REVIEW ON MEAN FLOW AND ACOUSTIC CHARACTERISTICS OF OFFSET JET

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Abstract:

An offset jet is one which is discharged at a distance from the solid boundary. In propulsion systems, the high-speed jet generated from the rear engine of an aircraft, flowing near the fuselage, can be treated as an offset jet. Jet interactive noise contributes significantly to overall sound emissions, impacting both urban and natural environments. The paper reviews different theoretical and experimental studies performed on offset jets to know the mean flow and acoustic characteristics. Therefore, addressing jet interactive noise is crucial for meeting regulatory standards, enhancing passenger comfort, and minimizing environmental disturbance. Understanding jet interactive noise is pivotal for designing quieter and more efficient systems while mitigating its adverse effects on human health and the environment.

Keywords: Aeroacoustics, Offset jet, Interactive Noise, Shock-associated noise, Reattachment distance, Coanda effect.

1. INTRODUCTION

Jets interacting with neighboring surfaces are called bounded jets. Three types of bounded jets are commonly encountered: (a) wall jets, where the fluid is discharged at the boundary, (b) impinging jets, where the jet is discharged towards the boundary, and (c) offset jets, where the fluid is discharged into a medium above the boundary/wall and the axis of the jet exit is parallel to the wall. The wall jet can be considered as a limiting case of an offset jet.

The offset jet configuration (Figure1) is one where the jet is discharged at some distance from a solid surface. Although the geometric configuration may look simple, the flow may involve several complexities.

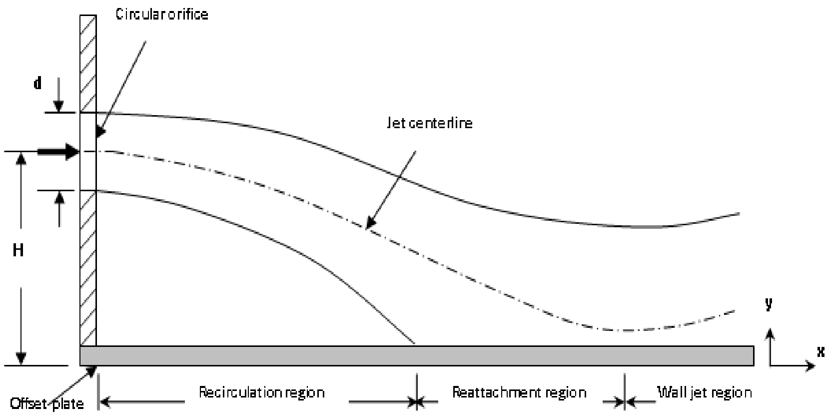

Fig.1. Schematic of an offset jet

A plane turbulent air jet is discharged into quiescent ambient surroundings, some distance from the boundary. Instead of spreading the air into atmosphere, due to entrainment, the fluid eventually attaches to the boundary. Reduced entrainment from the boundary side of the jet causes low pressure between the jet and the boundary results in jet to deflects downwards and eventually attaches the boundary.

The flow regime consists of mainly three different regions, namely, (i) pre-attachment region, which is just prior to the jet attachment, where pressures are generally lower than hydrostatic levels. As the jet approaches the boundary, pressure levels inside the jet increase, causing the jet to decelerate, eventually reaching the maximum as the jet is attached. By jet attachment with the boundary, a recirculation region is setup which is bounded by the discharge plane, boundary and reattaching stream line. Fluid entrained by the jet from the recirculation region is returned to the main flow resulting no net mass exchange. The fluid above the dividing streamline is accelerated due to jets positive pressure. After impingement, the fluid pressure deceases and reached hydrostatic pressure in region (ii), which is impingement region. In region (iii), the jet is formed in to two layers. Inner layer acts as boundary layer and outer layer acts as free jet and it undergoes turbulent diffusion analogous to wall jet, known as wall jet region.

It has gained extensive research interest primarily due diverse practical and engineering applications. Due to presence of wall at the bottom of the jet, entrainment of the fluid reduces and creates low pressure between the jet and boundary. This forces the jet to deflect towards the wall and eventually attached to it. This is called *Coanda effect*.

