POWER MEASUREMENT FOR AN ACOUSTICALLY PULSED JET FLOW

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Previous work[1] showed that acoustic modulation of the dilution-air jets of a small tubular combustor improved performance in that selective and progressive control of the exit plane temperature distribution was possible. Further work on acoustically pulsed free-jet mixing[2,3] showed that the entrainment coefficient of the jet, and therefore mixing, could be considerably increased, by up to 6 times. The effects correlated well with the amplitude of the jet pulsation velocity U_e. This new work therefore attempts to relate the jet pulsation velocity amplitude to the acoustic power modulating the jet flow $\dot{W}_{af}$ thereby leading to a more practical and direct correlation between mixing and acoustic power. This article is an abbreviated version of the Inter-Noise 93 paper, Leuven, Belgium, by the same authors.

Experimental. Figure 1 shows the apparatus whereby the modulating acoustic power and the corresponding exit air jet velocity pulsation amplitude U_e were measured for a flanged open ended copper tube and for a range of exit nozzle sizes, over a range of acoustic driver powers and exit jet velocities, at optimum excitation frequencies determined by frequency response testing. The acoustic power was measured using two Kistler 601L pressure transducers, transversely mounted in boss positions 2 and 3 in the air feed tube, air flow tube or driver tube as required. The measuring diaphragms were mounted flush with the tube bore, and unoccupied bosses were sealed by steel plugs. The exit air velocity pulsation amplitude was measured by a hot-film anemometer mounted on the centre-line in the exit plane. The air velocity in the flow tube U_f was varied from 0 to 8 m/s giving an exit jet velocity up to 78.6 m/s whilst the driver input electrical power W was varied up to a safe maximum of 32W.

From the pressure measurements, corrected for amplitude and phase differences, the acoustic power $\dot{W}_a$ was calculated from Munjal's Equn. (3.18)[4] using the computer and dual channel analyser.

Acoustic excitation, at a particular frequency, pulses the jet velocity U_j at its orifice exit plane causing the jet flow to develop a train of toroidal vortices. The entraining action of the travelling toroidal vortices is the primary mechanism of the acoustically augmented mixing process.

Figures 2 and 3 show typical measured acoustic power results. The influence of air flow velocity is shown to be of secondary importance. The three acoustical powers are approximately proportional to driver electrical power, but only for the 6.35 mm and 12.70 mm dia. nozzle systems is the sum of flow and feed tube acoustic powers approximately equal to that of the driver tube. For the open ended flow tube (maximum acoustic powers), the sum of flow and feed tube acoustic powers is less than that of the driver tube acoustic power. Also, the choked valve feed tube acoustic power is dissipated. This suggests that the acoustic power sum is less than the driver tube acoustic power by extra dissipation at the "T" junction. Furthermore the acoustic powers progressively decreased as the flow tube exit diameter was reduced by the nozzles.

Figure 4 presents typical jet pulsation velocity amplitude measurements versus the flow tube acoustic power $\dot{W}_{af}$ using the correlation of Ref. 2, where D is the jet orifice diameter and ρ is the jet flow density at the orifice exit plane. There is a distinct jet Reynolds number (Re_j) effect. Figure 5 summarises all the data and shows a geometrical effect. These figures show the jet excitation or pulsation strength U_e/U_j to be proportional to $(\dot{W}_{af}/\rho D^2 U_j^3)^{1/2}$, the acoustic power number. The correlation is well behaved giving confidence in the acoustic power measurement technique, and ought to be independent of the acoustic driver used. Because of the nozzle contraction ratio (lack of geometrical similarity) the acoustic intensity at the orifice (αU_e^2) is increased relative to that of the open flow tube. Thus all the data can be brought into approximate coincidence, except for Reynolds number effects, by scaling the acoustic power number by the ratio "flow tube bore diameter/jet orifice diameter". Because of the correlation, the acoustic power through U_e/U_j strongly correlates with pulsed jet mixing factors[2,3] eliminating the need for difficult pulsation velocity measurements.

Conclusions. The two pressure transducer technique for the measurement of acoustic power has been successfully developed for a tube air flow. The jet flow modulating acoustic power measured was approximately proportional to the driver electrical power, and was a maximum 8% of the driver power for the open ended tube and progressively decreased as the exit diameter was reduced by the nozzles. Significant acoustic power dissipation at the "T" junction was indicated. The % jet pulsation velocity amplitude was proportional to (flow modulating acoustic power)$^{1/2}$, inversely proportional to exit orifice diameter and inversely proportional to (jet velocity)$^{3/2}$. The well behaved correlation was approximately unique, except for Reynolds number effects, when the nozzle contraction ratio was accounted for. Because of the correlation acoustic power relates well with pulsed jet mixing factors eliminating the need for difficult pulsation velocity measurements.

References

1. P.J. Vermeulen, et al., "Acoustic Control of Dilution-Air Mixing in a Gas Turbine Combustor", ASME J. Engg. Power, 104, 844 (1982).
2. P.J. Vermeulen, et al., "Measurements of Entrainment by Acoustically Pulsed Axisymmetric Air Jets", ASME J. Engg. Power, 108, 479 (1986).
3. P.J. Vermeulen, et al., "Measurements of the Entrainment Coefficient of Acoustically Pulsed Axisymmetric Free Air Jets", ASME J. Engg. Power, 114, 409 (1992).
4. M.L. Munjal, Acoustics of Ducts & Mufflers (Wiley, 1987), Ch. 3.

