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Experimental Investigation of Disrtribution of Coefficient of Static Pressure on the Concave Curved Surface Due to Impingement of Air Jet from an Orifice for Confined Flow

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Abstract* – The jet impingement cooling have better mobility and effectiveness, because of this it has been broadly used in thermal or thermal related industrial systems. Jet impingement is one of the well defined techniques for cooling, heating of a surface. Such impingement flow allows small flow path on the surface with relative high heat transfer rate. Since local heat transfer coefficients depends on flow characteristics such as static pressure distribution. The present work is to study experimentally the distribution of static pressure on the concave curved surface due to air jet impingement from an orifice for confined flow. The experimental includes measurement of static pressure difference on concave curved surface for various parameters such as d=16mm (diameter of orifice), Z/d=1to 4(non dimensional distance between orifice exit plane and curved surface plane) $\theta=0^0$ to 40^0 (circumferential location indicated as angular position on concave curved surface measured from the direction of jet impingement at the centre of curvature) for Reynolds number of flow 5000 to 45000. It is observed that coefficient of static pressure C_p is independent of Reynolds number.

The results revels that higher value of C_P are observed up to $\theta=0^0$ and decreases along the circumferential location .Higher values of C_p are observed at lower Z/d ratio as the velocity decay is minimum at this position.

Keywords— Jet Impingement. Static Pressure. Confined Flow. Concave Surface.

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I. INTRODUCTION

Jet impingement is one of the well defined methods for cooling, heating and drying of surfaces. Such impingement allows small flow path on the surfaces with relative high heat transfer rates. Since local heat transfer coefficient depends on flow characteristics such as static pressure distribution, the present work is to study experimentally distribution of static pressure on the concave curved surface due to air jet impingement from an orifice for confined flow. Researches in these topics have accelerated in recent years because of its high potential local heat transfer enhancement. Application of jet includes thermal management of electronics equipment, glass tempering and annealing, paper and ceral drying, in gas turbine industry impingement cooling use in cooling of blades, vanes, of gas turbine.

In some of the advanced gas turbine inlet temperature gas is more than the melting point temperature of blade material hence, turbine blades are need to be cooled using the cool air bled from the compressor for improved performance. Van treurm[1] reports that reduction in the blade metal temperature by 40^0C, the blade life can be increased by ten times. Jet impingement for cooling blades are essentials with acknowledge of static pressure distribution and heat transfer [2]. Two regions are identified in gas turbine blade which needs to be cooled are leading edge region and mid-chord region, as shown in Fig1. The hot gases impinge at leading edge of aerofoil section of gas turbine.results obtained with single jet can be used for row of impinging jets on concave surface with little modifications .

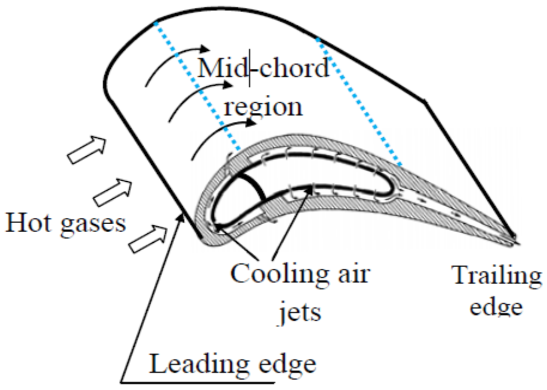

Fig.1.Gas turbine blade cooling with an impingement of jet

There are many research and development in jet impingement technique over a last few decades and maximum work conducted is related to flat surface but only few works are done on Curved surface. Tabakoff, W. and Clevenger, W[4] have done study on this topic by using slot jet on the curved surface and they stated that static pressure decreases along the curvature at higher at lower ratios of diameter of curved surface of slot width. Ramkumar and Prasad[5] have done experiment by using one row of jet and five row of jet(multiple jet) by varying a parameters like Reynolds number, nozzle to plate distance, and jet to jet spacing. And they come to conclusion that local pressure and heat transfer coefficients distribution showed the presence of secondary peak corresponding to the up to wash jet to jet interaction Vadiraj Katti et al, [6] have done experiment using single row of multiple jet on concave curved surface and stated that coefficient of static pressure decreases at higher jet to plate distance. And a secondary peak is seen between adjacent jets.

It is observed from above observation; jet impingement is well grown up method over a last few decades. Many Researchers and Scientists explained a various geometrical parameters which influence static pressure coefficients. Therefore it is necessary to study and understand the characteristics of jet and how it impinges on target surface.

