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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

1. Janjua, S.I., McLaughlin, D.K., Jackson, T.W., and Lilley, D.G., turbulence Measurements in a Confined Jet Using a Six-Orientation Hot-Wire Probe Technique, AIAA Journal, Vol. 21, No. 12, pp. 1609-1610.

2. Habib, M.A., Whitelaw, J.H., Velocity Characteristics of a Confined Coaxial Jet, ASME Paper 79-WA/FE-9.

3. Habib, M.A., Whitelaw, J.H., Velocity Characteristics of Confined Coaxial Jets with and without Swirl, ASME Paper 79-WA/FE-21.

4. Johnson, B.V., Bennett, J.C., Mass and Momentum Turbulent Transport Experiments with Confined Coaxial Jets, NASA Report CR-165574.

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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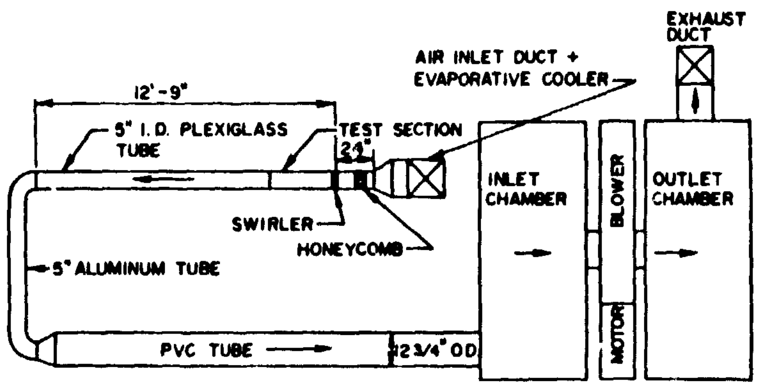

Schematic Diagram of the Flow System
(Note that the laser axis is perpendicular to the plane of the paper)

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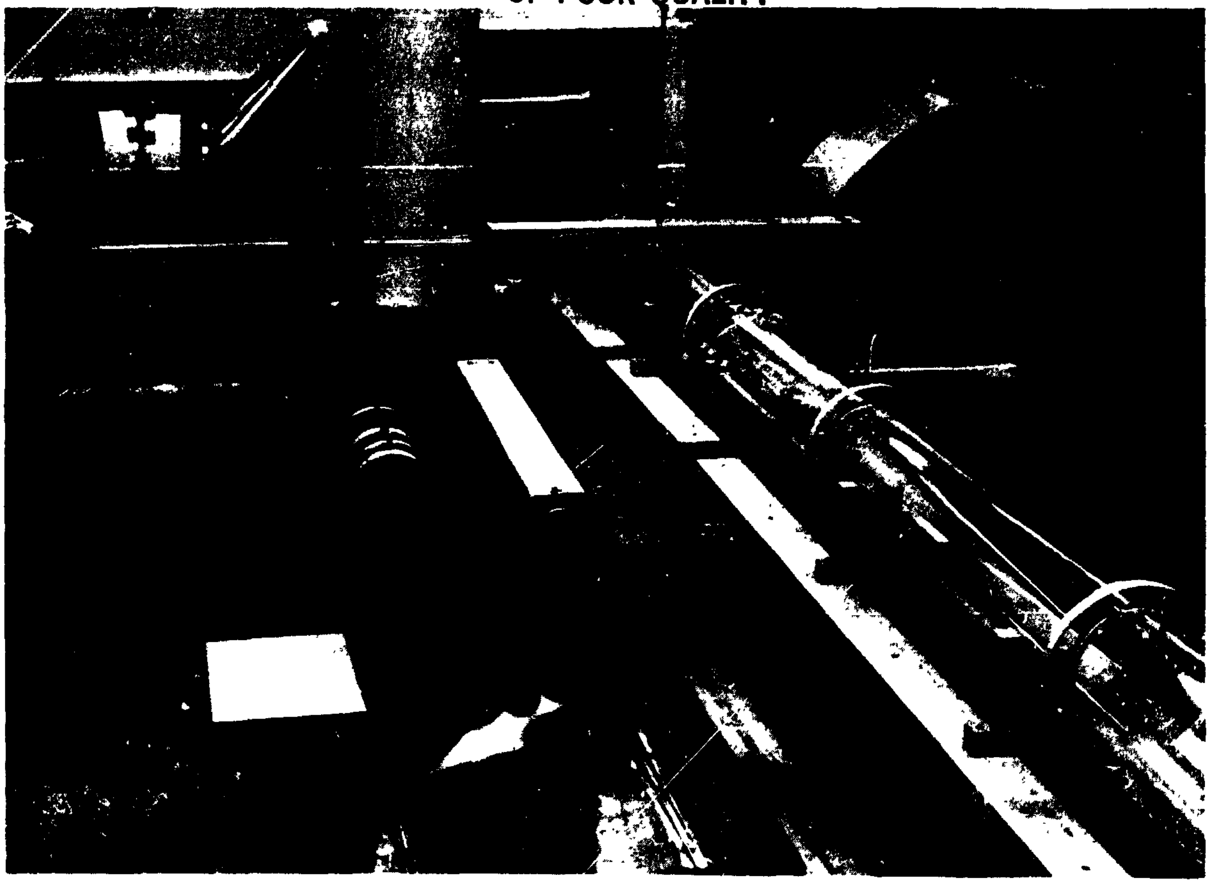

