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AN EXPERIMENTAL INSIGHT INTO DEFLECTION PHENOMENON IN FLOW WALL JETS

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ABSTRACT
Deflection effect in pressure driven flow jets impinging on a wall is experimentally explored. The work attempts to gain physical insight into heterogeneous phenomena of flow jet deflection and related implications. The role of controlling parameters viz., central wall location and orientation in altering flow characteristics of an impinging flow jet is investigated. Experiments were performed with configuration comprising of a cascade tunnel imparting efflux at 36 m/s. The observations were noted for wall placement in three regimes viz., nearby, intermediate and faraway from the exit. Results are accentuated in terms of rate of change in flow characteristics and related energy transformation. The potential core region is noted to undergo substantial transformation with the presence of wall at varying orientation and location. Wall placed far away from exit results in diminishing returns with a critical value beyond which the flow characteristics become insensitive. Jet deflection follows a non-monotonic trend with the wall orientation which primarily governs intensity of flow deflection and related implications.

Nomenclature

ρ_a Density of air (Kg/m^3)

ρ_w Density of water (Kg/m^3)

V Flow velocity (m/s)

g Gravitational acceleration (m/s^2)

h_o Reading corresponding to zero differential pressure

$h - h_o$ Liquid head corresponding to the dynamic head

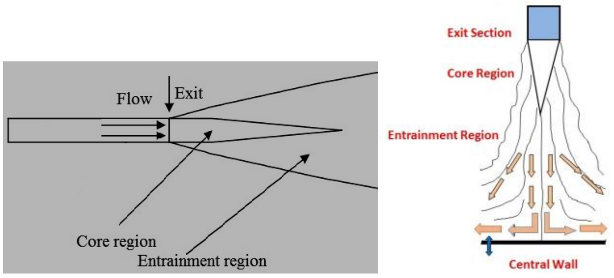
D Equivalent diameter of a circular exit (1D =18.54 cm)

W_θ Wall orientation

Keywords
Flow jet, wall position, flow deflection, pressure gradient, shear, momentum.

1. INTRODUCTION
Flow jet spreading is a phenomenon of practical and functional significance with wide range of applications. The phenomenon is broadly encountered and examples include aircraft gas turbine engines, liquid and solid rocket motors, boundary-layer separation control over a wing, film cooling on turbine blades, etc. The flow jet follows an expansion trend of processing through four distinct zones with distance viz., immediately after exit to highly energized region(core) leading to the fully developed core region and then entering into the entrainment and lastly into the termination zone.

Within each zone the flow undergo unprecedented energy and momentum transfer. The heterogeneous subject involves continuous mass and heat transfer and is broadly categorized as: Free and Wall Jet (Figure 1(a) & (b)). This classification is based on presence of a surface (i.e. wall) against the jet expelled.



(a) (b)

Fig 1: Schematic of (a) free jet (b) wall jet.

In free configuration, jet exit a nozzle into a stationary or moving fluid (same or different) and as it moves downstream, momentum drops owing to interaction with the surrounding fluid. Consequently, the efflux rifts into distinct regions of potential core (region where fluid interacts minimal with the surrounding medium and maintains nearly its initial speed) and entrainment (fluid interacts with surrounding fluid and loses momentum). Pilot fluid interacts with the surrounding fluid through a mixing layer (mixing of two fluids at different velocities) which contains shear having viscous stresses and significant velocity gradients perpendicular to the flow. The presence of shear layer dominates the momentum transport and causes vorticity owing to instability. The length of shear layer varies as empirically one-fourth of the downstream length. The fluid expansively interacts with the surrounding fluid in the entrainment region and it is identified by drastic change in flow characteristics. The unrestricted presence of entrainment region downstream leads to the flow jet devoid of all the momentum and into termination. With distance, the flow characteristics viz., pressure, velocity undergo rapid distribution resulting in significant energy transfer and transformation. The magnitudes of the core region in jets under different conditions is a prominent factor. Wall jets refer to the resultant efflux tangential/radial to the wall sides owing to presence of an obstruction to the flow. The presence of a surface obstructing the pressure driven flow is noted to results in large expanse of mass and thermal energy transfer between the surface and the fluid. The mixing shear layer is expected to get affected resulting in altered flow characteristics. However, this obstruction when placed at different location and orientation to the flow will bear momentous implications and is an aspect of fluid sciences yet to be comprehensively explored. Although much has been done but complexity of the problem has prevented a complete understanding. Therefore, a systematic study is needed to understand mechanisms controlling the behavior and flow characteristics of wall jets when subjected to diverse geometric arrangements (viz., varying wall location and orientation).

