PERFORMANCE OF COMBUSTOR WITH ACOUSTIC AUGMENTATION OF PRIMARY ZONE AIR-JET MIXING

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Introduction - Earlier work[1] established that the dilution-air mixing processes of a small tubular combustor of normal design could be beneficially controlled by acoustic means; specifically a desired exit-plane temperature distribution may be achieved. From these results it was inferred that the entrainment rate and mixing of the dilution-air jets was increased by the acoustic pulsation. These encouraging results promoted detailed investigations into acoustically pulsed free-jet mixing[2], and showed that the entrainment and entrainment coefficient of the jet could be considerably increased, by up to 6 times. Also, work on acoustically pulsed jet mixing with a confined crossflow[3], showed that mixing was significantly increased and penetration at least 100% increased.

The success of these activities has now resulted in the technique being applied to the air jets of the combustor primary zone of Ref. 1, because of the potential for control and improvement in combustor performance. These novel experiments were designed to examine the effectiveness and control by the acoustic drive, by means of temperature profile measurements in the combustor exit plane, and by combustion products measurements across the mid-plane diameter of the combustor secondary zone, Fig. 1, ie., just downstream of the primary zone. Tests were made over representative ranges of overall equivalence ratio ϕ_o (or air/fuel ratio A/F), reference Mach number M_r (load) and acoustic driver power $\dot{W}$.

Experimental - The method, Fig.1, channels air from upstream of the combustor inlet via six by-pass tubes connecting to a split manifold (3 separate segments) which feeds the 20 primary zone air-jet holes in the flame tube. Ten pairs of radial tubes cross the combustor annulus to connect the air holes of the flame tube to the manifold segments surrounding the combustor casing. Each manifold segment is connected by a driver tube to a 300W loudspeaker which provides the acoustic driving and control.

Figure 2 presents typical combustor exit plane local average dimensionless temperature contour maps, for symmetrical driving of all primary zone air jets, by the three-drivers at an average power of 151W per acoustic driver. T_3 is the exit plane local average temperature, T_{3m} is the exit plane mean temperature and T_2 is the combustor inlet temperature. This clearly shows that the acoustic drive produced a more uniform exit plane temperature pattern, resulting in up to 35% improvement in mixing relative to the "no-drive" state. The figure shows maximum effects for A/F = 56.2, a rich condition at about ¼ maximum air mass flow rate $\dot{M}_a$, and p_2, T_2 are inlet pressure and temperature respectively.

Figures 3 and 4 show the typical effect of acoustic drive on the distributions across the combustor diameter of local equivalence ratio ϕ (stoichiometric A/F/actual A/F) and the gas temperature T_g. In general, all the combustion parameters measured tended to increase with acoustic drive and as shown ϕ became distinctly richer and T_g became more uniform.

Conclusions - The acoustic drive produced a more uniform exit plane temperature pattern, resulting in up to 35% improvement in mixing relative to the "no-drive" state. The effects depended on air/fuel ratio and in general, improved relative to "no-drive" with richening. The effects of acoustic drive were controllable by means of the driving power, but saturated at about 150W when a single acoustic driver was used.

The acoustic drive enriches the primary zone and causes the primary zone temperature distribution to be more uniform.

Increased penetration of the primary zone air jets by the acoustic drive increased the combustor flow blockage and this constitutes the control mechanism. Overall, acoustic modulation improved mixing and produced favourable general progressive control over the combustor exit plane temperature pattern.

References

1. Vermeulen, P.J., Odgers, J. and Ramesh, V., "Acoustic Control of Dilution-Air Mixing in a Gas Turbine Combustor", Trans. ASME, Journal of Engineering for Power, Vol. 104, No. 4, Oct. 1982, pp. 844-852.
2. Vermeulen, P.J., Rainville, P. and Ramesh, V., "Measurements of the Entrainment Coefficient of Acoustically Pulsed Axisymmetric Free Air Jets", Trans. ASME, Journal of Engineering for Gas Turbines and Power, Vol. 114, No. 2, April 1992, pp. 409-415.
3. Vermeulen, P.J., Grabinski, P. and Ramesh, V., "Mixing of an Acoustically Excited Air Jet with a Confined Hot Crossflow", Trans. ASME, Journal of Engineering for Gas Turbines and Power, Vol. 114, No. 1, Jan. 1992, pp. 46-54.