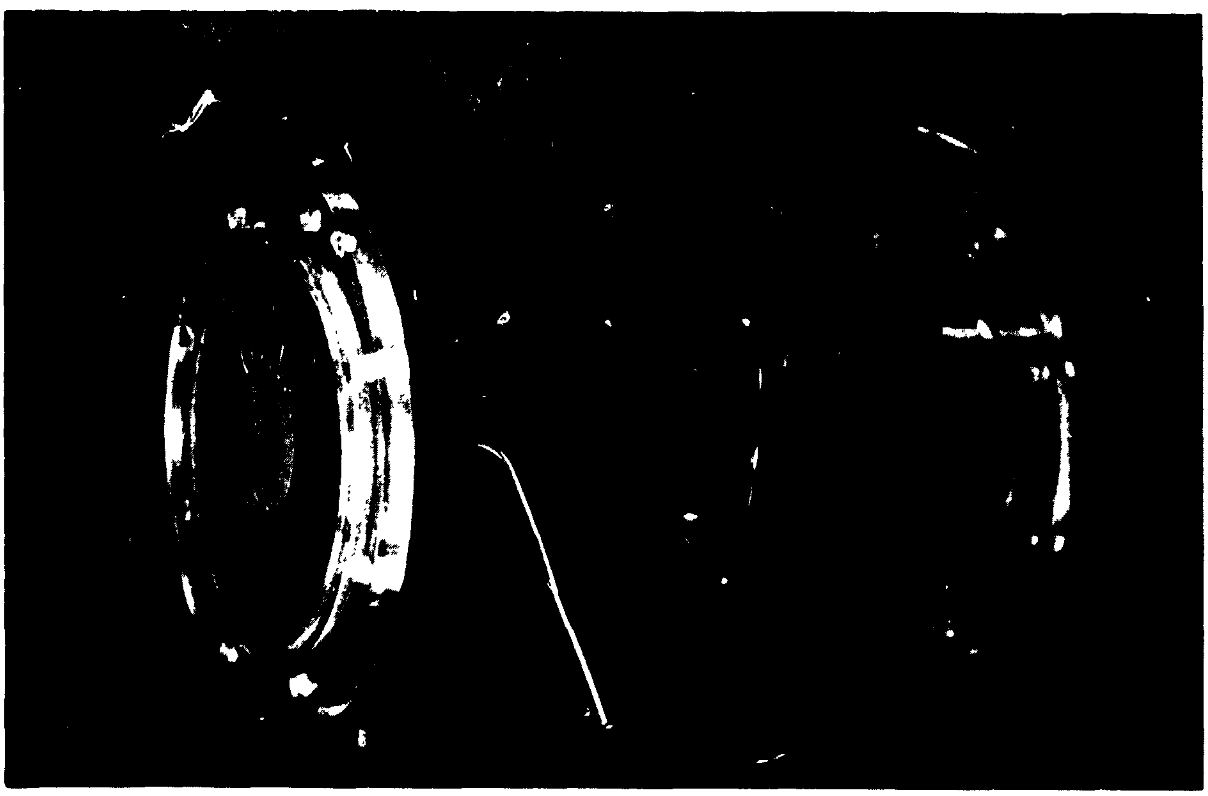

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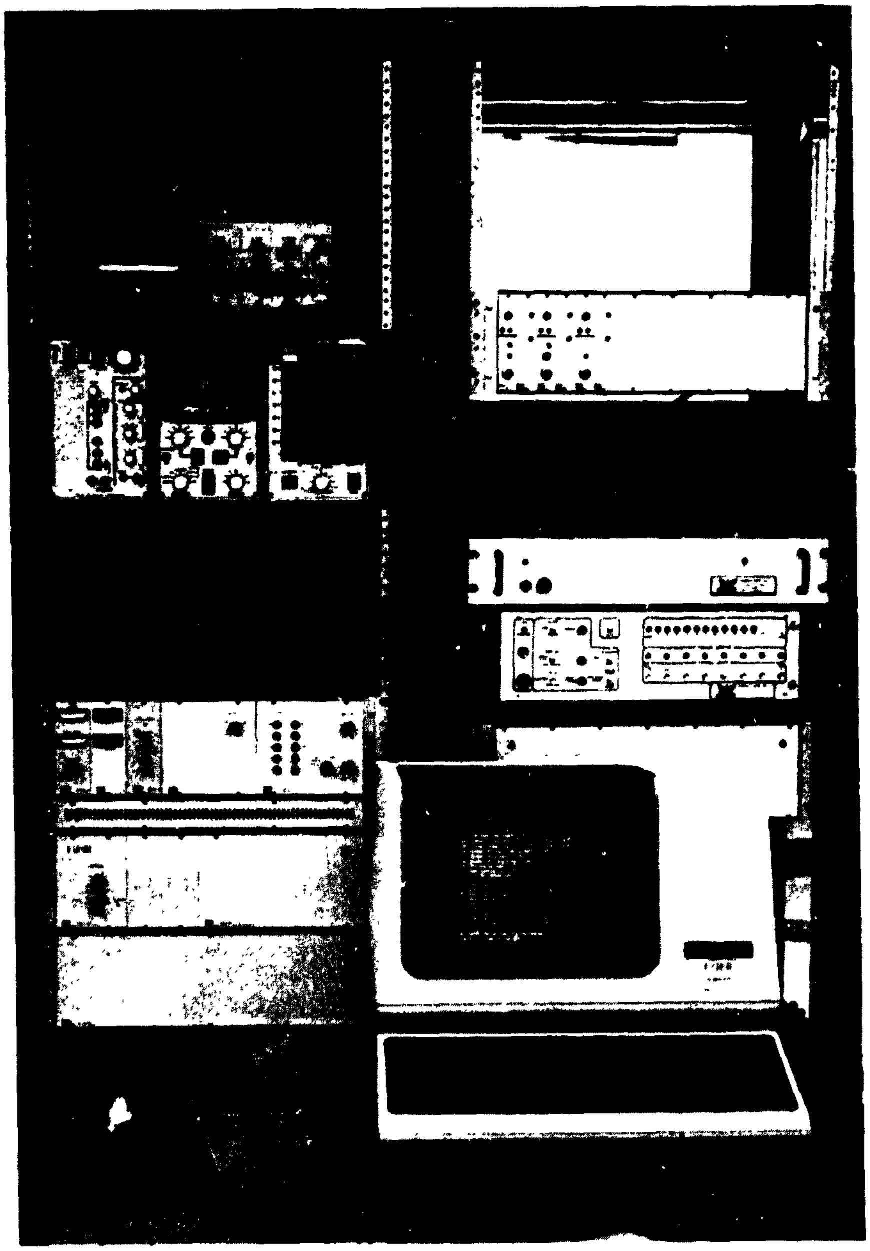
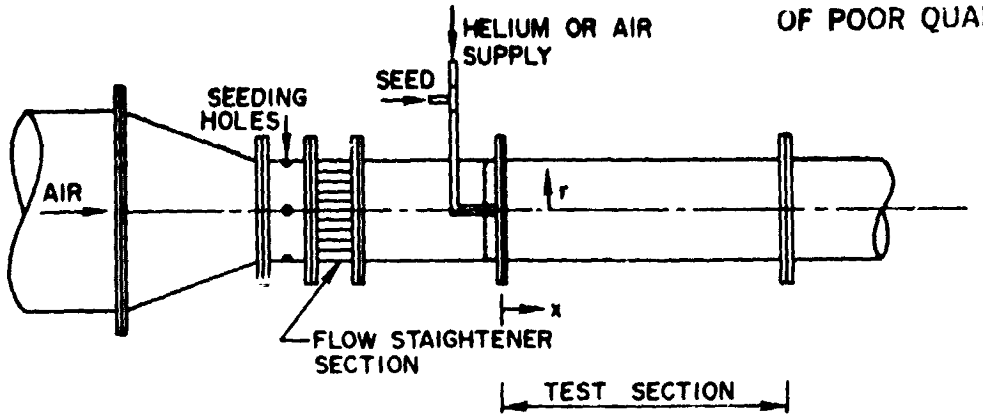
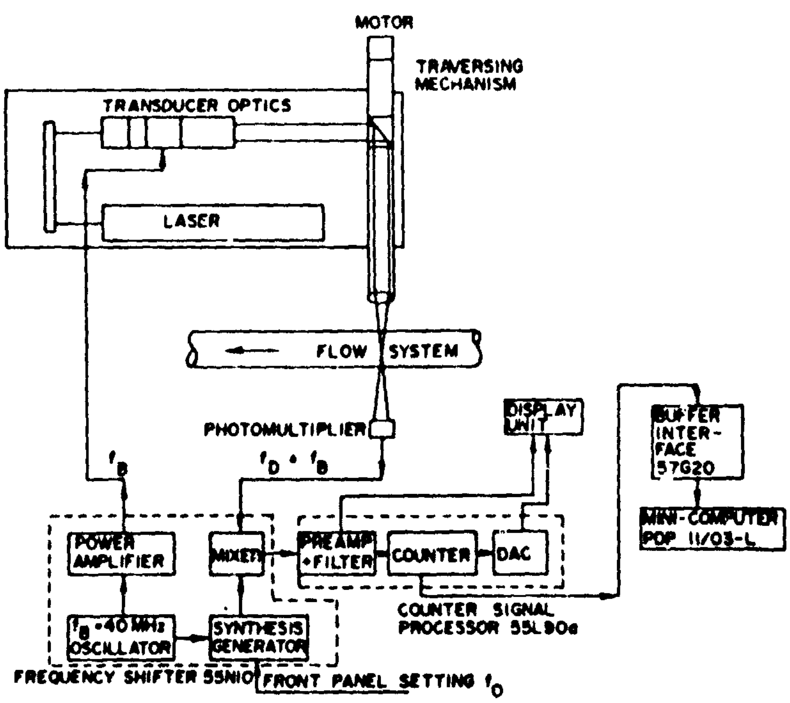




