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Investigation of Flow Uniformity and Pressure Recovery in a Turning Diffuser by Means of Baffles

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Abstract

Turning diffuser is an engineering device that is widely used in the industry to reduce the flow velocity as well as change the direction of the flow. Having a curvature shape causes its performance to decrease in terms of pressure recovery (C_p) and flow uniformity (σ_u). Therefore, this study presents the work done in designing baffles to be installed in the turning diffuser with ratio of AR=2.16 to improve the flow uniformity and pressure recovery. It also aims to investigate the mechanism of flow structure and pressure recovery in turning diffusers by means of turning baffles. The results with varying inflow Reynolds number (Re_{in}) between 5.786E+04 – 1.775E+05 have been experimentally tested and compared with previous study. Particle image velocimetry (PIV) was used to determine the flow uniformity. On the other hand, a digital manometer provided the average static pressure of the inlet and outlet of turning diffuser. The best produced pressure recovery of C_p=0.526 were recorded when the system were operated at the highest Reynolds number tested Re_{in}=1.775E+05. This result shows an improvement up to 54.625% deviation from previous study with C_p=0.239. The flow uniformity also shows an improvement of 47.127% deviation from previous study at the same Re_{in} with σ_u=3.235 as compared to previous study σ_u=6.12.

Introduction

Diffuser is a common engineering device which has the simplest design of an expanding area in the flow direction. The main and basic function of a diffuser is to reduce the velocity of the flow. Whenever a uniform cross-section of a diffuser is interrupted by the inclusion of pipe fitting such as bend, then a pressure loss will be incurred [1]. Baffles helps to act like a barrier and prevent carryover of flow in inner wall towards the outer wall and helps flow uniformity [2]. For straight diffuser, the optimum location for the vanes is slightly downstream from the narrowest diffuser throat and the number of vanes used should produce a small diffuser with maximum efficiency [3]. Previous studies has introduced many design factor to baffles design [4-8]. Simulation and numerical works also has been done previously. The velocity at the outlet of turning diffuser with baffles is more symmetrical than that without baffles [9]. Experiments using PIV were conducted having the same aim to investigate the flow uniformity in a turning diffuser with various Re_{in}. In 3-D setup of PIV, with increasing Re_{in}, pressure recovery is also increased. On the other hand, flow uniformity gets more distorted as Re_{in} increased.

Methodology

A turning diffuser with 90° angle of turn and area ratio 2.16, operated at inflow Re_{in}=5.786E+04-1.775E+05 is considered. The turning diffuser is installed with guide vanes. The guide vanes used are 3 units of acrylic plate with 3mm thickness and constructed using the same method as constructing the turning diffuser. Detailed design is shown in the next section. The experiment was run with the aim to eliminate flow separation near the inner wall and improve the turning diffuser's performance.

Turning diffuser with baffles was connected to the piping system. It was incorporated with several features to resemble a low subsonic wind tunnel system with multiple screen arrangement and 1:6 contraction cone. Air flow entering the diffuser has been measured to be steady, uniform and fully developed flow [12]. Upon measuring the velocity of air entering the system, the maximum inlet velocity which is at the center was measured. The inlet velocity then calculated using $V_{inlet}=0.862V_{max}$ [13]. Both static pressures at inlet and outlet of the diffuser were measured using pressure tapings at each side joined to the Triple-T design Piezometer and connected to digital manometer. Figure 1 shows the developed rig ready for test.

