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ON THE MIXING OF A ROW OF JETS WITH A CONFINED CROSSFLOW

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INTRODUCTION

Considerations in designing or tailoring temperature patterns at the exit of gas-turbine combustion chambers, necessary to maximize engine power and life, have motivated several studies of the thermal mixing characteristics of multiple jets injected into a confined crossflow (refs. 1 to 11). The objective of these studies was to identify the dominant physical mechanisms governing the mixing, to develop and extend empirical models for use as a near-term combustor design tool, and to provide a data base for the assessment and verification of three-dimensional numerical codes.

These investigations of dilution jet mixing were staged in complexity, beginning with experiments and analyses (refs. 1 to 5) that investigated the mixing characteristics of a single row of jets injected into an isothermal main-stream flow in a constant area duct. Recent experimental and analytical results (refs. 6 to 11) extended the earlier studies to investigate the role of several flow and geometric variations typical of gas-turbine combustion chambers, namely, variable temperature main stream, flow area convergence, opposed in-line and staggered injection, multiple rows of holes, and noncircular orifices.

From the data of references 1 and 2, an empirical model was developed (refs. 3 and 4) for calculating the temperature field downstream of a row of jets mixing with a confined crossflow. This model is the basis of an interactive microcomputer code which evaluates dilution-zone design alternatives (ref. 5). In this paper mean temperature profiles calculated with this routine are presented to show the effects of flow and geometric variables on the mixing of a single row of jets injected through sharp-edged orifices into a uniform flow of a different temperature in a constant area duct. In addition, this program is used to calculate profiles for opposed rows of jets with their centerlines in-line, by assuming that the confining effect of an opposite wall is equivalent to that of a plane of symmetry between opposed jets.

FLOW FIELD DESCRIPTION

The flow schedule and the principal flow and geometric variables are shown in figure 1. The independent flow variables are the momentum flux ratio J, the density ratio DR, and the orifice discharge coefficient CD. The primary independent geometric variables are orifice size and the spacing between adjacent orifices. These are expressed in dimensionless form as the ratio of the duct height to orifice diameter H/D and as the ratio of the orifice spacing to duct height S/H. Downstream stations are defined in terms of the ratio of the distance to the duct height X/H.

The calculated temperature fields are shown in three-dimensional oblique views where the local temperature is given by the dimensionless temperature difference ratio, $\theta = (T_m - T)/(T_m - T_j$. (Note that θ is bounded by 0 and 1, with the former representing unmixed mainstream fluid and the latter unmixed jet fluid.) Local values of this parameter are given on the abscissa in the three-dimensional plots. The ordinate Y and oblique coordinate Z are, respectively, normal to and along the orifice row, in a constant-X plane. The Z-distance shown in the oblique plots is twice the orifice spacing for each configuration. The flow and geometric variables specified as input to the empirical model were DR, J, CD, S/H, H/D, and X/H. All of the calculated profiles shown are for conditions that are within the range of the experiments against which the empirical model has been compared.

SUMMARY OF FLOW AND GEOMETRY EFFECTS

The calculated mean temperature profiles shown herein illustrate the effects of flow and geometric variables on the mixing. These confirm the conclusions reached previously (refs. 2 and 4) from examination of the experimental data that

(1) Mixing improves with downstream distance (fig.2)

(2) The momentum flux ratio is the most significant flow variable (fig. 3)

(3) Variations in orifice diameter and spacing can have a significant effect on the profiles (fig. 4)

(4) Similar distributions are obtained over a range of momentum flux ratios, independent of orifice diameter, if spacing and momentum flux ratio are coupled such that (S/H)(J) = constant (fig. 5)

(5) Increasing the orifice diameter at constant spacing increases the magnitude of the temperature difference, but jet penetration and profile shape remain similar (fig. 6)

(7) For opposed rows of jets with centerlines in-line, the optimum orifice spacing in one half of the appropriate value for one side injection (fig. 7).