Following the classical work of Glauert (1956) highlighting the flow due to a jet spreading out over a plane surface. In the last five decades, research works have contributed significantly to the advancement in understanding of the flow jets. The contributions have been reported in several reviews like Gardon and Akfirat (1966), Kercher and Tabakoff (1970), Sparrow and Alhomoud (1984), Gau and Chung (1991), Gori and Bossi (2000). The works provide an excellent review on the developments up to the end of the century. In the last decade, appreciable advancements have occurred. Roy and Patel (2003) studied the dominant fluid-thermal characteristics of a pair of rectangular air jets impinging on an inclined surface. Heat transfer modes and flow characteristics were studied with eight different Reynolds numbers ranging from 500 to 20000. Aldabbagha and Mohamadb (2009) carried out a Three-dimensional numerical study to determine the flow and heat transfer characteristics of impinging laminar array of square jets on a moving surface. They stated that a rather complex flow field with horseshoe vortices formed around the first column of jets due to the cross flow created by the moving surface. The velocity ratio of the moving plate increases the cross flow as a result a ground vortex cannot form in front of the second and third column jets compared with the case of fix surface. In recently, Azam et al., (2013) studied pressure distributions and oil flow on the plate to figure out the flow structures for the rectangular nozzles by comparing three-dimensional calculations to the experiments. They investigated at three different aspect ratios under-expanded impinging jet issued from rectangular nozzle. The results stated that the flow is separated on the impinging plate from center point toward outside and that the flow on the plate avoids the high-pressure areas. San and Chen (2014) explored the effects of jet-to-jet spacing and jet height on heat transfer characteristics of an impinging jet array. In the preceding part of the present work (Tiwari et al., (2014)) experiments were carried out to investigate the effect of wall location on flow characteristics of an impinging jet and the core region. The work revealed that centerline wall location in different zones affects the shear layer and enhances the velocity losses with an infrequent trend. For a fixed wall location, velocity drop with distance in radial direction with enhanced rates but results in diminishing returns beyond a critical value.

In the light of above-mentioned works, the role of central wall location and orientation on flow characteristics and deflection is yet to be investigated. The present work primarily focuses on varying centerwall orientation for fixed location and resultant jet features post deflection. Deflection phenomenon is explored articulately and necessary advancements are made to fundamentally understand the governing science. The interest in this class of problems is specifically driven by the need to have better understanding of fluid and thermal characteristics of flow jets for efficient engineering and scientific applications. To address the above-mentioned issue, the present work:

1. Experimentally explores the effect of centerwall location and orientation on flow characteristics of an impinging jet.
2. Evaluates the deflected flow jets under varying conditions.
3. Analyzes the role of key controlling parameters.

2. EXPERIMENTAL SETUP AND SOLUTION METHODOLOGY

A simple apparatus (Figure 2) was adapted for present study. The experimental setup comprises of a) Cascade tunnel with mild steel base b) a Pitot Static tube and c) Projection Manometer and d) a central wall (Fig. 2(b)). The cascade tunnel issues air jet using a centrifugal blower through an exit section of rectangular opening (30 cm × 9 cm) with a velocity of 36 m/s into the air in a quiescent room. The efflux impinges on a smooth central wall surface made up of cardboard with dimensions of 180 cm × 120 cm × 1 cm. The assembly is operated thoroughly from the central side of flow imposition. The central wall location and orientation are important parameter varied in the study. Changes in flow characteristics viz., velocity distribution is determined in streamline and radial direction by establishing the pressure balance between dynamic pressure and the hydrostatic pressure. The dynamic pressure is measured using Pitot static tube and the projection manometer calculates the hydrostatic pressure due to change in elevation of the fluid used (here distilled water) for different settings. The manometer exhibits an accuracy level of 0.001 cm height of the fluid and can measure the differential pressure up till the range of 300 mm of the used fluid. The flow is turbulent and the effect was noted in fluctuations in the reading, so for every reading taken here the average repeated value was accounted.

(a) (b)

Fig 2: Pictorial view of the (a) experimental setup (b) central wall.

The flow velocity is obtained by equating the dynamic head to pressure head obtained by the liquid height change as:

$$\frac{1}{2}\rho_a V^2 = \rho_l g(h-h_o) \qquad (1)$$

From equation (1), the flow velocity "*V*" is determined as:

$$V = \sqrt{\frac{2\rho_l g(h-h_o)}{\rho_a}} \qquad (2)$$

It is important to note that all the readings were taken systematically in proper time interval and represent the repeatability to the count of three of results obtained.

3. RESULTS AND DISCUSSION

An experimental study was carried out to understand the effect of parametric variation of central wall location and orientation on jet flow characteristics. The kinetic energy transformation was investigated systematically via. velocity distribution in centerline and axial direction. In presence of an obstruction, the science of spreading jet flow deflection and consequential deflected flow velocity is methodically studied. The entire assembly was placed at three different zones viz. far away from exit (15D), at an intermediate distance (5D-10D) and at location very close to exit (<5D). The change and extent of change in flow features and related energy transformation is examined in terms of **"VRM_PPT point"** (representing 10% momentum loss).

