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SPRAY COMBUSTION EXPERIMENTS AND NUMERICAL PREDICTIONS

by

Edward J. Mularz
U. S. Army Vehicle Propulsion Directorate, ARL
NASA Lewis Research Center

Daniel L. Bulzan
NASA Lewis Research Center

Kuo-Huey Chen
The University of Toledo

ABSTRACT

The next generation of commercial aircraft will include turbofan engines with performances significantly better than those in the current fleet. Control of particulate and gaseous emissions will also be an integral part of the engine design criteria. These performance and emission requirements present a technical challenge for the combustor: control of the fuel and air mixing and control of the local stoichiometry will have to be maintained much more rigorously than combustors in current production. A better understanding of the flow physics of liquid fuel spray combustion is necessary. This presentation describes recent experiments on spray combustion where detailed measurements of the spray characteristics were made, including local drop-size distributions and velocities. In addition, an advanced combustor CFD code has been under development and predictions from this code are presented and compared with measurements. Studies such as these will provide information to the advanced combustor designer on fuel spray quality and mixing effectiveness. Validation of new fast, robust, and efficient CFD codes will also enable the combustor designer to use them as valuable design tools for optimization of combustor concepts for the next generation of aircraft engines.

U.S. ARMY RESEARCH LABORATORY

NASA Lewis Research Center

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Edward J. Mularz
U.S. Army Research Laboratory
Lewis Research Center
Cleveland, Ohio

Daniel L. Bulzan
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio

Kuo-Huey Chen
University of Toledo
Toledo, Ohio

OBJECTIVES

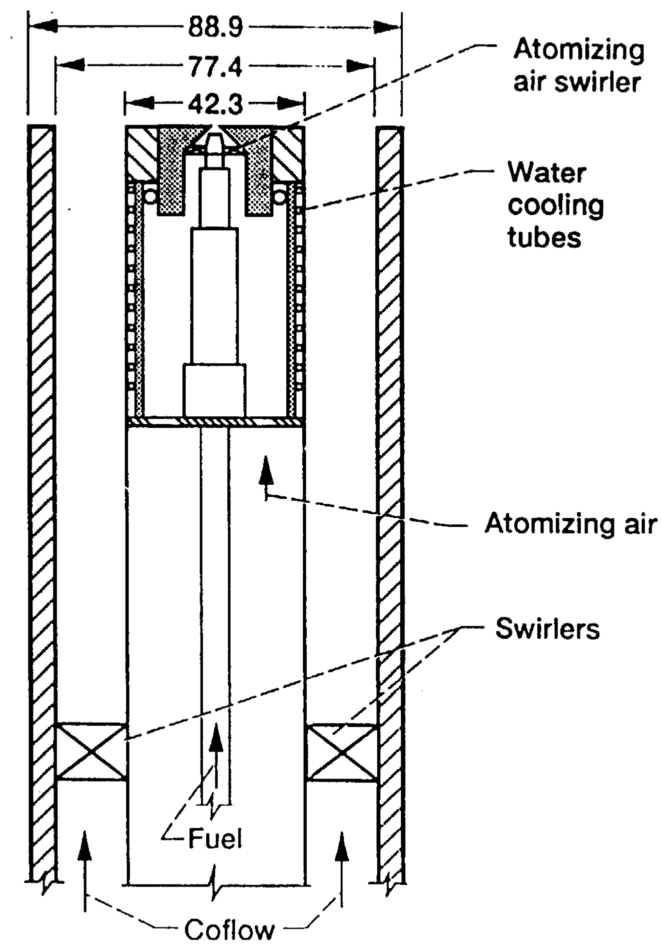
- Provide Measurements in Two-Phase, Reacting Flowfields for Better Understanding of Multiphase Flows and Serve as Database for Computer Model Validation

- Develop Robust, Efficient Computer Code for Internal, Chemical Reacting Flows

- Develop Numerical Solution Procedure to Efficiently Couple Spray Model with Strongly Implicit Flow Solution Algorithm