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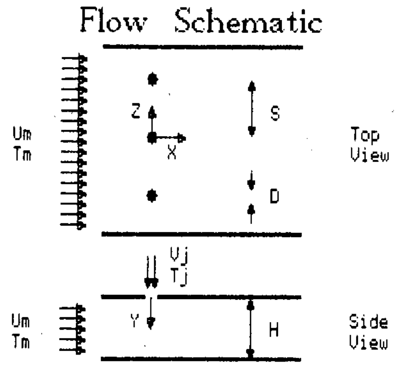


Independent Variables

DR = Tm/Tj	density ratio
J = DR $(Vj/Um)^2$	momentum flux ratio
CD	discharge coefficient
S/H	orifice spacing
H/D	orifice diameter
X/H	downstream distance

Dependent Variables

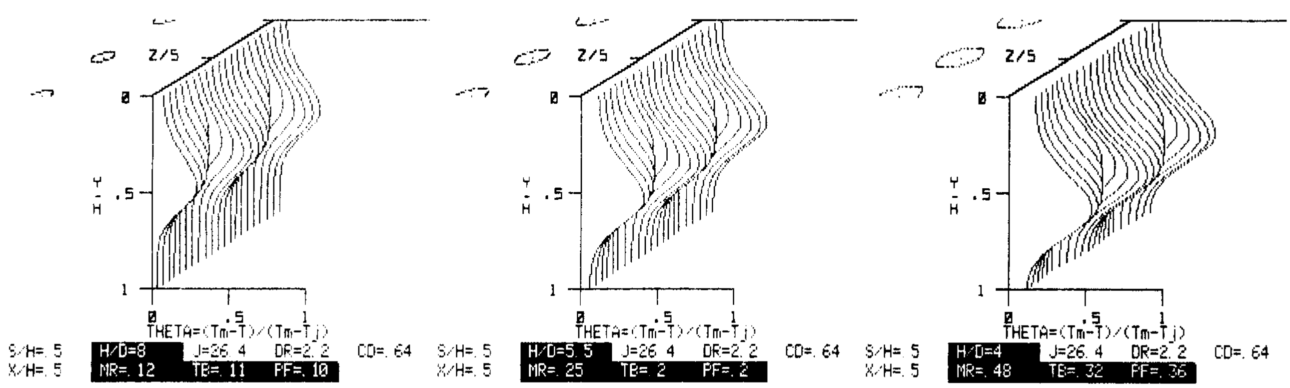
THETA = (Tm-T)/(Tm-Tj)	temperature
MR = m_J/m_M	mass flow split
TB = $m_J/(m_M+m_J)$	equilibrium THETA
PF = MR (1 - $THETA_{min}$/TB)	pattern factor
S/D	
X/D	

