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Impinging jet noise reduction using non-circular jets

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ABSTRACT

Experimental studies in the acoustic far field and flow visualization are carried out on circular and non-circular impinging jets at a nozzle to plate distance ratio of 5, for the nozzle pressure ratios of 1.8, 4, and 6. Spectra and directivity of the overall sound pressure level of circular jets are compared with those of non-circular jets for the same nozzle pressure ratios, at various emission angles. Non-circular jets mitigate the transonic impinging tones at around the critical pressure ratio, compared to the circular jet. Square jet is quieter at low nozzle pressure ratios by 5–8 dB compared to the circular jet. At higher under expansion conditions, the triangular and square jets almost completely eliminate the supersonic impinging tones. Elliptical jet is noisy at a nozzle pressure ratio of 6, even compared to the circular jet. Elliptical minor axis plane is quieter at lower nozzle pressure ratios compared to the major axis plane and the trend is reversed for the higher nozzle pressure ratios. Schlieren flow visualization studies reveal that the shock cell structures are weakened and symmetry of the shock cells are lost for the non-circular jets compared to the circular jet.

1. Introduction

Jet impinging perpendicular to a plate/ground and or any surface is widely recognized in many practical flows from subsonic to supersonic speeds. Turbine blade cooling, spraying systems, enhancement of heat transfer on impinging plates, thrust vectoring systems, vertical and/or short takeoff and landing (V/STOL), and rocket exhausts are the few examples. The noise generated from these types of high speed jets radiate a large amount of noise and cause noise pollution, ground erosion, acoustic loading, and sonic fatigue failure of nearby aircraft structures.

Usually, the noise emitted by the impinging jets are higher in amplitude compared to the free jet conditions for the same operating nozzle pressure ratios. The present experimental work comprises acoustic far field measurements of circular and non-circular impinging jets (Elliptical, Square and Triangular) at a nozzle to plate distance ratio (h/D) of 5, for the nozzle pressure ratios (NPRs) of 1.8, 4, and 6.

1.1. Acoustic characteristics

The noise emitted from the jets can be classified as transonic tones, turbulent mixing noise, shock associated noise, and screech/impinging tones. The transonic tones can occur in CD nozzles [1] or orifices/pipes [2], and are generated at low NPRs between 1.6 and 1.9, due to the unsteadiness of shock oscillations. Transonic resonance frequency usually increases with NPR; The turbulent mixing noise emerges from the mixing of the jet fluid itself and jet fluid with the ambient. The noise from the fine scale and large scale turbulence structures are responsible for the turbulent mixing noise and it can occur in both subsonic and supersonic conditions. The broadband shock associated noise (BSAN) occurs for an imperfectly expanded jet and arises from the downstream convecting large scale turbulence structures and their interactions with the shock cells. The impinging tones are generated due to the feedback loop mechanism between the flow field and acoustic pressure field. The instability waves originate in the shear layer and develop in size as they convect downstream. When they travel downstream the large scale turbulence structures interact with the shock cells/impingement plate, and induce fluctuations [3]. The shock fluctuations generate the upstream travelling waves and triggering new instability waves, thus completing an acoustic feedback loop. The shock oscillations depend on the nozzle dimensions and nozzle to

Abbreviations: BSAN, Broadband shock associated noise; NPR, Nozzle pressure ratio; OASPL, Overall sound pressure level; SPL, Sound pressure level.

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Nomenclature

D	Circular jet diameter, mm	P_o	Settling chamber pressure, Pa
h	Nozzle to plate distance, mm	t	Thickness of the orifice jet, mm
P	Ambient pressure, Pa	x	Coordinate along the horizontal axis
P_e	Jet exit pressure, Pa	y	Coordinate along the vertical axis

plate distance. The interaction of the shock cells with the plate generates the complex shock structures.

Fig. 1 shows the schematic of a supersonic circular impinging jet and its feedback loop. The free jet region is one in which the plate obstructions are not felt. When the jet feels the presence of the plate, the flow is decelerated due to the obstruction effect, and a stagnation point develops, forming an impinging region. Impinging region experiences high normal and shear stresses, along with a possible recirculation region. In the impinging region, behind the standoff shock waves, the pressure is lower compared to the outer regions of the jet. The pressure imbalance due to the plate obstruction causes a recirculation region in the center portion of high speed impinging jets. However, the role of recirculation regions on the tone generation is still unclear [4,5]. The recirculation regions and the flow passing through the Mach disk are separated by a contact surface. After the jet impinges on the plate, the flow is deflected radially along the plate surface. The wall jet thickness usually increases due to the entrainment.

