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Influence of multiple vortex generator on the hydraulic performance of air flow through a rectangular duct

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***Abstract:-* The influence of multiple delta wing vortex generators on the wall of rectangular ducts on the pressure loss penalty has been experimentally investigated in this study. The combined effects of geometrical parameters of multiple delta wing and duct aspect ratio on friction factor ratios are reported in the Reynolds number based on the duct hydraulic diameter in the range of 8000-24000. The geometrical parameters of vortex generators systematically varied in this study were the pitch to vortex generator height ratio (p/e), vortex generator height to duct hydraulic diameter ratio (e/Dh), aspect ratio of vortex generator (ar). The number of vortex generators (N) on a wall at a given axial location were also varied - an integer number of equal sized vortex generators spanned the entire width of the wall on which the vortex generators were used. Results are reported for 0.1 < e/Dh < 0.5, p/e=4,8,12,16, (ar)=2.31, N=2 in ducts having aspect ratio AR = 2.**

***Keywords:--* duct; friction factor; Reynolds number; multiple vortex generator; hydraulic performance.**

I. INTRODUCTION

An increase in the distance between the multiple delta wings tip and bottom surface of the duct have been made to get more friction factor ratio's that is a higher pressure drop which is used to analyze the efficient heat transfer surfaces for non-circular flow ducts. As technology progresses and efficiency requirements increase, greater requirement must be laid upon gas turbine development to meet the challenge of maximizing heat transfer at minimum pressure drop. Many researchers are studying extensively the heat transfer applications in engineering industry that involves mixed convection and internal flow in non-circular channels and ducts such as rectangular, rectangular, trapezoidal, polygonal and triangular. The hydrodynamics and thermal fields were strongly related to each other in these channels. In this paper experimental result of hydrodynamics inside a rectangular duct is recorded.

Turbulence promoters or multiple delta wing vortex generators are often used to manipulate the flow field and they can provide a beneficial effect on the thermal performance. Sedney (1973) reported that streamwise vortices are generated when a flow encounters a surface element protruding into the boundary layer. Jacobi and Shah (1995) investigated that effects of a three-dimensional surface bump are qualitatively Similar for laminar and turbulent boundary layers. A system of vortices is observed near the protuberance. Shakaba et al. (1985) experimentally studied the behavior of a single longitudinal vortex embedded in a developing turbulent boundary layer with a zero pressure gradient. Their measurements indicated that the streamwise vorticity is very persistent, being reduced only by the spanwise surface shear stress. They observed that the structure of the boundary layer turbulence is modified significantly and simple algebraic eddy viscosity models are not able to predict the measured quantities. Yang et al. (2001) studied the effects of the interactions between a pair of vortices generated by a pair of multiple delta winglets in a rectangular channel flow (AR = 4.7) on the flow field. Gentry and Jacobi (1997) presented data for flow over a flat plate at low Reynolds numbers using multiple delta wings, and reported 55% to 65% enhancement of average heat and mass transfer. Gentry and Jacobi (2002) presented heat transfer and pressure drop results for multiple delta wings placed at the leading edge of a flat plate for laminar flow. reported local enhancements as high as 300% compared to flat plate flow with no vortex generator in locations where the vortex flow was toward the heated surface. Fiebig et al. (1991) reported experimental results for the measurements in rectangular channels of different aspect ratios (AR = 2, 4, and 5). The VG configurations were limited to a single delta or rectangular wing, a single delta or rectangular winglet, or a single pair of rectangular winglets. Rectangular wings pressure drop increases by approximately 45%. Biswas et al. (1992) reported numerical study results for multiple delta wing and multiple delta wing with stamping for (AR = 2, Re = 500, Pr = 0.7, ar = 1, and β = 26o). Friction factor increased 79% over the plain channel geometry at Re500.

II. DESCRIPTION OF EXPERIMENTAL SET-UP

Different experiments are conducted in an experimental set-up as depicted in Fig. 1. The experimental system consists of a rectangular channel of hydraulic diameter 30mm and length 900mm. Blower sucks the air, air enters into the test section through a valve, which regulates the flow through the test section. flow rate is measured by using orificemeter which is placed about 25mm pipe diameters A simple U-tube manometer is used for the measurement of differential pressure head across the orificemeter. A differential manometer with a combination of water and benzyl alcohol (specific gravity = 1.046) as the manometric fluids is connected across the test section to measure the pressure drop across the test section. Two pressure taps give value of pressure of the test section where pressure measurement is required. The axial distance between the pressure taps for the differential manometer is 850 mm.

