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A Review on Spray and Jet in Cross flow

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Abstract- **The studies of the jet and spray in crossflow is reviewed in this paper. Many researches have been focused on the trajectory and breakup process of the jet in gaseous crossflow. Recently researchers are focusing on the spray in gaseous crossflow as it is significant than jet. This paper provides the several studies which are focused on the different aspects of spray as well as jet in gaseous crossflow. It shows that the mixing and fuel dispersion is enhanced in spray in crossflow.**

INTRODUCTION

Atomization is a transformation of the bulk liquid into small droplets. Combustion of liquid fuels in the diesel engines, spark ignited engines, gas turbines, rocket engines and industrial furnaces is dependent on effective atomization to achieve the high surface area of the fuel and thereby achieve high rates of the mixing and evaporation [1]. In most of the combustion system if the atomization is not takes place properly it may cause higher emission in the environment. To obtain the perfect atomization the fuel is injected in the form of spray or jet of the fluid. The basic phenomena in the fluid mechanics is a jet of fluid injected normal to a crossflowing stream of fluid, it has been studied over half a century [2]. It presents one of the easiest ways of mixing of two fluids. Transversely injected fuel in the jet form has many applications such as propulsion system, including the fuel nozzles and scramjet combustors. This jet is injected in the system into the airstream under crossflow condition. The jet is converted into small droplets when drag force increase than the intermolecular force of liquid. This take time to disintegrate into small droplets, eventually mixing with crossflowing air stream will be delayed. Another way to inject liquid in the crossflowing stream is in the form of spray. In case of the spray, the disintegration of the ligaments and larger droplets mostly in the nearfield of the nozzle. There are very few studies on spray in crossflow. Earlier researcher focused on the agriculture applications, spraying the pesticides, also there are certain application in spray painting etc. [2,3,4]. Recently researchers are working on the processes of utilization of spray in injection of fuel in combustion process.

As in the spray we can inject fuel in the form of droplets which should be easily mixed with air and there will be complete combustion. Eventually the emission will be controlled.

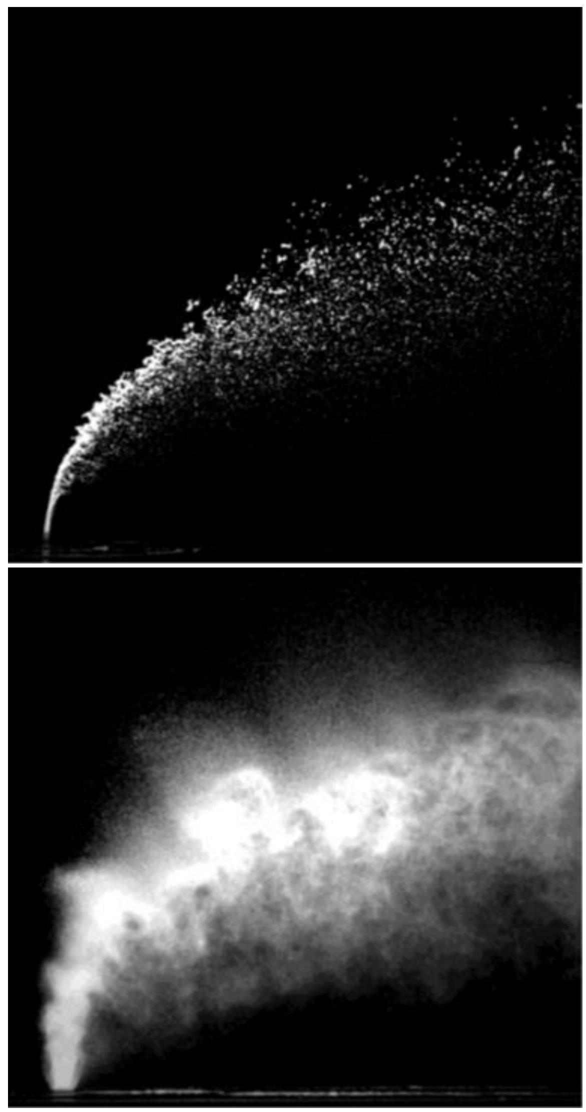

Fig:- Instantaneous images of liquid jet and spray in crossflow for same crossflow velocity and liquid flow rate. (Arrow shows the direction of air stream flow.) [7]

We can note that dispersion of the droplets is more in spray while jet accumulate less area. There is an additional advantage of using the atomizing gas, after droplet formation, the gas acts as a carrier and imparts high velocity to the droplets and aids in mixing of fuel with air.