Dilution Jet Mixing Flow and Geometric Variables

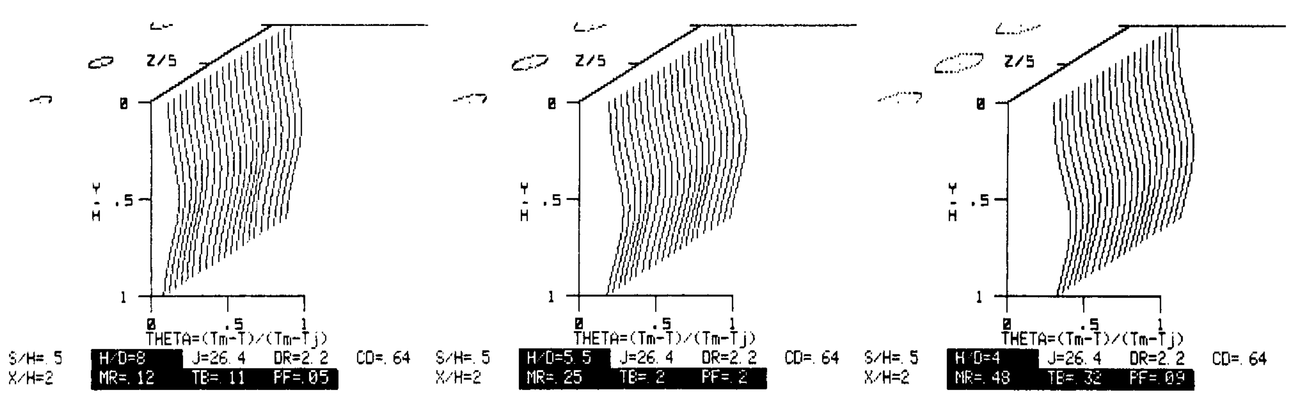
Figure 1

VARIATION IN TEMPERATURE DISTRIBUTIONS WITH INCREASING ORIFICE DIAMETER

CONSTANT SPACING S/H = 0.5; J = 26.4



(a) X/H = 0.5.



(b) X/H = 2.

Figure 2

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VARIATION IN TEMPERATURE DISTRIBUTIONS WITH INCREASING MOMENTUM FLUX RATIO

