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NOISE CONTROL OF INDUSTRIAL JETS: AN INVESTIGATION OF NOZZLE PERFORMANCE

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INTRODUCTION

Within the U.K. manufacturing industries jet noise ranks third as a major contributor to industrial deafness. Compressed air is exuded from small piping to form small supersonic jets which are used for part removal, swarf clearance, cooling, paint spreading, etc. Standard muffler-type nozzles which can provide effective noise control from blow-off mechanisms cannot be used in these cases as flow properties of the jet once it has left the nozzle are very important. There are now many commercially available nozzles which offer varying degrees of noise control but offer no information as to their effect on the flow properties of the jet they produce. The question "which nozzle for which task?" remains unanswered. A broad categorisation of available nozzles would be (a) micropore mufflers; (b) micropore diffuser mufflers; (c) Coanda nozzles. The performance of muffler-type nozzles has been studied in detail [1,2], and important prediction formulae established. In this paper, the performance of four commercially available Coanda nozzles is studied. A schematic diagram of these nozzles is shown in Figure 1.

EXPERIMENT AND DEFINITIONS

The apparatus used in this study is described in detail in reference [3]. This latter work concentrated on the noise production and compressed air usage characteristics of the nozzles. For the purposes of this paper a pitot tube was traversed in the jet wake to examine the stagnation pressure distribution. The thrust of a flow acting on a body is dependent on the volume, shape and orientation of the body. For simplification and the convenience of theoretical discussion, the stagnation force (F_s) is introduced instead of thrust, where

$$F_s = \int_0^a 2\pi P_s(r) r.dr. \qquad (1)$$

$P_s(r)$ is the stagnation pressure at a distance r from the jet axis and the jet flow is assumed to be axisymmetric. As $a \to \infty$ the stagnation force turns to total stagnation force, F_{ST}. We define the normalised stagnation force by the ratio (F_s/F_{ST}). Similarly, the ratio of P_s on a particular profile to its peak, P_{sp}, is the normalised stagnation pressure, P_{SN}. The r at which the P_s reduces to one-tenth of its peak is the radius of flow R, then the ratio (r/R) is the normalised distance r_N.

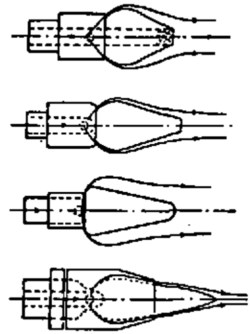

Figure 1.

In the far field the distributions of stagnation pressure of the nozzles are similar and the same as that of a free round jet. Figure 2 shows the radii of flow of Soundscreen, Agron, Thruster and Open Pipe at different distances from the tip of nozzle and at the same chamber pressure, 3.86 kg/cm^2 gauge (55 psi). There is only one data point for Braur, which is measured at a chamber pressure 6.59 kg/cm^2. The solid line is for a 7 mm bore steel pipe and its slope is 6.5^o, agreeing with the known value of spreading angle of a free round jet. All the data from the nozzles tested follow the same law except that of the Braur nozzle. The distribution of P_{SN} and F_{SN} with respect to r_N can be approximately described by a Gaussian distribution [4], that is,

$$P_{SN} = e^{-r_N^2/\sigma_1^2} \qquad (2);\qquad F_{SN} = 1 - e^{-r_N^2/\sigma_2^2} \qquad (3)$$

where σ_1 and σ_2 are dispersion coefficients. Profile distributions of F_{SN} and P_{SN} were obtained at 20 to 60 cm from the nozzle tip for a range of chamber pressures up to 10 kg/cm^2 gauge. The values of σ were then derived using the least squares method. Results from each nozzle gave close agreement of dispersion values with an average of σ = 0.64. From the experimental distributions of F_s for the nozzles it is clear that half of the total stagnation force is concentrated in the central circular area defined by the half radius of the flow.