Schematic Diagram Showing the Test Section in Detail



Block Diagram of the LDV and Data Acquisition System

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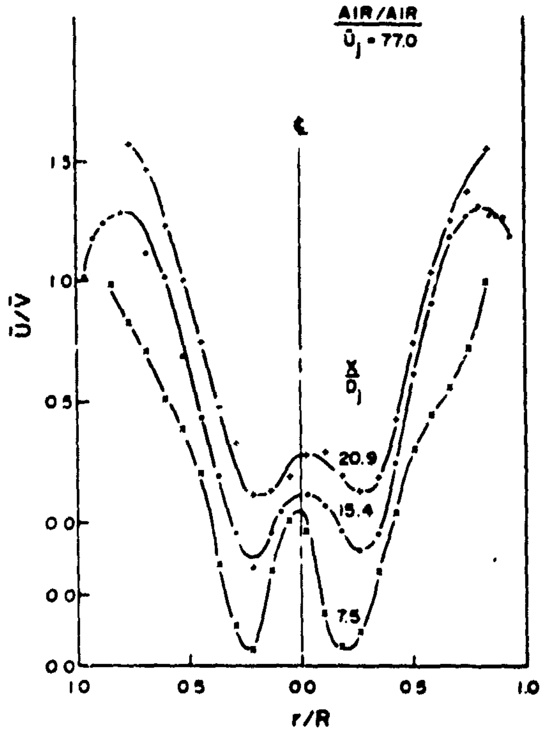
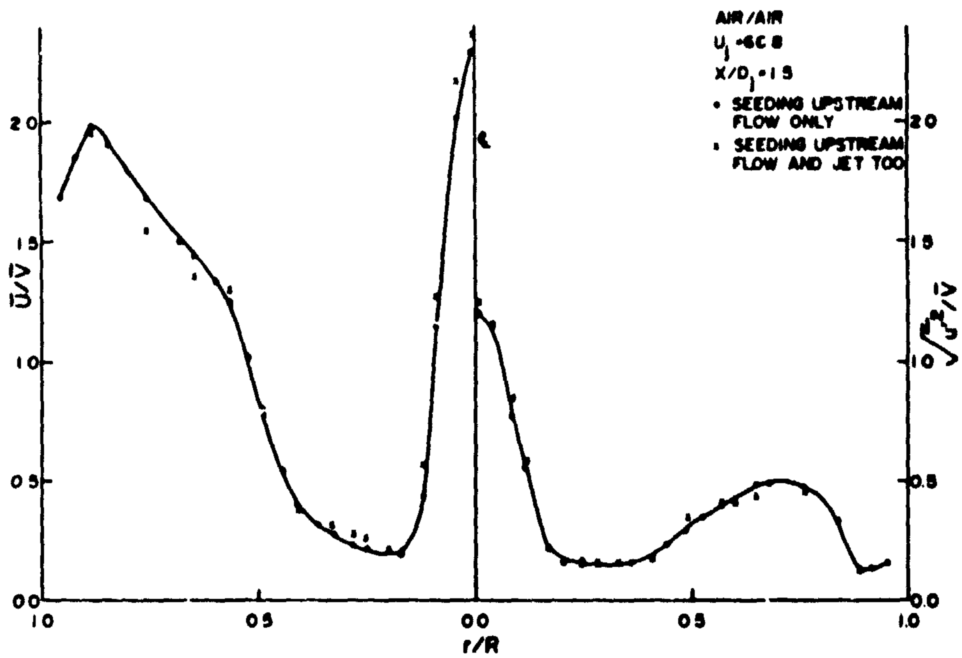
FLOW CONDITIONS

