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The Influence of Flexible Tabs On High Speed Jet Noise

Jesse Coombs (1), Tyler Schembri (1) and Anthony Zander (1)

(1) School of Mechanical Engineering, University of Adelaide, Adelaide, South Australia, 5005, Australia

ABSTRACT

Flexible tabs have been shown to be effective for noise reduction in a number of low speed aerodynamic applications, including aerofoils, and cylindrical bluff bodies, both square and circular. Although regular, non-flexible tabs have been investigated for the control of high speed jet noise, the application of flexible tabs does not appear to have been investigated previously. Therefore, the influence of flexible tabs on the noise produced by high speed jets issuing from circular nozzles was experimentally investigated. Single microphone measurements of the noise from air jets at flow speeds of Mach 0.8 and 1 with 3 different configuration flexible nozzles were obtained for a range of observation angles from 90 to 150 degrees from the jet axis. These results are presented as spectra and overall sound pressure levels. For the configurations of flexible tab nozzles and observation angles investigated the flexible tabs were found to increases overall sound pressure levels in all cases.

1 INTRODUCTION

The noise generated by high speed jets has significant impact in a range of applications, including venting noise from power plants and high pressure pipelines, and aircraft noise. Although less significant for commercial air transport, jet plume noise dominates the noise from tactical military aircraft (Tam et al., 2018). Such aircraft noise is a health concern for those that live and work near airfields (Bronzaft et al., 1998; Kaltenbach et al., 2008). Similarly, jet plume noise is a concern for high pressure pipeline operations (Johnson et al., 1998). Therefore, being able to accurately predict, as well as mitigate high pressure jet noise is of immediate practical interest. Jet noise has three principal components, turbulent mixing noise, shock noise, and screech noise, and has significant directionality. The directionality is defined in terms of the off-jet axis angle, or observation angle (θ), where the angle is measured from the jet centreline at the outlet plane and an angle of 0 corresponds to the upstream direction (although confusingly in some work the angle is measured instead from the downstream direction). The practical interest in being able to mitigate jet noise has resulted in a number of noise mitigation devices and strategies, including grooved nozzles (Norum, 1983), chevrons (Rask et al., 2007, Rask et al., 2006, Liu et al., 2009, Seiner et al., 2004, Khritov et al., 2005), bevels (Norum, 1983, Webster and Longmire, 1997, Tide and Srinivasan, 2009, Viswanathan and Czeck, 2011, Viswanathan et al., 2012, Viswanathan et al., 2011, Powers, 2012), fluidic inserts (Morris et al., 2013), corrugations and lobes (Seiner et al., 2004, Viswanathan et al., 2011, Powers, 2012, Mengle et al., 2002), post nozzle meshes and wires (Kweon et al., 2005), flow swirling (Yu and Chen, 1997, Neemeh et al., 1999, Balakrishnan and Srinivasan, 2017), nozzle plugs and porous inserts (Kibens and Wlezien, 1985), co-flows (Rask et al., 2007, Liu et al., 2009), reflection surfaces (Khan et al., 2003, 2004), flexible filaments (Anderson et al., 1999, Bhat et al., 2000a,b, Gutmark, 2000, Lucas et al., 2013), and tabs (Norum, 1983, Samimy et al., 1993).

Tabs are physical items placed to block flow at the nozzle outlet, changing the nozzle exiting flow structure and the resulting noise. Compared to the tapering, curved shapes, and largely flow aligned angles of other nozzle modifications such as chevrons, tabs are typically much simpler shapes such as rectangles and cylinders and placed bluntly and directly in the flow, typically blocking a portion of the flow. They achieve changes to jet noise by enhancing turbulent mixing of the jet, and modification of the shock structure. Norum (1983) investigated the influence of nozzle modifications on screech noise dependence, for the jet noise resulting from jets issuing from circularly cylindrical tubes. Concluding that even small modifications to the external tube surface at the jet exit or internal tube surface could significantly reduce screech noise. Specifically, thinner lipped tubes produced less screech noise than thicker lipped tubes, and that for some screech modes external tabs could reduce screech noise. Samimy et al. (1993) investigated the influence of 1 and 4 tabs on jets with flow Mach numbers of 0.3 to

