EFFECT OF SWIRL ON THE BOUNDARY LAYER THICKNESS THROUGH ANNULAR DIFFUSERS

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A thesis submitted in partial fulfillment
of the requirements for the Degree of
Master of Science

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ABSTRACT

This thesis is a study of a turbulent swirling flow through an annular diffuser to determine the effect of swirl intensity on the thickness of the boundary layer. The study includes both experimental and numerical investigations.

The flow was first investigated experimentally in a 15° cone angle diffuser with a total area ratio of 7.13, having a constant diameter central hub of 76 mm. The outer casing is 200 mm inlet diameter, 500 mm outlet diameter and 1140 mm long. The total and static pressures were measured by means of a wedge-type probe. The diffuser was traversed by the probe at several axial locations so that complete flow configuration is determined at different swirls. The swirl intensity is varied by varying the angle of the swirl vanes at diffuser inlet. This angle is considered as a measure of swirl intensity.

Experiments were performed at no-swirl, 5, 15, 25 and 35 degree swirl. The effect of these swirls on the static pressure variation at both hub and casing, on axial and tangential velocity profiles, on boundary layer separation and on the pressure-recovery coefficient was studied. As the pressure-recovery coefficient is the measure of the effectiveness of the diffuser performance, it was compared with those of other research workers. By adding the results of the present work to their results, the performance of conical and annular diffusers may be then predicted for different cone angles, different area ratios and different swirl intensities.

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In conclusion, as swirl is increased, the boundary layer gets thinner at the casing and thicker at the hub. This thick boundary layer tends always to separate from wall; the separation gets nearer to inlet as swirl is increased. Best performance occurs at moderate swirl (15° in the present work).

The theoretical investigation was based on the use of a general numerical method for solving the governing differential equations for swirling flows in annular diffusers. The computer program used in the solution of the problem is known by (2/E/FIX) Two-dimensional Elliptic and Fixed grid by Pun and Spalding (1976). The program was modified to suit geometrically and dynamically the problem considered in the present work. To get the flow pattern in the annular diffuser, the program was modified step by step; first to configurate a pipe flow case, then an annular flow between two concentric pipes, at last flow in an annular diffuser with no-swirl. The experimental results seem to be in good agreement with the numerical results. The flexibility of the program enables the prediction of flow pattern in such cases which are difficult to investigate experimentally.

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NOMENCLATURE

a	face area
A	finite-difference coefficient
B	finite-difference coefficient
c_p	pressure recovery coefficient
C	finite-difference coefficient
D	diameter
E	grid location east of P
F	body force
g	gravitational acceleration
h	stagnation enthalpy
K	thermal conductivity
n	exposant
N	grid location north of P
NX	number of grid lines in x direction
NY	number of grid lines in y direction
p	pressure
P	grid location of current interest
p_s	static pressure
p_t	total pressure
q	internal heat generation
q_r	radiation heat flux vector
r	radius: radial coordinate
S	source term

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S	grid location south of P
$S_{P,R}$	source term in pressure-correction equation
$S_{U,R}$	source term in pressure-correction equation
u	velocity component in axial direction
U	velocity vector
v	resultant velocity; velocity component in y or r direction
v_x	velocity component in axial direction
v_y	tangential velocity component
V	volume of control volume
W	grid location west of P
x	axial distance; axial coordinate
y	coordinate direction

Greek Symbols :

Δh	annular height
θ	angle between resultant velocity & x-direction
φ	angle around center-line from vertical
ρ	density
γ_w	specific weight of water
γ_{air}	specific weight of air
ψ	flow potential
ω	vorticity
η	efficiency
μ	dynamic viscosity

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λ	second coefficient of viscosity
ϕ	any scalor quantity
Γ	transport coefficient

Subscripts :

i	at inlet
e	at exit
av	average (in figures)
ave	average
*	guessed quantity or values based on it
'	correction term added to guessed quantity
c	at casing
h	at hub

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CHAPTER 1

INTRODUCTION

Diffusers are extensively used in numerous fields in engineering. For example, the discharge duct of some axial compressors, the outlet passage of volute casing of centrifugal pumps and the draft tube in water turbines are some of the applications of diffusers. They are considered as energy recuperators, governing both efficiency and stability in fluid machinery and wind tunnel test sections.

Due to the type of application, diffusers may be of various shapes. They may be conical, annular with conical casing and cylindrical hub or vice-versa i.e cylindrical casing and conical hub; or both conical hub and casing. They may be straight walled or have an involute shape, and in some applications, diffusers may have a "bell" or "trumpet" shape.

Diffusers are therefore expected to operate under a wide range of flow regimes. Improved understanding of the nature of flow in diffusers of different shapes enables designers to fulfill requirements for the particular application. Shorter diffusers, of moderate or large area ratio and hence with a potential for large static pressure recovery, remain the prime aim of diffuser designers. Due to the steep pressure gradient in large angle diffusers, the boundary layer develops quickly and it finally separates from wall before the exit of diffuser, and the pressure does not increase much downstream of the separation point. To achieve the objective of diffuser designers

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in short wide-angled diffusers, flow separation must be controlled with minimum energy expenditure.

Swirling flow is sometimes observed in the exit pipe of turbomachines and in some cases of pipe line flow. Flow is sometimes forced to be swirling to prevent separation from boundary walls. In cases of swirling flow, the flow is pressed toward the wall by the centrifugal force, and the wall boundary layer is less likely to separate even if the divergence angle of the diffuser is large; and a high pressure recovery coefficient is expected.

The object of the present work is to study experimentally the effect of swirl on the thickness of the boundary layer in annular diffusers.However, to achieve this, a non-swirling flow was first studied and then followed by the main object of our investigation. Moreover, a numerical analysis is also presented. A review of previous work is given in chapter 2, and the experimental investigation is described in chapter 3. Experimental results are presented and discussed in chapter 4. The numerical procedure used in the theoretical investigation is explained in chapter 5. The reliability of the numerical procedure used was assured by the excellent results obtained for the non-swirling flow through the annular diffuser. These results are presented in chapter 6. When swirl was introduced, convergence of the solution was found to be very slow and the numerical stability was affected.

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Throughout the whole work, the flow is assumed to be :

1. Steady, because enough time lapsed before measurements were taken.

2. Axisymmetric : axisymmetry is checked at inlet and outlet sections of the diffuser during experiments.

3. Incompressible, as the Mach number at inlet does not exceed 0.15.

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