INVESTIGATIONS OF FLOWFIELDS FOUND IN TYPICAL COMBUSTOR GEOMETRIES

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Studies are concerned with experimental and theoretical research on 2-D axisymmetric geometries under low speed, nonreacting, turbulent, swirling flow conditions. The flow enters the test section and proceeds into a larger chamber (the linear expansion ratio D/d = 2, 1.5 and 1) via a sudden or gradual expansion (side-wall angle α = 90 and 45 degrees). A weak or strong nozzle (of area ratio A/a = 2 and 4) may be positioned downstream at x/D = 2 to form a contraction exit to the test section. Inlet swirl vanes are adjustable to a variety of vane angles with values of ϕ = 0, 38, 45, 60 and 70 degrees being emphasized. The objective is to determine the effect of these parameters on isothermal flowfield patterns, time-mean velocities and turbulence quantities, and to establish an improved simulation in the form of a computer prediction code equipped with a suitable turbulence model. The goal of the on-going research is to perform experiments and complementary computations with the idea of doing the necessary type of research that will yield improved calculation capability. This involves performing experiments where time-mean turbulence quantities are measured and taking input conditions and running an existing prediction code for a variety of test cases so as to compare predictions against experiment. Hence the validity of turbulence model modifications can be assessed. If fact, they are also being deduced directly from the measured stresses and velocity gradients.

Three Ph.D. Theses (Rhode, Jackson and Abujelala) and five M.S. Theses (Janjua, Yoon, McKillop, Sander, and Scharrer) have evolved in connection with the investigation over the last three years. New features of the present year's study include the investigation of: a more complex range of swirl strengths; swirler performance; exit nozzle sizes and locations; expansion ratios; and side-wall angles. Their individual and combined effects on the test section flowfield are being observed, measured and characterized. Recent studies on the test facility include:

1. Swirler Performance - with five-hole pitot probe[1] and single-wire hot-wire[2] for time-mean and turbulence characteristics.

2. Gross Flowfield Characterization - flow visualization has been achieved via photography of neutrally-buoyant helium-filled soap bubbles and smoke produced by an injector and smoke wire.[3-5]

3. Time-Mean Flowfield Characterization - with five-hole pitot probe for time-mean velocity field and velocity gradients for a full range of swirl strengths.[3-6]

4. Turbulence Measurements - with single wire[7,8], cross-wire[9] and triple-wire[10] hot-wires, including an assessment of the accuracy and directional sensitivity of the single-wire technique[11], enabling all Reynolds stress components to be deduced.

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5. Turbulence Modeling - limitations and empirical extensions of the $k-\varepsilon$ model have been analyzed[12], but relating Reynolds stresses to appropriate time-mean velocity gradients are yielding effective model improvements[13].

6. Computer Predictions - using an advanced computer code[14], tentative predictions[3] have now been supplemented by predictions made using recently-acquired realistic inlet conditions for a complete range of swirl strengths[15], including expansion ratios and downstream nozzle effects[16].

