Noise Generated by Impingement of a Planar Jet on a Flat Plate

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1. Introduction

High speed impinging planar jet flows are used in a number of industrial applications such as hot dip galvanization, coating control and high performance cooling applications. These flows can be liable to flow-excitation mechanisms, leading to the generation of excessive acoustic tones, noise and vibration. Although the problem of flow excitation of axisymmetric impinging jets has been thoroughly investigated by many authors such as Petrie [1] and Ho & Nossier [2, 3], relatively little research has been performed on noise generated by impinging planar jets. The present study examines acoustic excitation of planar jets impinging on an infinite flat plate, as well as the effects of plate inclination on the generated acoustic tones.

2. Experimental Apparatus

All experimental work was conducted using a planar air jet constructed out of Plexiglas® and Aluminum. A series of internal baffles located immediately upstream of the nozzle outlet were utilized to ensure uniform flow exiting across the jet span. The jet allows the adjustment of the slot thickness *h*, to be varied within a range of $0 \leq h \leq 7.5$ mm, with a jet slot width of h = 1.45 mm used for all present testing. Additionally, the span of the jet was L = 406 mm resulting in an aspect ratio of L/h = 280. Reynolds numbers based upon the jet slot width vary between $Re_h \approx 7{,}000$ and 14,000.

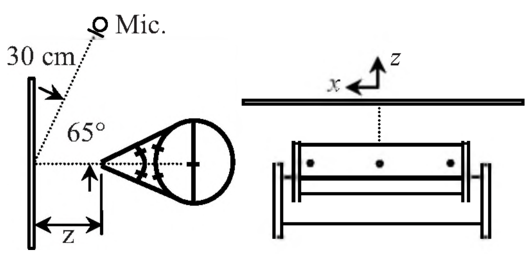

Fig. 1: Simplified schematic of experimental planar jet-plate impingement setup.

The jet was pressurized by a 10 HP Sonic Air Systems 70 Series centrifugal blower connected to a piping system and plumbed to an air plenum feeding both ends of the jet, to ensure uniform flow distribution. Measurements have been performed to ensure even flow across the entire span of the jet. Furthermore, the piping system employs several flow conditioning devices including screens and honeycomb sections to reduce the noise or turbulence levels exiting the blower. Plenum pressure was modulated from P = 0 to 0.315 Bar with a ball valve located well upstream of the jet and flow conditioners. The isentropic flow velocity (V_i) of the jet was calculated using Eq. (1) derived from compressible flow equations for a standard isentropic nozzle, where c is the speed of sound and P_∞ is standard atmospheric pressure.

$$V_i = C\sqrt{\frac{2\left[\left(\frac{P_\infty}{P+P_\infty}\right)^{-\left(\frac{\gamma-1}{\gamma}\right)}-1\right]}{\gamma-1}} \qquad (1)$$

The flat plate used for jet impingement was constructed of aluminum and measured 205 mm×490 mm. The plate was mounted on a 3-axis traverse which could be manipulated in the *x*-*y*-*z* directions to within ±0.025mm. In order to study the effects of plate inclination on noise generation, the plate could also be inclined up to κ = 5° in the span-wise direction, and the jet could be inclined up to ζ = 45° for testing of stream-wise inclination. Schematics of both stream-wise and span-wise inclination are shown in Figure 2.

Noise measurements were performed using a single ½" G.R.A.S. pressure microphone with a flat frequency response to 10 kHz, and a PC based data acquisition system utilizing LabView®.

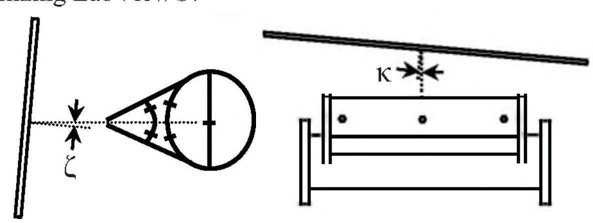

Fig. 2: Simplified schematic of stream-wise (ζ) and span-wise (κ) jet-plate inclination angles.

3. Results

3.1. Normal Jet-Plate Impingement

Experiments were performed for a series of jet-to-plate impingement cases with plenum pressure varying from 0.07 Bar to 0.315 Bar in 0.035 Bar increments for normal jet inclination (ζ = κ = 0°). Microphone measurements were taken at a point 65° from the jet plane, 30 cm from the point of impingement at the center of the jet span. Acoustic spectra up to 10 kHz were constructed using a 50s measurement broken down into 50 spectral averages to refine the acoustic spectra.

Figure 3 shows a series of waterfall plots of the jet-plate frequency response as a function of impingement ratio

(z/h) for varying plenum pressures. A strong acoustic tone was excited for all jet-plate impingement cases with plenum pressures exceeding P = 0.14 Bar ($V_i \approx$ 153 m/s). The acoustic tone strength increases with increasing plenum pressure and the tone is excited over increasingly larger ranges of impingement ratio as the plenum pressure increases. Furthermore, the frequency is proportional to the isentropic flow velocity of the jet and approximately the inverse of the impingement ratio, (z/h).