1.81, and tabs were seen to reduce shock spacing. The farfield acoustic measurements taken for a jet operating with Mach number of 1.63 showed reductions when using 4 tabs with even azimuthal spacing of around 4 dB at lower frequencies (below 40 kHz) and increases of around 2 dB at higher frequencies (above 40 kHz), at a 90 degree observation angle.

Flexible tabs (also sometimes called hairy flaps in the literature) have been shown to be effective for flow and noise control in a number of low speed aerodynamic applications, including aerofoils (Kamps et al. 2017), as well as square (Feuvrier et al. 2014) and circular (Pinelli et al. 2017) cylindrical bluff bodies. Kamps et al. (2017) found flexible tabs to most strongly reduce bluntness shedding noise from low speed aerofoils and reduced overall noise. Feuvrier et al. (2014) found flexible flaps to effectively modify the flow around square cylinders resulting in reduced drag as well as reduced pressure fluctuations on the cylinder surface. Pinelli et al. (2017) investigated the influence of flexible tabs and filaments on low speed flows over circular cylinders. The tabs significantly modified the vortex shedding, increasing vortex shedding frequency and reducing the strength of the shed vortices, as well reducing drag, while the filaments were found to reduce the growth rate of the mixing layer.

The successful use of flexible tabs in low speed noise reduction applications, and inflexible tabs for high speed jet noise mitigation, in combination with the understanding of the mechanisms by which numerous other high speed noise mitigation decides function, namely by modification of the outer jet mixing layer flow, provides reason to believe that flexible tabs could be used to influence high speed jet noise. However, this does not appear to have been extensively investigated previous. Therefore, the present work aims to experimentally investigate the influence of flexible tabs on farfield noise resulting from Mach 0.8 and 1.0 jets.

2 METHODOLOGY

Experiments were conducted in the anechoic chamber of the University of Adelaide (UoA) which has a volume of approximately 73.6 m^3 with low-density, fibreglass acoustic wedges of height 0.9 m lining all surfaces. The acoustic insulation provides a reflection-free or anechoic environment above approximately 250 Hz. The jet apparatus used to produce the Mach 0.8 and 1.0 jets is supplied from pressure tanks that are held at 650 kPa, the outflow of which is regulated by a closed-loop system involving a valve and a Measurex MRB20 6 bar pressure transmitter situated in a settling chamber immediately upstream of an adaptable nozzle. The system maintains the total pressure of the outflow to within 0.3% of its nominal value. The jet apparatus consists of the modified jet nozzle shown in Figure 1, connects the pressure supply tanks, to a pipe with inner diameter (D) of 26 mm, and length (L) to diameter aspect ratio L/D = 7. A series of flexible tabbed extensions were attached to the end of the pipe. The flexible nozzle design, an example of which is shown in Figure 2, has a sleeve section, with internal diameter equal to the outer diameter of the pipe to which is sleeves, and a tabbed section designed to have internal diameter of 26 mm and so join smoothly to vent pipe without a change in internal passage diameter. The tabbed extensions were 3-D printed from a flexible rubber-like UV curable elastomeric material (VisiJet M2 ENT), which has a tensile modulus of 0.27-0.43 MPa. The outer-wall thickness and number (or aspect ratio) of the flexible tabs around the extension circumference was varied, while the length of the tabbed section was held constant at 26 mm thoughout. This resulted in a total of 3 flexible tabbed nozzle configurations that were investigated in this study Nozzle A, Nozzle B and Nozzle C. The properties of each of the nozzles are summaried in Table 1, and resulting nozzles as manufactured are shown in Figure 3.