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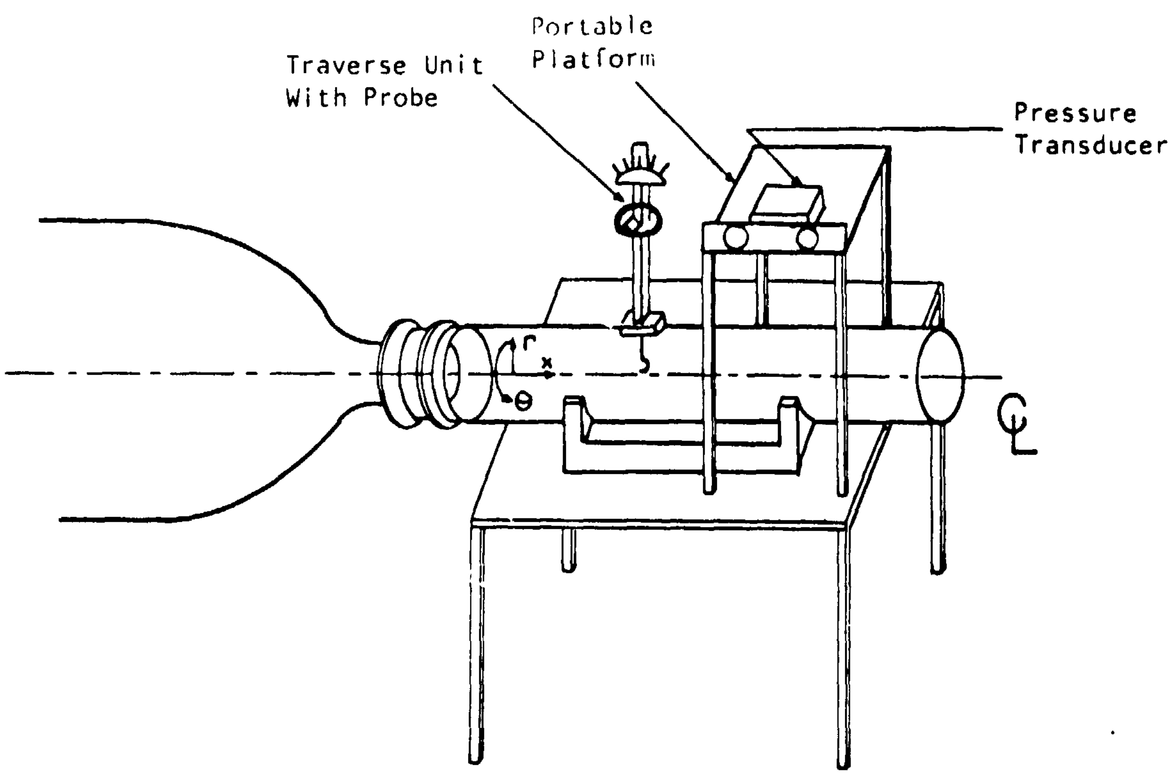
Contents

1. Introduction

1.1 The Test Facility



1.2 Research Objectives

1. To determine the effect of:
   * swirl vane angle ϕ
   * side-wall angle α
   * downstream blockage area ratio AR and location L/D

   on:
   * isothermal flowfield patterns
   * time-mean velocities
   * turbulence quantities
2. To establish an improved simulation in the form of:
   * computer prediction code
   * suitable turbulence model

1.3 Research Approach

1. Time-mean flowfield characterization by five-hole pitot probe measurements and by flow visualization.
2. Turbulence measurements by a variety of single- and multi-wire hot-wire probe techniques.
3. Flowfield computations using the computer code developed during the previous year's research program.

2. Progress

2.1 Progress During First Year (1981)

1. Test facility - design and construction, including variable angle swirler and expansion blocks.
2. Experimental techniques - flow visualization, five-hole pitot probe and reduction computer code.
3. Computational code development - advanced version of a primitive-variable solution procedure - STARPIC.
4. Flowfield characterization - emphasis on time-mean flow character, using flow visualization, five-hole pitot probe and tentative predictions.

