A PARAMETRIC STUDY OF PASSIVE FLOW CONTROL DEVICES FOR 90˚ CURVED DIFFUSER

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ABSTRACT

The 90˚ curved diffuser has been widely utilised in various applications. The sharp curved angle and diffusing have simultaneously tackled the problem of space restrictions in some applications. However, due to the nature of its geometry, the curved diffuser's performance is compromised and disrupted. The potential of the flow treatment device, vortex generator (VG), to improve the performance of curved diffusers in terms of pressure recovery, $\boldsymbol{C_p}$ and flow uniformity, $\boldsymbol{\sigma_{out}}$ was experimentally and numerically investigated in this research. Experiments have been done to obtain data in terms of $\boldsymbol{C_p}$ and $\boldsymbol{\sigma_{out}}$ for bare curved diffuser and curved diffuser with triangle vorter generator attached. Three (3) types of vortex generators (triangle, rectangle, tapered-fin) with varying geometrical and operating parameters (height, spacing, distance, length, angle, inlet Reynolds Number) were considered. It had been demonstrated that the triangle VG offered the most promising improvement of $\boldsymbol{C_p}$ and $\boldsymbol{\sigma_{out}}$ at 43.1% and 9.7%, respectively. Height (2.75d and 3.85d), Spacing (5.5h), Inlet Reynolds Number ($\mathbf{5.786 \times 10^4}$), Length (3.0h), Distance (6.0h) and Angle (18˚) have been recommended as the optimal configuration of geometrical and operating parameters of the VG. The onset flow separation was discovered to have varied outcomes. However, the velocity vector distribution at the diffuser outlet showed that the flow was considerably more distorted; the flow deficit region observed at the diffuser inner wall had more core flow present when compared to the curved diffuser without VG installed.

ABSTRAK

Peresap melengkung 90˚ telah digunakan secara meluas dalam banyak aplikasi. Sudut melengkung tajam dan meresap terbukti secara serentak menangani masalah berkaitan dengan sekatan ruang dalam sesetengah aplikasi. Walaubagaimanapun, disebabkan sifat geometrinya, prestasi peresap melengkung terjejas dan terganggu. Potensi peranti rawatan aliran, penjana pusaran (VG) untuk meningkatkan prestasi peresap melengkung dari segi pemulihan tekanan, $\boldsymbol{C_p}$ dan keseragaman aliran, $\boldsymbol{\sigma_{out}}$ telah dikaji secara eksperimen dan numerik dalam penyelidikan ini. Eksperimen telah dilakukan untuk mendapatkan data dari segi $\boldsymbol{C_p}$ dan $\boldsymbol{\sigma_{out}}$ untuk penyebar melengkung kosong dan peresap melengkung dengan penjana vorter segitiga dipasang Kajian ini mengambilkira tiga (3) jenis penjana pusaran (segi tiga, segi empat tepat, sirip tirus) dengan parameter geometri dan operasi yang berbeza-beza (tinggi, jarak, jarak, panjang, sudut, Nombor Reynolds masuk). VG segi tiga terbukti paling berpotensi meningkatkan $\boldsymbol{C_p}$ dan $\boldsymbol{\sigma_{out}}$ masing-masing pada kadar 43.1% dan 9.7%. Ketinggian (2.75d dan 3.85d), Jarak (5.5h), Nombor Reynolds Masuk ($\mathbf{5.786 \times 10^4}$), Panjang (3.0h), Jarak (6.0h) dan Sudut (18˚) disyorkan sebagai konfigurasi optimum bagi parameter geometri dan operasi VG. Didapati bahawa hasil pengasingan aliran permulaan adalah berbeza-beza. Namun, taburan vektor halaju di salur keluar peresap menunjukkan bahawa aliran itu jauh lebih herot; kawasan defisit aliran yang diperhatikan pada dinding dalam peresap mempunyai lebih banyak aliran teras hadir berbanding dengan peresap melengkung tanpa dipasang VG.

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LIST OF SYMBOLS AND ABBREVIATIONS

The following list gives the meaning of abbreviations used in this thesis unless otherwise defined in the text and appendices:

L_{in}	-	Inner wall length
W	-	Width
C_p	-	Pressure recovery coefficient
σ_{out}	-	Flow uniformity index
Re_{in}	-	Inlet Reynolds number
$Vout$	-	Outlet velocity
X	-	Length
D	-	Duct inlet diameter
D_h	-	Hydraulic diameter (m)
N	-	Number of measurement points
p_{dyn}	-	Dynamic pressure (Pa)
p_{in}	-	Average static pressure at the inlet (Pa)
p_{out}	-	Average static pressure at the outlet (Pa)
T	-	Operating temperature (˚C)
U	-	Mean velocity (ms^{-1})
V_i	-	Local outlet air velocity (ms^{-1})
$V_{i\,max}$	-	Maximum local outlet air velocity (ms^{-1})
V_{in}	-	Mean inlet air velocity (ms^{-1})
AR	-	Area ratio
AS	-	Aspect ratio
HVAC	-	Heating, ventilation and conditioning
2-D	-	Two dimensional
3-D	-	Three dimensional
VG	-	Vortex generator
SVG	-	Submerged vortex generator

KVG	-	Karman vortex generator
CFD	-	Computational Fluid Dynamics
AOA	-	Area of attack
PIV	-	Particle image velocimetry
FLT	-	First layer thickness
MMS	-	Mesh maximum size
k-e	-	k-epsilon turbulence model
k-e realizable	-	k-epsilon realizable turbulence model
RNG k-e	-	Renormalization-group k-epsilon turbulence model
k-ω	-	k-omega turbulence model
RSM	-	Reynolds stress model
ACFD	-	Asymptotic Computational Fluid Dynamics

