AERO-ACOUSTICS CHARACTERISTICS OF LAMINAR JETS OVER A FLAT PLATE

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This paper experimentally investigates the acoustics characteristics of laminar jets flowing over a flat plate surface. The objective of the study is to understand the physics of noise generation with velocity boundary layer growth along the surface. The Reynolds number at the nozzle exit is varied in the range of 0.5×10^5 to 3.0×10^5. A super-finished smooth plate having a low surface roughness value is considered for the study, having the dimensions of 10 cm along flow direction. Based on the input flow conditions, acoustic characterization is carried out to estimate the sound pressure levels and frequency using the microphones placed at different stream-wise observer locations. Due to the presence of the plate in the flow field, the overall sound pressure levels (OASPL) increased from 70 dB at $Re = 0.5\times10^5$ to around 88 dB at $Re = 3.0\times10^5$.
Keywords: Flat plate noise, wall jets, laminar jets, boundary layer noise, trailing edge

1. Introduction

Laminar jets over a one side of flat plate called wall jet is encountered in numerous engineering application such as turbine blade cooling [1], surface cooling of combustion chamber, flow over fins, deflectors in air conditioning system, automobile and so on. Flow characteristics of wall jets are well studied by several researchers but the noise studies from such wall jets are still in scarce. Most of the engineering appliances that were designed in the past did not consider the acoustic emissions in to their considerations as design parameters. However the scenario at present is such that the appliances need to be as *quiet* (silent) as possible. This has been the motivation of researchers to study the acoustic emissions due to the interaction of flow with the solid surface. The studies on aero-acoustics was initiated by Lighthill [2] where he pointed out that aerodynamically generated sound is a by-product of air flow. Curle [3] investigated that the influence of solid boundaries on the sound field due to reflexion and diffraction at the solid boundaries and also due to the resultant dipole at the solid boundaries. Bajura and Szewczyk [4] studied the stability of laminar wall jet flow and concluded the frequency of longitudinal velocity fluctuations increased with maximum velocity and decreases with local boundary layer thickness. Buhler *et.al* [5] numerically investigated near field acoustics of laminar and turbulent nozzle jet flows at a diameter based Reynolds number 18100. They considered the near field condition as 15times diameter of the jet nozzle. They found that sound pressure levels are strongly enhanced for laminar and transitional conditions compared to the turbulent one. Horne and Karamcheti [6] observed single frequency tones was generated at low Reynolds number wall jets depended on jets speed but less depended on wall length. Yu and Tam [7] reported that the region of noise sources due to oscillatory flow structure at the trailing edge of the wall jets. Howe [8] identified low frequency curvature noise; high frequency passive slot noise and separation noise are three principal sources of noise are identified at the vicinity at the trailing edge by using analytical method. He concluded that that passive slot noise is much higher than curvature noise at higher frequency. Karon and Ahuja [9] experimentally revealed nozzle exit boundary layer significantly affects the noise which produced by nozzle. An important observation from this study is fully developed boundary layer at the exit of the nozzle produced less noise. Edward *et al* [10] investigated the effects of boundary layer noise at velocity range 38m/s. The important observation from this studies that above 500Hz, noise due to boundary layer is significant. Bogey and Bailly [11] have performed computational studies on the significance of boundary layer effects on acoustic fields. They studied that acoustic components are strengthened by vortex rolling up and pairing. Moreau *et al.* [12] carried out experiments to study the noise at the trailing edge of the flat plate with mixed laminar, transitional and turbulent boundary layers at low to moderate Reynolds number. They have done experiments below the Reynolds number of Re=2.7x10^5 and found that trailing edge noise generated in three different flow regimes differ significantly in magnitude and spectral content. They concluded that noise radiated by the flat plate with mixed laminar and transitional boundary layers is broadband in nature due to random velocity fluctuations in the vicinity of the trailing edge. A brief literature survey shows noise emissions from wall jets at laminar regime had not given much attention. Present study reports acoustic emissions due to the laminar wall jets are investigated experimentally. The main objectives of present study are (i) investigate the noise emission characteristics of laminar wall jets at different linear observer locations (ii) study the influence of Reynolds number on aero-acoustic emissions in laminar regime.