And channel roughened with multiple delta wing vortex generators shown in fig-2. In this the multiple delta wing vortex generators are glued on the bottom surface of the rectangular channel for conducting the experiment. These multiple delta wing vortex generators are made up of 0.5mm thick aluminium sheet and having different aspect ratio's (ar=2b/c) also geometrical parameters of multiple delta wing vortex generators are systematically varied

Geometry and computational details

Multiple delta wing-shaped vortex generator are mounted into the bottom surface of this channel to analyze the flow characteristics' in the rectangular duct The sides of the channel are denoted L, H and W and channel aspect ratio(AR) is W/H The geometrical parameters of multiple delta wing vortex generators influencing the friction factor performance are shown in Fig 2. These parameters can be defined as,

Axial pitch (p): the axial distance between the identical points of adjacent vortex generators is the pitch of the vortex generator configuration. Vortex generator height (e): the normal distance between the tip of the vortex generator and the surface of the wall upon which it is glued is the vortex generator height.

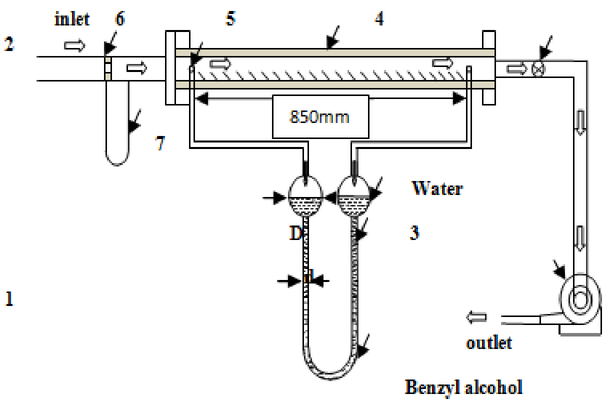

Fig-1 Experimental Set-up

Air blower 2.Controle valve 3.Micro deferential manometer 4.Rectangular duct 5.Pressuretap 6.orificemeter 7.U tube manometer

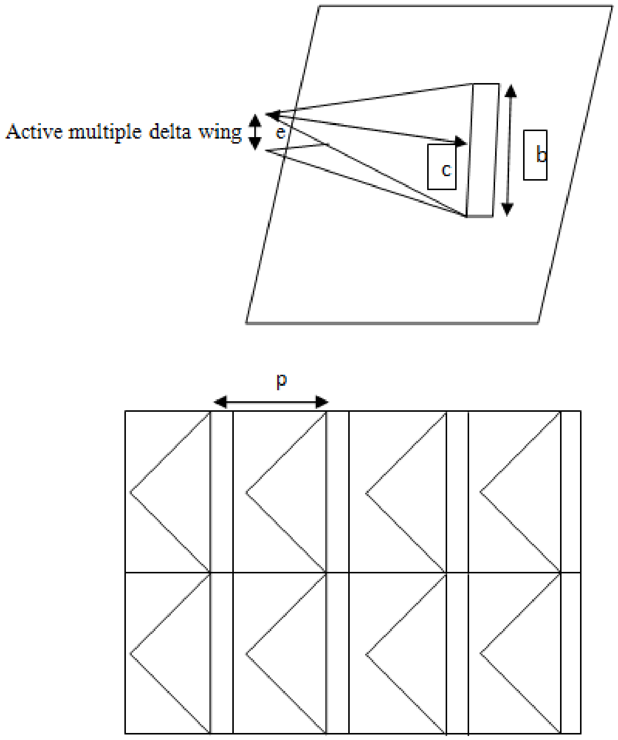

Fig-2 Geometry of multiple Vortex Generators

Vortex generator base (b): the span wise dimension of the vortex generator at which it is glued to the wall surface is the base or span of vortex generator. Chord length (c): the distance of the vortex generator tip from its base measured along the surface of the vortex generator is the chord length of the vortex generator.

The non-dimensional parameters are;

Vortex generator height to channel hydraulic diameter ratio (e/Dh): this is the ratio of the height of the vortex generator tip, measured above the surface upon which they are glued, to the channel hydraulic diameter. Pitch to height ratio (p/e): It is the ratio of the axial distance between two identical points of the adjacent vortex generators to the vortex generator height. Aspect ratio (ar): the non-dimensional parameter, which is a measure of the shape and size, is known as the aspect ratio of the vortex generator. The aspect ratio for multiple delta wing type vortex generator is given as [ar =b2/AVG or 2b/c]. Angle of attack (β): the angle subtended by the surface of the multiple delta wing vortex generator with the surface to which it is glued is known as the angle of attack of the vortex generator. The Roughened wall width of the channel to the vortex generator base ratio (N): this is the ratio of the width of the surface upon which vortex generators are glued to the base width of the vortex generator. Since, this value exactly equals the number of spanwise rows of the vortex generators it is an integer.