The flow and acoustic characteristics of non-circular free jets have been studied by many researchers [6–9] due to their benefits of enhanced entrainment rates and mitigation of noise. For example, Ghasemi et al. [6] studied the developing region of square jet and observed the higher inability in the jet shear layer for the square jet compared with a circular jet. Further, they observed the vortex population at the edge, which was different from the center plane. Min-Yi et al. [7] studied five non-circular jets and observed that higher entrainment rate and turbulent intensity compared to the circular jets. Gutmark et al. [8], observed that the triangular flat sides enhanced the jet spread and proposed that triangular and square jets are advantageous for combustion systems. Verma and Rathakrishnan [9] studied elliptical jet with and without notch. They also observed that the elliptical jet enhances the mixing and reduces the average shock cell length. Overall, it was observed from the literature that the non-circular jet usually enhances the mixing and entrainment rates compared to the circular jets.

In general, the non-circular jets are different from the circular jets with respect to eccentricity (elliptical) and/or the presence of the vertices and flat edges (triangular, square). Those characters of the non-circular jet change the exit flow structures and consequently, the mixing characteristics, entrainment rates, potential core characteristics, and shock cell structures compared to a circular jet. Further, this effect may lead to change in noise characteristics also and that can be observed from the present experimental work.

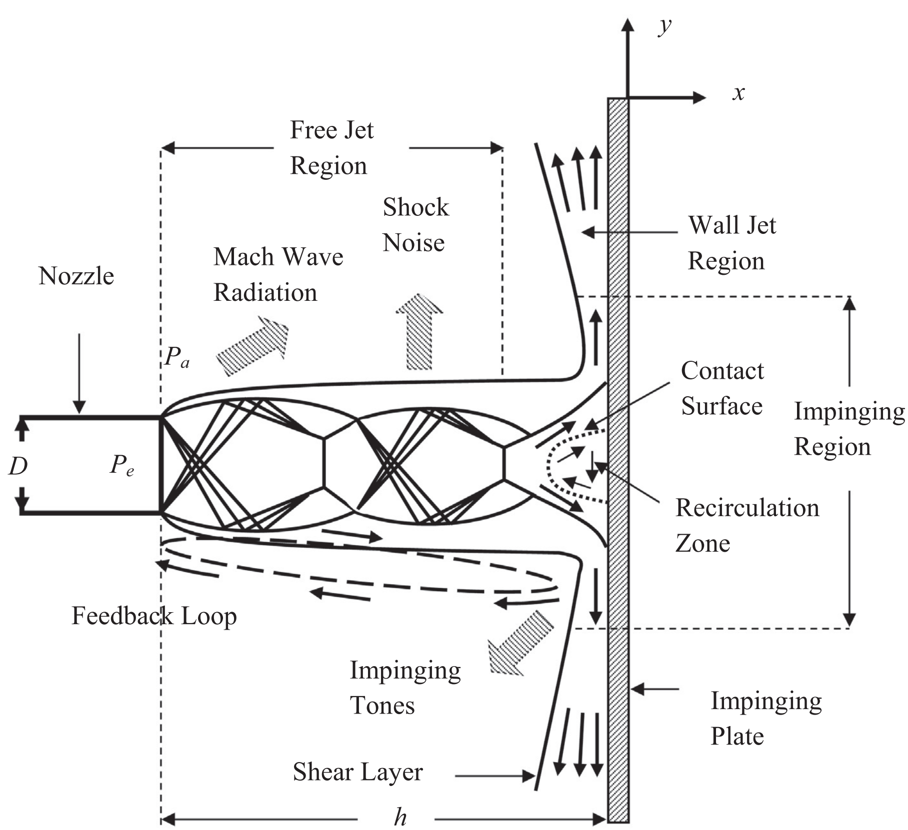

Fig. 1. Supersonic circular impinging jet.