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# Empirical modelling of noise from high aspect ratio rectangular jets

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ABSTRACT

Noise measurements have been performed on rectangular jets of aspect ratios ranging from 49 to 987 with the aim of determining the appropriate velocity and length scaling to be used in an empirical noise prediction model. The results have shown that the velocity exponent is a function of the nozzle aspect ratio, decreasing with increasing nozzle aspect ratio. In an effort to establish a general prediction model, the velocity exponent of 7 was chosen as the best compromise to represent all the measured data. The analysis of the noise measurements from high aspect ratio nozzles of varying jet height and width has shown that, for the range of aspect ratios considered, the jet sound power level scales with the nozzle height to the power of 3 and the nozzle width to the power of 1. The derived jet noise scaling has been validated with independent experimental data and shows good agreement.



## 1. Introduction

High aspect ratio rectangular jets have seen a wide range of applications in aerospace (e.g. flow control to reduce noise from the flap side edge (Kanjere et al., 2012)), manufacturing (e.g. air knives), environmental control (e.g. air conditioning units) and recently on high speed hand dryers. On a high speed hand dryer, the air is accelerated through a high aspect ratio nozzle and is used to wipe water off the surface of the hands. The noise of the jet on a high speed hand dryer represents the main contribution to the overall product noise (Etaix et al., 2014). In order to reduce the jet noise a better understanding of the parameters that affect the noise is required.

Unlike circular jets, the noise from high aspect ratio rectangular jets (here defined as having an aspect ratio greater than 100) has received less attention. Coles (1959) performed noise measurements on rectangular nozzles of aspect ratios of 14 and 100, with the same exit area. He hypothesised that the sound power generated by a high aspect ratio rectangular jet is half that of a circular jet of equal exit area. The results showed that this was true only for the rectangular jet of an aspect ratio of 100. Schrecker and Maus (1975) performed noise measurements on rectangular jets of aspect ratios ranging from 30 to 120. They found that the dependency of the jet noise on the jet velocity was a function of the nozzle aspect ratio. The jet noise scaled with the velocity to the power of 8 for the nozzle of aspect ratio of 30 and velocity to the power of 7 for the nozzle of aspect ratio 120. For the nozzle with aspect ratio between 30 and 120, a velocity exponent between 8 and 7 was found. Kouts and Yu (1975) found that the sound power scaled with the mean jet velocity to the power of 7 on a rectangular nozzle of aspect ratio of 10. Bjørnø and Larsen (1984) carried out a theoretical and experimental study of the noise of a jet issuing from rectangular slits of aspect ratios ranging from 33.3 to 100. They found that the sound power scaled with the velocity to the power of 8 following Lighthill (1952) and an equivalent length scale $hL$, where $h$ and $L$ are the rectangular jet height and width respectively. Munro and Ahuja (2003) performed flow and noise measurements on a rectangular nozzle with aspect ratios ranging from 100 to 3000. They found that the jet noise data collapsed when scaled by the jet velocity to the power of 8 and an equivalent length scale $h^{3/2}L^{1/2}$.

A review of the existing literature shows that there is no agreement on the velocity scaling and length scaling of the noise from high aspect ratio rectangular jets. In this work, noise measurements are performed on different rectangular nozzles of aspect ratios ranging from 49 to 987. The aim of the paper is to determine an appropriate velocity and length scale that can be applied to predict the noise from high aspect ratio jets. The paper is divided into four sections. Section 2 presents the details of the jet rigs and experimental set-up for the noise measurements. The results of the noise measurements, the derivation and validation of the empirical jet noise model are presented in Section 3. Finally,

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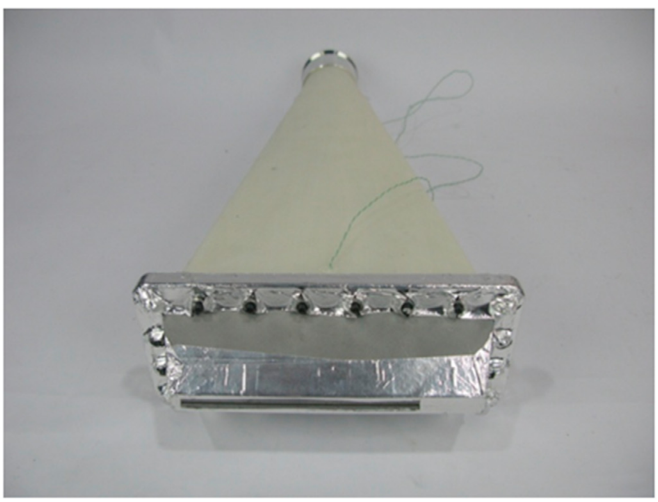
(a) Aluminium nozzle.