It must be noted that 'D' represents the equivalent diameter of a circular exit when compared to exit of the cascade tunnel (here rectangular). To cover broad range, 'D' is used to normalize the distance (streamline direction) and 'Vmax' (velocity at the exit here, 36.18 m/s) is utilized to normalize all the flow velocity.

Prior to the main study, the experimental predictions were validated with the benchmark free and wall jet fluid dynamics. Readings were taken for cases of free jet and wall jet (placed at 15D) and results were compared with the standard cases to understand the jet related implications. Figure 3 shows the variation of normalized centerline velocity distribution as a function of normalized streamline distance for a free jet. The velocity value at center of exit section (0D) represents the maximum value(V_{max}) as no loss or ideal condition.

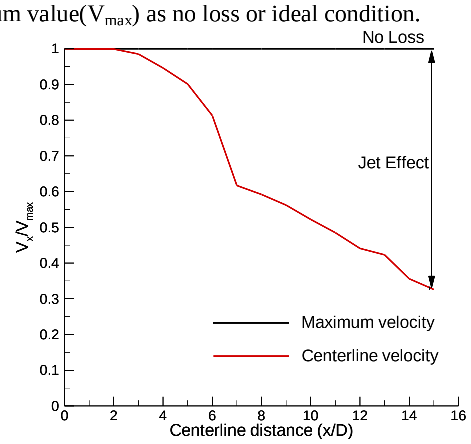


Fig 3: Variation of normalized centerline velocity as a function of normalized streamline distance for free jet.

Looking at the plot one can note that, experimental results highlight the "Jet effect (momentum loss with distance)" till flow termination zone with streamline distance. An infrequent trend of the flow momentum loss with axial distance is noted in core region (negligible flow momentum loss) which extends till 2.5D. Whereas, **5%** momentum loss occurs at 4D and **10% loss** (**"VRM_PPT point"**) at 5D. In the intermediate zone, momentum drops drastically to **40%** at 7D followed by linear drop till the end of zone(10D). In the faraway zone, gradual drop is noted viz., **50%** at 11D leading to enormous **65%** at axial location of 15D. Similar trend "Jet effect" was noticed in radial direction with distance. Figure 4 shows the variation of normalized radial velocity with radial distance at selected axial locations of 0D, 2D, 5D, 10D, 12D respectively.

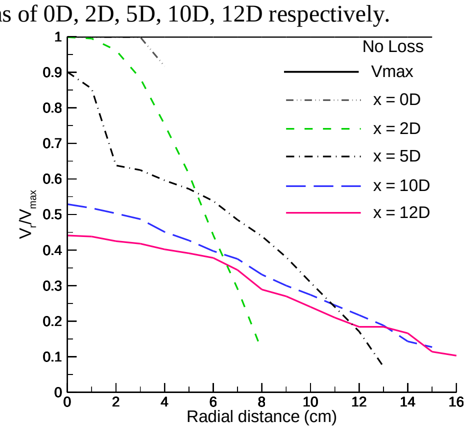


Fig 4: Variation of normalized radial velocity as a function of radial distance.

The variation of flow velocity was noted at a differential of 5 mm. Qualitatively, as streamline velocity variation dictates length of potential core region, the radial velocity component represents the width of core region. Zone wise, in nearby exit, minimal momentum loss was noted till 3 cm which extends to **5%** at 4 cm before termination. With increase in location at 2D, the core region was noted to reduce to 1 cm with **5%** loss noted at 2.5 cm and **10% loss** (VRM_PPT point) at 3 cm. At axial location of 5D, the flow is at transition of core and entrainment region and flow starts radially with **10%** drop from 'Vmax'. With increase in radial distance, **5%** momentum drop was noted at 1.2 cm leading to drastic drop of **35%** at 2 cm with **40%** drop at 4 cm and drops gradually till termination. In the intermediate zone (10D), the flow was noted to be in entrainment region and momentum drop rate reduces significantly viz., from centerline, **5%** momentum loss at 3.5 cm and VRM_PPT point at 6 cm respectively. Whereas, in the faraway zone (12D), flow follows trend similar to 10D with gradual drop in momentum. From the centerline, **5%** loss was noted at 5 cm and VRM_PPT point at 7 cm. It is interesting to note that the radial velocity components for 10D and 12D overlap at radial location of 13 cm which represents a region closer to flow termination. It is noteworthy that with consideration of practical and functional application of flow jets, from the free jet readings, the core region was noted to outspread till 5D in streamline direction and drops from 3 cm at exit(0D) to 1 cm at 2D and ~0.5 cm at 5D. The reason for above mentioned changes in axial and radial direction can be attributed to the interactions of pilot (jet) and surrounding fluid (atmosphere) within shear layer leading to strong energy conversions. Results were found to match reasonably well with the distinguishable physics and the preceding fluid dynamic theories. This validates the predictions of experimental setup and substantiates that it is likely to offer good physical insight into flow jet deflection phenomenon.