2.2 Progress During Second Year (1982)

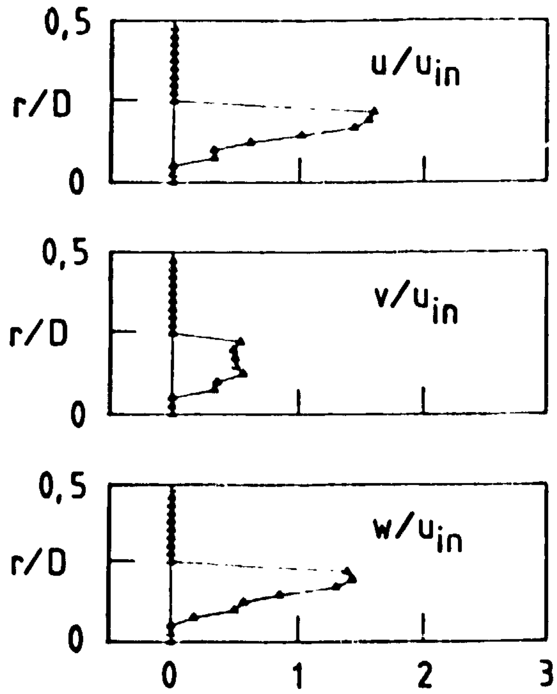
1. Higher swirl strengths - flow visualization and five-hole pitot probe measurements.
2. Swirler effectiveness - exit profiles of u, v, w, and p accurately established.
3. Flowfield predictions - the need for specifying the inlet conditions very precisely.
4. Downstream blockage - effects of area ratio and axial location studied by flow visualization, five-hole pitot probe and corresponding computer predictions.
5. Turbulence measurements - in nonswirling and swirling flow via one-wire, two-wire and three-wire hot-wire methods.

2.3 Progress During Third Year (1983)

1. Smaller expansion ratios - D/d = 1, 1.5 and 2
2. Turbulence measurements - at higher swirl strengths, with and without downstream blockage
3. Turbulence modeling - developments from measured Reynolds stresses and time-mean velocity gradients
4. Flowfield predictions - for corresponding situations