(b) Sintered metal nozzle

**Fig. 1.** Rectangular jet rigs.

Section 4 presents the conclusions and recommendations for future work.

## 2. Experimental set-up

### *2.1. Jet rigs*

The jet rigs used in the current study consisted of rectangular jets of varying aspect ratios from 49 to 987 and circular jets of varying diameters from 8.25 to 16.51 mm. Fig. 1 shows the rectangular jet rigs used in the study. Both jet rigs consisted of a large plenum where the flow is diffused followed by a convergent section where the flow is accelerated towards the exit. For the aluminium jet rigs, the nozzle convergence angle, in the direction perpendicular to the span, is approximately 10° whereas for the sintered metal nozzle rigs it is 30°. The nozzle height of the aluminium rigs was adjusted using precision metal shims positioned between the two nozzle sections. Tie-down rods were used to hold the nozzle sections together under pressure. The nozzle height and width of the sintered metal rigs were fixed during prototyping. Table 1 summaries the nozzle dimensions of all the rectangular jet rigs.

**Table 1**
Geometrical details of the rectangular jet rigs.

| Rig name | $h$ (mm) | $L$ (mm) | $AR = L/h$ |
|---|---|---|---|
| Aluminium rig 1 | 0.30 | 296 | 987 |
| Aluminium rig 2 | 0.36 | 296 | 822 |
| Aluminium rig 3 | 0.49 | 296 | 604 |
| Aluminium rig 4 | 0.73 | 296 | 405 |
| Sintered metal rig 1 | 0.50 | 163 | 326 |
| Sintered metal rig 2 | 0.57 | 103 | 181 |
| Sintered metal rig 3 | 1.60 | 146 | 91 |
| Sintered metal rig 4 | 1.06 | 52 | 49 |

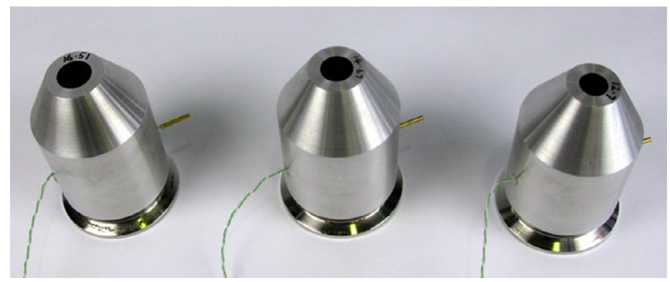


**Fig. 2.** Circular jet nozzle rigs.

In order to validate the experimental methods, noise measurements were performed on circular nozzles. Unlike high aspect ratio rectangular jets, there is a lot of literature pertaining to noise from circular jets (see a review paper by Karabasov, 2010) hence a good validation case. Fig. 2 shows the circular jet nozzles used in the study. The nozzles were machined from aluminium with a convergence angle of 30° and a sharp edge exit profile. Four circular nozzles were used in the test with diameters of 8.25, 12.70, 14.67 and 16.51 mm.

### *2.2. Flow apparatus set-up*

The tests were performed in the hemi-anechoic chamber facility at Dyson HQ in Malmesbury. Air was supplied to the jet rigs using a 7.5 kW blower rig. A silencer was located downstream of the blower to attenuate any upstream noise coming from the blower and pipes. Both the blower rig and the silencer were located outside the semi-anechoic chamber. A venturi flow meter tube, located downstream of the silencer and upstream of the jet nozzle rig, was used to measure the volumetric air flow rate through the nozzle. Noise measurements were performed at jet velocities ranging from approximately 40 to 240 m/s. For the rectangular jets, this corresponds to a variation in the Reynolds number based on the nozzle height from $Re_h = 800–2.43 \times 10^4$. For the circular jets, the Reynolds number based on the nozzle diameter, $Re_D$, ranged from $2.09 \times 10^4$ to $2.5 \times 10^5$.

The jet velocity is calculated based on the static pressure and temperature measured behind the nozzle using the isentropic flow relationships. The jet Mach number, $M_j$, is given as,

$$M_j^2 = \left[\left(\frac{P_j}{P_{amb}}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]\left(\frac{2}{\gamma - 1}\right), \tag{1}$$

where $P_j$ and $P_{amb}$ are the static pressure in the plenum behind the nozzle and the ambient pressure respectively, and $\gamma$ is the specific heat ratio for ideal gas, equal to 1.4 for air. The jet Mach number is then used to compute the jet exit temperature, $T_j$, as follows,

$$T_j = \frac{T_{amb}}{\left[1 + \frac{2}{\gamma-1}M_j^2\right]}, \tag{2}$$