Following the free jet case, the pressure driven unrestricted flow was tested with the presence of a wall normal to the jet at varying locations. The wall effect was investigated in the capacity of wall placement in selected three zones viz., very near to exit (5D), intermediate zone (10D), at a location far away from the exit (12D) horizontal respectively. Figure 5 shows the variation of centerline velocity as a function of streamline distance for different wall location in comparison to the maximum velocity.

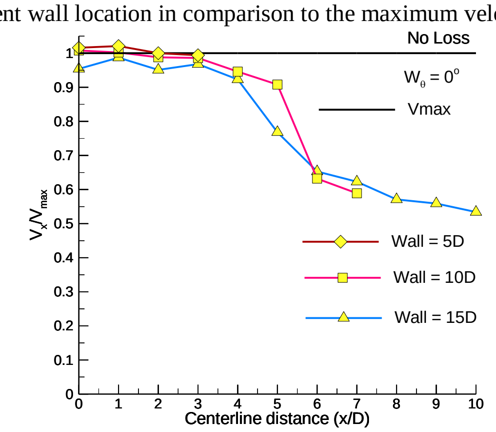


Fig 5: Variation of normalized centerline velocity as a function of normalized streamline distance for varying wall locations.

Looking at the plot one can note that, qualitatively a trend similar to free jet is observed the centerline velocity is seen lower than maximum indicating the kinetic energy loss. With increment in the central wall location, the momentum loss increases. The velocity profiles were seen to merge and overlap each other. It is interesting to note that, for wall at 10D, the momentum loss at 6D and 7D is more than 15D which indicate enhanced resistance owing to transformation. The fact dictates that up to a fixed wall location, the effect of shear interaction is within a closer range but as wall location increases, it behaves as a case of free jet and

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Volume 4 – No.1, February 2017

significant losses incur. The core region is signified by "VRM-PPT point" and exists in streamline and radial direction till 3 units = 56 cm. Till centerline distance of 3 units, the flow velocity loss was noted to be low for all profiles signifying the core region presence. Trend similar to far located wall (15D) is noted at a location of 10D. Beyond "VRM-PPT point" sharp drop in flow velocities is noted as all profiles fall drastically. Interestingly, at certain centerline distance the velocity profiles converges to corroborate the loss. For wall located at 10D the applicability of the flow can be more in comparison to the wall placed far away as the loss. The wall located close to exit paves way for strong flow deflection and vortices formation. The presence of wall acts as obstruction to the flow resulting in formation of vortices which strengthen over time reducing the momentum of flow and as a consequence limits the applications of the flow jets. When the assembly is placed far away from exit viz., 15D, the efflux approaches the assembly with already reduced velocity. Owing to reduction in kinetic energy due to shear interaction with surroundings, the formation of vortices or deflection of flow back will not be strong so it behaves like free jet. When the assembly is placed at some intermediate the reduction in flow momentum is minimized to a low level so the formation of vortices and deflection back is stronger than previous case and so it facilitates better mixing. The assembly placed closed to exit experiences the strong vortices formation and strong deflection of flow back so useful in rapid mixing. However, with this the chances of back flow with flow coming back to exit portion are strong. To understand the results in figure 5, we explore the effect of varying wall location on radial component of velocity. Figure 6 shows normalized radial velocity variation with radial distance for varying wall location.

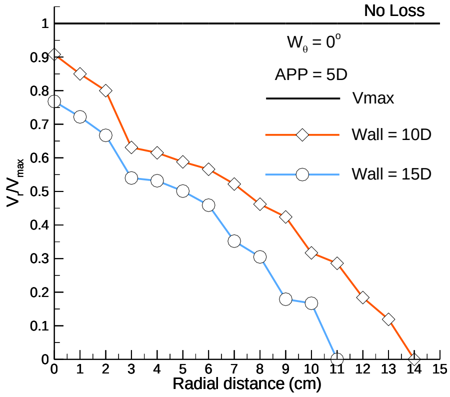

Fig 6: Variation of radial velocity at radial location of 5D as a function of radial distance.

The effect in radial direction is catapulted at axial location of 2D for all the profiles. All the profiles are in comparison to maximum centerline velocity. For all the profiles, a gradual drop till radial limit of "VRM-PPT" point is noticed followed by sharp drop. One can note that "VRM-PPT" point exists till 1 cm radial distance for the wall at 15D and 2 cm for 10D. The drastic momentum drop is noted with higher rate of reduction in flow velocity than far away placed wall (here 12D and 15D). Experimentation substantiates the core region as 2.5 units in axial direction and 1cm in radial direction. The above-mentioned result shows that the "VRM-PPT" point is low in comparison to flow impinging on a single wall. Wall locations of 12D and 15D almost follows same trend showing insensitiveness beyond a critical value. The above-mentioned fact indicates that, beyond a certain location the losses are insignificant to the wall position as most of the profiles look similar and follows same trend. The reason for this can be attributed to the shear interaction of flow as it starts expanding. The presence of walls edicts vortices formation which results in increased flow losses. When central wall is placed far away the exit, the flow reaches the wall location with reduced momentum. In the radial direction, profiles are more affected when the assembly is placed closer to the exit. Similarly, when central wall is placed far away the radial component becomes insensitive after some distance.