3. Results [ϕ = 45 degrees]

3.1 Swirler Performance



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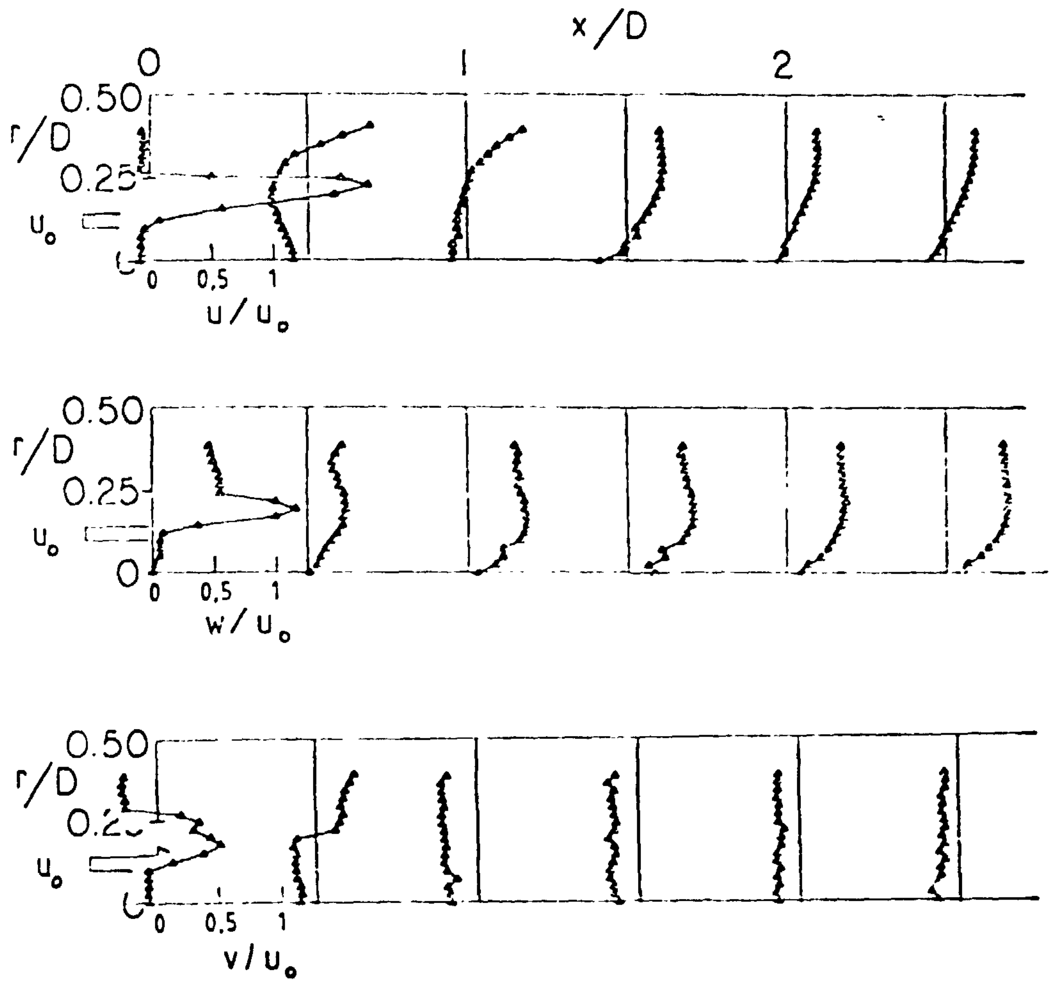