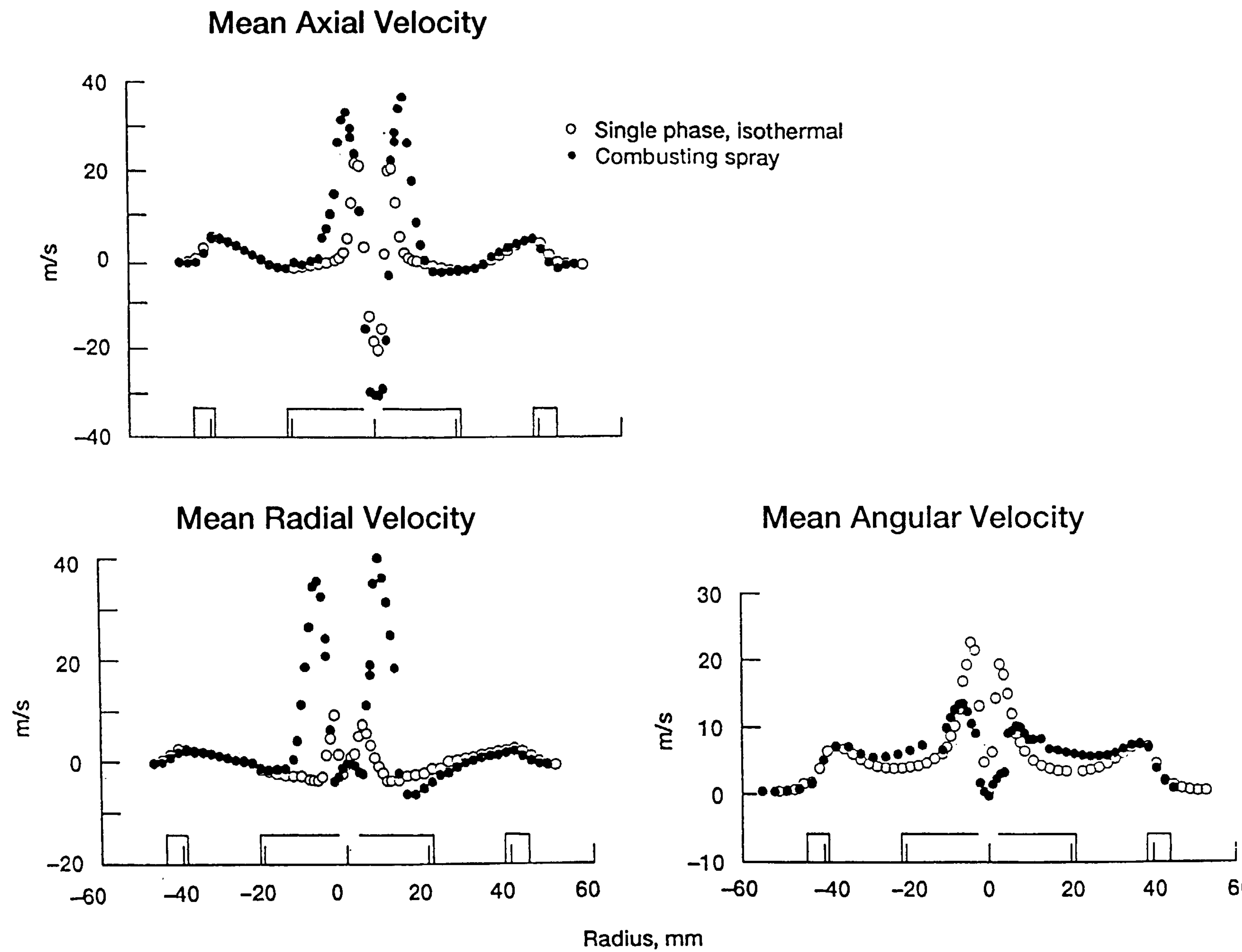
- Validation of CFD Code

COMBUSTOR



88.9
77.4
42.3
Atomizing air swirler
Water cooling tubes
Atomizing air
Swirlers
Fuel
Coflow

Gas Phase Velocity at 5 mm Downstream



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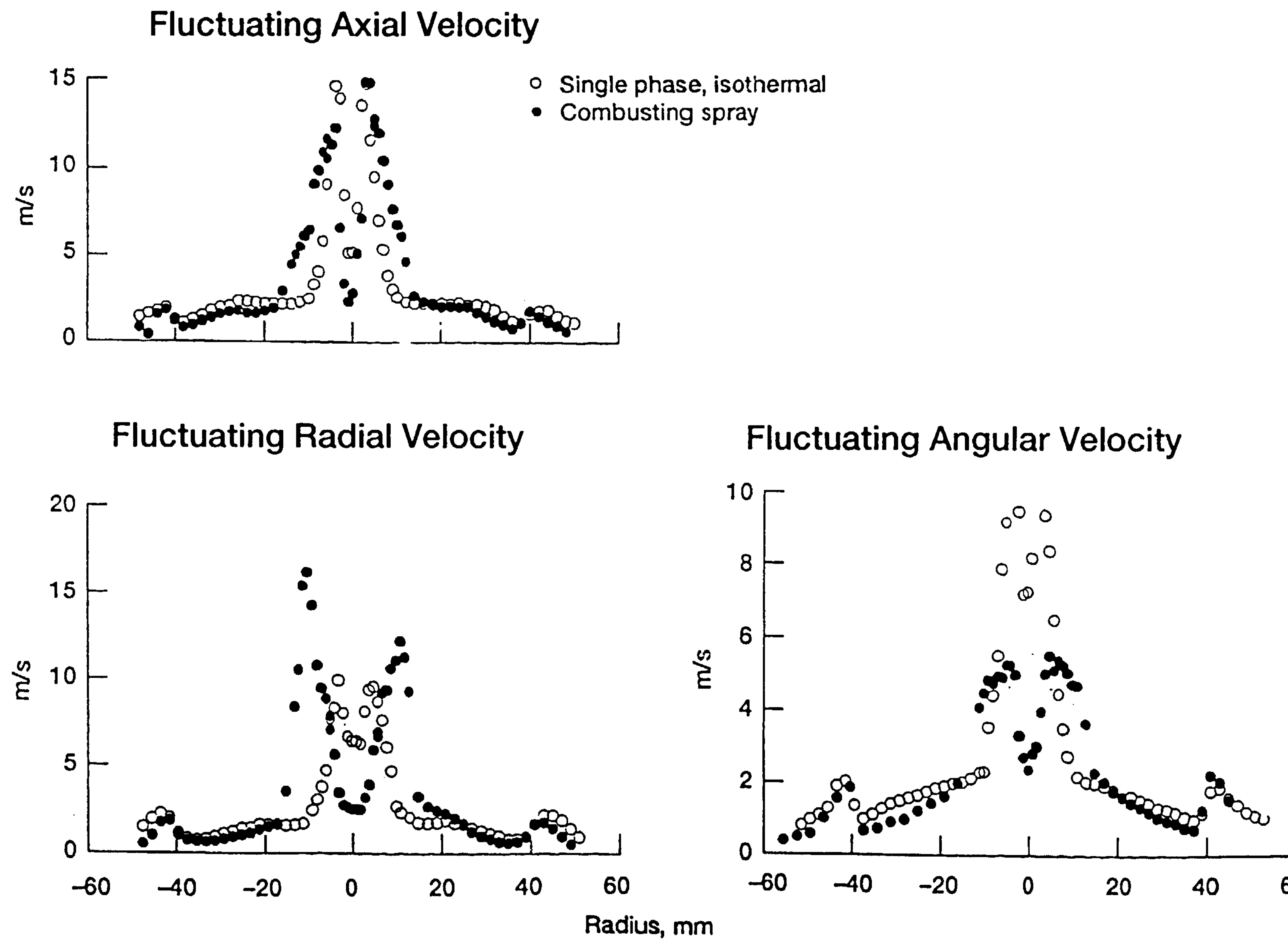
Gas Phase Velocity at 5 mm Downstream