2. Experimental Setup and Methodology

Experiments were conducted in an acoustically treated semi-anechoic chamber having the cut-off frequency of 300 Hz. Air is supplied to the chamber using a centrifugal blower. Blower operations are controlled by using variable frequency drive. Experimental facility consists of a cubic contoured rectangular cross section nozzle having aspect ratio 1:10. Schematic of the flat plate attached to the nozzle and photograph of the experimental setup as shown in Fig. 1 and 2. The flat plate having dimension 10cm length (L) along a stream-wise direction and 25cm along the cross-stream direction which was carried by two steel plates are attached to the exit of the nozzle. For smooth exit of the jet flow from the flat plate, the trailing end of the plate is curved. The maximum velocity acquired at the exit of the nozzle is 60m/s. Experimental conditions while taking the data are 71% humidity and air temperature having 303K. The noise data are acquired using ¼ inch condenser microphone (PCB model no:378C01 SN 123983) having sensitivity of 2 mV/Pa. Throughout the experiments microphone is placed 20cm from the jet axis and varying the microphone position along the stream-wise direction from $0.5 \le x/L \le 1.5$. At each positions Reynolds number is varied from $0.5\times10^5 \le Re \le 3\times10^5$ with 50,000 increments. Microphone acquired data at a sampling rate of 150 kSa/s. The acoustic data acquisition was carried using NI DAQ system using LABVIEW software and data processing was done using MATLAB R2016a.

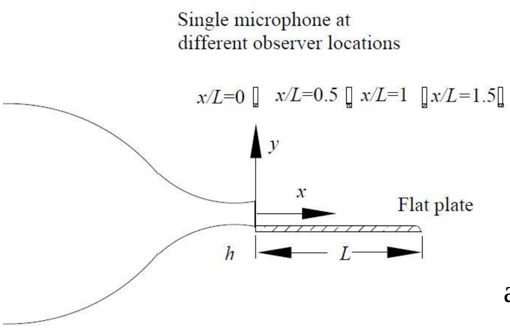

Figure **1**: Flat plate attached to the nozzle

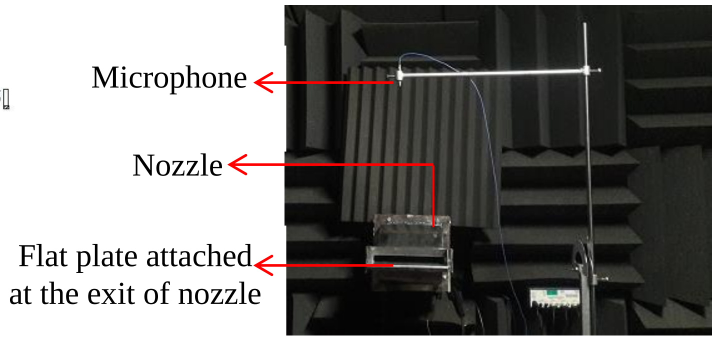

Figure **2**: Experimental set-up

3. Results and Discussion

Power spectral density at all Reynolds number and at different stream wise location was compared with and without the flat plate. The spectra comparison is presented in Fig. 3 at *x/L*=1 and for *Re* = 3×10^5. From the figure it was evident that spectrum obtained for the case with flat plate is higher compared to the one without the flat plate. The difference is observed within the frequency of 1 kHz. The low frequency broad band peaks formed may due to noise of velocity boundary layer. The OASPL variation along the *x/L* is shown in Fig. 4a at *Re* = 3×10^5. This plot shows the increase in the OASPL along the direction of jet flow. It is corroborated that the physical phenomenon responsible for this variation is velocity fluctuations along the surface of the flat plate leading to the increase in the OASPL. The corresponding spectrum at different values of *x/L* is shown in Fig. 4b. It can be noted that the most of the variations are in the low frequency regions (< 100 Hz)

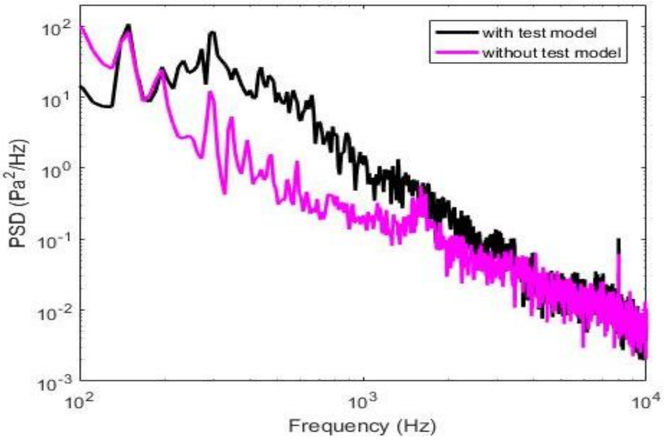

Figure **3**: Acoustic spectra for the wall jets compared to back ground noise level at *x/L*=1 and for Reynolds number 3.0 $\times10^5$

