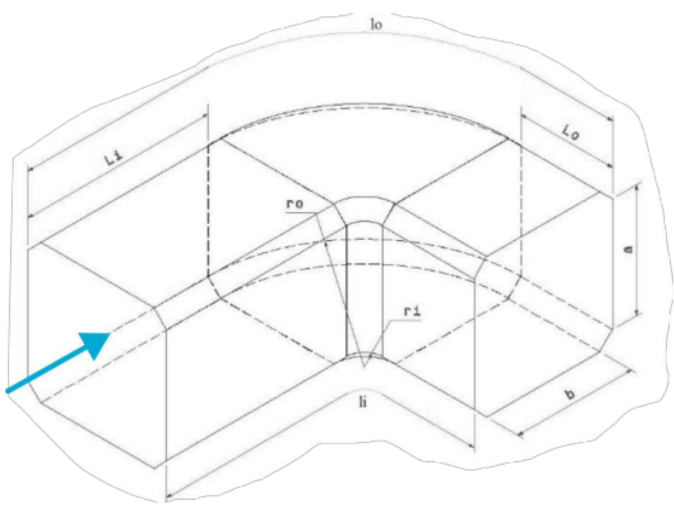


Figure1. Secondary flow phenomenon in circular elbow: a velocity streamline [9]

2. Research Method

The closed-circuit wind tunnel installation has dimensions length of 6490 mm, a width of 2250 mm, and a height of 770 mm. While specifications and dimensions of the elbow ducting are shown in Figure 2.



Material: acrylic and plywood
L_i =1000 mm
L_o = 510 mm
r_i = 100 mm
r_o = 870 mm
l_i = 1666 mm
l_o = 2876 mm
a = b = 770 mm
D_h = 806 mm
r_m/D_h = 0.6

Figure 2. Test section: elbow ducting and specifications

Figure 3 describe the flowchart of the experimental study of secondary flow phenomenon in elbow ducting of closed-circuit wind tunnel. The experimental begin with preparing measurement tools, validation of measurement tools, data acquisition, data processing and data analysis.

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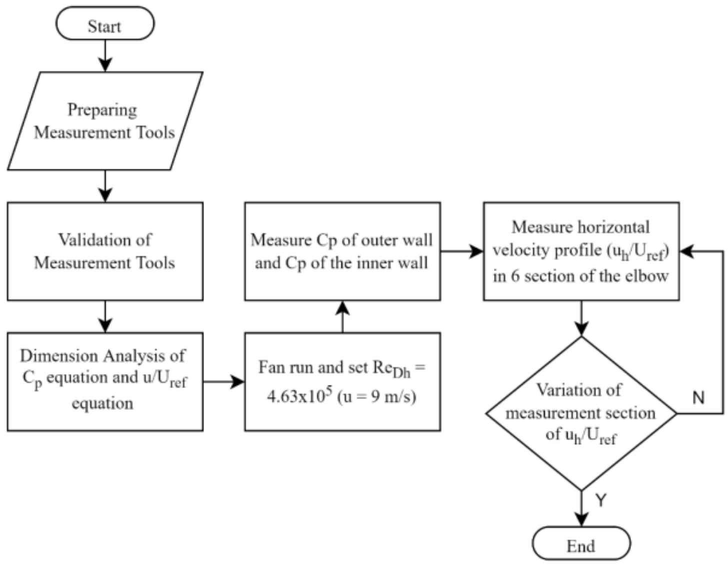

Figure 3. The flowchart of the experimental study of secondary flow investigation in elbow ducting

The experiment was started by preparing the measurement tools such as pitot tube, inclined manometer, thermometer, pressure transducer and computer. The pitot tube and manometer need to be validated to verify that these tools are working properly. Then, dimensional analysis was carried out to obtain non-dimensional equations of the pressure coefficient and velocity profile. These two non-dimensional equations are important in experimental study due to the measured parameters depend on this non-dimensional basis. For instance, the non-dimensional of velocity profile, $u/U_{ref} = f(x/D_h, Re_{Dh})$, so the measured parameters must be x/D_h and Re_{Dh} to obtain velocity profile in experimental study. Afterwards set the air flow velocity at 9 m/s or $Re_{Dh} = 4.63x10^5$ and measure the pressure coefficient (C_p) of the outer and inner walls to get the value of the pressure drop on the ducting elbow. Finally, measure the horizontal velocity profile in 6 sections (the location of the pitot tube when measuring airflow) elbow, each section taken 17 airflow data points. The 6 measurement sections shown in Figure 4.

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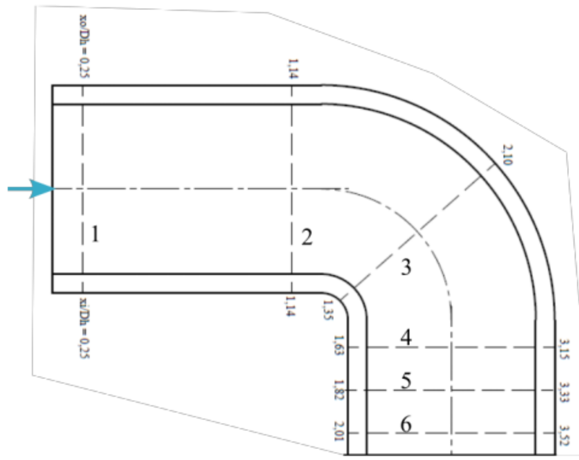

Figure 4. The location of the pitot tube when measuring airflow in ducting elbow of wind tunnel

3. Result and Discussion

The data result of this study is the pressure drop and the horizontal velocity profile.

a. Pressure drop (ΔC_p)

As shown in Figure 3, the coefficient pressure measured in both outer and inner wall of elbow. In order to obtain the pressure drops, we only measure the maximum Cp value of the outer wall and minimum Cp value of the inner wall, Table 1 shown the detailed result of Cp value.

