“STUDY OF FLUID FLOW AND HEAT TRANSFER IN A TRIANGULAR DUCT WITH RECTANGULAR VORTEX GENERATOR”

MAJOR PROJECT REPORT
PHASE I

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

BACHELOR OF TECHNOLOGY
(Mechanical Engineering)

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CANDIDATE'S DECLARATION

I certify that

a. the work contained in this report is original and has been done by me under the guidance of my supervisor(s).
b. the work has not been submitted to any other Institute for any degree or diploma.
c. I have followed the guidelines provided by the Institute in preparing the report.
d. I have conformed to the norms and guidelines given in the Ethical Code of Conduct of the Institute.
e. whenever I have used materials (data, theoretical analysis, figures, and text) from other sources, I have given due credit to them by citing them in the text of the report and giving their details in the references. Further, I have taken permission from the copyright owners of the sources, whenever necessary.

Signature of Student

CERTIFICATE

This is to certify that the Major Project Report Phase I entitled, “Study of fluid flow and heat transfer in a triangular duct with rectangular vortex generator” submitted by Mr. “Ganpat Ram” to Dr. B R Ambedkar National Institute of Technology Jalandhar, India, is a record of Bonafide Project work carried out by him under my supervision and guidance and is worthy of consideration for the award of the degree of Bachelor of Technology in Mechanical Engineering of the Institute.

Supervisor	Head of the Department

Date:

ACKNOWLEDGEMENT

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ABSTRACT

The study of fluid flow and heat transfer in a triangular duct with a rectangular vortex generator focuses on improving the thermal performance of heat exchangers through innovative geometric and flow-control methods. Heat exchangers are critical components in numerous industrial and engineering applications, including HVAC systems, electronics cooling, and aerospace technology. The triangular duct, characterized by its compact design and reduced pressure drop compared to conventional circular ducts, serves as the fundamental geometry for this research. The addition of rectangular vortex generators introduces controlled disturbances in the flow, thereby enhancing turbulence and disrupting thermal boundary layers to improve heat transfer efficiency.

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CHAPTER 1

INTRODUCTION

1.1 Vortex Generator :-

The vortex generator has been used as a passive flow control approach in both external and internal aerodynamics, especially for boundary-layer separation and flow-separation since the 1940s. It was first proposed for flow-induced noise reduction in the mid-1980s for the interior noise of the Gulf-stream III aircraft. It was found that VGs can effectively delay separation and break up the Kármán vortex street. To date, VGs have been implemented in different engineering applications related to the flow induced noise reduction, such as for wind turbines and of course aircraft. Regarding airframe noise reduction, it was considered to be applied for wing noise control, arranged on the end surfaces of a control surface and particularity of a flap. It has been tested in wind tunnels with good results attained. Also, VGs can be used to suppress the shear layer of a cavity orifice, when installed upstream to it. This has been implemented in the Airbus A320 for the circular openings on the underside of each wing. These openings are designed to vent pressure in the under-wing fuel tanks, shown in Fig.1. Flow separation and cavity resonance are the main noise sources for landing gear. Therefore, it is believed that VGs could be also applied for landing gear noise reduction. For example, on the edge of the bay doors, on the main strut and particularly upstream to pin holes etc.