Hence the present work focuses on static pressure distribution on confined concave curved surface due to impingement of air jet from an orifice. The work is carried out for various geometrical parameters such as Reynolds number (5,000 to 45,000), Z/d (1 to 4) and influence of curvature angle θ= (10^0 to 40^0) with confinement. The results from experiments could find a significant role in modifying and designing the gas turbine blades.

NOMENCLATURE

- d — Diameter of orifice (m)
- Re — Mean jet Reynolds Number
- ρ_a — Density of air (kg/m^3)
- H_w — Manometer head (m)
- Z — Distance between nozzle exit plane and curved surface plane(m)
- Z/d — Non dimensional distance between nozzle exit plane and curved surface plane
- T_j — Jet air temperature (^{0}C)
- ρ_a — Density of air at nozzle exit (kg/m^3)
- μ — Absolute viscosity of air (kg/ms)
- C_d — Co-efficient of discharge of venturimeter
- V_j — Velocity of jet(m/s)
- θ — Circumferential location indicated as angular position on the concave curved surface with respect to centre of curvature measured from direction of impingement of jet(^{0})
- C_p — Static pressure coefficient
- C_{po} — Stagnation pressure coefficient
- $\dot{m}$ — Mass of air(kg/s)
- ΔP — Difference between gauge wall static pressure and atmospheric pressure

EXPERIMENTAL SETUP AND PROCEDURE

The experimental set up for the current work is as shown in the Fig.2. The Experimental setup consists of Air screw compressor (make ELGI Airmate, with capacity of 1.1m^3/min and maximum supply pressure of 7 bars), flow control valves, venturimeter, sliding table, pressure gauge, pressure regulator, millivoltmeter, and micro manometer

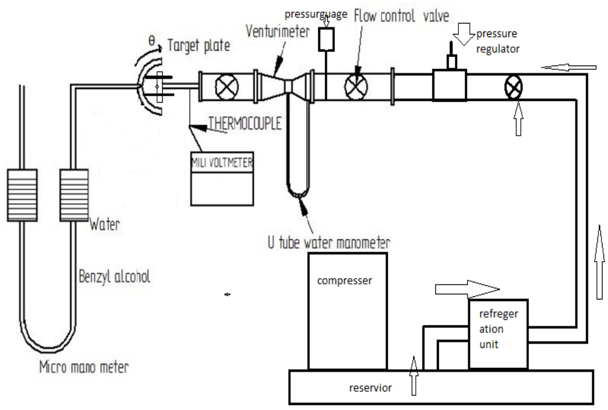

Fig.2. schematic layout of the experimental setup

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The Venturimeter is designed and calibrated whose coefficient of discharge C_d is found to be 0.92 ±2%. The flow rate is adjusted by flow control valves, the Reynolds number is set by adjusting the flow rate with the calibrated venturimeter. The temperature of jet and room temperature is measured by calibrated K type thermocouple placed near nozzle exit. In addition, all experiments were performed under a steady state.

The target surface of inner diameter 50mm and 10mm thickness is used as concave curved surface as shown in Figure.3. The curved surface is mounted on calibrated compound sliding table so that it can be fixed at a particular *Z/d* position and curved surface can also be moved circumferentially at a particular angular position with respect to centre of curvature, measured from the direction of impingement θ. The Slider of 15mm width with 0.5mm diameter hole at the centre used as pressure tap to measure stagnation pressure, and this slider is inserted at the middle of the target surface to measure the pressure at different Circumferential angles (θ=0-40°).confinement plates for different *Z/d* are attached to the target surface. The air is blown through orifice of diameter 16mm over the confined concave curved surface at a particular Reynolds number of flow at the orifice exit. Janatics air-pressure regulator is used to regulate air pressure. The static pressure difference is measured by double bulb, two fluid micro manometer using benzyl alcohol and water as manometer fluids, with magnification factor 14.59.