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Diffuser has been commonly used and applied in aero-engineering, oil and gas, automotive and other industries that benefit from their fluid mechanic capabilities. The employment of diffusers with turbines has been a growing interest for their ability to increase the axial hydrodynamic load on the powertrain of the turbine as it presents a challenge to start the turbine due to its frictional torque [1]. A diffuser's simplest and basic form is a straight duct with an expanding cross-section on its end. Diffusers are mainly used to decrease flow velocity while increasing pressure. Many diffusers have been designed with different parameters such as area ratio (AR), divergence angle, length-to-width ratio (L_{in}/W_1) and aspect ratio (AS) to make improvements for its performance characteristics such as pressure recovery, flow uniformity and pressure losses.

Theoretically, expanding a straight duct would easily increase static pressure at the end of the expansion. Unfortunately, this is not the case due to the fact that there is a phenomenon known as flow separation and secondary flow, which its geometry would create. They would still occur even with the most optimum divergence angle of the diffuser [2]. Moreover, the curved diffuser would have a higher degree of secondary flow than the simple straight diffuser because of its complex geometry.

A diffuser performance is measured in terms of the pressure recovery coefficient(C_p) and outlet flow uniformity (σ_{out}). A higher C_p value represents high-pressure recovery, while the lower value of σ_{out} represents high flow uniformity. Some diffusers are curved and bent to meet their space availability and applications. A standard wind tunnel would incorporate the curved diffuser to save space. In order to increase its power source efficiency, diffusers were installed in wind tunnels to convert the kinetic energy of the stream to the potential energy of pressure [3]. Calautit et al. [4] utilised a highly porous safety mesh and guide vanes to prevent parts from entering the axial fan section and improve flow characteristics.

El-Askary and Nasr [5] considered using a bend-straight diffuser as the system required a diffuser with optimum divergence angles and the right spacer length, which can produce a uniformly distributed flow depending on the inflow Reynolds number. However, this would significantly increase the duct length, thus, increasing the energy wasted on skin friction. The utilisation of a curved diffuser would be a more viable option for this case, while it can simultaneously save space and reduce the effect of skin friction in the duct.

In order to further improve the performance of the turning diffuser in terms of pressure recovery and flow uniformity, obtaining the optimum design for the flow control device is essential. This would mean reducing flow separation to achieve maximum efficiency for the curved diffusers. Several past studies have reported that the diffuser's performance can be increased by introducing flow control devices such as vortex generators, mesh screens, honeycomb and guide vanes [6]. Therefore, this study investigated the flow control device's potential to improve the curved diffuser's recovery and flow performance.

1.2 Problem Statement

Most of the time, diffusers are associated with flow separation and secondary flow. Flow separation occurs due to the more significant deceleration of shearing force than the pressure force pushing it at its boundary layer [6]. Riffat et al. [2] reported that flow separation would still occur even if the diffuser were at its optimum divergence angle. Fox and Kline [7] developed a correlation for the curved diffuser up until 90˚ and proved that a higher angle of curvature affects the diffuser's performance significantly. Thus, the diffuser with a high angle of curvature, such as 90˚, which is widely used in various applications, should have some flow control device installed to assist the flow and increase the diffuser's performance.

The implementation of flow control devices in curved diffusers has been previously studied. It was observed that some flow control devices had more significant effects on the curved diffuser's performance than others [6]. However, this does not imply that one flow control device is better. This research investigated one of the flow control devices, namely the vortex generator, while determining its most optimum geometrical parameters for the 90˚ curved diffuser.

1.3 Objectives

The main objectives of this study were as follows:

1. To assess the potential of several shapes of vortex generators installed in a 90˚ curved diffuser through experiment and CFD simulations.
2. To evaluate the effects of varying the geometrical and operating parameters of vortex generators on the performance of 90˚ curved diffuser.
3. To propose the most optimum geometrical and operating parameters of vortex generator for the best performance of 90˚ curved diffuser.

1.4 Scope of Study

The scopes of this study were as follows:

1. A 90˚ curved diffuser with a rectangular cross-section with AR=2.16, $L_{in}/W_1 = 4.37$, $Re_{in} = 5.786 \times 10^4 - 1.775 \times 10^5$
2. Various vortex generator shapes were considered, including triangle, rectangle, and tapered-fin.
3. The parameters considered to test the performance for each vortex generator shape were the height, spacing, length, distance, angle and inlet Reynolds number.
4. The performance of curved diffusers was evaluated primarily in terms of pressure recovery coefficient, C_p and flow uniformity, σ_{out}.

5. ANSYS version 19.2 intensively simulated the performance of a curved diffuser by employing different vortex generator geometrical parameters.

1.5 Significant of study

The curved diffuser has been widely employed in numerous engineering applications, from wind tunnels to smaller devices such as centrifugal compressors. As technology improves, the capacity to save power and boost machine efficiency is becoming a significant characteristic to consider in the design process. Although it has inferior flow properties than a straight diffuser, a curved diffuser is employed when space is restricted and complex arrangements are complex. The current research focused on further establishing the most optimum geometrical parameters for the vortex generators to improve the performance of a 90˚ curved diffuser. Past research for existing vortex generator designs was evaluated and analysed to offer an improved vortex generator design for better flow performance. For this purpose, both numerical and experimental approaches were employed. With minimal flow distortion at the output, a vortex generator design that has been improved will increase pressure recovery.

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