Table 1: Nozzle configurations

Nozzle	Tab wall thickness (mm)	Number of tabs
Nozzle A	1	4
Nozzle B	4	16
Nozzle C	4	4

Two operating Mach numbers (M) were examined, $M = 0.8$ and $M = 1.0$. It is noted that in the present experimental set-up, only unheated (or cold jets) of dry air is investigated, i.e. the jet temperature ratio, the ratio of total upstream temperature (T_r) to the ambient temperature (T_a), is taken as equal to 1. Since the jet or the dry air was unheated, the effect of temperature on air density was assumed to be negligible for the purpose of these experiments.

The farfield acoustic pressure data was measured using a Bruel & Kjær type 4954-A 1/4" pre-amplified microphone which has a flat frequency response between 4 Hz and 100 kHz. The microphone was located in the acoustic far-field at a distance of 1300 mm from the centre of extended nozzle centre-line axis, this corresponds to a distance of 50 nozzle diameters, at observation angles of 90, 100, 110, 120, 130, 140, and 150 degrees (recall that angle was defined such that 0 degrees corresponds to the upstream direction). The microphone was mounted on a sting held by a tripod the upper section of which was treated with with acoustic foam to help minimise reflections and which was positioned manually. A 24-bit National Instruments PXI-4472B signal acquisition module stored the data recorded by the far-field microphone, with sampling frequency of 102400 Hz and with sampling period for each measurement of 32 seconds. The acoustic measurements for each microphone across these periods were processed into spectra calculated using Welch's periodogram, and both spectra and overall sound pressure levels (OASPLs) were calculated using a reference pressure of 20 micro Pascals.

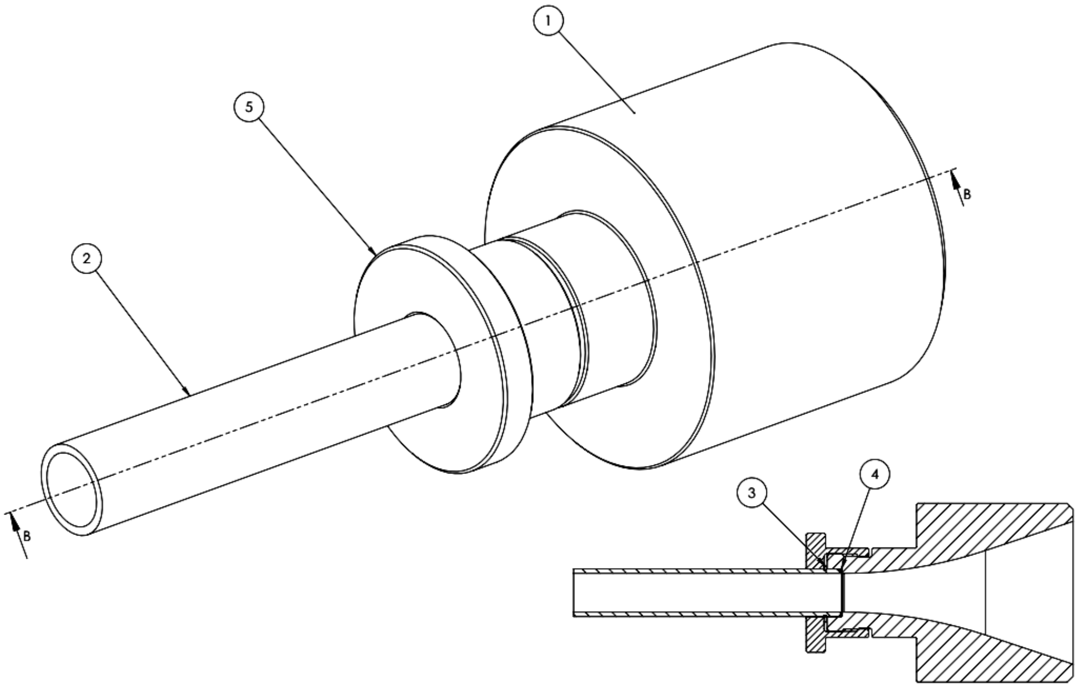


Figure 1: Cross-sectional and 3-D views of the assembly drawing of the modified jet nozzle rig which consists of the following components: (1) Pipe adaptor insert with a smoothly converging section (to eliminate separation noise), (2) cylindrical pipe of circular cross-section, (3) circular clip, (4) O-ring and (5) a collar.