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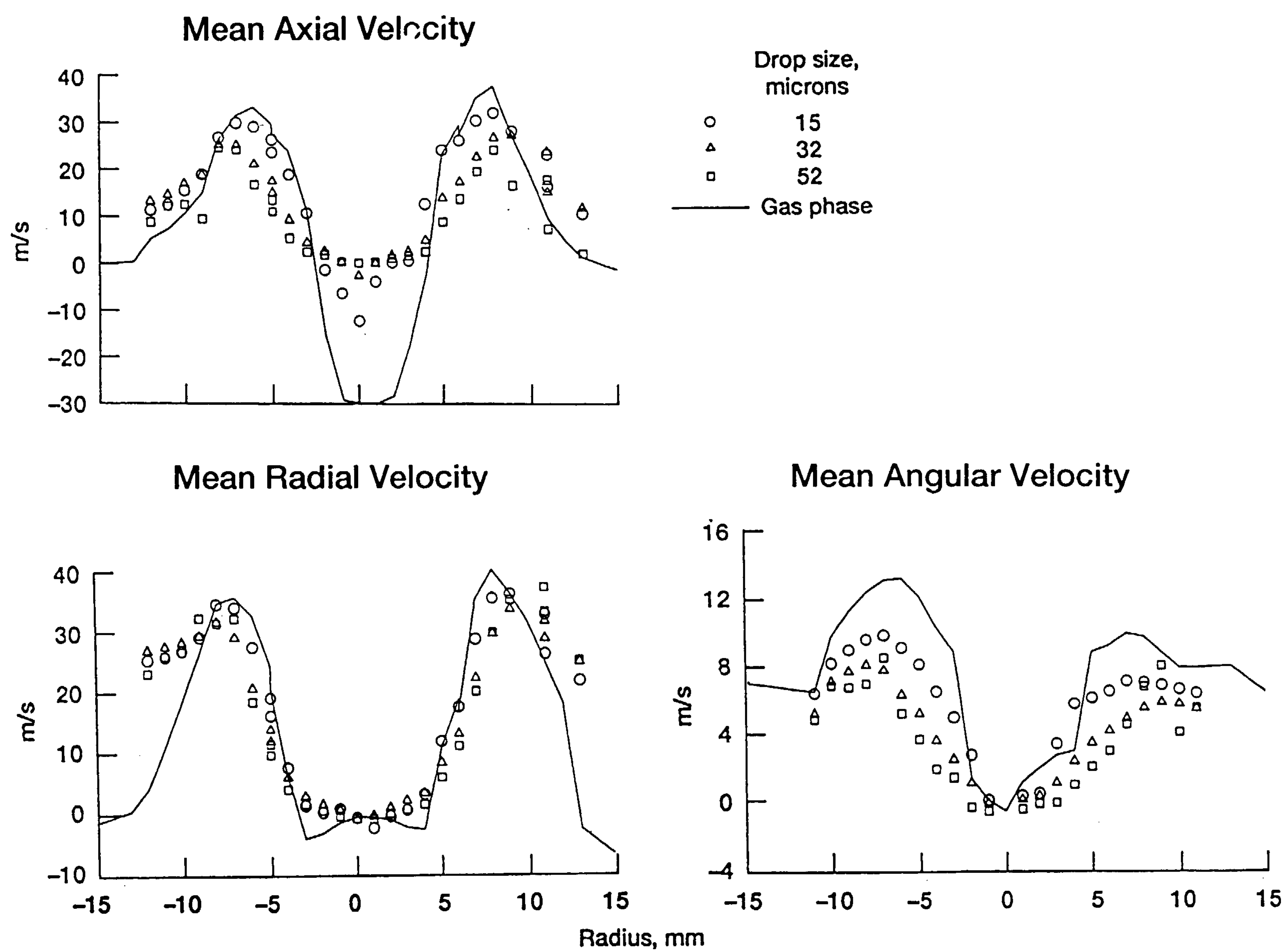
Drop Velocity at 5 mm Downstream