This review paper focused on the recent work done on spray and jet in crossflowing stream. Many people worked on this topics with the help of the laser diagnostics methods.[1] This study especially focused on not only work took place in spray in cross flow but the major findings in the jet in crossflow also. Following is the recent literature survey of spray in crossflow and jet in crossflow

SPRAY IN CROSSFLOW

There are very few studies focusing on this particular topic. This is one of the concept which can utilize in the combustor of the gas turbine. Philips and Miller [3] carried out an experimental and computational study of flat fan spray in crossflow. A single nozzle was used in experiments and efforts were made to compare experiments and simulations. Experiments are carried out both in field and in the wind tunnel. The airborne spray volume measured at 2 m downstream of the injector was found to increase approximately linearly with the crossflow air velocity, which varied between 2 m/s to 3 m/s. The inlet velocity profile was found not to have any significant effect on droplet dispersion. The computational model was found to under-predict the airborne spray volume by around a factor of 2 to 3. It was suggested that the entrained air field controlled the initial droplet dispersion, while flow structure near the plant canopy top affected the droplet deposition.

While there are certain studies which focused on the larger droplets. Generally agriculture has the large droplets application Building on the models proposed on air entrainment in spray jets in their previous work [2], Ghosh and Hunt [3] presented a theoretical study of spray jets in crossflow. They used multi-zone analysis to show that for weak cross flow, the near nozzle region acts like a link sink and entrains external crossflow air. They also predicted the formation of a counter rotating vortex pair as the crossflow air flows past the spray jet. Equations are formulated for spray droplets in the crossflow and trajectories are presented for various droplet diameters. These investigations essentially pertained to agricultural applications, and typically involved a large test section spanning a few meters, large spray momentum, larger droplets and small crossflow velocities, not relevant to gas turbine conditions. Deshpande et al. [5] employed a computational approach based on the Lagrangian-Eulerian (LE) methodology for treating liquid sprays to study the mean characteristics of a hollow cone spray in a crossflow. They have revisited the categorization given by Ghosh & Hunt (1998) but they have applied this to hollow cone spray. They have also found out the two distinct regions – nearfield and far field. They have also find out characterization based on the ratio of the jet velocity and crossflow velocity as a key parameter in nearfield. They identified in a weak crossflow mean streamline of the crossflow do not penetrate. Also there is implications of the weak and strong crossflow on overall spray. They have also discussed above two regions using computational results.

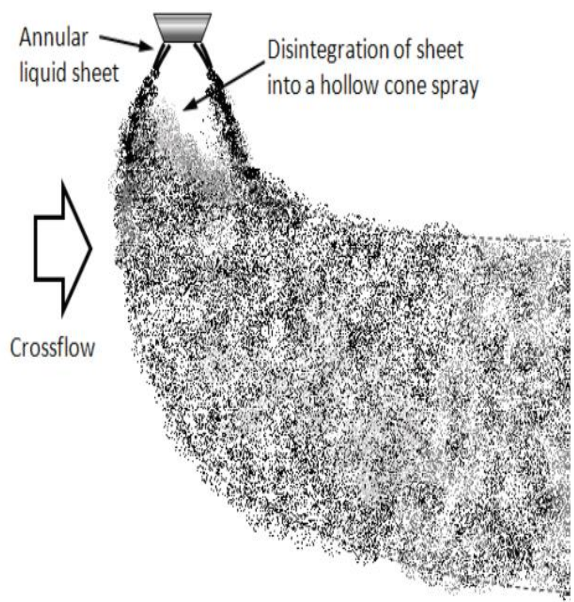

Fig:- Hollow cone spray in crossflow (adopted from [5]).

