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Flow Characteristics of Round Air Jet over a Rectangular Cavity

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Abstract

Experimental investigation is carried out to investigate the pressure distribution in a rectangular cavity due to impingement of round air jet. The present investigation shows the dependence of the pressure on jet exit Reynolds numbers. It was observed that, the overall pressure coefficient C_p, decreases with the increase of jet exit Reynolds number. The jet exit Reynolds numbers of 11406, 11933, 12924, 13326, 13518 are considered for the experiment. The coefficient of pressure decreases with the increase of jet exit Reynolds number because of the fluid moving with high kinetic energy initially and decays along the length of the surface due to frictional effect. The cavity length to depth ratio 4, 5, 18 for the investigation are considered.

Keywords: *Cavity, Laminar, Coefficient of pressure, Recirculation.*

1. Introduction

Many investigations, both experimental and computational have been conducted to study the flow field and define the mean pressure distribution within a rectangular cavity. The present work is concerned with reducing the pressure load inside the cavity for a number of current and future applications. Active control of these pressure load is desired due to the cavity exposure to dynamically changing flow condition. In case of flow over a cavity, a surface discontinuity in the form of a sudden expansion and the resulting adverse pressure gradient cause separation. The flow then basically behaves as a free shear layer, with high speed fluid on one point and low speed fluid on the other. A jet is a steam of fluid ejected from a nozzle as shown in ***Figure 1***.

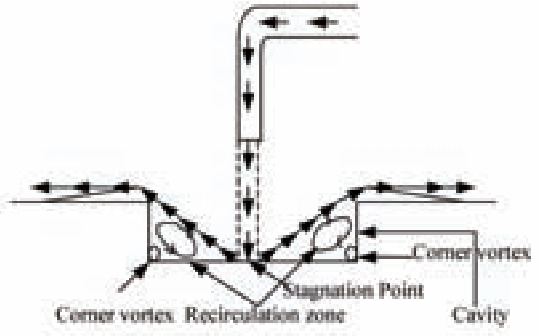

Figure 1. *Fluid flow along the open cavity.*

The cavity pressure distribution consists of both broadband & small amplitude pressure fluctuations typical of turbulent shear layer. The most interesting aspect of cavity flow is the initiation of self sustained oscillations of the cavity shear-layer between the free stream flow and the cavity fluid. Flow past a cavity has a wide range of applications, from the aeronautical to the nautical fields. Much aeronautical applications, with less attention given to the low speed case, such as automobile and marine applications. In order to explain the behavior of the fluid motion in this system, there is a need for research on low speed flow past over cavities. Thus the first aim of this study was to experimentally characterize low Reynolds number laminar flow over a rectangular cavity using both qualitative and quantitative methods. In the present work, a systematic experimental study of the pressure distribution of the cavity flow for impingement of round air jet is current interest of various aspect ratio in the incompressible flow. In turbulent flow, the molecules in the flowing fluid are moving in a random manner. The molecules of flowing fluid transfer momentum and energy from one place to another by the mixing of the fluid particles typically termed as eddy mixing.

Investigations have been reported in last few decades emphasized on various aspects of fluid mechanics pressure distribution of free jet. However, most of the earlier studies are confined to free jet on smooth surfaces. This study has been encountered to investigate the pressure distribution due to flow of round air jet over a rectangular cavity. In this case, pressure distribution between the smooth cavity and round air jet was investigated experimentally to investigate the fluid flow characteristics in a cavity. The jet of fluid with high kinetic energy exits from a nozzle of relatively narrow circular hole. Just before the nozzle tip, the fluid has the high pressure, but after the nozzle tip, the fluid moving with high velocity and then the pressure remains at atmospheric. In the present investigation the fluid with high kinetic energy exits from the nozzle, impinges on the rectangular cavity and flows over the solid surface as shown in ***Figure 1***. As a result, the velocity of the fluid will decrease when it gets into contact with the solid surface, and a boundary layer will develop. The jet of fluid flows over the surface and gradually boundary layer develops. After the flow of jet, the surrounding fluid will move and energy is transferred from the jet to the surrounding fluid. As a result, the jet of fluid decays gradually. The maximum pressure decreases with the increase of X.

In order to properly describe the pressure distribution in the cavity, it is necessary to introduce the flow phenomena along the cavity. As shown in the cavity a roll-up vortex formed near the leading edge of the cavity and a shed vortex formed near the trailing edge of the cavity. The cavity flows are said to be closed, if the shear layer reattaches on the bottom wall of the cavity. For a closed cavity, the shear layer reattaching on the bottom wall, encloses recirculation zone on each side.