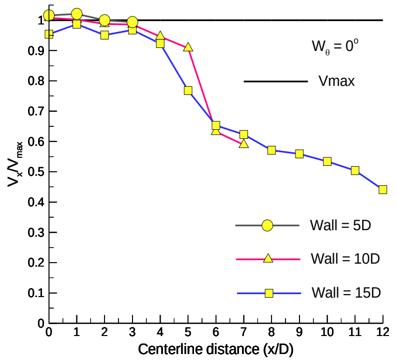

Fig 7: Streamline velocity variation with wall location (Central Wall orientation 0°).

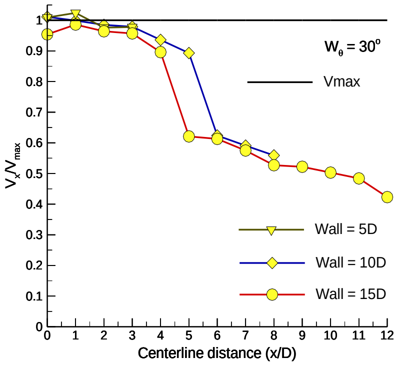

Fig 8: Streamline velocity variation with wall location (Central Wall orientation 30°).

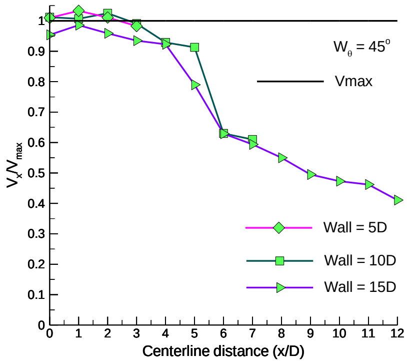

Fig 9: Streamline velocity variation with wall location (Central Wall orientation 45°).

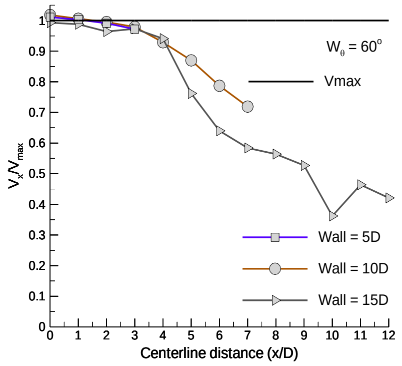

Fig 10: Streamline velocity variation with wall location (Central Wall orientation 60°).

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Volume 4 – No.1, February 2017

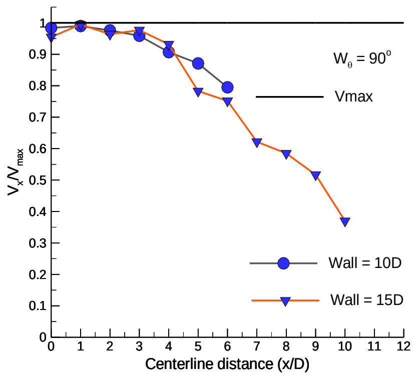

Fig 11: Streamline velocity variation with wall location (Central Wall orientation 90^o).

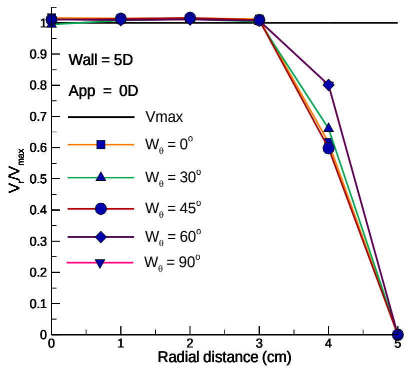

Fig 12: Variation of normalized radial velocity with varying wall orientations for varying central wall location.

The importance of proper wall placement was established and next, we look at the effect of wall orientation. Figure 7-11 shows variation of streamline velocity for varying wall location with fixed orientation. The study presents selected cases of centerwall oriented at 0^o, 30^o, 45^o, 60^o, 90^o and located at 15D,10D,5D respectively. The VRM_PPT point increases for all orientation up to 4D. It is interesting to note that the velocity profile undertakes a sudden drop at 10D location for 60 and 90 degrees and come back again to the following pattern after this distance. The reason attributed for this is the area of the wall faced, the distance from the exit and flow redirection while facing the wall at selected orientation. It shows a significant inter-energy conversion and increased entrainment region but at a lower velocity. Wall oriented at 90 and 60 degrees dissipates easily and early then other orientation profile. The phenomenon can be seen as the movement of the stagnation point which was created on the wall and the area of the wall which dissipates the flow. The flow hitting the wall have a less area to face and this cause a strong deflected flow which further disturbs the incoming flow. The energy transformation was widely seen in 30degree. The molecular interaction increases with increase in the orientation. The outer molecule transfers heat to the inner region which is termed as the energy cascading and this lead to the maximum momentum. As soon as the wall orientation changes, the stagnation point move from the center of the wall to the edge of the wall. This lead the heat transfer along with the deflected flow with further interacts with the incoming and hence enhancement of the momentum due to this heat transfer is seen. The next wall location is 5D where, at any orientation the effect remains in within VRM-PPT point. The results are verified by the variation of normalized radial velocity with varying wall orientations for varying central wall location (please see figure 12).