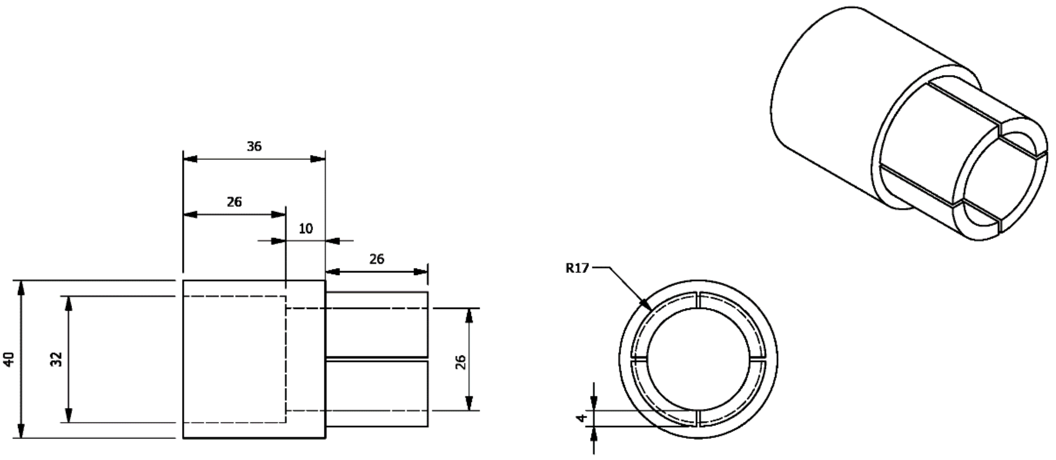


Figure 2: Nozzle C design, showing sleeve section for mounting to pipe and tabbed section.

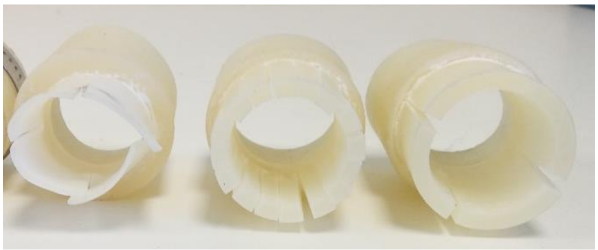


Figure 3: The flexible tab nozzles, left to right, Nozzle A, Nozzle B, and Nozzle C.

3 RESULTS

The OASPLs for each flexible tabbed nozzle as well as the pipe without any nozzle (“No nozzle”) were calculated, and these are presented in Figure 4. These show that the nozzle modifications have in all cases increased the observed noise, with the smallest increase over the unmodified pipe being for the thin flapped nozzle at the largest observation angle and highest speed jet investigated. Figure 5 shows scaled spectra results for θ = 90, 120 and 150 degrees, at both jet speeds. The oscillations observed in the spectra, which may be observed most readily for the 90 degree observation angle and which decrease as the observation angle increases, are attributed to reflections to the microphone from the tripod support and the outer jet nozzle rig surface. These oscillations have been observed to be significantly reduced by the partial treatment of the jet nozzle rig and microphone tripod with acoustic foam. However, acoustic treatment of venting pipe stacks is uncommon in industry, and so in order to most closely match this condition, no attempt was made to acoustically treat the pipe exterior. At the 90 degree observation angle a flater broadband spectrum indicating the dominance of fine-scale turbulent mixing noise is observed, while the spectrum at the 150 degree observation angle exhibits a dip in the higher frequencies, which indicates increased dominance of large-scale turbulent noise or Mach wave radiation over the fine-scale turbulent structures.