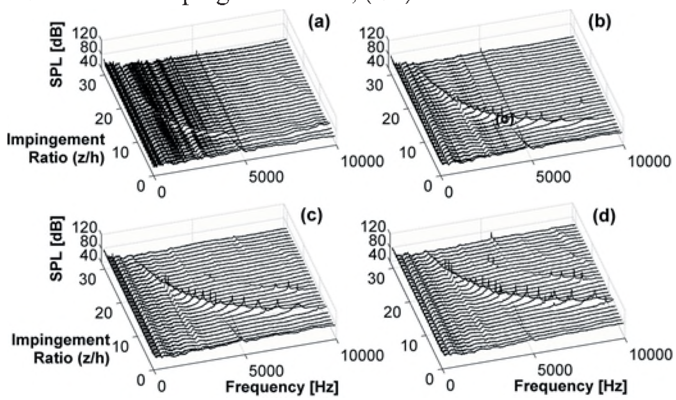

Fig. 3: Aeroacoustic response of planar jet-plate impingement as a function of impingement ratio (z/h) for isentropic jet velocities of V_i = 108 m/s (a), 153 m/s (b), 187 m/s (c) & 216 m/s (d).

The frequency of the jet-plate acoustic tone divided by the isentropic flow velocity as a function of impingement ratio for varying plenum pressures is shown in Figure 4. The data points of all three flow velocities with jet-plate mode excitation collapse on a single curve, showing that the frequency of the tone scales with the flow velocity of the impinging jet. The frequency of the jet-plate tone can be accurately predicted by the expression given in Eq. (2).

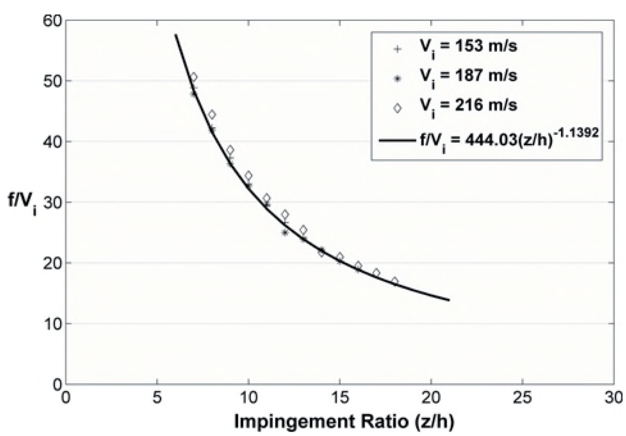

Fig. 4: Frequency of jet-plate acoustic tone divided by the isentropic jet velocity, V_i as a function of impingement ratio (z/h).

$$f = 444.01\left(z/h\right)^{-1.1392} V_i \qquad (2)$$

4. Effect of Plate Inclination

The effect of jet-plate inclination, both in the stream-wise and span-wise directions, was investigated as a method to reduce the intensity of the tone generation of the jet-plate tones. Stream-wise inclination angles of ζ = 0°, 5°, 10° and 15° have been tested, in addition to span-wise inclination angles of κ = 0°, 1.25°. The results of changing the plate inclination angles for both cases is shown in Figure 5, with the peak SPL of the jet-plate tone shown as a function of varying impingement ratio. The amplitude of the acoustic jet-plate tones is much more sensitive to span-wise inclination (κ) than to stream-wise inclination angle, with a complete suppression of the jet-plate mode occurring for inclination of only κ = 1.25°. Stream-wise inclination angle was also effective at suppressing these modes, however, much larger inclination angle were required in order to adequately suppress these modes.

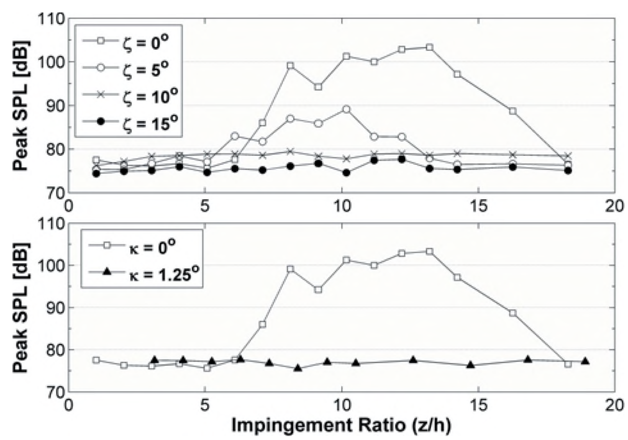

Fig. 5: Effect of jet-plate inclination in the stream-wise (ζ) and span-wise (κ) directions.

5. Conclusions

The acoustic excitation of a planar jet impinging on an infinite plate was investigated. The frequency of the dominant tone was shown to be proportional to the flow velocity of the jet and the inverse of the dimensionless impingement length as given by Eq. (2). Jet-plate inclination was shown to be an effective method to suppress acoustic excitation, with the pulsations being roughly 10 times as sensitive to changes in span-wise inclination compared to stream-wise inclination.

6. References

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