Jet engines are ubiquitous in modern transportation, powering aircraft, vehicles, and industrial machinery. However, they also produce considerable noise, particularly during takeoff, landing, and high-speed operations. Jet interactive noise contributes significantly to overall sound emissions, impacting both urban and natural environments. Therefore, addressing jet interactive noise is crucial for meeting regulatory standards, enhancing passenger comfort, and minimizing environmental disturbance.

The paper reviews different theoretical and experimental studies performed on offset jets to know the mean flow and acoustic characteristics.

2. MEAN FLOW CHARACTERISTICS OF AN OFFSET JETS

Bourque and Newman [1], Sawyer [2] are among the early authors who studied turbulent offset jets and its flow characteristics. The position of the reattachment length of two-dimensional, incompressible jet was determined by using small flexible paper flags (two-dimensional tufts) fixed to the surface with hinge lines perpendicular to the direction of mean flow. They found that reattachment length is independent of offset ratio and plate length for large Reynolds number and is constant whose limiting value is 35.

Pelfrey and Liburdy [3] used Laser Doppler Anemometry (LDA) to measure the mean turbulent flow characteristics of an offset jet with offset ratio 7 and Re=15000. Theoretical model of Hoch and Jiji [4] was developed based on conservation equations in three different regions namely pre-attachment, impingement ,and wall jet regions. This model is used to predict the reattachment distance, velocity, and pressure fields.

Ali Assoudi et al., [5] used particle image velocimetry technique to study the flow characteristics if three-dimensional offset jet. The results were compared with previous results and results from the numeric model, Reynolds stress Model (RSM).

3. ACOUSTIC CHARACTERISTICS OF AN OFFSET JETS

Jet interactive noise refers to the complex acoustic phenomena generated by the interaction between high-velocity jet flows and surrounding environments or obstacles. This distinctive form of noise arises in numerous applications such as aviation, automotive engineering, and industrial processes involving jet propulsion systems. Understanding jet interactive noise is pivotal for designing quieter and more efficient systems while mitigating its adverse effects on human health and the environment. Before reviewing the literature on acoustic characteristics, let’s see the noise generation mechanisms of a jet.

3.1 Noise Generation Mechanism in Jets:

The generation of noise in jets is a complex process involving various aerodynamic phenomena and turbulence within the exhaust flow. Several mechanisms contribute to the generation of noise in jet engines. They are:

i. **Turbulent Mixing Noise:** One of the primary sources of noise in jets is turbulent mixing noise, which occurs as high-velocity exhaust gases from the engine mix with the surrounding air. Turbulence in the jet flow leads to fluctuations in pressure and velocity gradients, generating broadband noise across a wide range of frequencies.

ii. **Shear Layer Instabilities:** As the jet exhaust exits the engine nozzle, it forms a shear layer where high-velocity jet flow interacts with the surrounding ambient air. Instabilities within this shear layer, such as Kelvin-Helmholtz instabilities, contribute to the generation of noise through pressure fluctuations and vortex shedding.

iii. **Jet Screech:** In supersonic jets, particularly in afterburning engines, jet screech can occur. This phenomenon arises from the interaction of shock waves within the jet exhaust, resulting in a self-sustained feedback loop that amplifies certain frequencies of noise. Jet screech typically manifests as a high-pitched tone.

iv. **Shock-Associated Noise:** Shock waves generated within the jet exhaust can interact with each other or with solid surfaces, leading to the generation of shock-associated noise. These shock wave interactions produce intense noise, particularly in high-speed jet flows, and can contribute to the overall noise signature of the engine.

v. **Turbulent Boundary Layer Noise:** The interaction of turbulent boundary layers with solid surfaces or obstacles within the engine, such as nozzle components or engine internals, can also generate noise. Turbulent boundary layer noise results from pressure fluctuations and flow separations within the boundary layer, contributing to the overall noise emissions of the engine.

vi. **Vortex Shedding:** Vortices shed from the jet boundaries or from components within the engine can interact with each other and with solid surfaces, producing tonal components in the noise spectrum. Vortex shedding noise is particularly prominent in the near-field of the jet exhaust and can be influenced by the engine's geometric configuration and operating conditions.