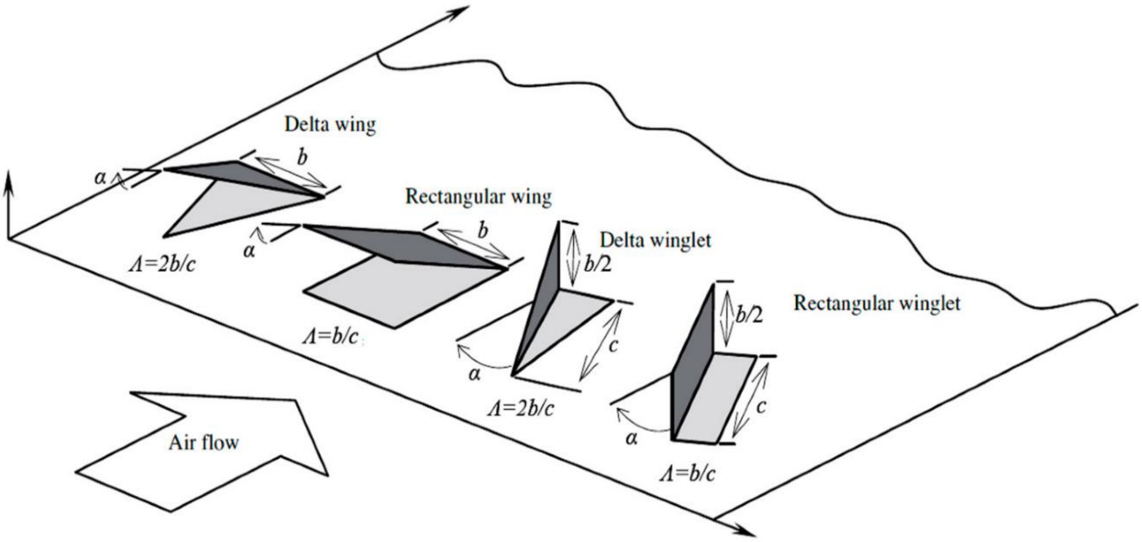

Fig.1 Vortex geometry

CHAPTER 2

LITERATURE REVIEW

The enhancement of heat transfer in compact heat exchangers has been an active area of research due to its critical importance in industrial applications. Several studies have focused on passive techniques, such as the use of vortex generators, to improve thermal performance while minimizing energy losses. Vortex generators (VGs) are widely recognized for their ability to induce secondary flows and disrupt thermal boundary layers, which significantly enhance heat transfer. Rectangular vortex generators (RVGs) have gained particular attention due to their simple design and strong vortex generation capability.

Researchers have extensively studied the effects of vortex generators in different duct geometries. Biswas and Mitra (1996) analyzed the influence of longitudinal vortex generators on heat transfer in rectangular channels and observed significant enhancement due to the generation of swirling flows. Similarly, Wang et al. (2008) conducted a numerical investigation of delta-winglet VGs in a rectangular duct and reported improved heat transfer, albeit at the cost of increased pressure drop. Their findings highlighted the importance of optimizing VG geometry and placement to balance thermal and hydraulic performance.

In triangular ducts, the challenges of achieving uniform heat transfer and overcoming stagnant flow zones are particularly pronounced. Sharifi et al. (2014) studied the thermal performance of triangular ducts and demonstrated the potential for heat transfer enhancement using passive methods. However, their work revealed that the inherent flow characteristics of triangular ducts often lead to non-uniform heat transfer distributions, especially in corner regions. To address this, researchers began integrating VGs into triangular ducts. For instance, Zhang et al. (2016) investigated the effects of rectangular vortex generators in a triangular duct and observed significant improvement in heat transfer, with the vortices effectively redistributing thermal energy. Their study emphasized the role of VG positioning and orientation in achieving optimal performance.

An investigation of the two-phase flow and forced convection of hydrogen gas for Reynolds numbers ranging from 5000 to 25000 quantitatively using fins and baffles in a solar channel was conducted by Menni etc. According to their analysis, the dynamic pressure values were significantly lower at the baffle's left and right edges and significantly higher near its top and bottom margins. Moreover, areas close to the duct walls—that is, the space between the fins' front edges and the baffle's back side—showed notable dynamic pressure values. The thermal enhancement factor increased in tandem with an increase in Reynolds number. Thermal enhancement factor reached about 4.18 at the maximum Reynolds number of 25,000, which exceeded the factor reported for typical gaseous fluid (air) applications by a factor of 275 as a consequence of the high flow rate of the heat transfer fluid, hydrogen gas, the study found that the suggested structure increased the dynamic pressure and transfer of heat while concurrently lowering values of the skin friction. The channel global thermal enhancement factor was increased as a result of this improvement.Numerical simulation techniques have proven invaluable for understanding the complex flow phenomena associated with VGs. Computational Fluid Dynamics (CFD) studies, such as those by Chen et al. (2018), have provided detailed insights into the interaction between vortex structures and thermal boundary layers. These simulations enable the visualization of secondary flow patterns, helping to optimize VG configurations. Moreover, researchers like Li et al. (2020) have used CFD tools to explore the effects of Reynolds number, VG spacing, and duct shape on thermal-hydraulic performance. Their work underscores the need for a systematic approach to VG design for different duct geometries.

Despite significant progress, challenges remain in optimizing vortex generators for triangular ducts. Most studies focus on rectangular or circular ducts, leaving triangular geometries relatively underexplored. Additionally, there is limited research on the long-term effects of vortex-induced pressure drops and their implications for system efficiency. This study aims to address these gaps by conducting a detailed investigation into the use of rectangular vortex generators in triangular ducts, with a focus on achieving a balance between heat transfer enhancement and flow resistance.

Geometric dimensions of the triangular duct and Vortex Generator.		
Name of partition	Symbol	Dimension
Duct length	L	25.115 D_h
Duct hydraulic diameter	D_h	5.33 mm
Cross-sectional area of the duct	A	4.33 x 10^{5} m^2
Distance between VG and leading edge of duct	s	3 D_h
Length of the Vortex Generator	l	0.6928 *Dh*
Height of the Vortex Generator	h	0.2996 D_h
Attack angle of the Vortex Generator	P	30°
Distance between tips of the Vortex Generator pair	a	0.1732 *Dh*
Thickness of the Vortex Generator	t	0.0866 D_h