Table 1. Cp value of outer and inner wall of elbow ducting

Re_{Dh}	C_p inner	C_p outer	ΔC_p
$4.63 x 10^5$	-0.62	0.84	1.46

In Table 1, the C_p inner value shows a negative value due to the airflow is accelerated in the inner wall. This fact follows the Bernoulli's principle, an accelerated flow caused a low pressure. Meanwhile, the pressure drops velue, ΔC_p = 1.46, that can say higher enough. This pressure drops mainly caused by separation flow in the inner wall and secondary flow.

b. Horizontal velocity profile

Figure 5 shows the velocity distribution profile on the horizontal for several locations in the elbow ducting at Re = 4.63 x 105 or equivalent to 9 m/s at the upstream inlet. The horizontal velocity profile consists of 6 section (see Figure 4), that are x_i/D_h = 0.25, x_i/Dh = 1.14, x_i/D_h = 1.35, xi/Dh =1.63, x_i/D_h = 1.82, and x_i/D_h = 2.01, respectively. Data collection in each section consists of 17 data points, measured from the inner wall toward the outer wall.

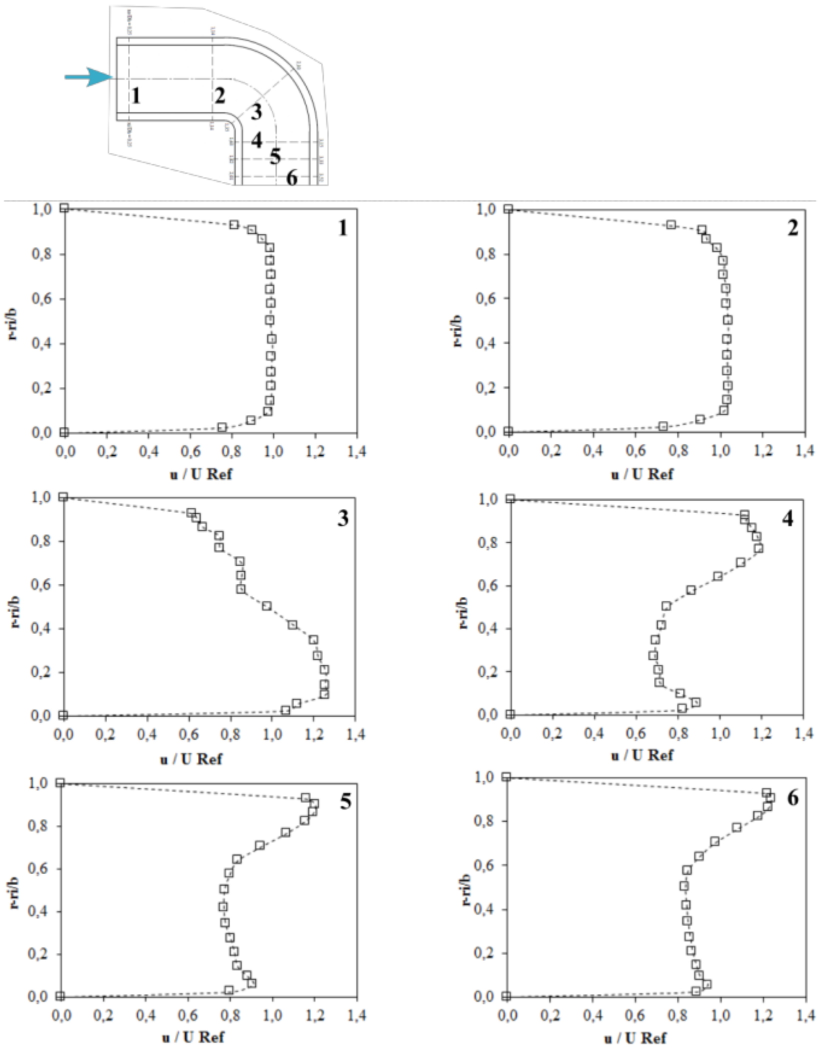

Figure 5. Horizontal velocity profile in 6 section of elbow ducting at $Re_{Dh} = 4.63x10^5$

At section 1 and section 2 the velocity profile distributes in uniform profile. In section 3, the velocity profile is accelerated on the inner wall because the airflow is at favourable pressure gradient area. The airflow is accelerates indicated by the maximum velocity at inner wall. by contrast to the outer wall, which is an area of adverse pressure gradient, the airflow is deaccelerates. In section 4, section 5 and section 6 occurs a deflection velocity location where the maximum velocity gradually shifts from the inner wall to the outer wall. This shifting phenomenon of the airflow changes in spatial-temporal, this phenomenon called the secondary flow. This fact was also observed numerically by Gajbhiye [9] where the flow separated and shifted from outer wall to inner wall in the elbow of circular pipe. In summary, the phenomenon of flow separation and secondary flow in the elbow ducting results in a decrease in the momentum of the airflow.

4. Conclusion

The closed-circuit wind tunnel has advantage in term of power efficiency and easy to control the airflow. However, the closed-circuit design has disadvantage in term of large of pressure drop due to the elbow ducting installation. This study shown, the pressure drop occurs in high enough fashion, that is 1.46. The elbow ducting is also a favourites site to occurs the secondary flow (see Figure 5, in section 4 up to section 6). Thus, in the future, the design of the closed-circuit wind tunnel must consider the vane installation in the elbow ducting.

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