X/H 0.5; S/H = 0.5; H/D = 5.66

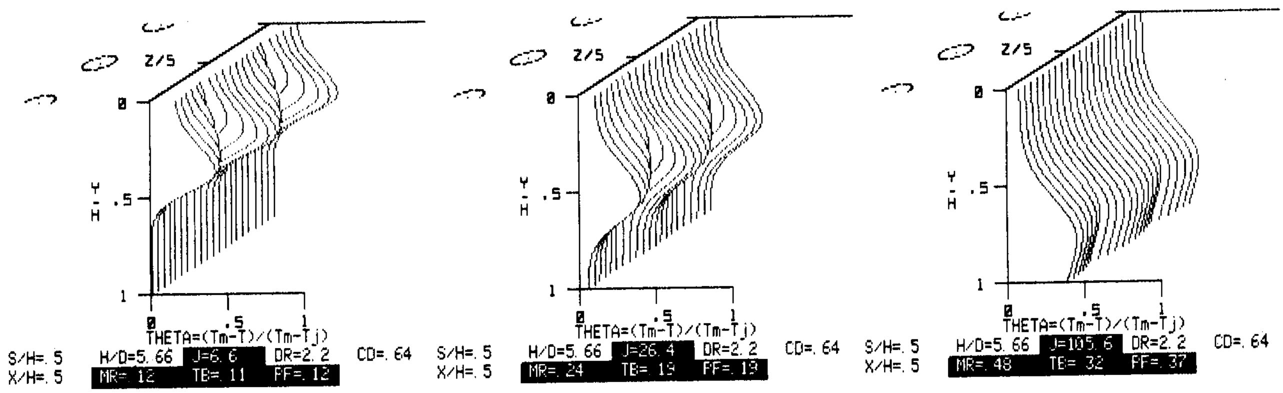


Figure 3

VARIATION IN TEMPERATURE DISTRIBUTIONS WITH INCREASING DOWNSTREAM DISTANCE

OPPOSED JET INJECTION; J = 26.4; S/H = 0.25; H/D = 11.3

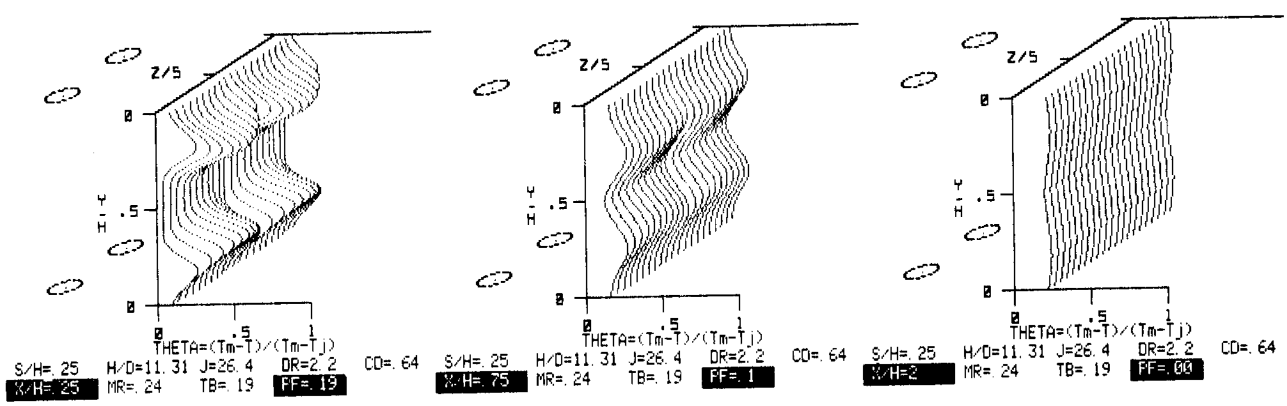
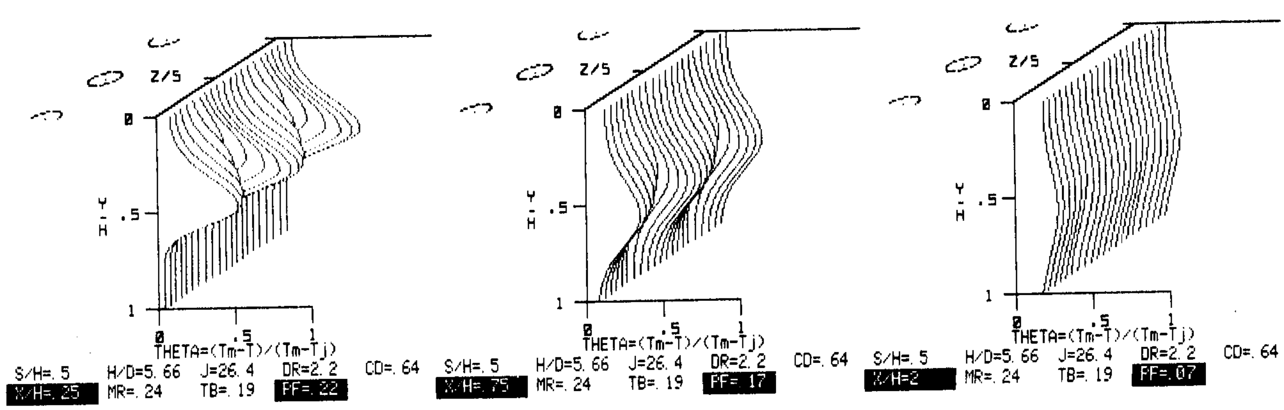