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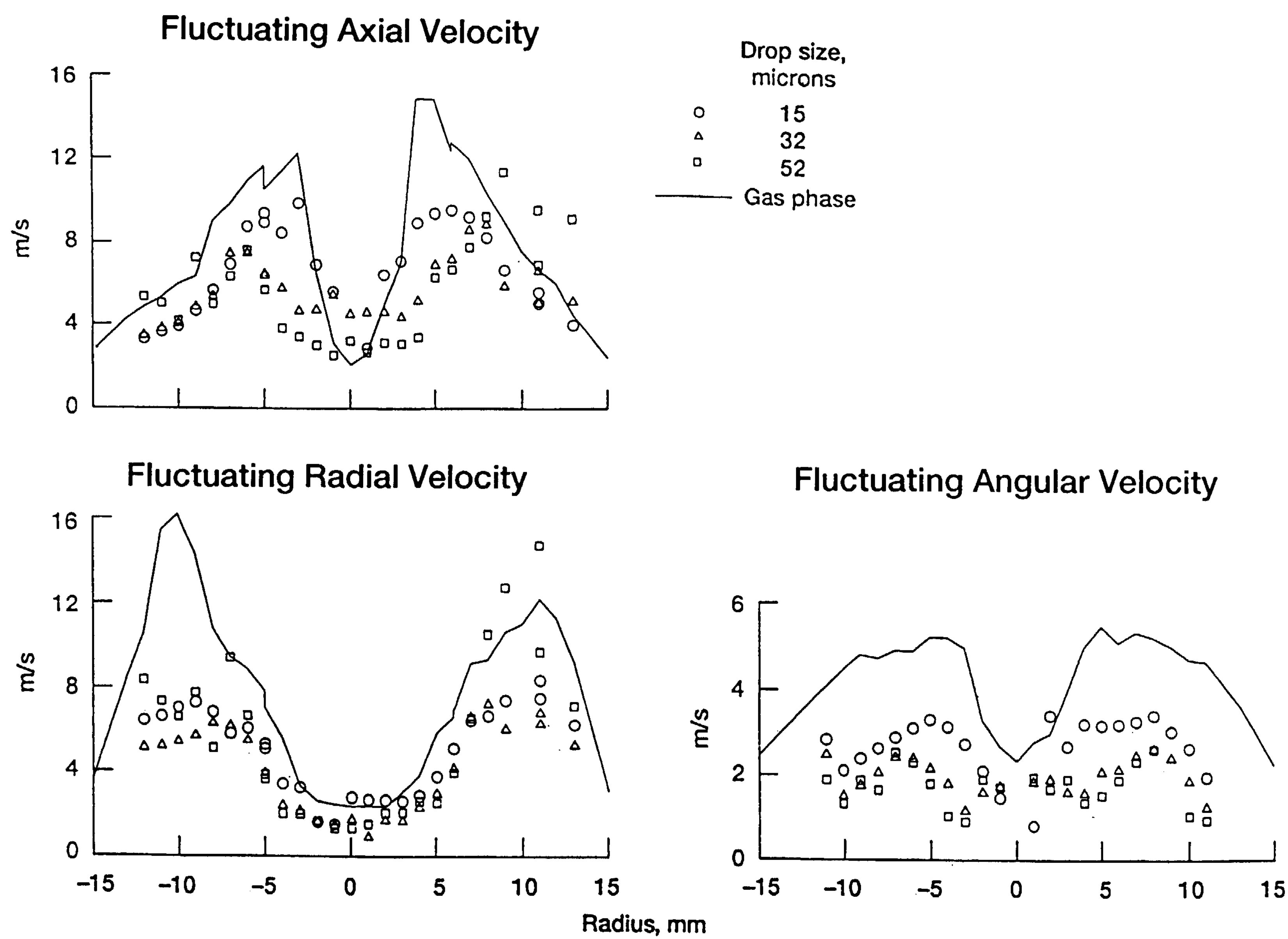
Drop Velocity at 5 mm Downstream



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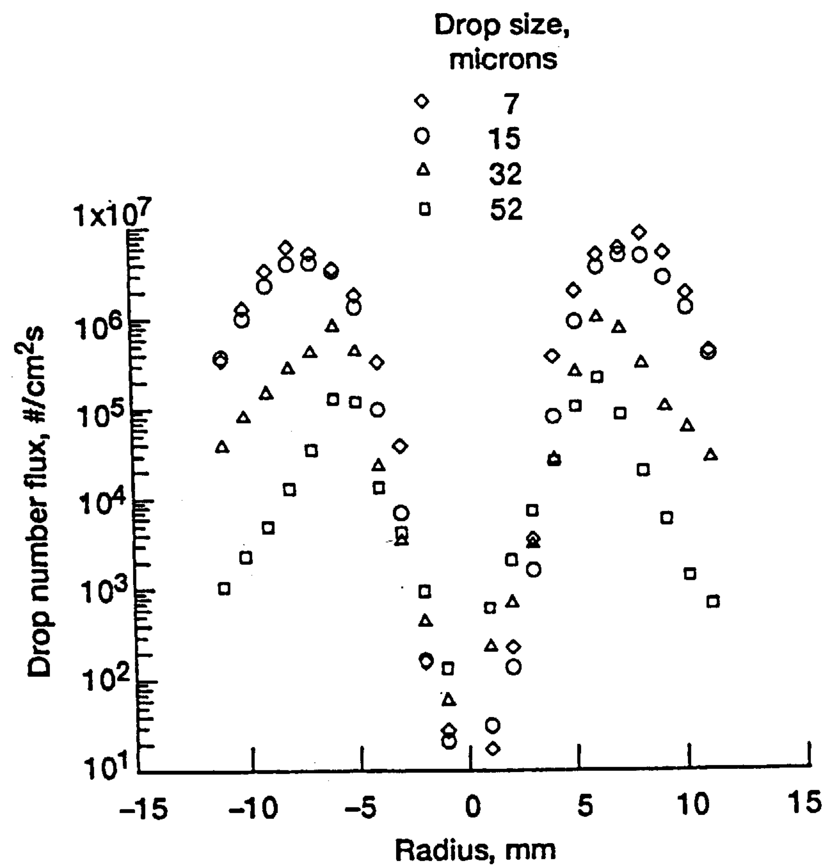
Drop Number Flux at 5 mm Downstream



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NUMERICAL ALGORITHM

- Gas-Phase - ALLSPD code
- Liquid-Phase
  - Droplet motion equations (ODE) - Runge-Kutta method.
  - Droplet internal equations (PDE) - implicit method (Thomas algorithm).
  - Determination of spray time step for integration.
  - Stochastic separate flow model.
- Interaction Between Two Phases

Difficulties with Compressible Flow Algorithms at Low Mach Numbers

- Disparities among system's eigenvalues (stiffness), u, $u+c$, $u-c$, resulting in significant slowdown in convergence rate.

- Singular behavior of pressure gradient term in momentum equations as Mach number approaches zero,

$$\rho^* u^{*2} + \frac{p^*}{\gamma M_r^2}$$

As Mach number is decreased, pressure variation ($\Delta p^* \propto M^2$) becomes of similar magnitude as roundoff error of the large pressure gradient term ($p^*/\gamma M_r^2$).

METHOD OF APPROACH

Pressure Singularity Problem

- Pressure decomposed into two parts:

$$p = p_o + p_g$$

  p_g replaces p in momentum equations and retains p_g as one of the unknowns.

- Employs conservative form of governing equations, but uses primitive variables

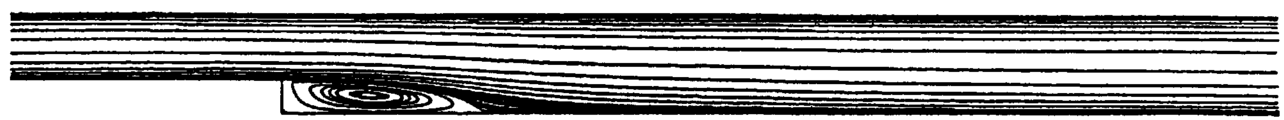
$$(p_g, u, v, h, Y_i)$$

  as unknowns. Conservation property preserved and pressure field accurately resolved for all Mach numbers.