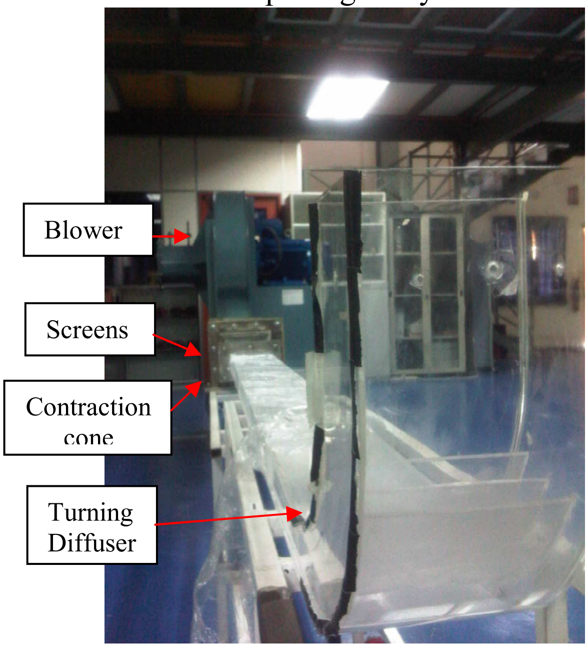

Figure 1: Test rig

Flow uniformity was examined using Particle Image Velocimetry (PIV) 3-Dimensional stereoscopic setup and flow structure inside the turning diffuser using 2-Dimensional setup. Smoke was injected into the airstream through the blower inlet using Eurolite smoke fluid with average diameter of 1 μm as seeding particle.

Pressure recovery can be measured using equation (1). When the value of C_p is obtained, the pressure loss coefficient is then calculated using equation (2). As for the flow uniformity, less flow distortion implies high flow uniformity. Outlet velocity was captured and measured using PIV and the least of absolute deviation corresponds to the greatest flow uniformity. Standard deviation (σ_u) can be expressed as equation (3).

$$C_p = \frac{2(P_{outlet} - P_{inlet})}{\rho V_{inlet}^2} \quad (1)$$

P_{outlet} = average static pressure at diffuser outlet (Pa)
P_{inlet} = average static pressure at diffuser inlet (Pa)
ρ = air density (kg/m^3)
V_{inlet} = inlet air velocity (m/s)

$$K = 1 - C_p \quad (2)$$

K = pressure loss coefficient
C_p = pressure recovery

$$\sigma_u = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(V_i - V_{outlet})^2} \qquad (3)$$

N = number of measurement points
V_i = local outlet air velocity (m/s)
V_{outlet} = mean outlet air velocity (m/s)

Results and Discussion

Design of Baffles

As described previously, the design of baffles closely resembles the construction of turning diffuser. This is to make sure that guide vanes installed will behave like a small diffuser without interrupting the smoothness of flow in the turning diffuser. Referring to Chong et al. [7] and discussed in previous section, the leading edge of the guide vanes were located at 28.6° of 12cm radius. The centerline of the turning diffuser with 17.5cm radius acts as the middle guide vane. Detailed design is shown in Figure 2.