The flow redirection was investigated with radial velocity profiles. Figure 13-14 represents the radial velocity variation for centerwall fixed at 15D and orientation is varied. The VRM-PPT for all orientation is found to be at 5cm. The increase in orientation show less resistance from the flow and reduced radial distance viz., change for 45 and 60 degrees are same. The distance between the wall and the apparatus is very close in this case. The 0 degree is termed as enhancer of the flow as the resistance is high to the obstacle in the flow. Whereas the increase in the orientation increase the depletion in the flow and hence the entrainment region falls early. The placement of the wall is far from the exit nozzle i.e. (278.1 cm) whereas the apparatus to measure the flow is far too from the exit nozzle but near to the wall placement. This arrangement shows the highest entrainment region for the 0 degree in radial direction and the reason attributed to it is that the wall is flat and the apparatus can easily detect the back flow due to the object in the flow path. The stagnation point generates on the wall which creates the sound which itself is a pressure wave. This pressure wave further leads to the increment in the temperature in the flow. The average velocity of the flow particle increases as the result increase in the entrainment region.

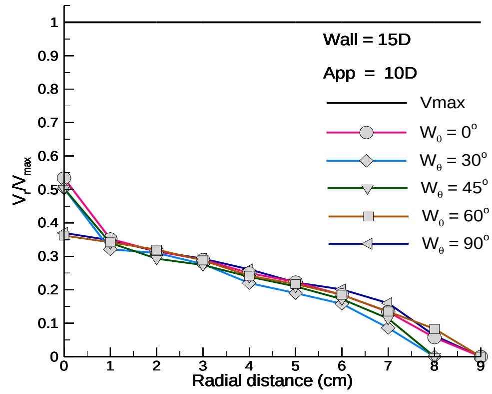

Fig 13: Radial velocity variation with wall orientation (Wall at 15D and apparatus at 12D).

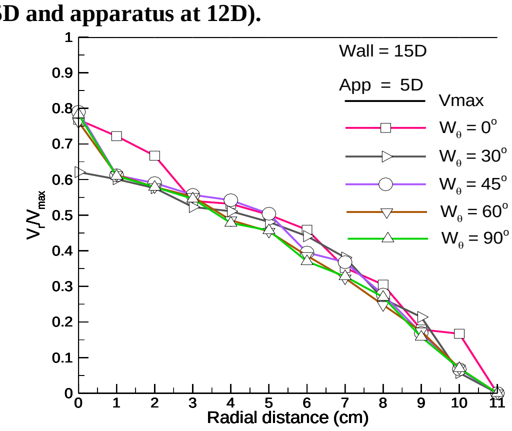

Fig 14: Radial velocity variation with wall orientation (Wall at 15D and apparatus at 5D).

The least value of the velocity at the central line distance i.e. 0cm radial distance is obtained by 30, 60 and 90 degrees. The least radial distance is obtained for 30 and 45 degrees. Interestingly the value of velocity is obtained **28%** less for 30, 60 and 90 degrees. "VRM-PPT" point exist for this profile only up to 1 cm radial distance for others it directly comes out of the core region. It shows that impact of the deflected flow as the velocity of the deflected flow is unidirectional and hence the incoming flow lose the momentum which further affects the velocity profile. This is the interesting part of the results which indicates 0 and 30 degrees as the velocity enhancer when the wall placement is far but the apparatus is in intermediate region. The molecule interaction happens as the flow gets deflected. The deflected flow in which the molecules are well stabilized after the increment of the average velocity get the addition momentum to the incoming flow. Like earlier case, increment was noted in the 0 degree but additionally 30 degrees also shows the same results due to the increment of the distance of the apparatus which further neglects the effect of the orientation. The apparatus was moved 37 cm and the enhancer of the entrainment region account 30degrees. For the apparatus kept at 5D three different VRM-PPT point is observed with different surface orientation. For 30 degrees, the VRM-PPT point is up to 3cm for 0 degree exists till 1cm and beyond comes out of VRM-PPT point with a unit change in radial distance. At 0 degree, 9 cm and 10 cm shows no effect to the distance as flow really gets affected there. As observed the increment in the distance of the apparatus and wall placement neglects the account of the increased deflected velocity. This further shows that the average increased flow velocity is not more than the exit velocity and hence depleted easily with the distance. For the apparatus kept at the exit the VRM-PPT point extends up to 4 cm for all orientation. Then it drops sudden and dissipate in with environment.