The dimensionless friction factor is defined as ff/ffs where ff is the friction factor of rectangular duct with vortex generator and ffs is the friction factor of rectangular duct without vortex generator or smooth duct. The Reynolds number is defined as Re=ρv*Dh/μ where v is velocity of air in duct Dh is hydraulic diameter and μ is Dynamic viscosity of air.

Governing equations

$$\Delta P=\rho_2 gh[1-(\rho_1/\rho_2)+\{(a/A)*(\rho_1/\rho_2)\}] \quad (1)$$

$$ff \text{ or } ffa = \Delta P/[(4L/D_h)(\rho_a v^2/2)] \quad (2)$$

$$fft=0.046Re^{-0.2} \quad (3)$$

A differential manometer connected to pressure taps measures the pressure drop across the test duct. The schematic arrangement and dimensional details of the differential manometer are given in Fig1. The measurement of pressure drop was done at the atmospheric temperature condition (i.e., tests without heating). In a fully developed duct flow using equation ΔP=ρ2gh[1-(ρ1/ρ2)+{(a/A)*(ρ1/ρ2)}]. The friction factor was determined in terms of pressure drop across the test duct and the mass velocity of air as. ff or ffa = ΔP/[(4L/Dh)(ρav2/2)]. The friction factor of the present study was normalized by the friction factor for fully developed turbulent flow in smooth duct (l04< Re < 106) proposed by Blasius as. fft=0.046Re-0.2

Results and discussion

Figure3 is the graph of friction factor vs Reynolds number for the smooth rectangular channel ffa means actual friction factor obtained from experiment fft is the theoretical friction factor obtained from the Blasius equation for the smooth channels. From this graph we can say that the experimental results for friction factor in smooth rectangular duct agree well with values estimated from correlation proposed by Blasius.

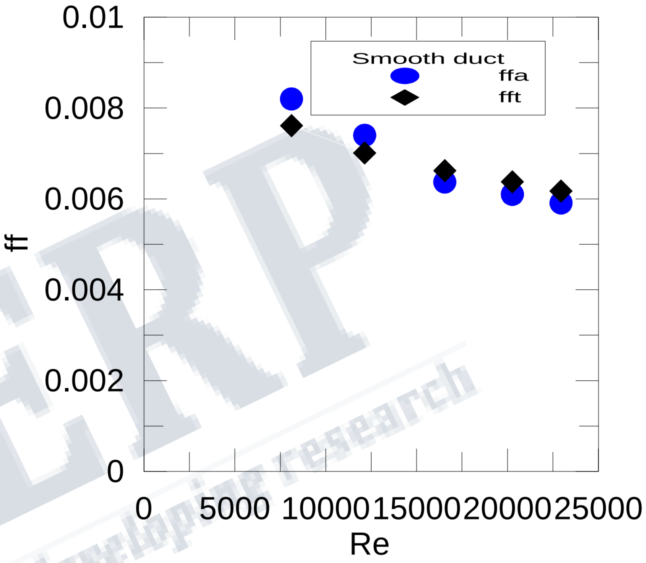

Figure3. Results obtained from smooth duct

Effect of Pitch to height ratio *(p/e)* on friction factor ratio *(f/fs)* for given Reynolds numbers and for different Vortex generator height to channel hydraulic diameter ratio *(e/Dh)*. Figure 4 to 7 shows the effect of pitch to height ratio on friction factor ratio *(f/fs)* for different Reynolds number with wings having aspect ratios *ar*=2.31 and *e/Dh*=0.2,0.3,0.4,0.5 in a rectangular duct.

The friction factor ratio increases with reducing pitch to height ratio as shown in Fig 4 for different Reynolds numbers. The smaller *p/e* ratio provides shorter axial distance before flow gets obstructed by the axially placed next vortex generator which results in a higher friction factor ratio. The increased overall mixing of the flow at lower *p/e* ratios also contributes to the increased pressure drop.