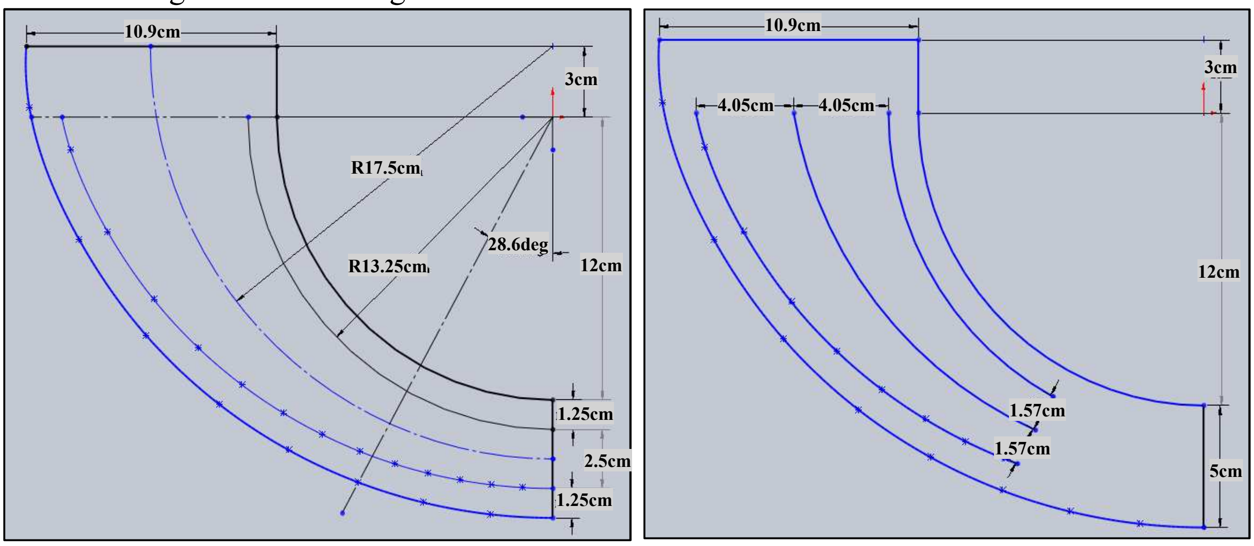

Figure 2: Baffles detailed design

Vector plots from PIV

In 3-D PIV setup, after the vector plots obtained were analyzed with both cross correlation and average filter between both cameras, the velocities in the Z-direction, *w* (m/s) were then produced by the software and shown in Table 1. There are more vectors directed towards the outer wall and more oriented as compared to previous study as shown in Figure 3. The velocity at the outer wall is much higher as compared to the inner wall. This proves that baffles acted like a barrier to direct the flow efficiently and eliminate most of the flow separation, thus improve the performance of turning diffuser.

Table 1: Numerical values of w_{PIV}

Re_{in}	w_{pitot} (m/s)	Δt(μs)
5.786E+04	6.474	70
6.382E+04	7.468	70
1.027E+05	10.492	50
1.397E+05	13.613	20
1.775E+05	17.546	20

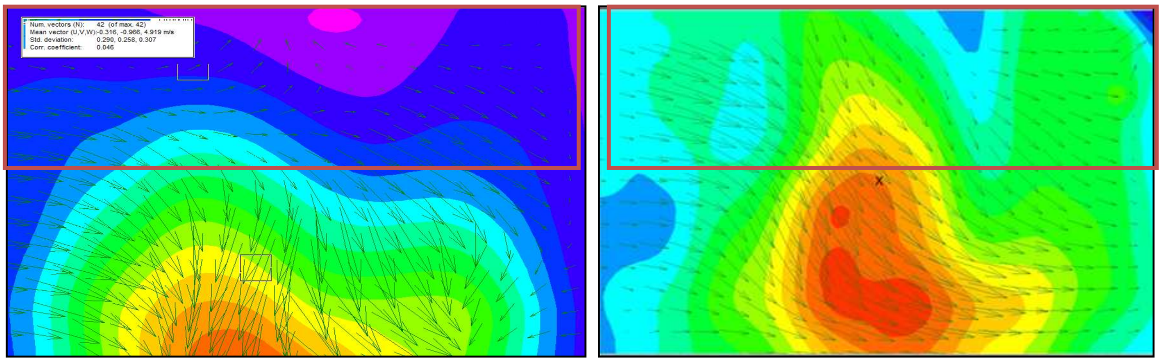

Figure 3: Vector comparison at diffuser's outler

Flow uniformity and pressure recovery

Flow uniformity was determined by calculating standard deviation of velocity using equation 3. Numeric data from scalar map analysis using PIV were exported and extracted to calculate the mean outlet velocity and thus calculating the standard deviation. From these results, when compared to results from Normayati et al. [11] in Table 2, it proves that with the installation of baffle, flow uniformity distortion can be reduced up to 63%. This proves that flow uniformity improves with the installation of baffle as expected, thus improve the performance of turning diffuser.Pressure recovery increases with increasing Reynolds number. This shows that with higher Reynolds number, turning diffuser with baffles could give higher performance as shown in Table 2. As described earlier, baffles help reduced the flow separation. Even with additional of friction drag from the installation of baffles, the total pressure loss still reduced. This is because pressure drag due to flow separation is a lot higher and significant compared to friction drag.

Table 2: Comparison of flow uniformity, σ_u

Re_{in}	σ_u (m/s) (current)	σ_u (m/s) ([8])	Improvement (%)
5.786E+04	0.719	1.75	58.864
6.382E+04	0.683	1.85	63.032
1.027E+05	2.437	2.91	16.240
1.397E+05	2.621	4.9	46.492
1.775E+05	3.235	6.12	47.127

Table 3: Comparison of pressure recovery, C_p

Re_{in}	C_p (current)	C_p ([8])	Deviation (%)
5.786E+04	0.413	0.191	53.849
6.382E+04	0.418	0.209	50.100
1.027E+05	0.433	0.216	50.225
1.397E+05	0.491	0.221	55.035
1.775E+05	0.526	0.239	54.625

Conclusion

In conclusion, the newly designed baffles improve the overall performance of the turning diffuser in terms of pressure recovery and flow uniformity. The best produced pressure recovery of $C_p = 0.526$ was recorded when the system operated at maximum $Re_{in} = 1.775E+05$, compared to $C_p = 0.239$ recorded by Normayati et al. [12] at the same Re_{in} with 54.6% deviation of improvement.