Li et al. [6] studied spray painting process experimentally using a viscoelastic liquid and also water in an airblast spray subjected to a crossflow.

The momentum ratios used in this study varied from 134 to 1382. They utilized Mie scattering images to estimate equations for the centreline trajectory. They accounted for the droplet diameters in the trajectory equation and added a term consisting of the volumetric mean diameter. They also measured droplet velocities in the central plane of spray jet.

A. Sinha et al. [7] have done the experimental investigation of the airblast spray structure and the trajectory of the spray. They have used water and ethanol spray for this investigation. Certain techniques such as Laser shadowgraphy and Particle/Droplet Imaging Analysis (PDIA) are used to derive spray trajectory and drop size information while Particle Tracking Velocimetry (PTV) is used to measure droplet velocities. They have derived new phenomenon of the spray bifurcation for the low Gas to Liquid ratio. They have found certain reasons for this spray bifurcation such as, There may be presence of the large ligaments and the droplets at the early region of the spray i.e. nearfield of the spray, another reason for this is secondary breakup experienced by the droplets and the ligaments, and the final reason can be the crossflow causing the differential dispersion of small and large droplets. They have incorporated the momentum ration and liquid surface tension which in terms help to obtain a correlation for the spray trajectory, this correlation ultimately help to predict the trajectory over the large range of conditions for different liquid sprays such as water, ethanol and Jet-A. The have also observed that the larger droplets penetrate further into the crossflow, in the direction of injection. Thus, with increase in height of the measurement location from the injection plane, the droplet Sauter Mean Diameter (SMD) is found to increase. Moreover, as the droplets travel downstream in the crossflow direction, the droplet SMD is observed to decrease. The effect of drag is assessed by comparing velocity of different sizes of droplets at various locations. Smaller droplets are entrained into the crossflow at much lower elevations, whereas larger droplets tend to penetrate further into the crossflow.

Surya Prakash et al. [8] investigated the breakup process of the spray obtained from the pressure swirl atomizer in the crossflow. In this research he has focused on the breakup process experimentally. The atomizer produce a swirling sheet of spray which interact with crossflowing medium. This creates the complex interaction which is studied through not only still but high speed photography also. They have considered wide range parameters such as Weber number (2-300) and liquid to air momentum flux ratio (5-150). Various breakup regimes exhibiting different breakup processes are mapped on a parameter space based on flow conditions. This map shows significant variations from breakup regime map for a plain liquid jet in cross-flow. It is observed that the breakup of leeward side of the sheet is dominated by bag breakup and the windward side of the sheet undergoes breakup through surface waves. Similarities and differences between bag breakup present in plain liquid jet in cross-flow and swirl spray in cross-flow are explained. Spray images are used to obtain multimodal drop size distribution from bag breakup, frequency of bag breakup, wavelength of surface waves and trajectory of spray in cross-flow. In this study, they have attempted to characterize the pressure swirl spray in the presence of cross-flow over a wide range of operating parameters. Fuel flow rate is significantly affected by the engine loading or unloading that’s why they kept this objective.

JET IN CROSSFLOW

A jet of fluid injected normal to a crossflowing stream of fluid is one of the basic phenomena in fluid mechanics. Depending upon the nature of the fluids involved, the phenomenon can be classified as single-phase [9], where both fluids are either liquid or gases, or two phase [10], where one of the fluids is a liquid and the other is a gas. Following are some experimental studies on Jet in Crossflow.

A. Kushari et. al. [11] focused on understanding the primary breakup of a liquid jet in swirling cross flow of air in an annular passage. They have presented the results of an experimental investigation of liquid jet breakup in a cross flow of air under the influence of swirl (swirl numbers 0 and 0.2) at a fixed air flow Mach number 0.12 (typical gas turbine conditions). The experiments have been conducted for various liquid to air momentum flux ratios (q) in the range of 1 to 25. High speed (@ 500 fps) images of the jet breakup process are captured and those images are processed using MATLAB to obtain the variation of breakup length and penetration height with momentum flux ratio.