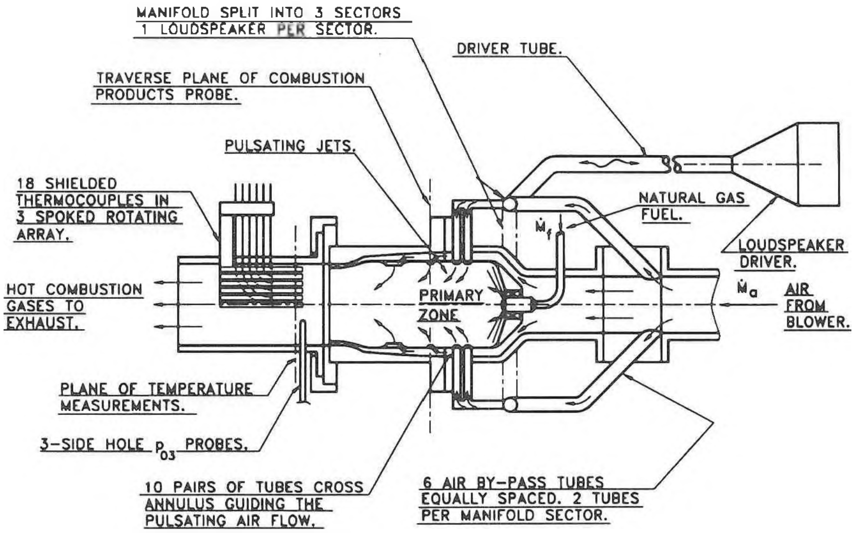

Fig. 1 Method for Acoustic Control of Combustor Primary Zone Air-Jet Mixing.

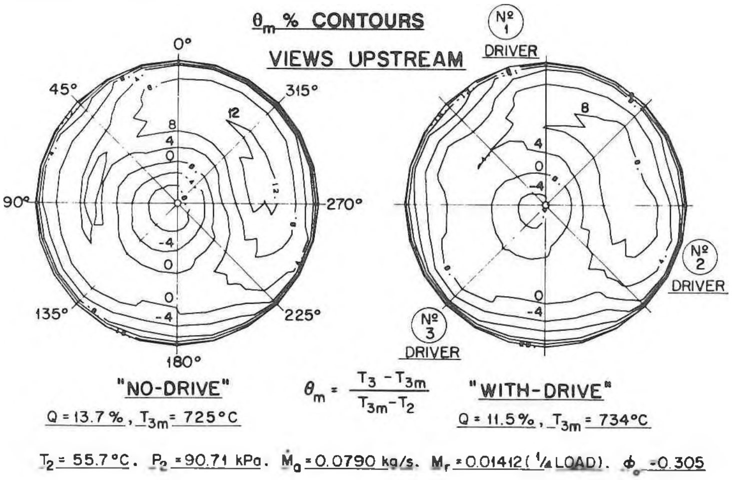

Fig. 2 Typical Exit Plane Local Average Temperature Contour Maps, 3 Drivers 151W Each, 227 Hz.

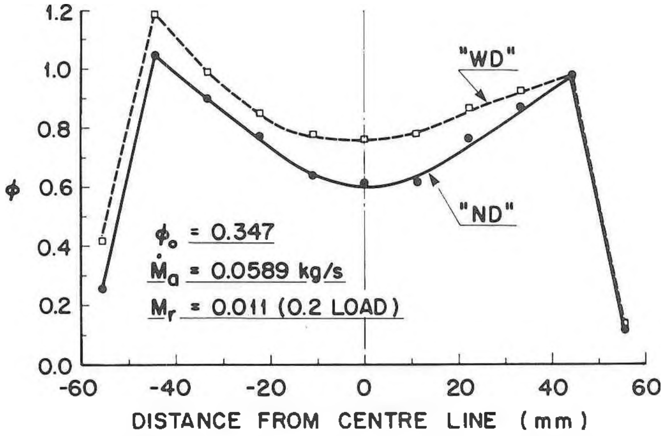

Fig. 3 Typical Downstream Primary Zone Local Equivalence Ratio Distribution, 3 Drivers, 94W Total Power, 225 Hz.

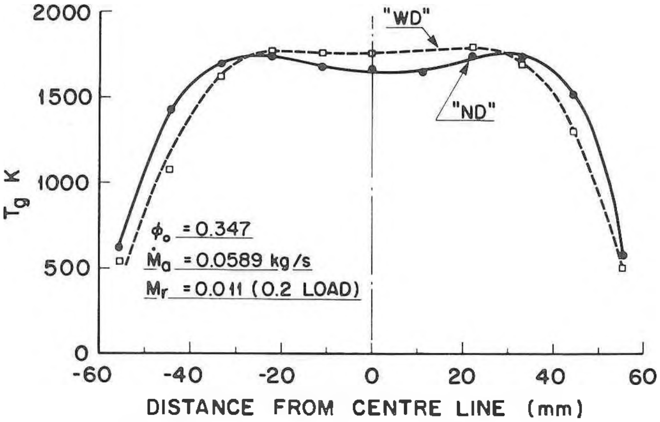

Fig. 4 Typical Downstream Primary Zone Local Gas Temperature Distribution, 3 Drivers, 94W Total Power, 225 Hz.