As for the flow uniformity, it has been recorded by previous study a distortion of $\sigma_u = 6.12$ when the system operated at maximum $Re_{in} = 1.775E+05$, as compared to current study with distortion only $\sigma_u = 3.235$ with 47.1% improvement.

As for the flow within the baffles, with current PIV setup shows no result of vector has been captured. In order to capture the vectors, the camera location has been moved closer to the targeted area. The camera will focus on the area between the baffles only and capture the vector at the designated area.

References

[1] El-Askary, W.A., and Nasr, M., 2009, "Performance of a Bend Diffuser System: Experimental and Numerical Studies," Journal of Computer & Fluids, **38**, pp. 160-170.

[2] Modi, P.P., and Jayanti, S., 2004, "Pressure Losses and Flow Maldistribution in Ducts with Sharp Bends," Chem. Eng. Res. Des., **82**, pp. 321-331.

[3] Fox, R., and Kline, S., 1962, "Flow Regime Data and Design Methods for Curved Subsonic Diffusers," ASME J. Basic Eng., **84**, pp. 303-312.

[4] Lindgren, B., and Johansson, A. V., 2002, "Design and Evaluation of a Low-Speed Wind-Tunnel with Expanding Corners," Technical Report No. TRITA-MEK, 2002:14, Dept. of Mechanics, KTH, SE-100 44 Stockholm, Sweden.

[5] Farsimadan, E., Mokhtarzadeh-Dehghan, M.R., 2010, "An Experimental Study of the Turbulence Quantities in the Boundary Layer and Near-Wake of an Airfoil Placed at Upstream of a 90° bend," Journal of Exp. Thermal and Fluid Science, **34**, pp. 979-991.

[6] Nakano, T., Fujisawa, N., Oguma, Y., Takagi, Y., and Lee, S., 2007, "Experimental Study on Flow and Noise Characteristics of NACA0018 Airfoil", Journal of Wind Engineering, **95**, pp. 511-531.

[7] Chong, T. P., Joseph, P. F., and Davies P.O.A.L., 2008, "A parametric Study of Passive Flow Control for a Short, High Area Ratio 90 Degree Curved Diffuser," ASME J. Fluids Eng., **130**(11), pp. 212-220.

[8] Majumdar, B., Mohan, R., Singh, S. N., and Agrawal, D. P., 1998, "Experimental Study of Flow in a High Aspect Ratio 90 Degree Curved Diffuser," ASME J. Fluids Eng., **120**(1), pp. 83-89.

[9] Nordin, N., Raghavan, V.R, Othamn, S., and Karim, Z.A.A., 2012, "Compatibility of 3-D Turning Diffusers by Means of Varying Area Ratios and Outlet-Inlet Configurations", ARPN Journal of Engineering and Applied Sciences, **7**, ISSN 1819-6608

[10]Nordin N., Raghavan, V.R., Othman, S., and Karim, Z.A.A., 2012 "Numerical Investigation of Turning Diffuser Performance by Varying Geometric and Operating Parameters", Journal of Applied Mechanics and Materials, **229**, pp. 2086-2093.

[11]Nordin N., Raghavan, V.R., Othman, S., and Karim, Z.A.A., 2012, "Experimental Investigation of Turning Diffuser Performance by Varying Inflow Reynolds Number", Post Graduate Symposium, Universiti Teknologi Petronas, Perak, Malaysia.

[12]Nordin N., Raghavan, V.R., Othman, S., and Karim, Z.A.A., 2012**,** "Design and Development of Low Subsonic Wind Tunnel for Turning Diffuser Application", Journal of Advance Materials Research, **614**, pp. 586-591.

[13]Kim. J., Moin P., and Moser R., 1987 "Turbulence statistics in fully developed channel flow at low Reynolds number", J. Fluid Mech., **177**, pp. 133-136.