Eigenvalue Stiffness Problem

- Pressure rescaled so that all eigenvalues have the same order of magnitude. Physical acoustic waves removed and replaced with pseudo-acoustic waves which travel at speed comparable to fluid convective velocity.

Particle Traces



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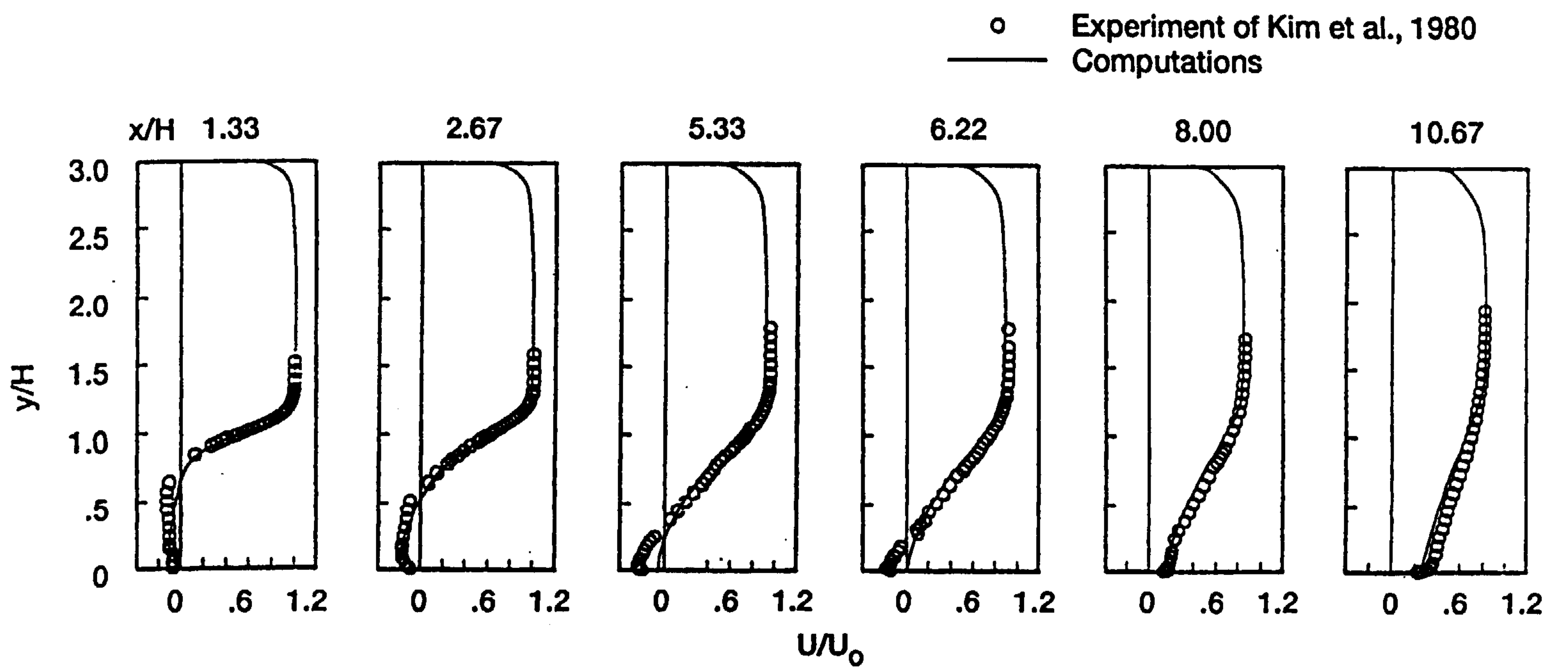
Mean Velocity Profiles