$\bar{R}_e = 5.5 \times 10^4$

QUANTITY MEASURED	AIR JET		HELIUM JET	
U_j (mt/sec)	25.4	66.8	25.4	66.8
R_{e_j}	1.4×10^4	3.8×10^4	1.8×10^3	4.8×10^3
$M_j/\bar{M}$	0.071	0.491	0.010	0.068

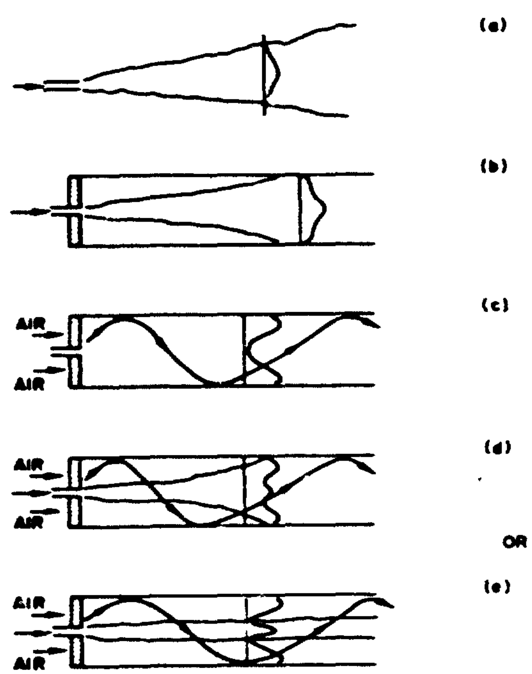


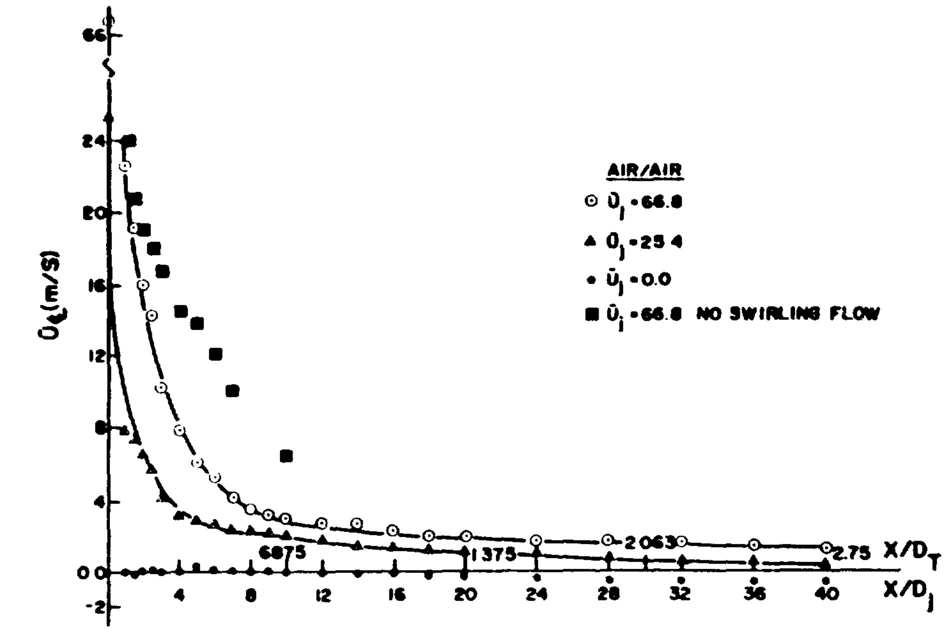
Check on the Flow Symmetry



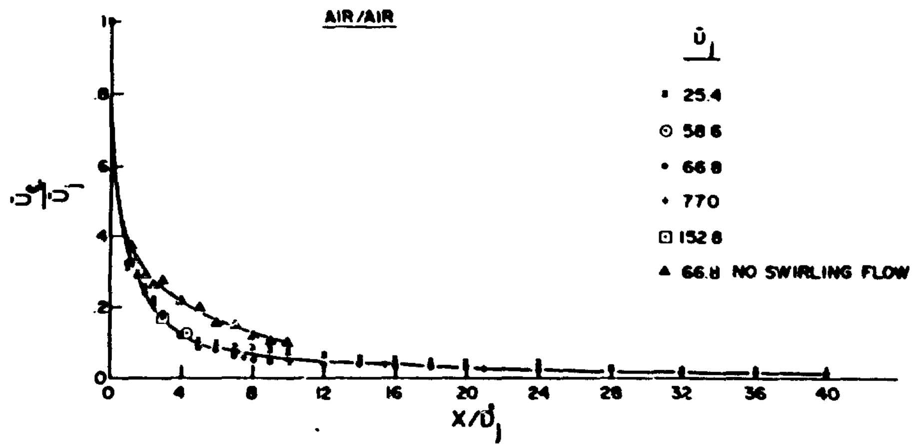
Check on the Seed Effects

AIR JET - SPECULATED FLOW BEHAVIOUR