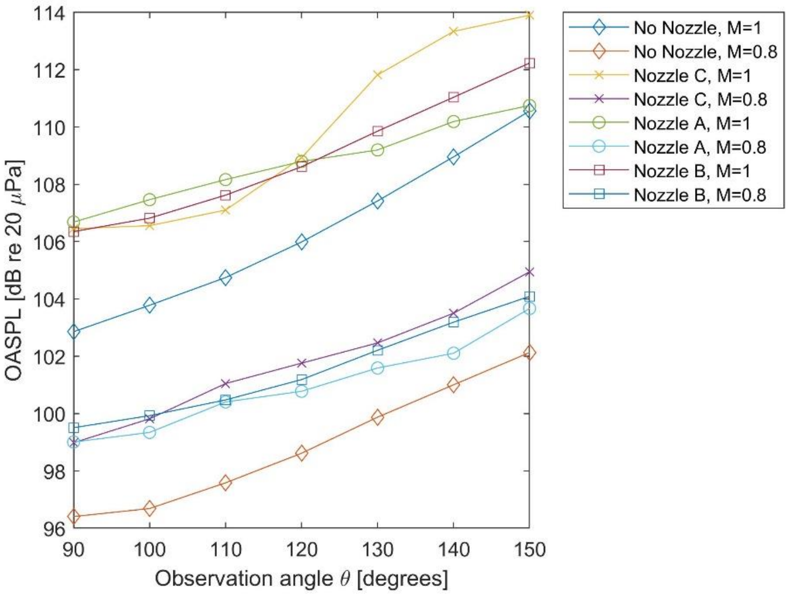
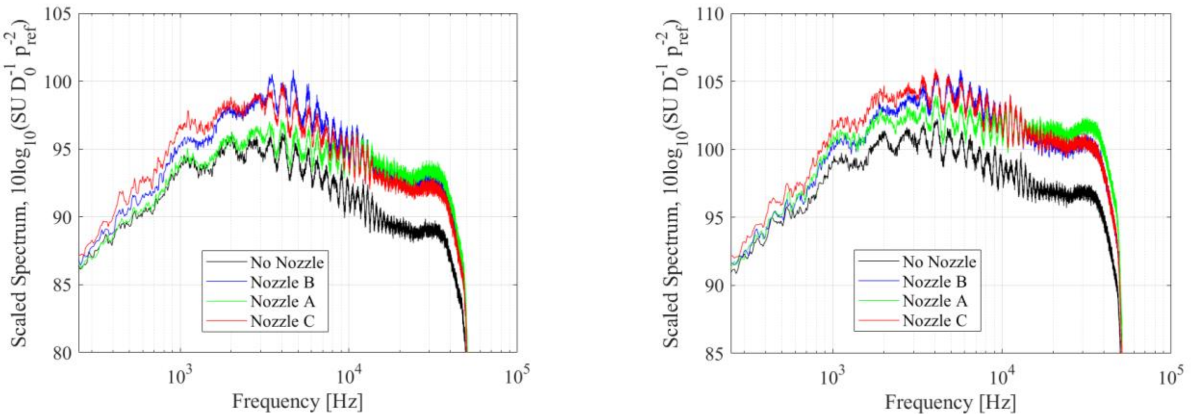
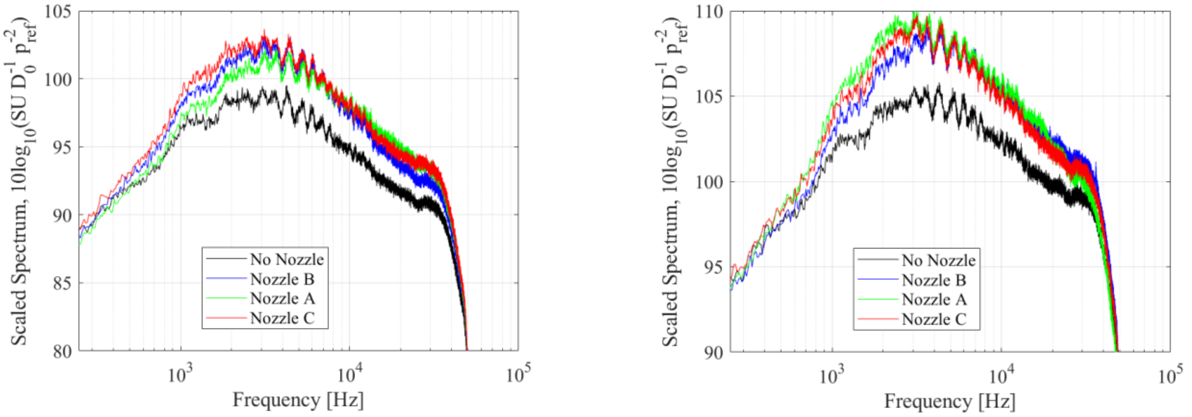