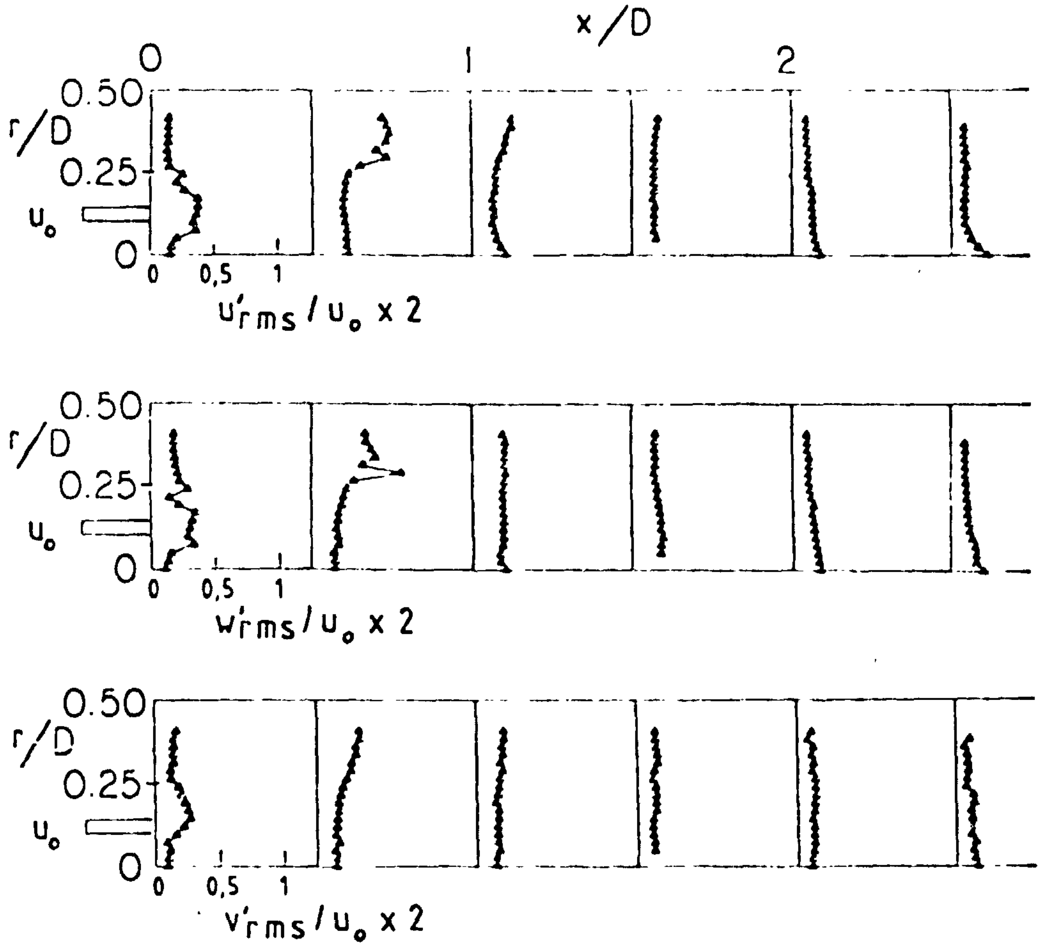
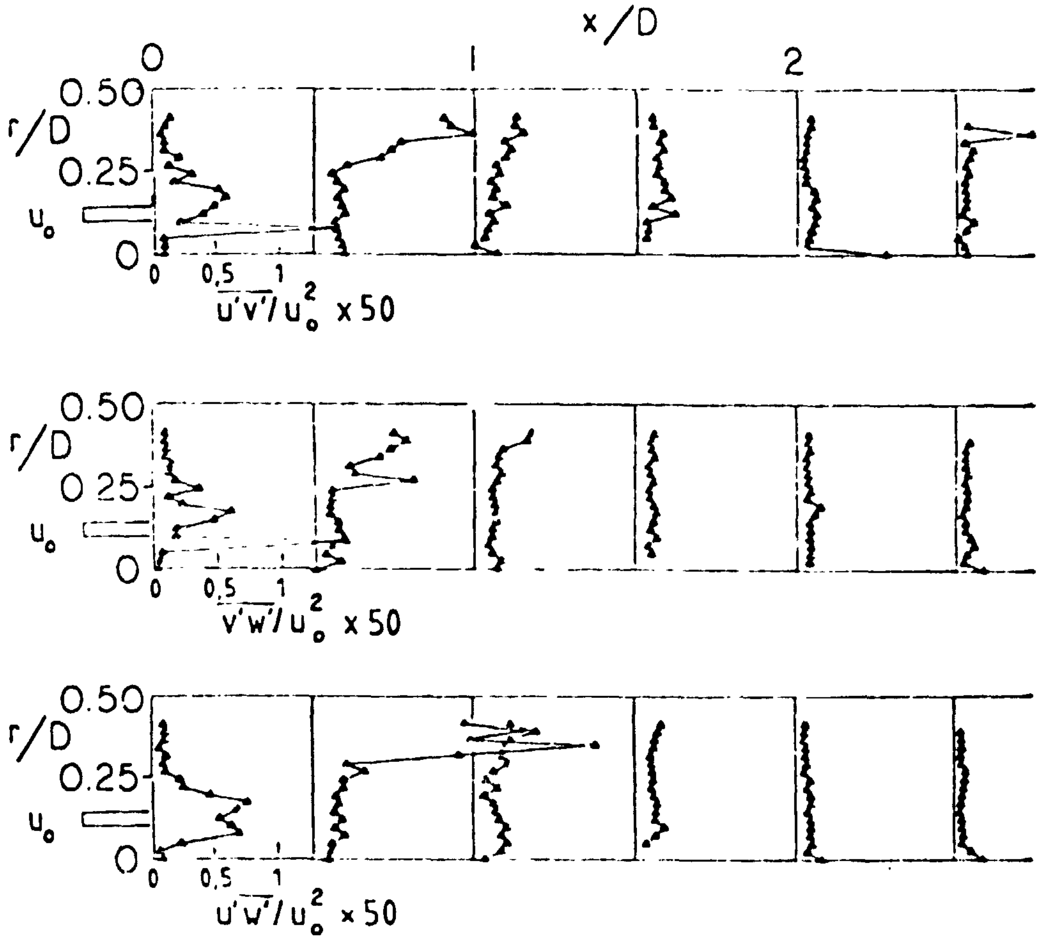
3.2 Time-Mean Velocity Profiles