Understanding these noise generation mechanisms is crucial for the development of quieter engine designs and the implementation of noise mitigation strategies in aviation and aerospace applications.

Jet engines are most widely used in modern transportation, powering aircraft, vehicles. However, they also produce considerable noise during take-off, landing, and high-speed operations. Jet interactive noise contributes significantly to overall sound emissions, impacting both urban and natural environments.

Therefore, addressing jet interactive noise is crucial for meeting regulatory standards, enhancing passenger comfort, and minimizing environmental disturbance.

3.2 Literature on Aeroacoustics of an offset jets:

The acoustics of jet surface interaction with flat plates was studied by numerous authors. Powell [6] was the first author to describe that the jet surface interaction can generate an acoustic tone equivalent to a dipole source due to the trailing edge fluctuating flow that disturbs the jet flow instabilities generation in a feedback loop process. Powell's study confirms accurately the Lighthill's theory on noise generation under experimental conditions. Also confirm that, dipole instability characteristics depends on Reynolds number, Strouhal number and orifice-edge distance.

Lawrence et al. [7] experimentally investigated the interaction noise of a circular subsonic jet with a flat plate by considering the near field and far field analysis data. Near field streamwise microphone phase analysis and far field measurements reveal the deep understanding of link between jet hydrodynamic field and interaction noise generation mechanism.

The noise characteristics of rectangular subsonic and supersonic jets interacting with solid surfaces were studied by Brown [8]. They have developed to improve the noise predicting tools for current generation aircraft and has done different experiments with simple geometries and different flow conditions including jet velocity, jet temperature.

Zaman et al. [9] conducted the experimental study on rectangular jet noise interaction with flat plate and observed an increase in the noise level compared to free-jet for reflected and shielded sides of the plate.

Mora et al. [10] simulated the supersonic jet exhaust interaction with the airframe and ground during take-off and landing of high-speed modern aircraft. Scrubbing and scattering noise were observed due to plate interaction with the jet.

Far-field noise measurements were done by moving the plate through different axial positions (x/D) and radial positions (h/D), and the effect of the length of the plate and offset height on noise characteristics was studied.

Brown [11] developed an empirical model to be used in preliminary design system-level studies. They also investigated how airframe surfaces might affect the shock-cell structure in the jet plume and hence the broadband shock-associated noise.

Advanced aircrafts are moving their engines closer to aircraft frame to reduce the drag which causes additional noise. Baier et al. [12] studied the presence of a flat surface on acoustic characteristics of a supersonic jet from a rectangular converging-diverging nozzle for different NPRs. Also, the effect of offset height on noise characteristics was studied. Shadowgraph and Schlieren images gave clear picture on the noise components present in the supersonic nozzles.

Tam and Chandramouli [13] have provided the theoretical analysis for the experiments conducted by Zaman et al. [9]. Also, they proposed that there is a feedback loop closure due to downstream propagating Kelvin-Helmholtz instability waves and the upstream propagating internal acoustic waves.

The biggest problem of offset jets in propulsion systems is the jet-flap interaction noise, which is generated at the wing's trailing edge if the engine is mounted under the wing. The pressure near-field of the jet is scattered at the trailing edge. This problem has been investigated in numerous papers because of its importance in the aircraft industry.

4. CONCLUSIONS

This paper gives clear picture on the mean flow and acoustic characteristics of an offset jet. This distinctive form of noise arises in numerous applications such as aviation, automotive engineering, and industrial processes involving jet propulsion systems. Understanding the mean flow characteristics like velocity, pressure, reattachment distance in the flow regime is importance. Also jet interactive noise is pivotal for designing quieter and more efficient systems while mitigating its adverse effects on human health and the environment. Hence this paper helps in understanding the offset jet, its mean flow and acoustic characteristics.

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