In this figure results are compared and it was found that the value of friction factor ratio for the lower value *of p/e (p/e*=8) is 38% higher than the larger value of *p/e (p/e*=16) similar trend continue in the figures 5,6,7

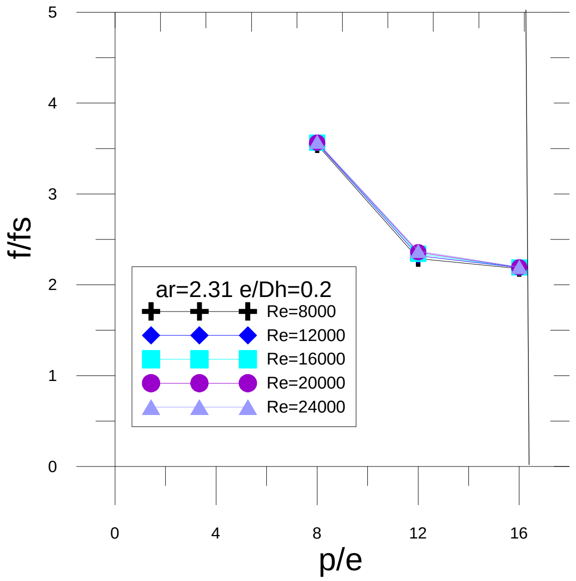

Fig-4 Variation in f/fs with p/e(ar=2.31,e/D_h=0.2)

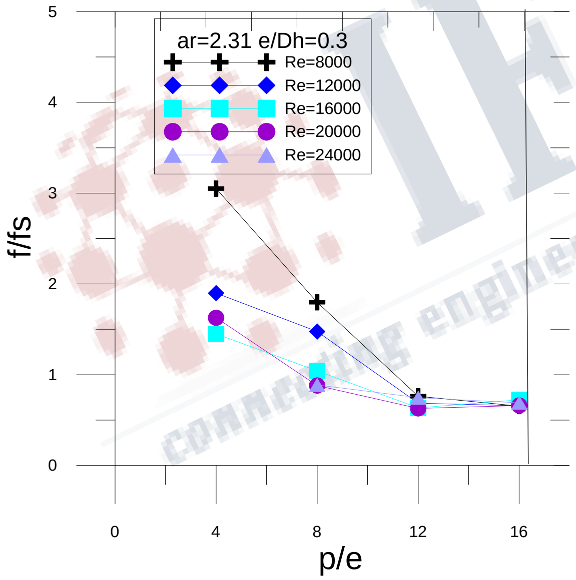

Fig-5 Variation in f/fs with p/e(ar=2.31,e/D_h=0.3)

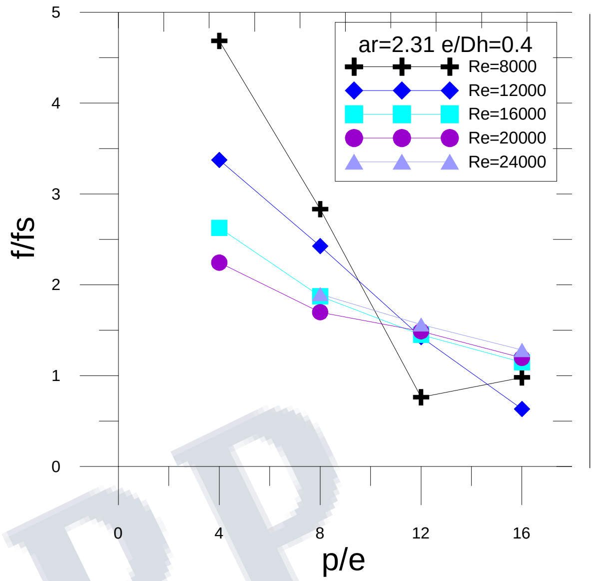

Fig-6 Variation in f/fs with p/e(ar=2.31,e/D_h=0.4)

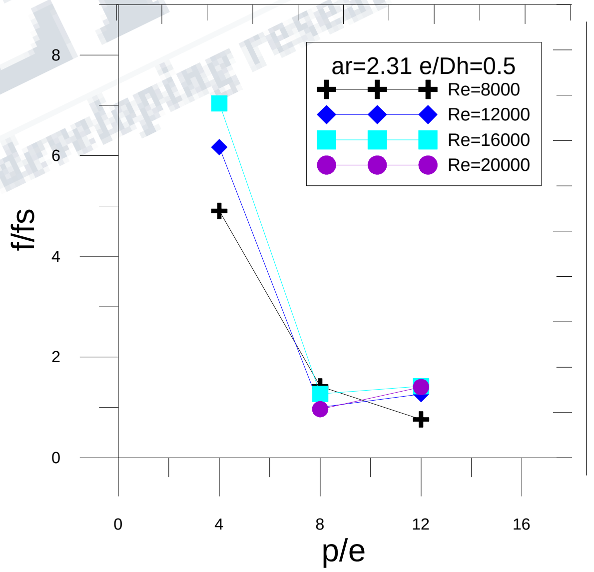

Fig-7 Variation in f/fs with p/e(ar=2.31,e/D_h=0.5)