3.3 Turbulent Normal Stress Profiles

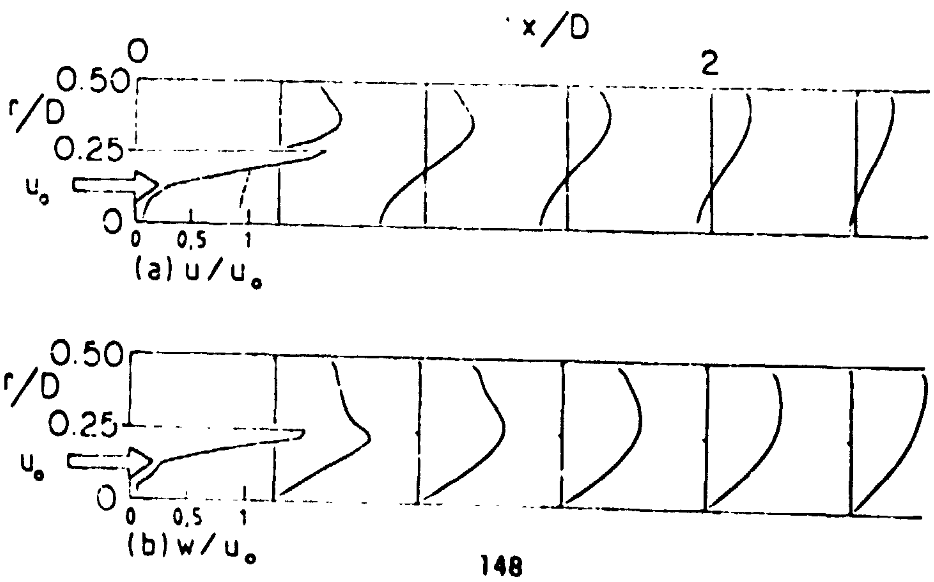


3.4 Turbulent Shear Stress Profiles

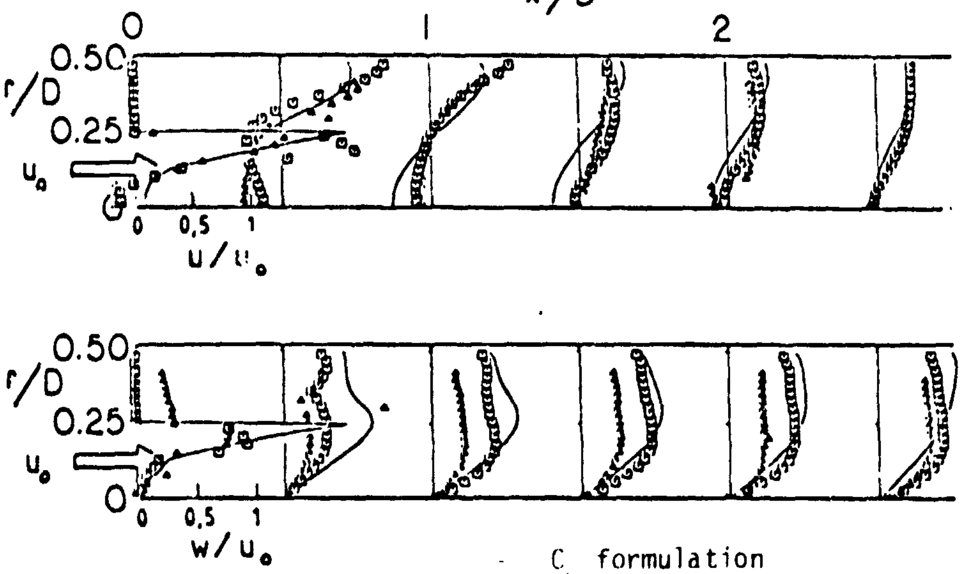


3.5 Predicted Profiles

Using optimum k-ε parameters of Ref. 12



3.6 Predicted Profiles