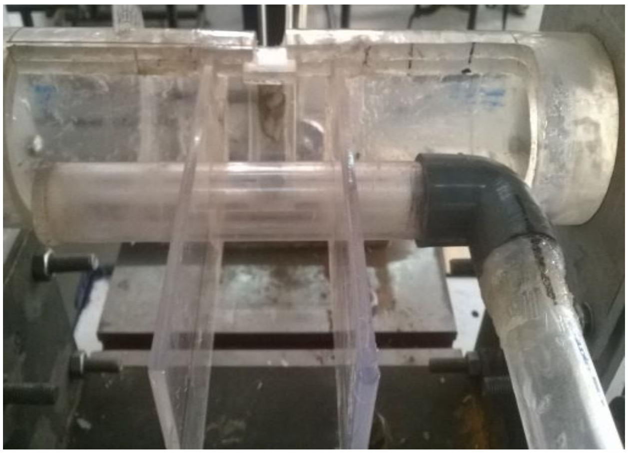

Fig.3.An Image of Concave Curved Surface with Confinement plates

The total length of target surface is 300mm including the slider. Confinement plates of 150mm length and 70mm width and one end with curvature of 50mm which provides confinement flow for the jet, for different Z/d different plates are used and these confinement plates are attached to concave curved surface with help of Anna bond, the care has to be taken to maintain the smooth concave surface while attaching these confinement plate and also there is no stepped surface created between the slider and reaming part of target surface, the movement of slider along circumferentially must be smooth.

III. DATA REDUCTION

- The jet Reynolds number is defined on the basis of orifice diameter and is estimated using the following equation

$$\mathrm{Re} = \frac{4 \times \dot{m}}{\Pi \times d \times \mu}$$

d = Nozzle Diameter

μ = coefficient of dynamic viscosity

The actual mass inflow rate through the jet-tube $\dot{m}$ is measured using the calibrated venturi flow meter.

- Temperature of jet at exit of orifice in (c^0)

$$T_j(^0C) = 23.188 \times v + 3.843$$

- Density of Air from jet in (kg/m^3)

$$\rho = \frac{P_{atm}}{0.287 * (T_J + 273)}$$

- Difference between gauge wall static pressure and atmospheric pressure in (Pascal's)

$$\Delta p = 1000 * 9.81 * H_w$$

- Velocity of Jet at exit of Orifice in (meter/sec)

$$v_j = \frac{4 * \dot{m}}{(\pi * d * \rho_a)^2}$$

- The coefficient of pressure (C_p) is calculated as the ratio of the static pressure (gauge) at a given location on the concave semi-circular surface to the velocity head at the jet exit.

$$C_P = \frac{P - P_\infty}{0.5 \rho Vj^2} = \frac{\Delta P}{0.5 \rho Vj^2}$$

IV. RESULTS AND DISCUSSION

An experiment is conducted on the concave curved surface to determine coefficient of static pressure distribution ($C_p = \Delta p / 0.5 \rho A V_j^2$) by impinging jet of air through an orifice for confined flow at steady state, for different geometrical parameters.

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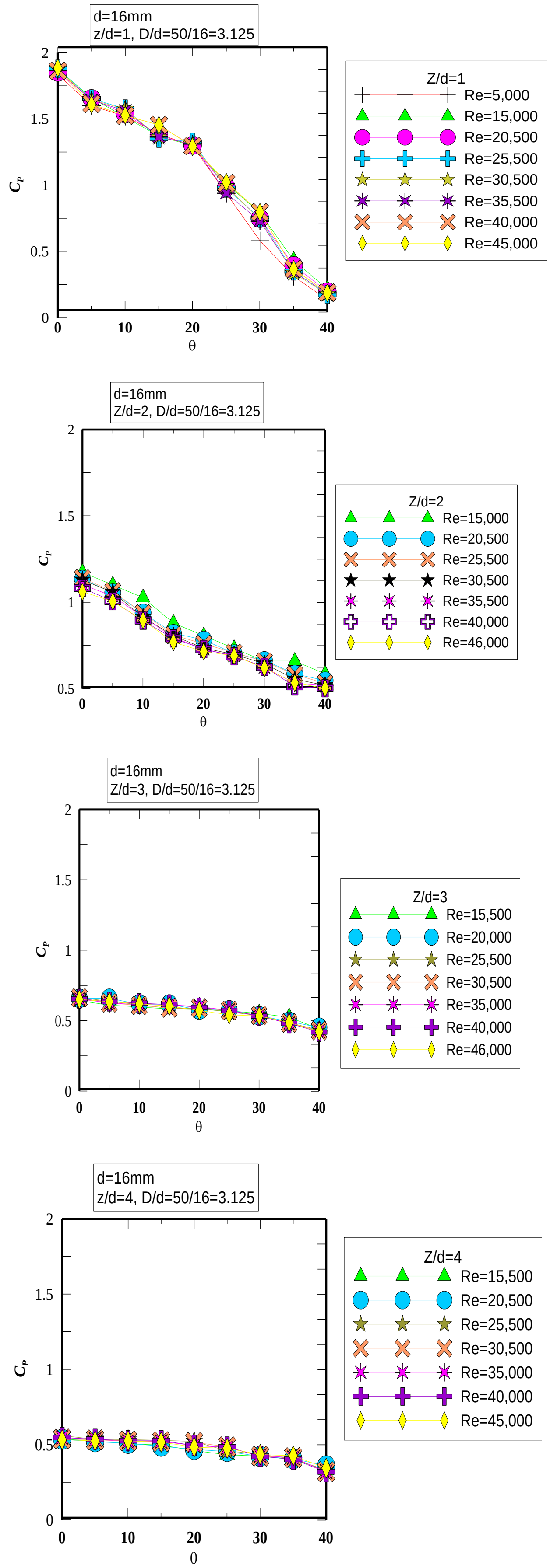