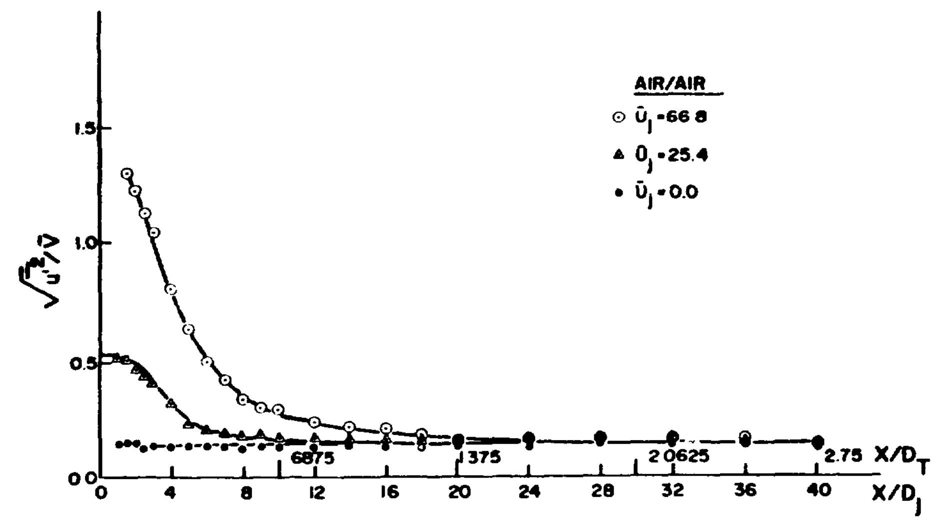




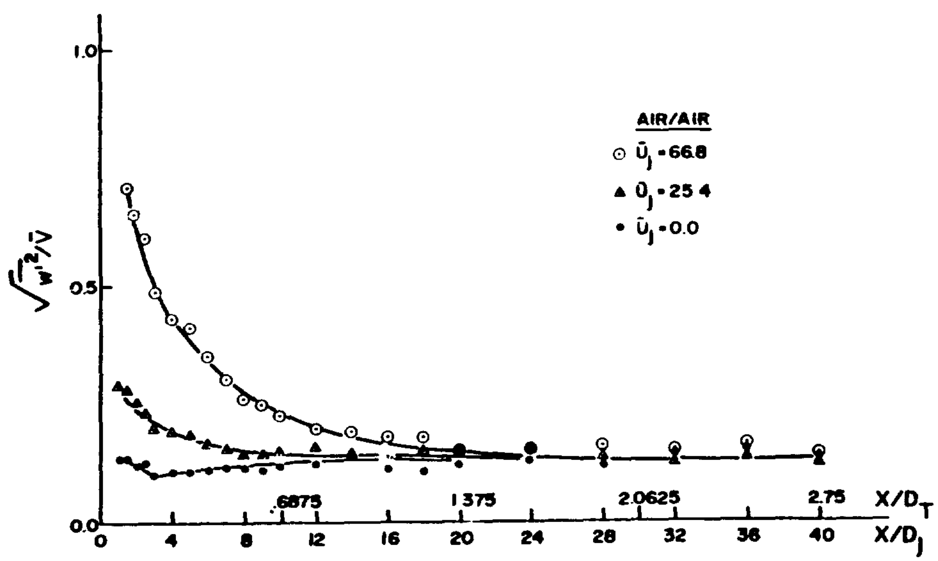
(a) Centerline Velocities at Different Flow Conditions



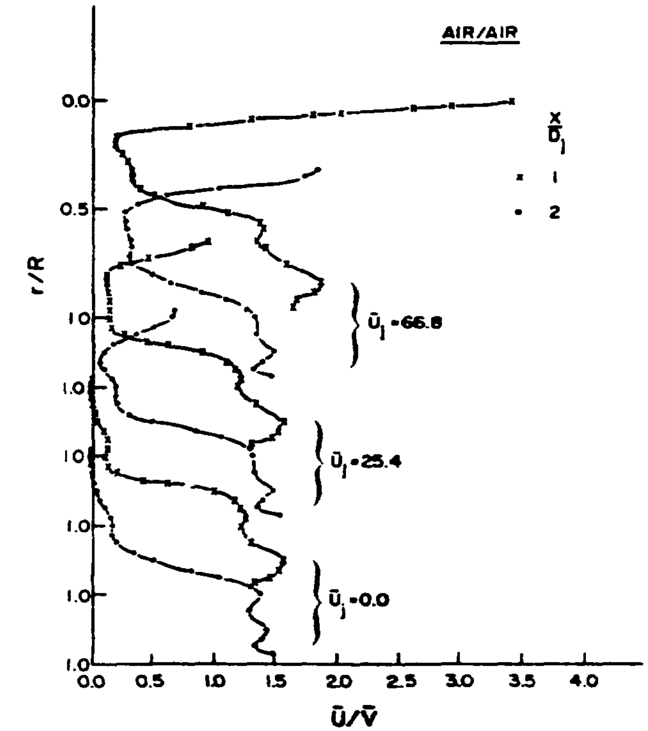
(b) Normalizeo Centerline Velocities at Different Conditions



(c) Axial Distributions of $\sqrt{\overline{u'^2}}/\bar{V}$ at Different Flow Conditions



(d) Axial Distributions of $\sqrt{\overline{w'^2}}/\bar{V}$ at Different Flow Conditions