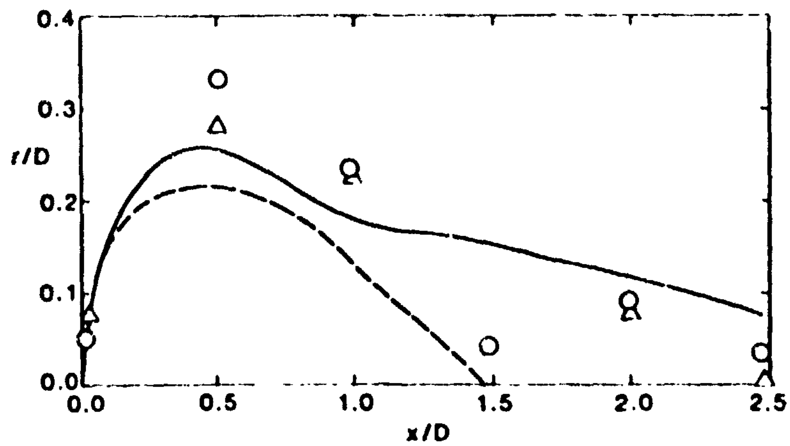


- C_μ formulation

□ Ref. 6

Δ Ref. 8

3.7 Central Recirculation Zone Envelope



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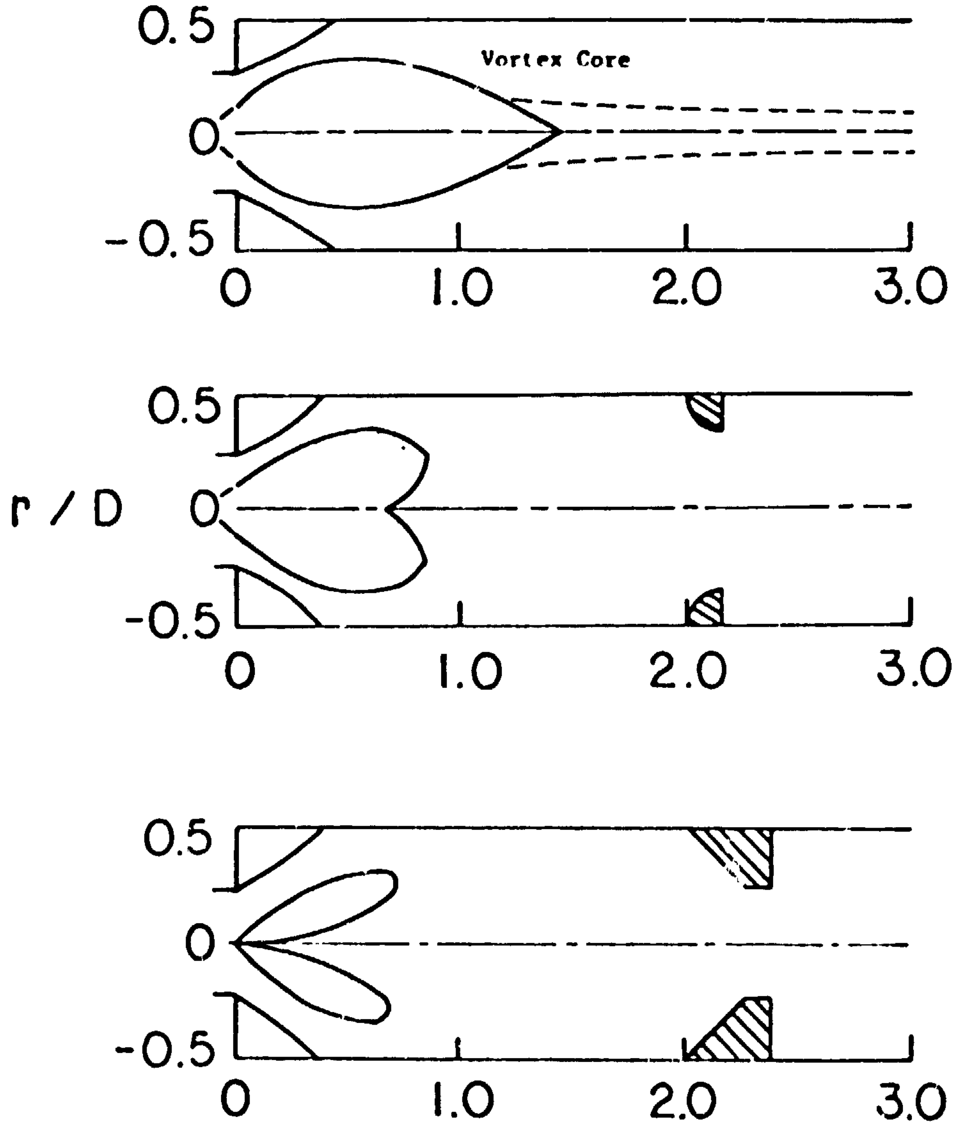
3.8 Experimental Streamlines - Nozzle Effect