The location of the separation point depends primarily on the geometry of the body and the direction of flow or nature of flow. If the body has an abrupt change in geometry and change in flow direction as shown in figure, separation will occur at the abrupt change. In addition, reattachment will occur at some location as shown in the above figure. Consider the flow, impingement of round jet on the cavity; the first separation occurs just near the front lip and just before the rear wall of the cavity. The stagnation point occurs at the floor of the cavity and the reattachment occurs just after the rear wall and front lip of the cavity.

2. Literature Review

The self sustained selection results from an aero acoustic feedback loop, as described by Powell [1] in the case of the jet edge interaction. The study of the flow field in a rectangular cavity has been carried out by theoretical and experimental investigations of the acoustic response of cavities in a aerodynamic flow by Plumbee *et al* [2]. Rossiter [3] is one of the first investigators who related the flow oscillations to the presence of concentrated vortices. R.A. Bajura and Albin A. Szewczyk [4], made an experimental investigation of a two dimensional circular jet at low Reynolds number with small disturbances in the jet. The main characteristics of the laminar regime were in agreement with theoretical results. The stability of the flow was studied for the Reynolds number ranging from 270 to 770. H. Miyazaki and E. Silberman [5], analyzed theoretically the two dimensional laminar jets issuing from a nozzle of half width, which terminate at height above a flat plate normal to the jet. Sato. Y. *et al*, investigated experimentally and numerically the interaction between dispersed particles and fluid turbulence for a vertical down-flow turbulent circular jet embedded in a uniform stream. Modifications of the mean fluid velocity by the particles induced reduction in the Reynolds stress, this alters the turbulence production. Turbulence modification by particles, with stokes number of order of unity, is due primarily to the extra dissipations, which is a function of particle mean concentration and fluid turbulence in the fully developed region. On the tones and pressure oscillations induced by flow over rectangular cavities has been carried out by Tam, C.K.W & Black , P.J.W [6].

At subsonic speeds, four types of mean cavity flow were designed by Wilcox [7] & Stallings [8], and these four types (open , closed, transitional closed and transitional open) will be briefly discussed. The first flow type generally occurs when the cavity is deep, as found in bomb bays and is termed open cavity flow. This flow type generally occurs for $L/h < 10$ at subsonic speeds. For open cavity flow, the flow essentially bridges the cavity and a shear layer is formed over the cavity. A weak shock wave can form near the leading edge of the cavity as a result of the flow being compressed slightly by the shear layer. A nearly uniform static pressure distribution is produced where the cavity flow is open, which is desirable for safe store separation. The second type of cavity flow is found with shallow cavities and is termed close cavity flow. The cavity configurations typical of missile bays on fighter aircraft are sallow cavities. At subsonic speeds, closed cavity flow generally occurs for $L/h > 13$. In this flow type, the flow separates at the forward face of the cavity, reattaches at some point along the cavity floor, and then separates again before reaching the rear cavity face. This creates two distinct separation regions, one downstream of the forward face and one upstream of the rear face. This flow produces an adverse static pressure gradient that can cause the separating store to experience large nose-up pitching moments.

The third and fourth mean cavity flow types (transitional-closed and transitional-open) occur for cavities with values of L/h that fall between those for closed cavity flow and open cavity flow, (i.e. the values of L/h range between 10 and 13). Transitional-closed cavity flow in the past has been referred to as transitional cavity flow described by Stallings [8]; however, the impingement shock and the exit shock that normally occur for closed cavity flow coincide and produce a single shock. Similar to the result for closed cavity flow, large longitudinal pressure gradients occur in the cavity that can contribute to large nose-up pitching moments. Plentovich E.B., Stallings, R.L. and Tracy M.B [9], investigated the experimental pressure measurements at subsonic and transonic speeds. An experimental investigation was conducted to determine cavity flow characteristics at subsonic and transonic speeds and in particular to determine the cavity length to depth ratio L/h for the boundaries of the different cavity flow types. The flow characterization within a rectangular cavity at low Reynolds number and for a length to depth ratio of 10 is described with a representation of velocity vectors and turbulence intensity. The stagnation zone in the flow is specially focused on and a detailed description of the flow evolution downstream and upstream from the cavity is given. These measurements show that no reattachment point exists at the bottom of the cavity. The results show that the area including the separated shear layer upstream from the stagnation zone is unaffected by the rearward facing step and in the same time by the second recirculation zone. The body of free jet and jet impingement is large. Most early works were concentrated on impingement of round air jet on smooth surfaces. Hossain, K.A. and Arora, R.C. [10] described that impinging jet behaves essentially like a free jet ahead of stagnation point. The pressure does not remain constant. Pressure increases as the flow approaches the stagnation region. In the stagnation region, the centerline velocity decreases to a zero value and pressure approaches to the maximum at the stagnation point. The unsteady flow structure due to a turbulent boundary layer past a rectangular cavity was characterized by Lin & Rockwell [11] in a large open water tunnel. Geveci *et al.* [12] perform the first study to provide instantaneous global representations of flow acoustic coupling in a cavity. T.K. Ganesh. and S. Pannersalvam [13] investigated the experimental and numerical investigation of confined unsteady flow over cavities. The present study serves to investigate the pressure distribution over the rectangular cavity at various jet exit Reynolds numbers Re.