Figure 3 shows the distribution of stagnation pressure along a horizontal diameter adjacent to the tip of nozzle tested. Within a few centimetres of the nozzle tip the flow distribution resorts to that of a simple open pipe due to the violent turbulent mixing.

DISCUSSION AND CONCLUSIONS

The distributions of stagnation pressure in the flow of the four nozzles and the open pipe are similar and the normalised relation of them can be described by a Gaussian distribution with dispersion coefficient σ = 0.64. Figure 4 shows that the relationships between the total stagnation force and chamber pressure are approximately linear in the range of 2 to 8 kg/cm^2 gauge and can be formulated by linear regression. The results are listed in Table 1. A_e is the equivalent area of nozzle [3].

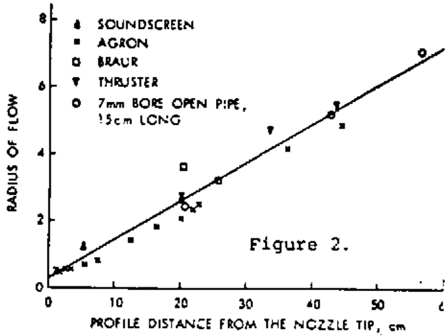

Figure 2.

Table 1: Formulae for calculating total stagnation force

Nozzle	F_{ST} (kg)	A_e (cm^2)
Open pipe	0.156 (P_c - 0.06)	0.28
Agron	0.0542 (P_c - 0.48)	0.075
Thruster	0.0349 (P_c - 0.60)	0.075
Soundscreen	0.0240 (P_c - 0.43)	0.030

If we assume that the initial total stagnation force of the flow is the product of the equivalent area of the nozzle and the chamber pressure and the final is the total stagnation force on the profile chosen, then the difference between the two represents a force loss for the nozzle design. Using the relationships between (F_{ST}) and (P_c) defined in Table 1, but neglecting the constant term the relative losses of force of the flow of open pipe, Agron, Thruster, Soundscreen are 0.44, 0.28, 0.53 and 0.20, respectively. The

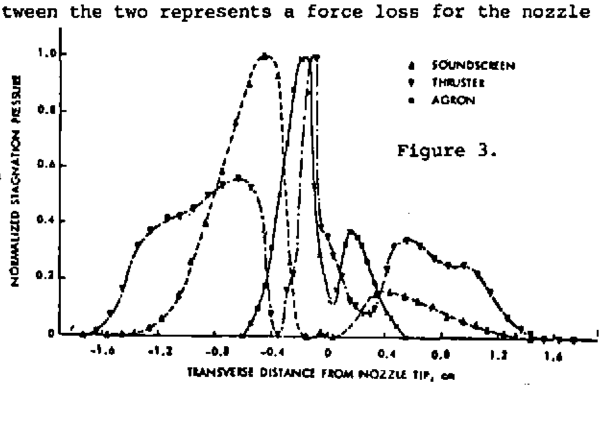

Figure 3.

loss of force of Thruster ranks first and is certainly due to the flow negotiating the porous material. Soundscreen and Agron show the least loss and are superior in performance to the open pipe. Figure 3 shows the distributions in the near field are asymmetrical and is is not ideal for low noise generation and low loss of thrust. Nozzle manufacturers should concern themselves to produce a symmetrical and even distribution of flow in the near field of the nozzle. In summary, the Thruster nozzle produces superior noise reduction but Soundscreen offers the best design for low noise and high efficiency of thrust. The latter is also superior in terms of efficiency of compressed air usage [3].

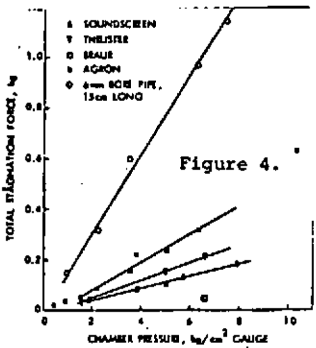

Figure 4.

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