With Wall kept wall at a central distance of 10D and apparatus at 5D with varying wall orientation (please see Figure 15). VRM-PPT point is 1 cm for both the orientation. There is a sudden drop in the velocity after 2 cm for 0degree wall orientation. 0 degree also shows less entrainment region whereas 30 degrees follows a simple pattern. The contribution of the deflected flow can be seen in 30-degree wall orientation. When the wall placement was at 15D and the apparatus is at 5D the entrainment region was found to be 11cm but as the wall moves to the 10D with the same location of the apparatus i.e. 5D the entrainment region increased to 15cm.

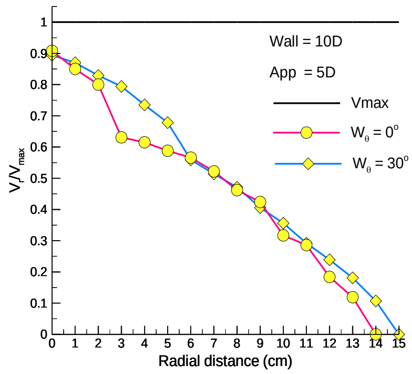

Fig 15: Radial velocity variation with wall orientation (Wall at 10D and apparatus at 5D).

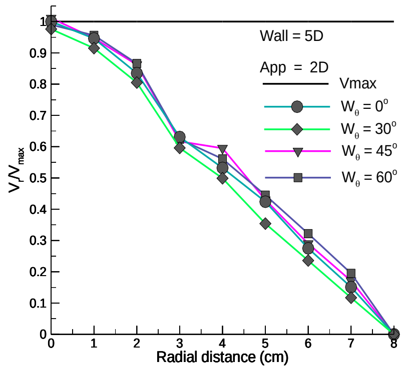

Fig 16: Radial velocity variation with wall orientation (Wall at 5D and apparatus at 2D).

It is noteworthy that the flow momentum loss is less and the increased flow particle interaction due to the deflection which was caused by the wall orientation interacting with the high momentum carrying flow and hence the energy transfers. Whereas in the 0degree the wall area lead the flow dissipation in all the direction because of the stagnation point generated in the center of the wall. This also shows how to use the deflected velocity in terms of application and how the energy transfers with the movement of the stagnation and pressure point which was generated on the wall due to the striking of the flow. 45 degrees shows the highest value of velocity profile when the apparatus kept at 2D and wall 10D. For this orientation VRM-PPT point is 2cm and 1cm for the rest of the orientation. It is interesting to note that all the orientation shows same radial distance i.e. 9 cm. 45-degree wall orientation velocity profile can be termed as the enhancer of the flow. Whereas the other profile decreases the velocity profile and hence termed as resistance to the flow. The reason for the above figure is that apparatus is already very close to the exit and hence discards much variation in term of the entrainment length. The only variation was seen is in term of decrement in the flow velocity. The 45-degree orientation contributes to the incoming flow but the magnitude is very less from the exit velocity, as it only resists the flow from falling drastically which further enhance the VRM-PPT point. The momentum increase due to the shear interaction of the molecules contributes to the flow but experiences depletion due to the distance of the wall placement.

Next, we look for the apparatus at 0D at wall location 10D. The value of VRM-PPT point is obtained 3cm then it drops and diminishes for all wall orientation except for the 60degrees. The 60 degrees' wall show the flow region up to 5cm in radial distance. Looking at the plot one can notice that the value of velocity obtained is least when the wall orientation is 30 degrees and 45degrees maximum when the wall is kept at 5D and the apparatus at 2D. The VRM-PPT is obtained at 1cm for all the orientation. In this case, also 45 degree shows the property of the enhancer of the velocity profile whereas the 30 degrees shows as velocity reducer. The flow carries a high momentum and the deflected velocity interaction creates the vortex in that region. This vortex formation dissipates the energy or the momentum of the flow which results as the reduced entrainment region. The value of VRM-PPT point increases as soon we move the apparatus near the exit and the value obtained is 3cm in radial direction. This value obtained when the apparatus kept at 2D and the wall at 5D (please see Figure 16). The highest resistance was obtained for 45degrees as there is no sudden drop is found in that. But the radial distance is obtained same i.e. 5cm. The resistance in the 0degree can be dedicated to the shear interaction of the large vortex formation or the back flow. The increased in the distance between the wall placement and apparatus gives the space to the back flow which carries the heat and contributed it to the incoming flow. Whereas the other orientation profile seems no effect due to this shear interaction. The two value of VRM-PPT point is obtained in this case i.e. one for the wall 5D and one for wall 10D and 15D. The highest core found is for the 10D and 15D i.e. 4cm after that the velocity drops. The highest resistance is obtained is wall 10D as it tries to maintain the velocity and drop after 5cm only. The above graph shows the variation of centerline distance and velocity for different wall location for 0degree. For the wall at 5D the value is obtained till 3D and it remains in core region. This result obtained for the 30degree wall orientation for the centerline distance and velocity. The 5D shows same behavior. Whereas the 10D again show the resistance to the disturbance. The value of VRM-PPT obtained for 10D is 4cm whereas for 15D it is 3cm.

