CHARACTERISTICS OF INHOMOGENEOUS JETS IN CONFINED SWIRLING AIR FLOWS

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Flow fields in the neighborhood of confined jets proved to be of great interest for gas turbine combustor designers. Although there have been numerous investigations on the characteristics of confined (1-4) jets, very little quantitative data exist for confined jets in a swirling flow. We have recently started an experimental program to study the characteristics of inhomogeneous jets in confined swirling flows to obtain detailed and accurate data for the evaluation and improvement of turbulent transport modeling for combustor flows. Our work was also motivated by the need to investigate and quantify the influence of confinement and swirl on the characteristics of inhomogeneous jets.

The flow facility at Arizona State University was constructed in a simple way which allows easy interchange of different swirlers and the freedom to vary the jet Reynolds number. The velocity measurements were taken with a one color, one component DISA Model 55L laser-Doppler anemometer employing the forward scatter mode. Standard statistical methods are used to evaluate the various moments of the signals to give the flow characteristics.

The current project started with the measurements of the velocity field. The second phase of the work will concentrate on the investigation of the scalar fluxes utilizing concentration probes. Finally, the two different sensors will be used simultaneously to determine the turbulent momentum and mass fluxes in the whole flow field.

The present work was directed at the understanding of the velocity field. Therefore, only velocity and turbulence data of the axial and circumferential
components are reported for inhomogeneous jets in confined swirling air flows. Results to date show that the jet centerline velocity decreases rapidly in a short distance for both Helium and air jets. However the similarity between Helium and air jets ends here. For air jets, the jet-like behaviour in the flow disappears at about 20 diameters downstream of the jet exit. This phenomenon is independent of the initial jet velocity. When this stage is reached for the mean flow, the turbulence field also decays to that of the background swirling flow. For Helium jets, the jet-like behaviour is noticed even at 40 diameters downstream of the jet exit. The turbulence field also reflects the same behaviour. Since the jets are fully turbulent (therefore, independent of jet Reynolds numbers) and the jet momentum fluxes for both air and Helium jets are the same, the cause of this difference in behaviour is attributed to the combined action of swirl and density difference. This behaviour could explain some of the common observations in gas turbine combustors.

The completion of the proposed work will make a substantial contribution to the understanding and predictive capability of complex turbulent swirling flows with inhomogeneous jets.

References

OBJECTIVE

- MIXING IN COMBUSTOR
- ISOTHERMAL VARIABLE DENSITY MIXING
- SWIRL EFFECTS
- SCALE INFORMATION FOR COMBUSTOR DESIGN
- DATA FOR MODEL VERIFICATION

PROGRAM OF WORK

- EXPERIMENTAL STUDIES
  1 - AIR JETS
  2 - HELIUM JETS
  3 - CONCENTRATION AND FLUX MEASUREMENTS
  4 - EFFECTS OF VARYING SWIRL

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Schematic Diagram of the Flow System
(Note that the laser axis is perpendicular to the plane of the paper)
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Schematic Diagram Showing the Test Section in Detail

Block Diagram of the LDV and Data Acquisition System
FLOW CONDITIONS

\( R_e = 5.5 \times 10^4 \)

<table>
<thead>
<tr>
<th>QUANTITY</th>
<th>AIR JET</th>
<th>HELIUM JET</th>
</tr>
</thead>
<tbody>
<tr>
<td>( U_j , (\text{m/s}) )</td>
<td>25.4</td>
<td>66.8</td>
</tr>
<tr>
<td>( R_{e_j} )</td>
<td>( 1.4 \times 10^6 )</td>
<td>( 3.8 \times 10^6 )</td>
</tr>
<tr>
<td>( M_j/\bar{m} )</td>
<td>0.071</td>
<td>0.491</td>
</tr>
</tbody>
</table>

Check on the Flow Symmetry

Check on the Seed Effects
AIR JET - SPECULATED FLOW BEHAVIOUR

(a)

(b)

(c)

(d)

(e)

AIR JET - SPECULATED FLOW BEHAVIOUR

(a) Centerline Velocities at Different Flow Conditions

(b) Normalized Centerline Velocities at Different Conditions

AIR/AIR

- \( \dot{Q}_1 \cdot 4.4 \)
- \( \dot{Q}_1 \cdot 2.4 \)
- \( \dot{Q}_1 \cdot 0.0 \)
- \( \dot{Q}_1 \cdot 66.8 \) NO SWIRLING FLOW

AIR/AIR

- \( \dot{Q}_1 \cdot 25.4 \)
- \( \dot{Q}_1 \cdot 58.6 \)
- \( \dot{Q}_1 \cdot 66.8 \)
- \( \dot{Q}_1 \cdot 77.0 \)
- \( \dot{Q}_1 \cdot 152.0 \)
- \( \dot{Q}_1 \cdot 66.8 \) NO SWIRLING FLOW

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Flow Field Near the Jet at Different Flow Conditions
Axial Velocity Measurements at Different Locations

Axial velocity measurements at different locations.
Circumferential Velocities at Different Axial Locations

Disturbance Profiles at Different Axial Locations
HELIUM JET - SPECULATED FLOW BEHAVIOUR

GRAVITATIONAL BUOYANCY = g = 9.8 m/s²

CENTRIFUGAL ACCELERATION = \( \frac{N^2}{R} \)

\[ (19 \text{ m/s}^2) \]

\[ = 6.2 \times 10^{-2} \text{ m/s}^2 \]

\[ \approx 6 \times 10^3 \text{ m/s}^2 \]

RATIO = 600

DISTANCE FOR He TO RISE ONE R

\[ x = \frac{\dot{u}_1 t}{5} \]

\[ \text{IF} \]

\[ \rho_A = 7 \rho_H \]

\[ \tau = \left( \frac{t}{70} \right)^{1/2} \]

\[ \frac{x}{\dot{u}_1} = \frac{\dot{u}_1 (R/70)^{1/2}}{\dot{u}_1} \]

\[ = 800 \]

EFFECTS OF ROTATION ON MIXING

FLUID PARTICLES ARE IN RADIAL EQUILIBRIUM DUE TO

RADIAL PRESS. GRAD + CENTRIFUGAL FORCE

PROMOTE MIXING

A \rightarrow B

\[ \rho_A < \rho_B \]

\[ \rho_A \]

\[ \rho_B \]

\[ \Omega \downarrow \]

DISPLACED FLUID B CONTINUES TO MOVE TOWARDS FUEL SURFACE

IMPEDE MIXING

B \rightarrow A

\[ \rho_B > \rho_A \]

\[ \rho_A \]

\[ \rho_B \]

\[ \Omega \downarrow \]

DISPLACED FLUID A WILL BE FORCED BACK TOWARDS \( \ell \)
**Helium/Air**

- $\bar{u}_i = 66.8$
- $\bar{u}_i = 25.4$

**Centerline Velocities at Different Flow Conditions**

**Axial Distributions of $\sqrt{\frac{\bar{u}^2}{\nu}}$ at Different Flow Conditions**
Axial Velocity Measurements at Different Locations

Disturbance Profiles at Different Axial Locations