But in our present work , we want to measure the pressure along the cavity surface for impingement of round air jet over a rectangular cavity. Impingement of round air jet on rectangular cavity has been investigated in the present investigation. In this investigation experimental data have been presented describing the pressure distribution of two dimensional round jet.

3. Experimental Setup and Procedure

The blower with filter is connected to an A.C. power supply as shown in ***Figure 2*** and the cavity is shown in ***Figure 3***. A variable switch is also connected to the blower so that the air velocity can be controlled. Throughout the experiments, the jet was centered along the surface, air flow was adjusted by rotating the knob of the variable switch. Then velocity of the air flow was measured by pitot tube and digital manometer from which velocity of the air and jet exit Reynolds number was calculated. When the flow become stable and fully developed the manometer head of the fluid is measured and the jet exit Reynolds number is calculated. Then the cavity with the plate is placed in the test section that is, on the table with some screw arrangement, so it can remove when cavity is not in use. The flexible vinyl rubber tubes are attached at one end of the copper tube as shown in ***Figure 4*** and the other end of the rubber tube is attached with the digital manometer (Model: METRAVI PM-01). The ambient temperature of air is recorded. During the experiment, the density and kinetic viscosity of the air is required to determine from a table of properties of air. Then, the flow of the air is supplied by the nozzle from the above of the cavity. Then the pressure reading is taken from every point of the cavity by manometer. After then, the flow velocity is increased by changing the power supply arrangement and the manometer readings are noted.

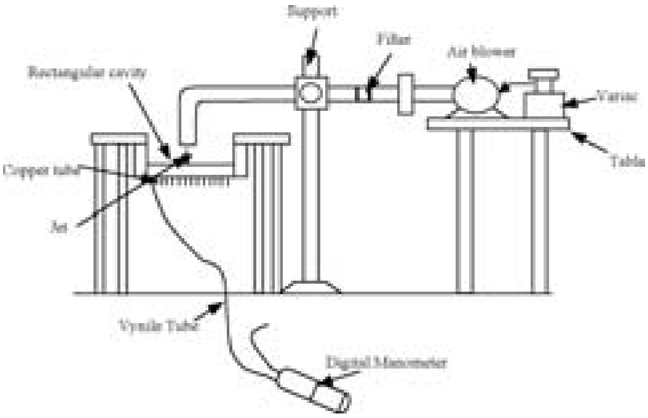

Figure 2. *Schematic diagram of experimental setup.*

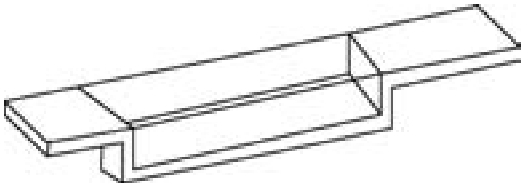

Figure 3. *Three dimensional view of rectangular cavity.*

Figure 4. *SchematicView of the experimental test section.*

A flat plate with a rectangular three dimensional cavity was mounted on the table. A flat plate was chosen as the present body to separate a well defined two-dimensional flow field, developed from the test section or inside the cavity. The model was supported in the centre of the table by four screws.

The cavity model, which is used for the current study, has a depth of 42 mm with a length of 756 mm for aspect ratio 18, depth of 15 mm with a length of 75 mm for aspect ratio 5, depth of 15 mm with a length of 60 mm for aspect ratio 4, and has a width of 116 mm. A drawing of the main components of the cavity model is shown in ***Figure 3***. The cavity frame is mounted on the table with a screw arrangement and its long cut-out that forms in the front, rear and side walls of the cavity. The bottom plate is then used to form the cavity floor. On the centerline of the cavity in the front wall, rear wall and floor it is drilled 1.5 mm at a spacing of 4 mm to place the pressure probe capillary tubes in the hole to measure the pressure readings from the manometer. The cavity material was selected as the transparent Perspex sheet. The copper tubes were fixed with the cavity and vinyl tubes are connected with the digital manometer and other end of the manometer is kept open to atmosphere.