The deflected part of flow for varying wall location was probed at varying wall orientation for cases of 5D,10D and 15d respectively. Figure 17 shows the intensity of flow deflection for above mentioned cases.

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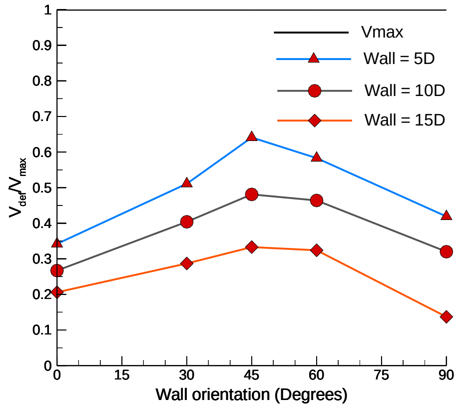

Fig 17: Variation of deflected velocity with varying wall orientations for varying central wall location.

Looking at the plots one can note that the, flow deflection at 45degrees shows the maximum velocity and interestingly the enhancement of the core region is seen at the wall location of 10D. The reason attributed to this is the interaction of the deflected velocity and the incoming flow. Next, we look at the deflected flow part of the work. The implications of the normal flow interacting with a deflected wall. The redirected flow with wall at different orientations is a source of diverse application based on them.

4. CONCLUSIONS

An experimental exploration was carried out to understand the effects of wall location on flow characteristics of a free jet. The results predicted by existing experimental setup were validated with benchmark preceding free jet theory and extended further to note the implications of wall location. Based on results obtained following conclusions may be drawn from this study. The increase in wall location, enhances the velocity losses beyond a critical distance (i.e., core region). The location of wall near to exit results in low velocity losses and consequently strong deflection of flow resulting formation of vortices with more chances of back flow. For a fixed wall location, increase in radial distance enhances the velocity losses, but it results in diminishing returns beyond a critical value indicating insensitiveness of wall orientation after a certain distance. The core region indicated by "VRM-PPT" point reduces with the flow impinging in a confined space indicating elevated losses. The deflected flow intensity for varying wall location is maximum at 45 degrees' orientation owing to assisted flow redirection.

Applicability of the work: Flow jets are of many uses to the practical and scientific world. The understanding of deflected flow with varying wall orientation highlighting change and extent of the change will be very useful for preventive measures, efficient utility and advances in design systems.

5. REFERENCES

[1] Glauert, M. B., 1956, "The wall jet". Journal of Fluid Mechanics, vol. 1, pp. 625–643.

[2] Gardon. R. & Akfirat J. C., 1966, "Heat transfer characteristics of impinging two-dimensional air jets". Int. Journal of Heat and Mass Transfer, 88, 101-108.

[3] Kercher. D. M. & Tabakoff, W.,1970, "Heat Transfer by a Square Array of Round Air Jets Impinging Perpendicular to a Flat Surface Including the Effect of Spent Air". J. Eng. Power, 92, 73-82.

[4] Martin, H.,1977, "Heat and mass transfer between impinging gas jets and solid surfaces". Adv. in Heat Transfer, 13, 1-60.

[5] Sparrow, E.M. & Alhomoud, A., 1984, "Impingement heat transfer at a circular cylinder due to an offset or non-offset slot jet". Int. J. Heat Mass Transfer, 27, 2297-2307.

[6] Gau, C. & Chung, C.M., 1991, "Surface curvature effect on slot-air-jet impingement cooling flow and heat transfer process". Journal of Heat Transfer, 113, 858-864.

[7] Gori, F. & Bossi, L., 2000, "On the cooling effect of an air jet along the surface of a cylinder". Int. Communications in Heat and Mass Transfer, 27, 667-676.

[8] Roy, S. & Patel, P., 2003, "Study of heat transfer for a pair of rectangular jets impinging on an inclined surface". Int. J. Heat Mass Transfer, 46, 411-425.

[9] Aldabbagha, L.B.Y. & Mohamadb, A. A., 2009, "A three-dimensional numerical simulation of impinging jet arrays on a moving plate". Int. J. Heat Mass Transfer, 52, 4894-4900.

[10] San, Jung-Yang. & Chen, Jenq-Jye.,2014, "Effects of jet-to-jet spacing and jet height on heat transfer characteristics of an impinging jet array. Int. J. Heat Mass Transfer, 2014, 71, 8-17.

[11] Tiwari, P.; Mahathi, P.; Choudhury, N.R.; & Malhotra, V., 2014, "Effects of wall orientation on flow characteristics of an impinging jet". Proc. Int. conference on recent trends in engineering and technology, Cochin, Kerala, January 18-19.