Flow Field Near the Jet at Different Flow Conditions

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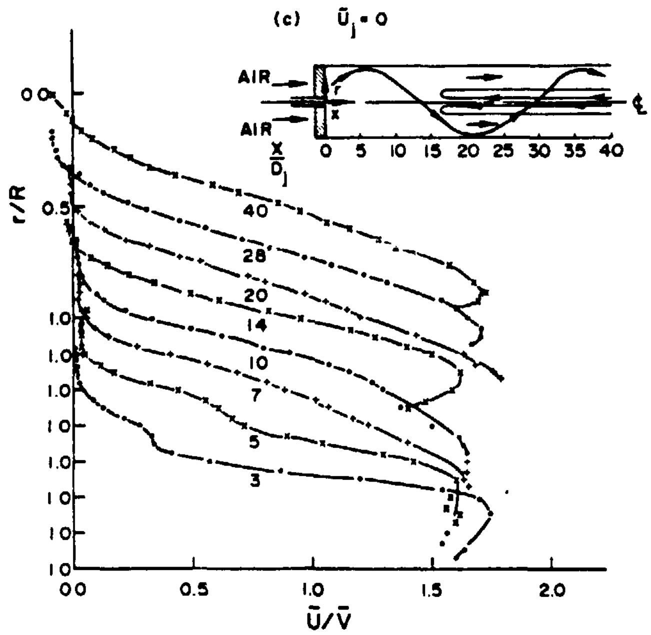
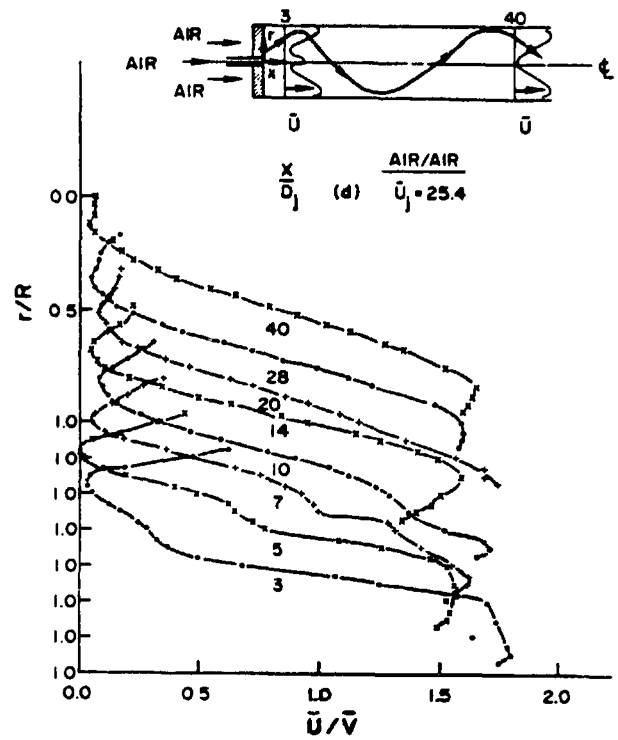


Axial Velocity Measurements at Different Locations



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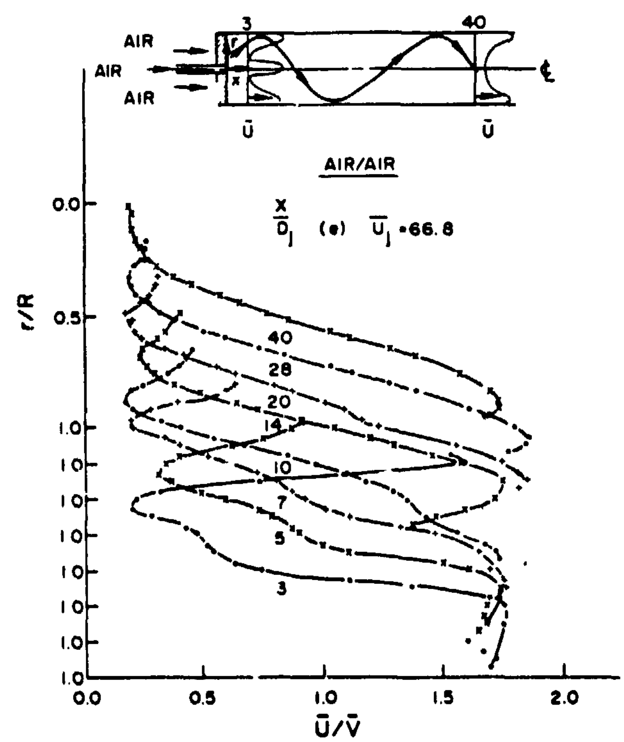
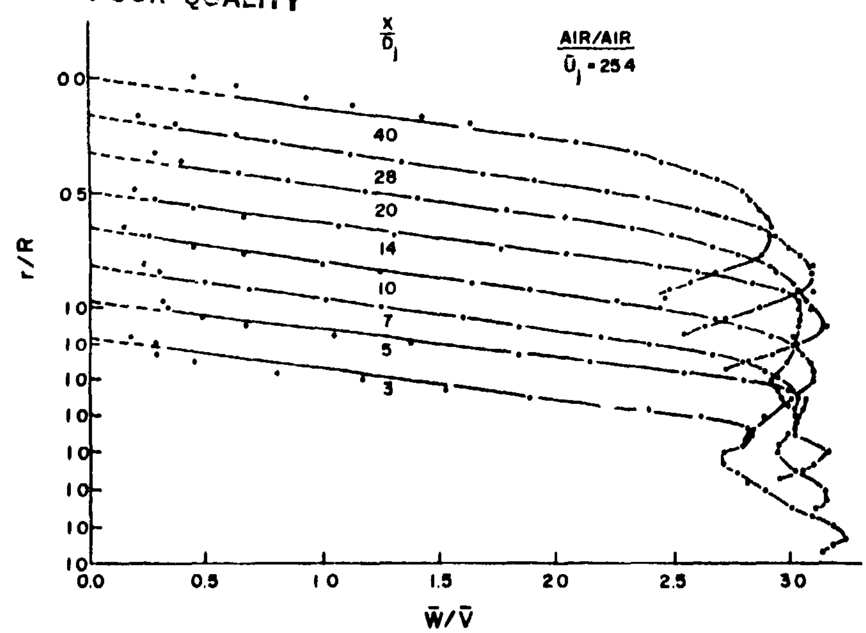
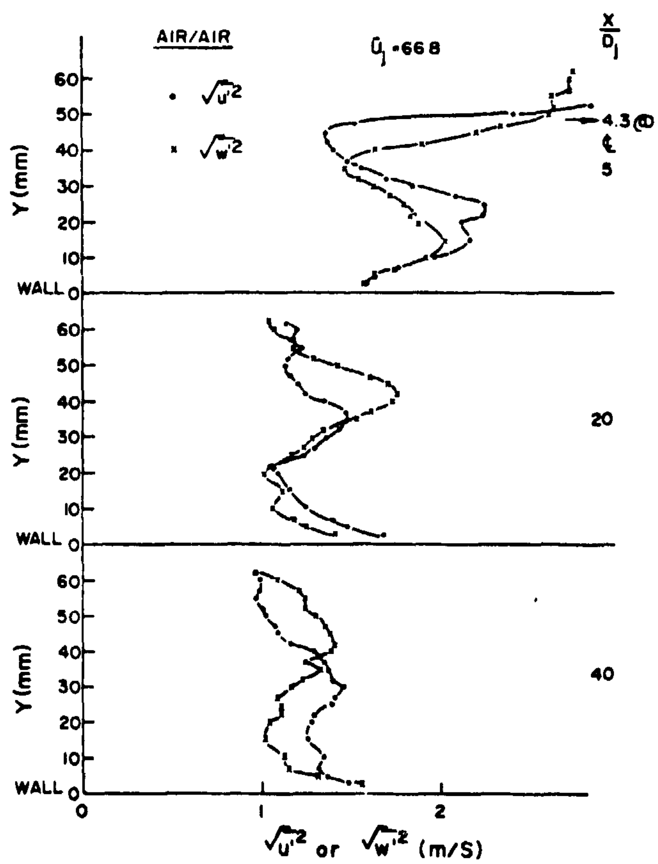