4. Results and Discussion

After fixing up the aspect ratio, the experimental test section, that is, rectangular cavity was placed and various readings were recorded with changing different Reynolds numbers. In the present investigation, the pressure distribution over a rectangular cavity due to round air jet was investigated. Experiments were performed for jet exit Reynolds number 11406, 11933, 12924, 13326 and 13518 for jet diameter of 5 mm. The cavity was considered a smooth surface.

Pressure measurements were made for cavity lengths in the range 60, 75 and 756 mm, in steps of 4 mm. The depth was varied in the approximate range 15 and 42 mm, in steps of 1 mm. ***Figure 5***, shows the variations of pressure coefficient along the cavity bottom surface. It is observed that at the stagnation point maximum pressure coefficient is obtained and the velocity is zero at the stagnation point. The coefficient of pressure decreases with the increase of jet exit Reynolds number. Beyond a short distance the coefficient of pressure remains almost constant.

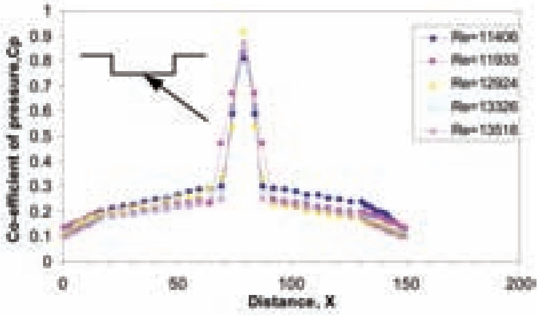

Figure 5. *Distribution of coefficient of pressure along the bottom wall at different Reynolds number at aspect ratio 18.*

The distribution of coefficient of pressure along the left and right surfaces were plotted for different Reynolds number and shown in ***Figure 6*** and ***Figure 7***. It is observed that the co-efficient of pressure decreases with the increase of Reynolds numbers, because of the fluid moving with high kinetic energy initially and decays along the height of the vertical surface due to frictional effect. The coefficient of pressure also decreases along the height of the vertical surface and becomes steady, but showed maximum value at the corner point. The decreasing rate of coefficient of pressure is higher at lower Reynolds number. If the Reynolds number increases with the increase of coefficient of pressure, then the flow is separated from the surface.

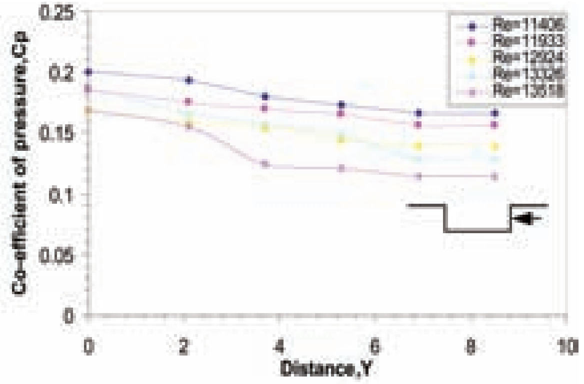

Figure 6. *Distribution of coefficient of pressure along the right side Wall at different Reynolds number at aspect ratio 18.*

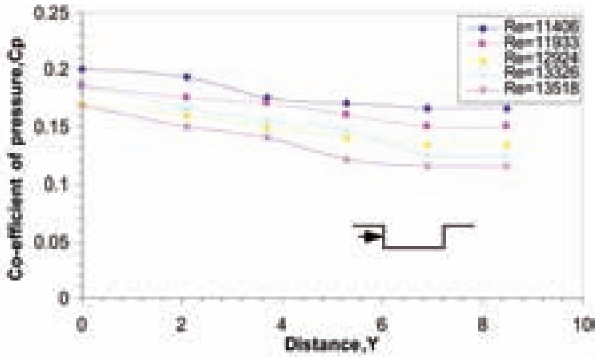

Figure 7. *Distribution of coefficient of pressure along the left side wall at different Reynolds number at aspect ratio 18.*

Figure 8 to ***Figure 10***, show the variation of coefficient of pressure at different Reynolds numbers at aspect ratio 5. The variation of aspect ratio shows that the magnitude of coefficient of pressure changes with aspect ratio. The changes of pressure variations were decreasing gradually on the left and right side wall of the cavity at each aspect ratio and the decreasing rate is almost similar.