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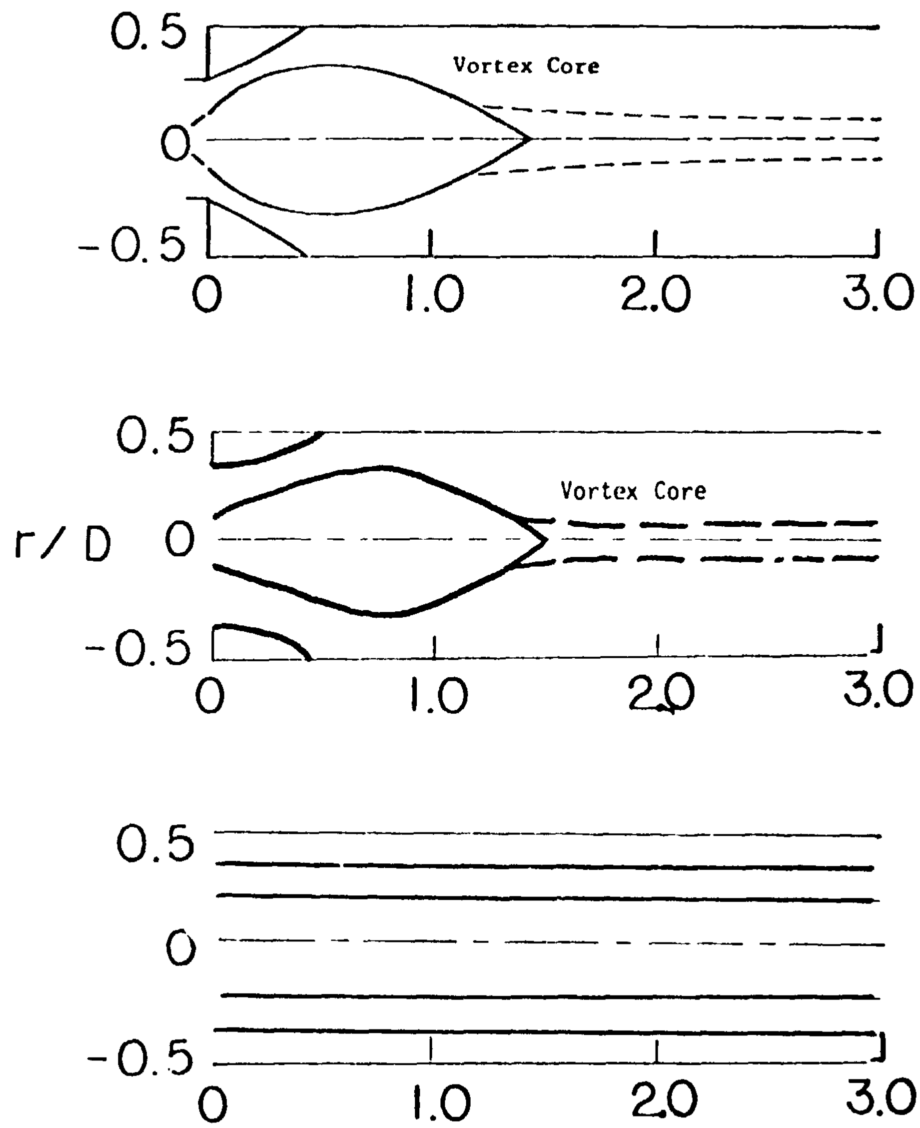
3.9 Experimental Streamlines - Confinement Effect



4. Closure

1. Measurements of effect of swirl, expansion angle and contraction blockage on flowfield patterns.
2. Computer prediction studies of associated phenomena.
3. Turbulence modeling developments for the simulation of swirling recirculating flow.