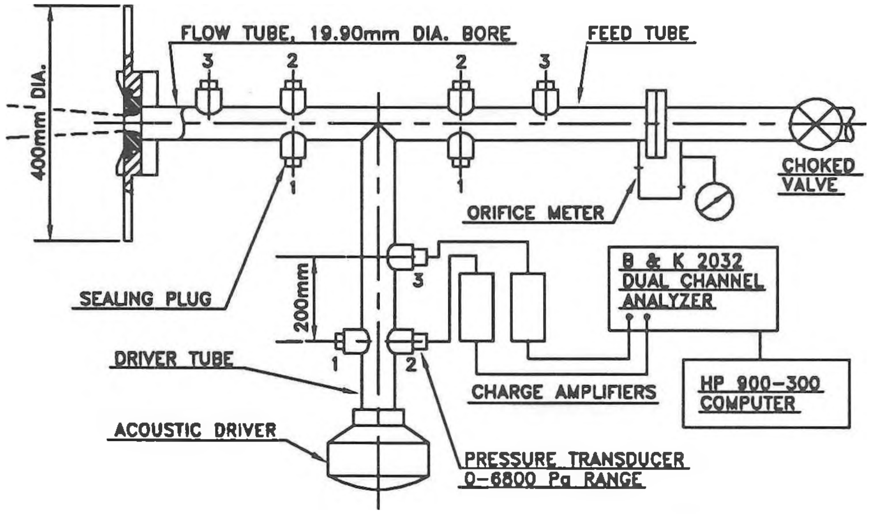

Fig. 1 Apparatus for Acoustic Power and Exit Pulsation Velocity Measurement.

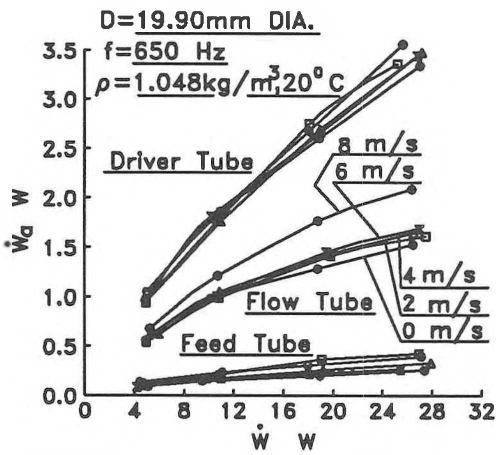

Fig. 2 Acoustic Power Versus Driver Input Electrical Power, Open Ended Tube.

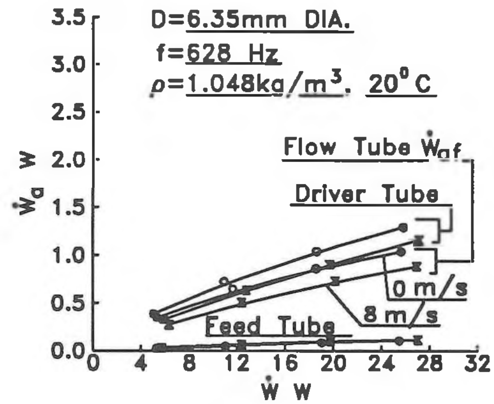

Fig. 3 Acoustic Power Versus Driver Input Electrical Power, 6.35mm Dia. Nozzle.

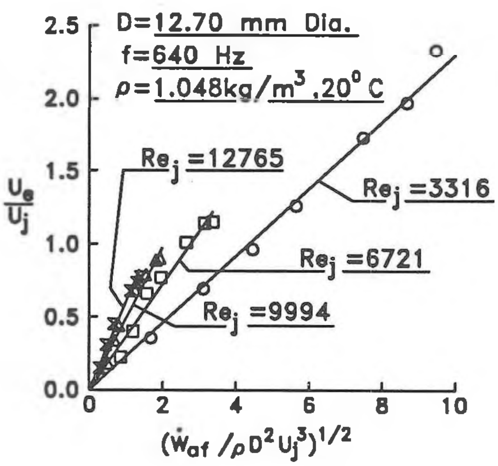

Fig. 4 Pulsation Strength Versus Acoustic Power Number, 12.70mm Dia. Nozzle.

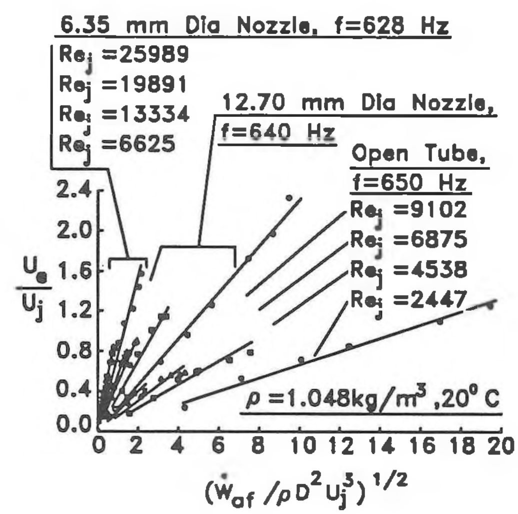

Fig. 5 Pulsation Strength Versus Acoustic Power Number for all Data.