Table:- 1 Geometric Dimension

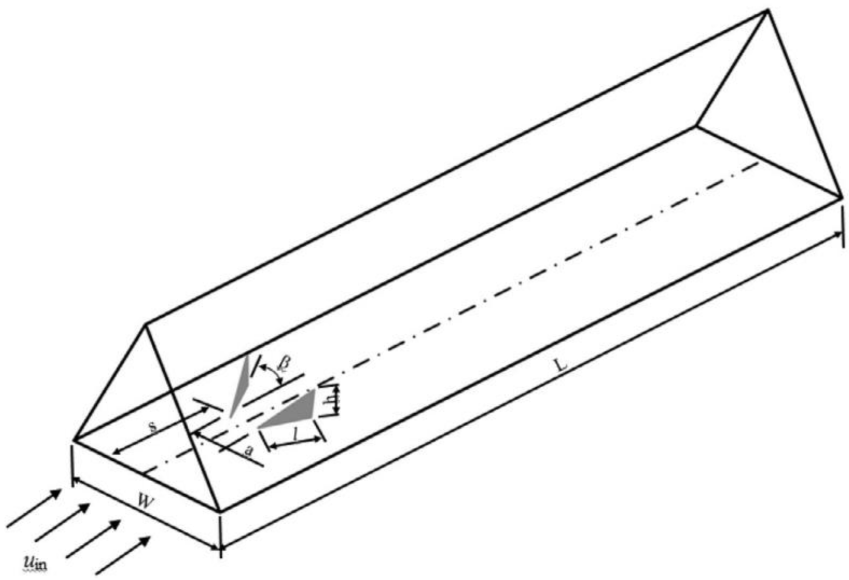

Fig. 2. Scheme of physical domain and vortex generator

METHODOLOGY

1.CAD Modeling

The triangular duct is modeled based on realistic dimensions relevant to compact heat exchanger applications.

The duct geometry includes:

Cross-section: Equilateral triangular cross-section for uniformity.

Length: Sufficient to ensure fully developed flow conditions.

Rectangular vortex generators Design: Rectangular vortex generators are integrated within the duct. Key geometric parameters of the rectangular vortex generators include height, width, length, and angle of attack. These parameters are systematically varied during the study to understand their effects.

The placement of rectangular vortex generators is also varied to examine their influence on flow structures and heat transfer performance, including configurations such as single-row, staggered, and inline arrangements.

2. Boundary Conditions:-

Inlet Boundary: Uniform velocity profile corresponding to various Reynolds numbers.

Outlet Boundary: Zero static pressure condition.

Wall Boundary: Constant heat flux is applied to the walls to simulate heat transfer. The walls are assumed to be no-slip and thermally conductive.

3. Meshing and Grid Independence Study:-

The duct geometry is discretized using high-quality structured or unstructured meshes. A grid independence study is conducted to ensure that the simulation results are not sensitive to the mesh size. Fine meshing is applied near the rectangular vortex generators and duct walls to accurately capture boundary layer phenomena. The total number of elements is optimized to balance computational cost and accuracy.

4. Numerical Simulation:-

The flow and heat transfer are analyzed using Computational Fluid Dynamics (CFD) simulations. The methodology involves:

Governing Equations: The Navier-Stokes equations for incompressible flow and the energy equation for heat transfer are solved.

Turbulence Model: A suitable turbulence model is used to accurately capture secondary flow structures and vortex dynamics.

Solver Settings: Steady-state or transient solvers are used depending on the flow conditions. A second-order upwind scheme is employed for spatial discretization to ensure accuracy.

Simulation Software: Industry-standard CFD tools ANSYS Fluent are used for simulations.

5. Parametric Study:-

A systematic parametric study is conducted to evaluate the influence of design and operating parameters:

Rectangular vortex generators Parameters: Height, length, width, angle of attack, and longitudinal placement are varied to examine their effects on flow and thermal performance.

Reynolds Number: Simulations are performed over a range of Reynolds numbers to understand the performance under laminar and turbulent flow regimes.

The performance metrics considered include:

1. Nusselt Number (Nu): Indicates heat transfer enhancement.
2. Friction Factor (f): Represents the pressure drop due to flow resistance.

6. Visualization and Analysis:-

The simulation results are post-processed to visualize and analyze:

Flow Patterns: Velocity contours, streamlines, and secondary flow structures induced by the rectangular vortex generators.

Temperature Distributions: Surface and cross-sectional temperature contours to evaluate heat transfer uniformity.

References:-

1.Hamdi E. Ahmed et al Experimental study of heat transfer augmentation in non-circular duct using combined fluids and vortex generator

2.Ali, S., Habchi, C., Menanteau, S., Lemenand, T., & Harion, J. L. (2015). Heat transfer and mixing enhancement by free elastic flaps oscillation. International Journal of Heat and Mass Transfer, 85,

3.Turbulent heat transfer and nanofluid flow in a triangular duct with vortex generators research paper by M.Z. Yusoff.

4.R. Vasudevan, V. Eswaran, G. Biswas

Winglet-type vortex generators for plate-fin heat exchangers using triangular fins

5. G. Munish, K. Kasana, R.A. Vasudevan

Numerical study of the effect on flow structure and heat transfer of a rectangular winglet pair in a plate fin heat exchanger

J. Mech. Eng. Sci., 223 (Part C) (2009), pp. 2109-2115