Axial Velocity Measurements at Different Locations



Circumferential Velocities at Different Axial Locations



Disturbance Profiles at Different Axial Locations

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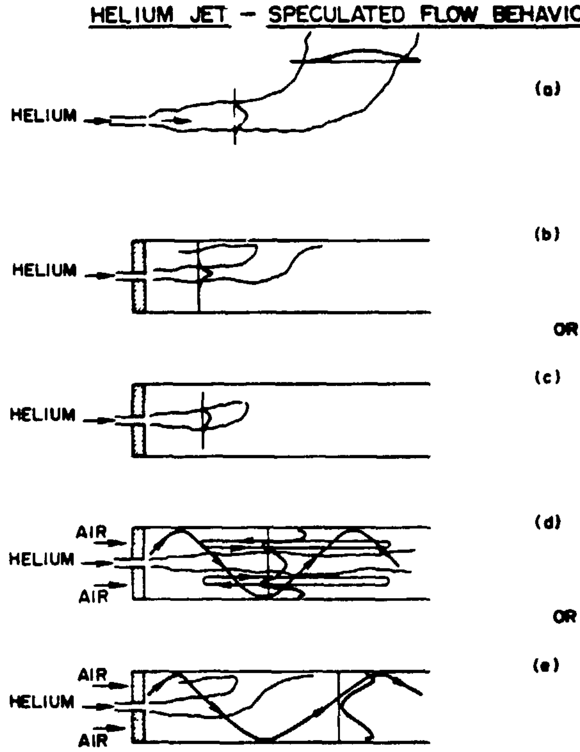
<u>HELIUM JET – SPECULATED FLOW BEHAVIOUR</u>



GRAVITATIONAL BUOYANCY $= g = 9.8\ m/s^2$

CENTRIFUGAL ACCELERATION $= \frac{\overline{W}^2}{R}$

$$= \frac{(19\ m/s)^2}{6.2 \times 10^{-2}\ m}$$

$$\doteq 6 \times 10^3\ m/s^2$$

RATIO $= 600$

DISTANCE FOR He TO RISE ONE R

$$x = \overline{U}_j\, t$$

SINCE $\left(\rho_H + \frac{1}{2}\rho_A\right)\frac{d^2r}{dt^2} = g\left(\rho_A - \rho_H\right)$