CONCLUSIONS

Friction factor characteristics in the rectangular channel with the multiple multiple delta wing vortex generators (MDWVGs) are investigated for Reynolds numbers ranging from 8000 to 24,000. The effects of the Vortex generator height to channel hydraulic diameter ratio (e/D_h) on friction factor in the rectangular channel is explained in this paper. The concluding remark is increasing e/D_h friction factor ratio increases up to 30 to 60% from lowest e/D_h to highest e/D_h it means the pressure drop is increases in the channel with increase in generator height to channel hydraulic diameter ratio (e/D_h) and also friction factor ratio is reducing with increasing p/e value. From the observation of figures 4 to 7 we can also conclude that friction factor ratio is increasing with increasing Reynolds number.

NOMENCLATURE

D_h	Hydraulic diameter of test section
H	Channel height
D or A	Inside diameter or area of the micro manometer bulb
b	Vortex generator base
c	Chord length
e	Height of Vortex generator tip above roughen wall
h	Pressure head difference measured by manometers
N	Number of span wise rows of vortex generator
L	Distance between pressure taps
Re	Reynolds number
V	Velocity of fluid in a four-sided smooth duct
W	Width of the duct
D or a	Inside diameter or area of the micro Manometer tube
f	Experimental value of friction factor
fs	Theoretical Friction factor in a four-sided Smooth duct
Δp	Pressure drop across the test section measured by micro manometer

Greek Symbols

ρ_a	Density of air
ρ_1	Density of water
ρ_2	Density of benzyl alcohol
μ	Dynamic viscosity of fluid

REFERENCES

1. Biswas G and Chattopadhyay H, “Heat transfer in a channel with in wing type vortex generators.” Int. J. Heat Mass Transfer, Vol.35, No.4, pp.803-814, 1992
2. Sedney R., “A survey of the effects of small protuberances on boundary-layer flows”, AIAA J. Vol. 11, pp 782-792, 1973
3. Gentry M. C., and Jacobi A. M., “Heat transfer enhancement by Delta-winggenerated tip vortices in flat-plate and developing channel flows”, ASME Journalof Heat Transfer, Vol. 124, pp 1158-1168, 2002
4. Griffith T. S., Hadhrami L. A., and Han J. C., “Heat transfer in rotating rectangular cooling channels (AR = 4) with dimples” ASME Journal of Turbo machinery, Vol. 125, pp 555-564, 2003
5. Jacobi A. M., and Shah R. K., “Heat transfer surface enhancement through the use of longitudinal vortices: A review of recent progress.” Experimental Thermal and Fluid science, Vol. 11, pp 295-309, 1995
6. Shakaba I. M. M. A., Mehta R. D., and Bradshaw P, “Longitudinal vortices embedded in turbulent boundary layers. Part 1. Single vortex”, J. Fluid Mech., Vol. 155, pp 37-57, 1985
7. Tiggelbeck S., Mitra N., and Fiebig M., “Flow structure and heat transfer in a channel with multiple longitudinal VGs.” Experimental Thermal and Fluid science, Vol.5, pp.425-436, 1992
8. Tiggelbeck S., Mitra N. K., and Fiebig M., “Comparison of wing-type vortex generators for heat transfer enhancement in channel flows”, ASME Journal of Heat Transfer, Vol. 116, pp 880-885, 1994
9. Zhu J. X., Mitra N. K., and Fiebig M., “Effects of longitudinal vortex generators of heat transfer and flow loss in turbulent channel flows”, Int. J. Heat Mass Transfer, Vol. 36, pp 2339-2347,
10. 1993 Gentry M. C., and Jacobi A. M., “Heat transfer enhancement by Delta-wing vortex generators on a flat plate: vortex interactions with the boundary Layer”, Experimental Thermal and Fluid Science, Vol. 14, pp 231-242, 1997
11. Fiebig M., Kallweit P., Mitra N. and Tiggelbeck S., “Heat transfer enhancement and drag by longitudinal VGs in channel flow.” Experimental Thermal and Fluid science, Vol.4, pp.103-114, 1991
12. Gentry M. C., and Jacobi A. M., “Heat transfer enhancement by Delta-winggenerated tip vortices in flat-plate and developing channel flows”, ASME Journal of Heat Transfer, Vol. 124, pp 1158-1168, 2002

13. Yang J. S., Seo J. K., and Lee K. B, “A numerical analysis on flow field and heat transfer by interaction between a pair of vortices in rectangular channel flow”,Current applied physics, Vol. 1, pp 393-405, 2001.