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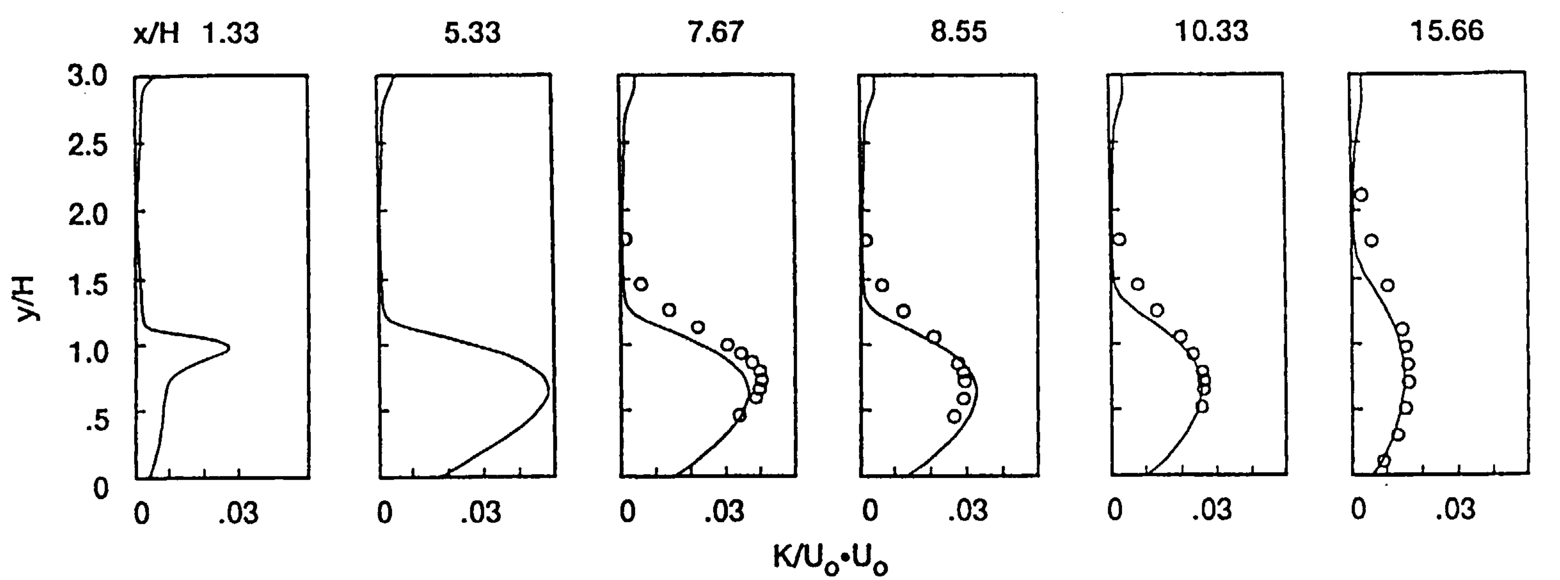
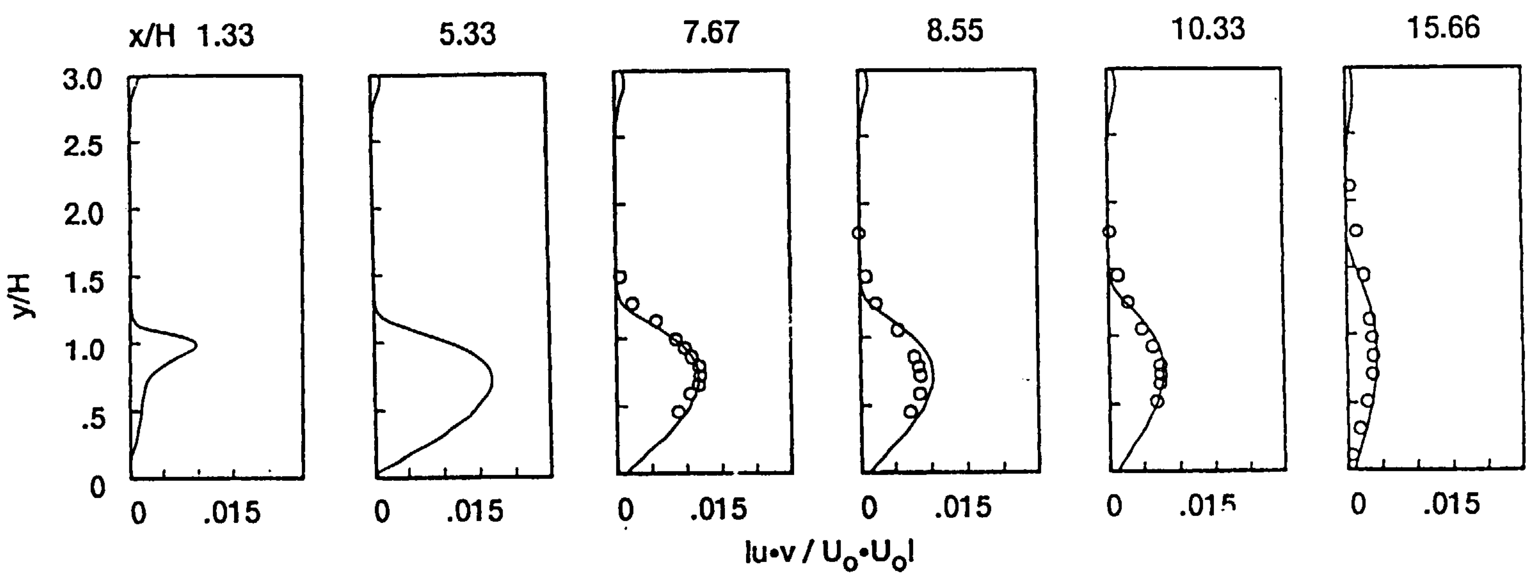
Turbulence Quanities

Turbulent Kinetic Energy



Turbulent Shear Stress



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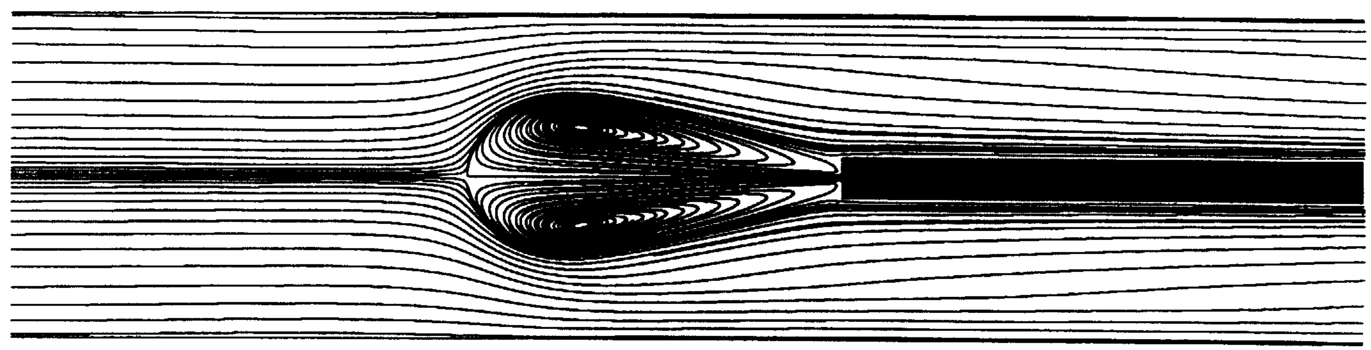
Particle Traces