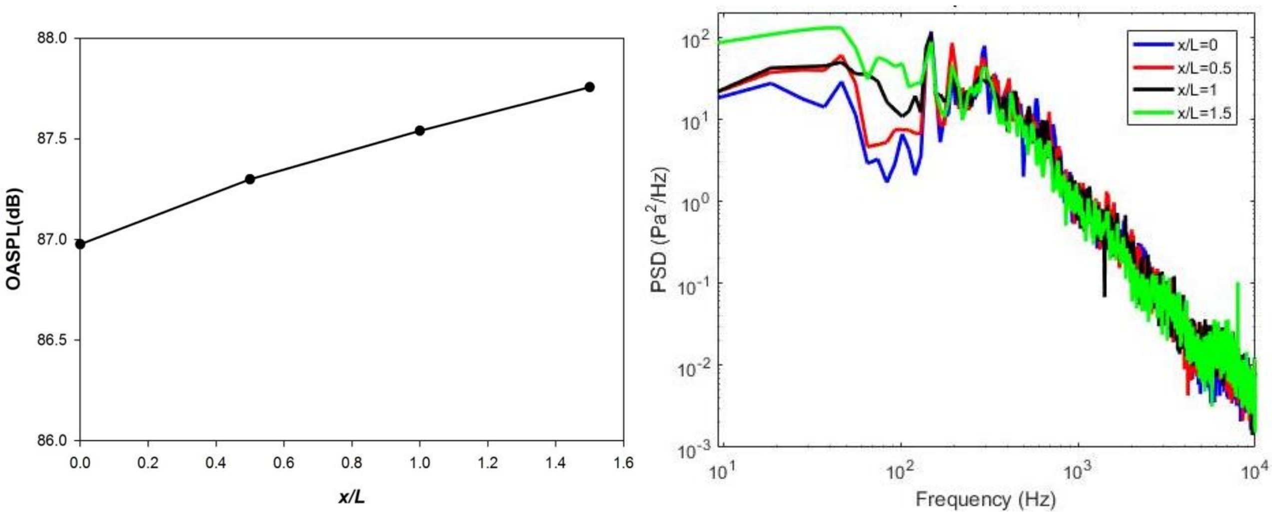

Figure 4: Variation of (a) OASPL and (b) spectrum with respect to *x/L* for *Re* 3×10^5

Fig. 5 shows the variation of OASPL with Reynolds number at *x/L* = 1. The variation is seen to be linear above the Reynolds number of 1.0×10^5 having a constant gradient may be due to wall jet mixing layer noise.

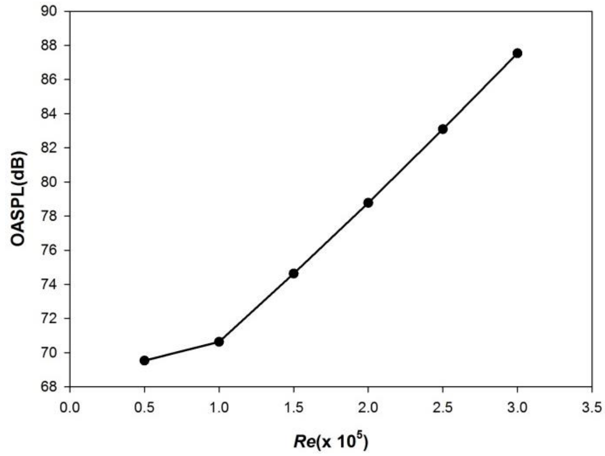

Figure **5**: Variation of OASPL with Reynolds number at *x/L*=1

4. Conclusion

In the present study experiments have performed to estimate aeroacoustic emissions of laminar wall jets. The acoustic characteristics are studied at different stream wise locations of $0.5 \le x/L \le 1.5$ and at different Reynolds number ranging from $0.5\times10^5 \le Re \le 3\times10^5$. The following conclusions are deduced from the study. Spectra at different *x/L's* for $Re=3\times10^5$ indicate that noise emissions are falls in broad-band frequency range. The overall sound pressure levels increases along the stream wise direction of the flat plate. The sound pressure levels of wall jets linearly increases from 70 dB to 88 dB for the increase in Reynolds number from 0.5×10^5 to 3.0×10^5, respectively.

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