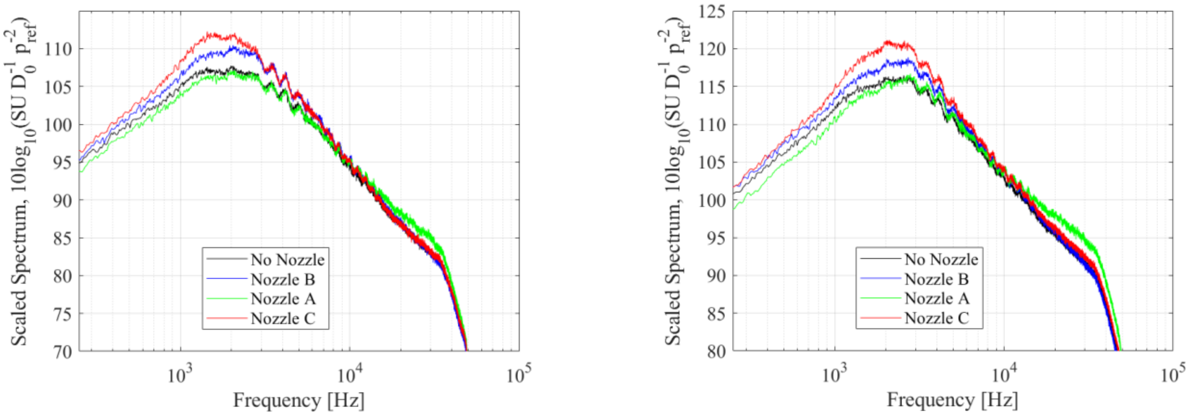
Figure 4: OASPL results



a) $M = 0.8$, θ = 90 spectra b) $M = 1.0$, θ = 90 spectra



c) $M = 0.8$, θ = 120 spectra d) $M = 1.0$, θ = 120 spectra



e) $M = 0.8$, θ = 150 spectra f) $M = 1.0$, θ = 150 spectra

Figure 5: Spetra results for θ = 90, 120 and 150

4 CONCLUSIONS

Based on previous work showing the effectiveness of flexible tabs in low-speed aerodynamic noise control applications, it was proposed the flexibly tabbed nozzles may well influence the noise generated by high speed jets. This was found to be true, however rather than noise reductions compared to a nozzle without flexible tabs, noise increases were observed for all the tabbed nozzle configurations and at all observation angles investigated. It is possible that noise reductions would be observed at higher observation angles, or that alternative combinations of tab flexibility, aspect ratio, number and/or spacing would produce noise reductions at the observation angle of interest. Additionally, the extent the flexible tabs project into the flow, which has been seen to influence the noise reduction properties chevrons and grooved nozzles for high speed jet noise (Seiner et al. 2004; Seiner et al., 2005; Norum 1983), could be further investigated. However, such investigation was beyond the scope of the current project and is therefore highlighted as a potential avenue for future work.

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