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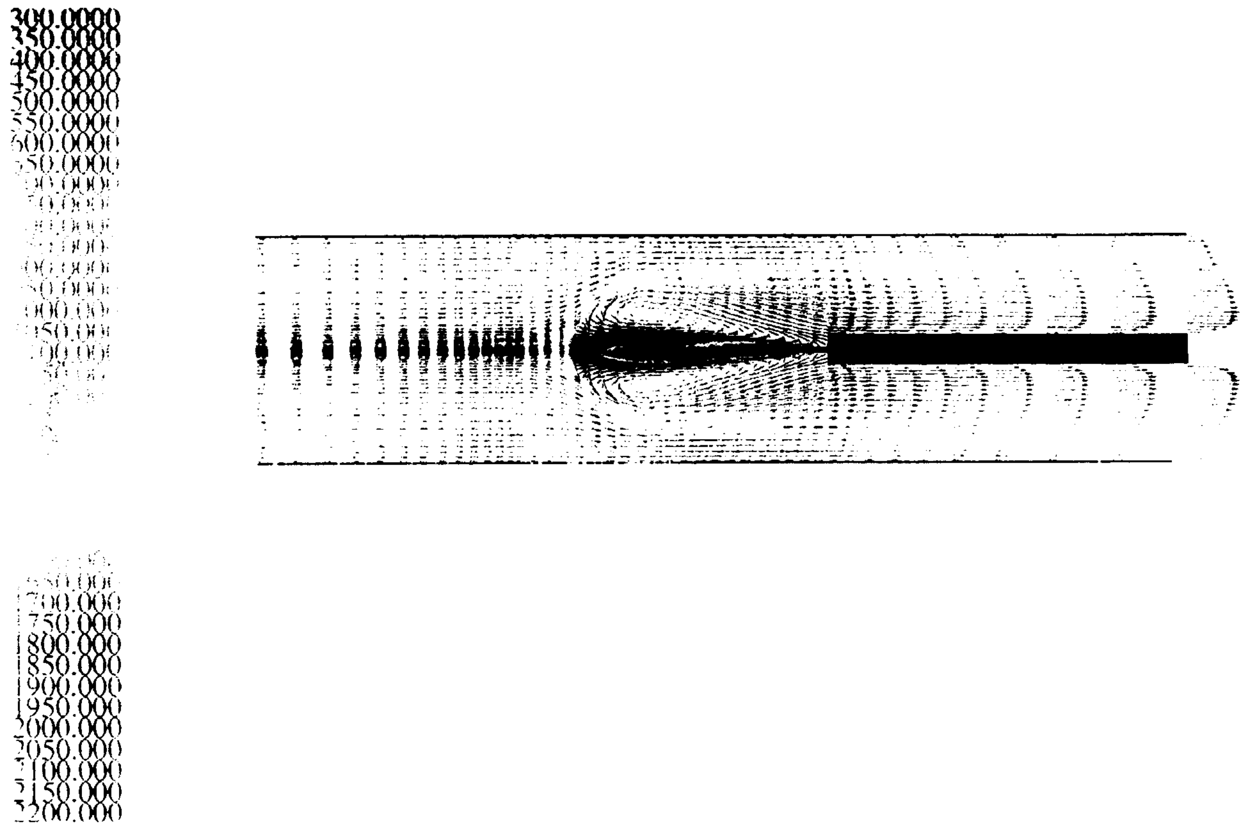
Velocity Vectors



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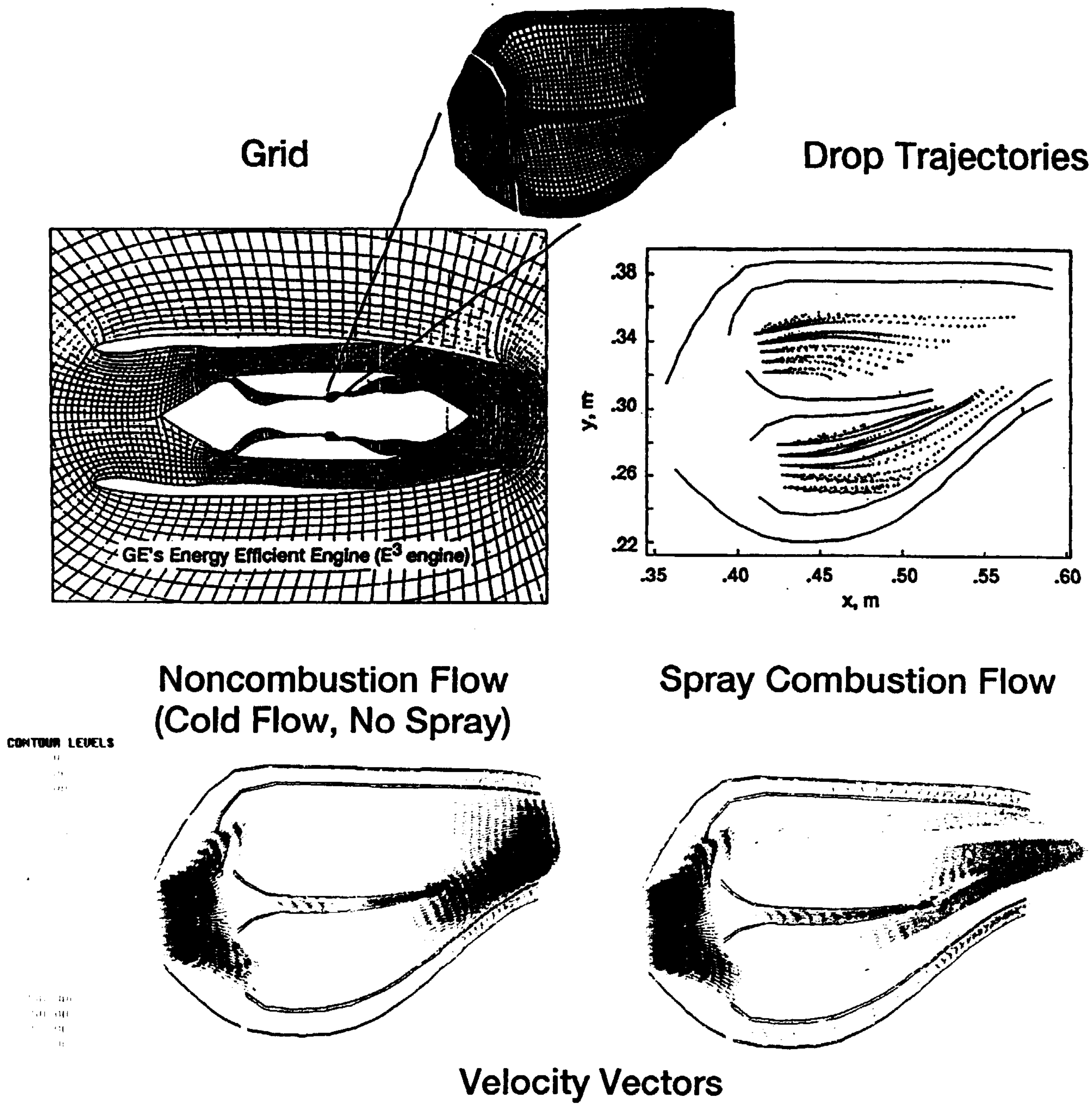
Gas Turbine Combustor