Fig.4. C_p v/s θ for various Reynolds number at different Z/d

The Static Pressure co-efficient C_p for different Reynolds numbers are determined for *Z/d* 1, 2, 3&4. From the Figure 4, **C_p v/s ϴ,** it is observed that co-efficient of static pressure *Cp* is independent of Reynolds number as the curve overlaps to each other and same trends observed for all *Z/d*. Hence further analysis is carried out for one representative Reynolds number (Re =40000).

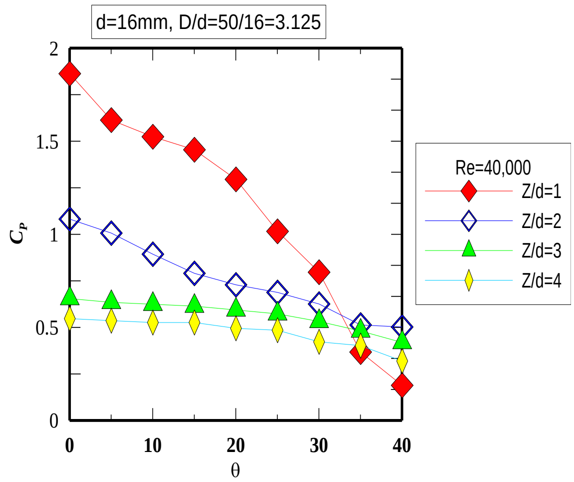

Fig.5. C_P v/s θ at *Re*=40000 for various *Z/d*

From the Figure 5, Static pressure co-efficient **C_p vs. ϴ**, the higher values of C_p are obtained at stagnation because of higher center line velocity. The value of C_p decrease gradually up to ϴ=10^0 and decrease appreciably for higher value of ϴ, atmospheric condition is reached on the concave curved surface at circumferential angle higher than from the point of impingement

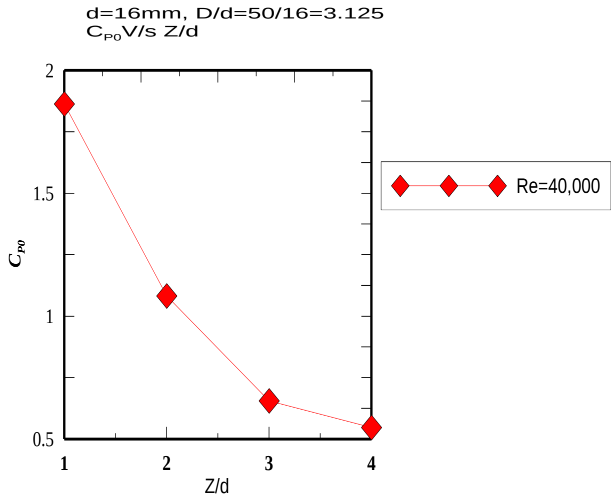

Fig.6. C_{po} v/s Z/d at Re=40000

From the Figure 6, of Stagnation pressure co-efficient C_{po}v/s *Z/d,* revels that stagnation pressure co-efficient are higher at lower Z/d ratio. It decreases gradually from *Z/d* 1 to 4. So the value of C_{po} is 1.5 to 1 for the *Z/d* = 1 to 2, this is due to target surface is located within the potential core of free jet. Then the appreciable decrease of is observed for further increase in *Z/d* ratio.

V. CONCLUSIONS

The Experimental determinations of static pressure distribution on concave curved surface due to impingement of air jet from an orifice for confined flow along various geometrical parameters are studied.

The following conclusions that are obtained from this study.

- The static pressure distribution on the target surface due to impingement of air jet is independent of Reynolds Number of flow.
- The C_P on the concave curved surface are almost uniform up to $\theta=10^0$ & decreases appreciably for higher value of θ.
- The values of Stagnation pressure co-efficient C_{po} is higher at lower *Z/d* ratio and they decreases appreciably for higher value of *Z/d* this is because decay of velocity of jet after the potential core region.
- The potential core of free jet is observed for the *Z/d* ratio between 1 & 2. The velocity decay is minimum for this range of *Z.*

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