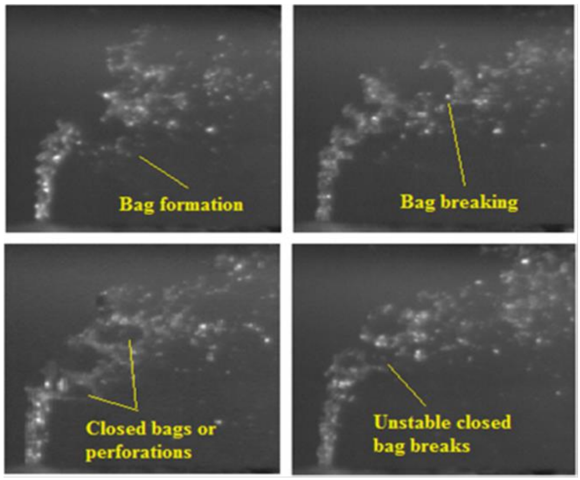

Fig:- Temporal images of q521 for 15 deg vane showing bag breakup mode.[11]

Using the high speed images, an attempt has been made to understand the physics of the jet breakup process by identification of breakup modes— bag breakup, column breakup, shear breakup, and surface breakup. The results show unique breakup and penetration behaviour which departs from the continuous correlations typically used. Furthermore, the images show a substantial spatial fluctuation of the emerging jet resulting in a wavy nature related to effects of instability waves. The results with 15 deg swirl show reduced breakup length and penetration related to the non-uniform distribution of velocity that offers enhanced fuel atomization in swirling fuel nozzles.

Many studies have focused on the jet trajectory and penetration, similar to single phase jets in crossflow. For liquid jets in crossflow, penetration is usually defined as the maximum transverse location of the liquid jet. Wu et al.[12] modelled the jet trajectory by balancing liquid acceleration with aerodynamic drag forces in the stream wise direction. Studies focused on penetration include experimental as well as computational studies.

S. Tambe et. al. [13] has been conducted experimentation to study the effect of a swirling crossflow on transversely injected liquid jets. They have used three swirlers with different vane exit angles of 30°, 45° and 60°. Water jet has been injected from the injector with the orifice diameter 0.5 mm. It is located on a cylindrical centerbody that protruded through hub of the swirler. They have used 2-D PIV method to measure the velocity of the droplets and Mie scattering. The crossflow generated by the swirlers was observed to be fully-developed, axisymmetric and had a vortex structure similar to solid body rotation. Total crossflow velocities peaked at a radial location near r = 15 mm. Liquid jets injected in this crossflow were observed to spin along with the crossflow. The radial penetration of the jet continued to increase even at far downstream locations due to centrifugal forces and a reduction in crossflow velocities at high r. The radial penetration of the jet increased with an increase in the swirl strength of the crossflow and with the momentum flux ratio (q). The jet plume continued to expand as it moved downstream.

CONCLUSION

An extensive review based on present literature on jet in cross flow and spray in cross flow is carried out. Jet in cross flow is a classical liquid fuel mixing strategy which has been used in many combustion applications. Many studies are focused on primary breakup of a liquid jet injected in gaseous uniform cross-flow at non-evaporative conditions. Non-uniform cross flows such as shear layer, swirling or vitiated cross flow, may be help to improve the breakup of the liquid jet in the cross flow. A few studies report on non-uniform cross flow, however detailed investigations are missing in the literature. Therefore, there is need for a detailed study on jet in cross flow in non-uniform cross flow conditions.

Due to stringent emission norms, it is necessary to achieve uniform and lean air-fuel mixture. The uniform and lean air-fuel mixture may be obtained using spray in cross flow configuration. Further, short mixing length may be achieved with spray in cross flow. The present literature shows a need of parametric and detailed research on spray in cross flow. Most of the present literature focuses on macroscopic spray characteristics, however, spray in cross flow needs to be studied using microscopic spray characteristics such as drop size, drop velocity etc.

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