In the first portion of the distribution of pressure coefficient curve along the bottom wall at different Reynolds number and aspect ratio 18 increases slowly and near the stagnation point it increased rapidly, because of the change of pressure gradient is sharp.

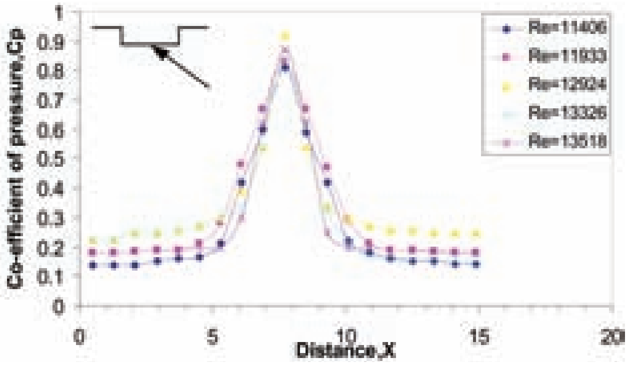

Figure 8. *Distribution of coefficient of pressure along the bottom wall at different Reynolds number at aspect ratio 5.*

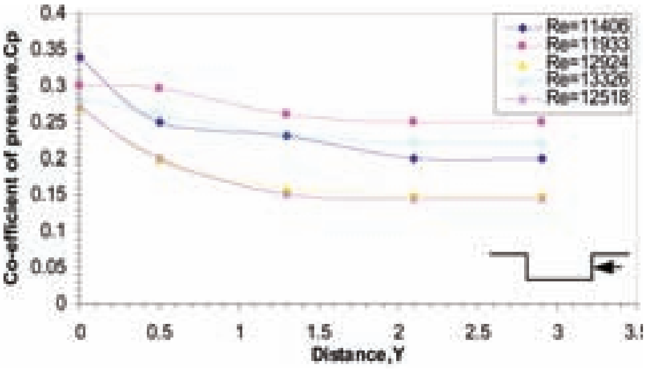

Figure 9. Distribution of coefficient of pressure along the right side wall at different Reynolds number & at aspect ratio 5.

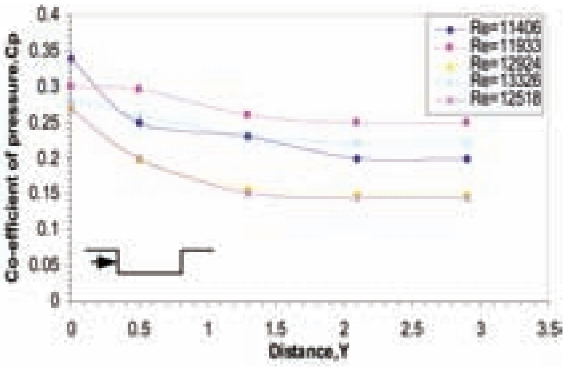

Figure 10. Distribution of coefficient of pressure along the left side wall at different Reynolds number & at aspect ratio 5.

Nomenclatures

C_p	$2(p-p_\infty)/ \rho V_\infty^2$
d	Diameter of the jet.
H	Manometer height, m.
L	Length of the cavity.
P	Pressure at any x direction,
P_∞	Ambiant Pressure
R_e	$\rho V_\infty d/ \mu$
W	Width of the cavity.
X	x/d, Distance along the flow direction at the bottom of the cavity.
Y	y/d, Distance on the left wall of the cavity from the top.
Y	y/d, Distance on the right wall of the cavity from the top.
ρ	Density of the air at the room temperature. Kg/m^3
μ	Viscosity of the air at the room temperature. $N\text{-}S/m^2$.

Conclusion

Analyzing the above results, the following conclusions were drawn as a consequence of the present work. Variation of pressure distribution due to impingement of round air jet over a rectangular cavity depends on jet exit Reynolds number in the following manner:

Coefficient of pressure decreases with the increase of jet exit Reynolds number and jet exit Reynolds number has significant effect on pressure distribution. Coefficient of pressure is maximum at the stagnation point for all jet exit Reynolds numbers within the range of parameters considered in the experiment. The magnitude of pressure coefficient is high at low aspect ratio for vertical walls, but at stagnation point aspect, ratio has no significant effect.

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