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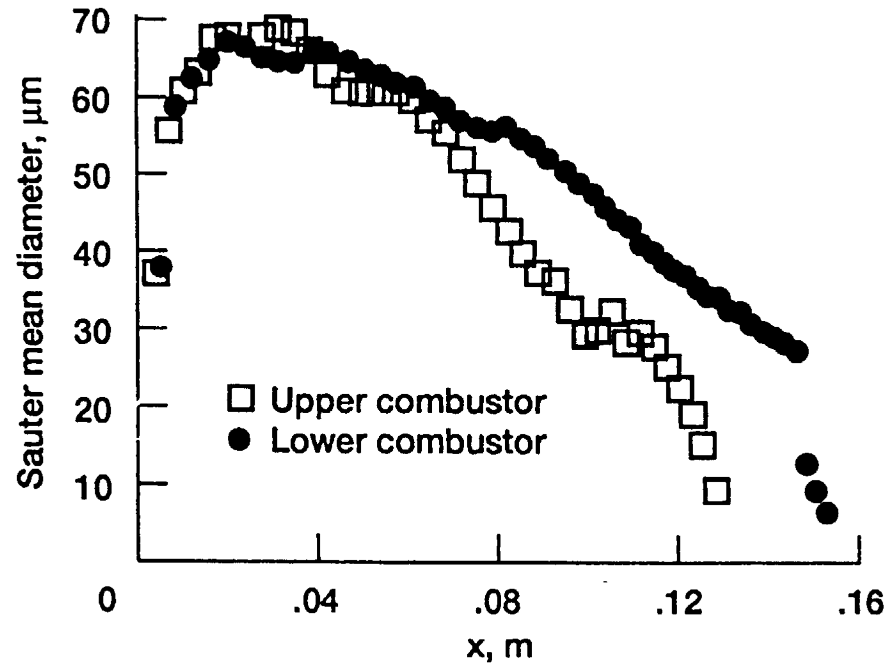
SMD Distribution



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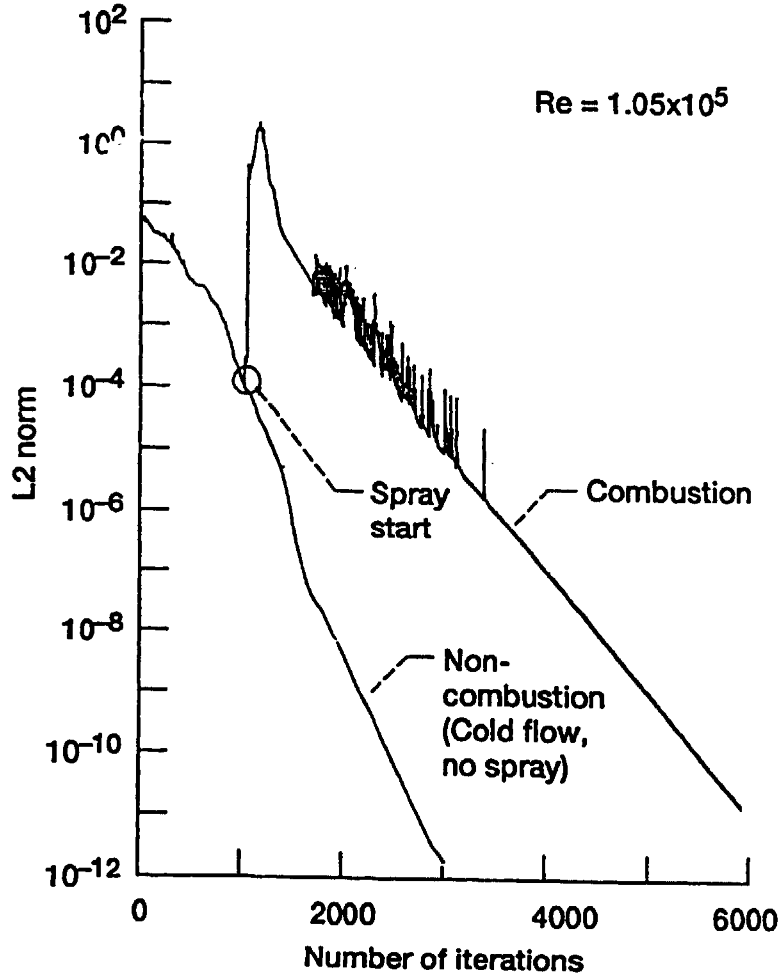
C-8

Convergence History



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CONCLUSIONS

- Flowfield Symmetric Making Data Useful for Comparison With Axisymmetric Model Predictions
- Both Drop Size and Velocity are Important in Two-Phase, Reacting, Swirling Flowfields
- ALLSPD 2-D Algorithm Demonstrated for Non-Reacting, Turbulent Flow and Turbulent, Reacting, Single-Phase Flow
- Spray Model Incorporated into CFD Code and Preliminary Results Obtained for Two-Phase, Turbulent, Reacting Combustor Flowfield