Figure 4

VARIATION IN TEMPERATURE DISTRIBUTIONS WITH INCREASING DOWNSTREAM DISTANCE

J = 26.4; S/H = 0.5; H/D = 5.66



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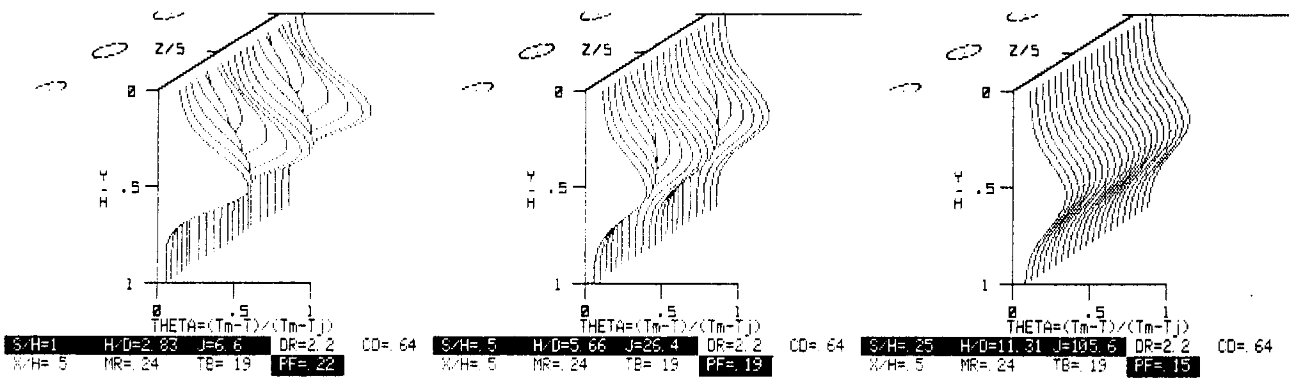
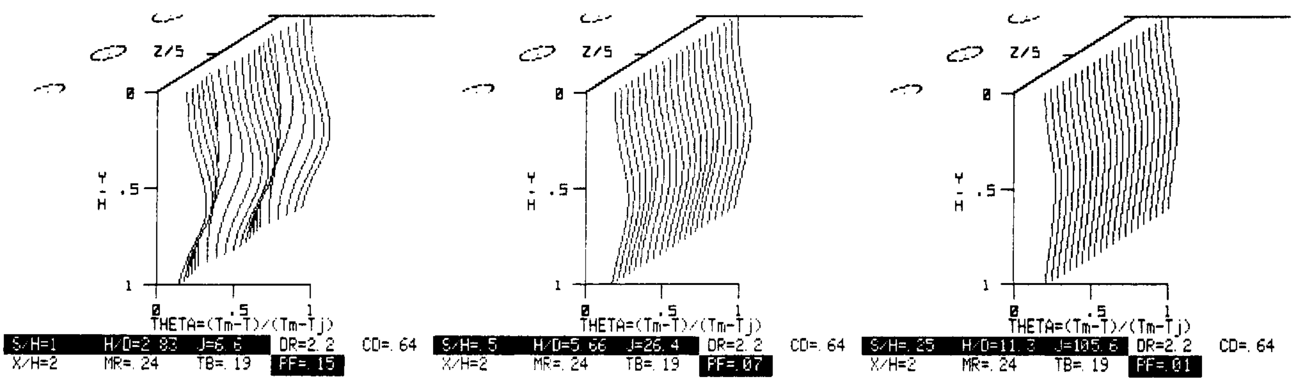
VARIATION IN TEMPERATURE DISTRIBUTIONS WITH COUPLED SPACING AND MOMENTUM FLUX RATIO



(a) X/H = 0.5.



(b) X/H = 2.

Figure 6

VARIATION IN TEMPERATURE DISTRIBUTIONS WITH ORIFICE SPACING AND DIAMETER

CONSTANT ORIFICE AREA; X/H = 0.5; J = 26.4

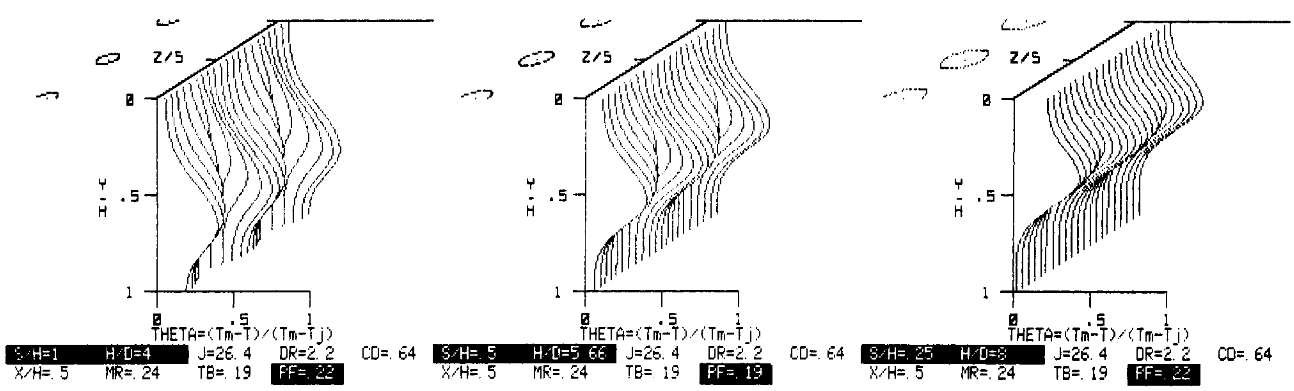


Figure 7

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