IF $\rho_A = 7\rho_H$

$$t \doteq \left(\frac{r}{.7g}\right)^{1/2}$$

$$\frac{x}{D_j} = \frac{\overline{U}_j\,(R/.7g)^{1/2}}{D_j}$$

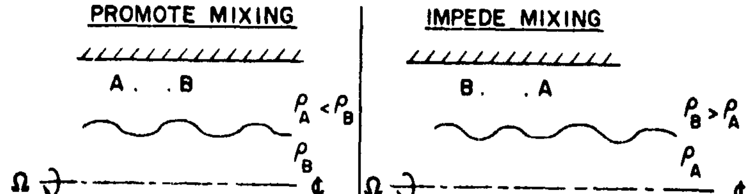
$$= 800$$

EFFECTS OF ROTATION ON MIXING

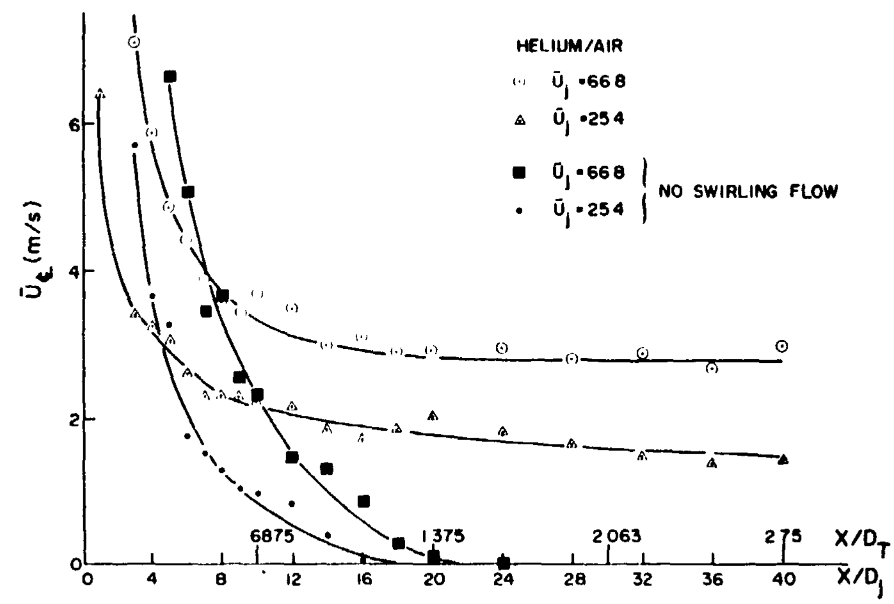
FLUID PARTICLES ARE IN RADIAL EQUILIBRIUM DUE TO

RADIAL PRESS. GRAD = CENTRIFUGAL FORCE

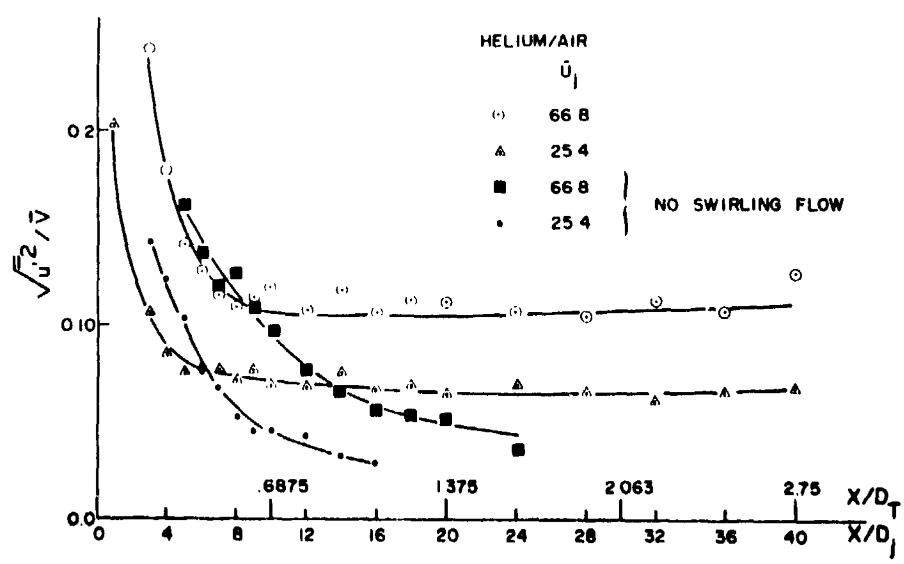
PROMOTE MIXING	IMPEDE MIXING



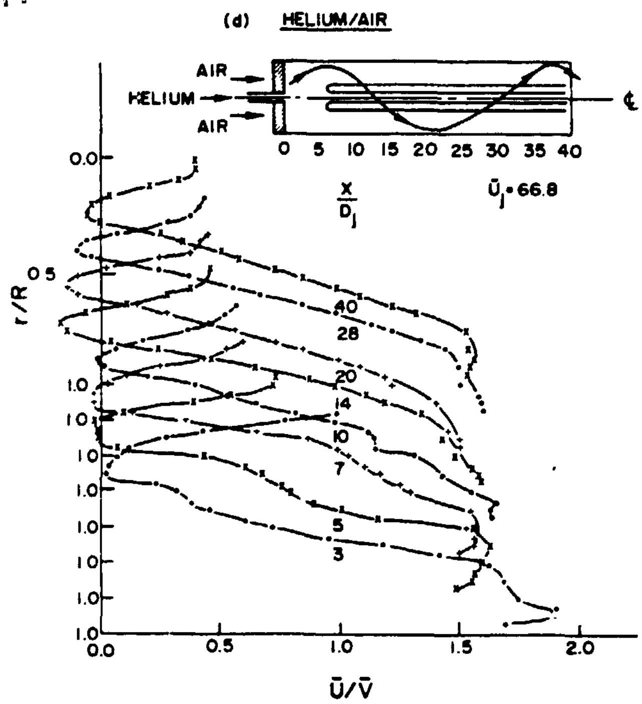
DISPLACED FLUID B CONTINUES TO MOVE TOWARDS FUEL SURFACE	DISPLACED FLUID A WILL BE FORCED BACK TOWARDS ℄



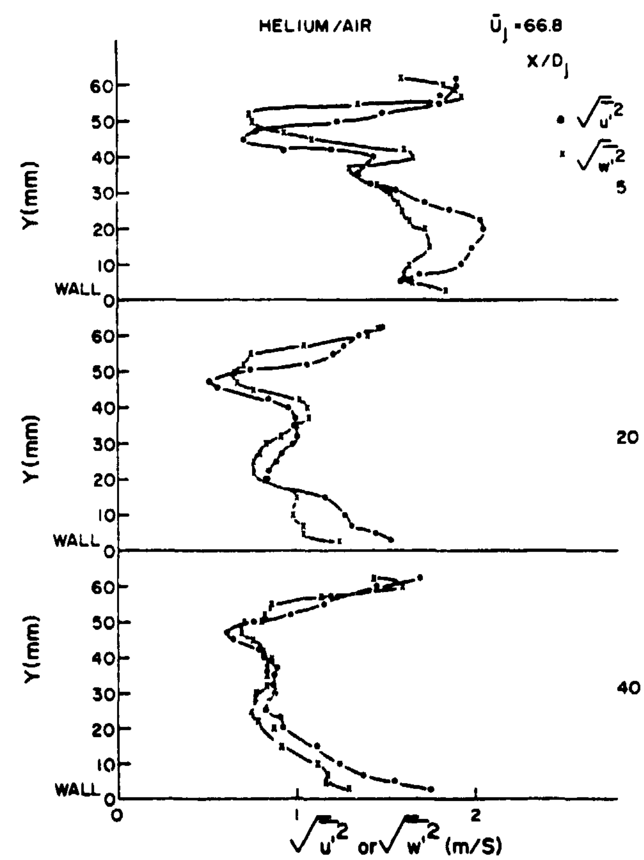
Centerline Velocities at Different Flow Conditions



Axial Distributions of $\sqrt{\overline{u'^2}}/\bar{V}$ at Different Flow Conditions



Axial Velocity Measurements at Different Locations



Disturbance Profiles at Different Axial Locations