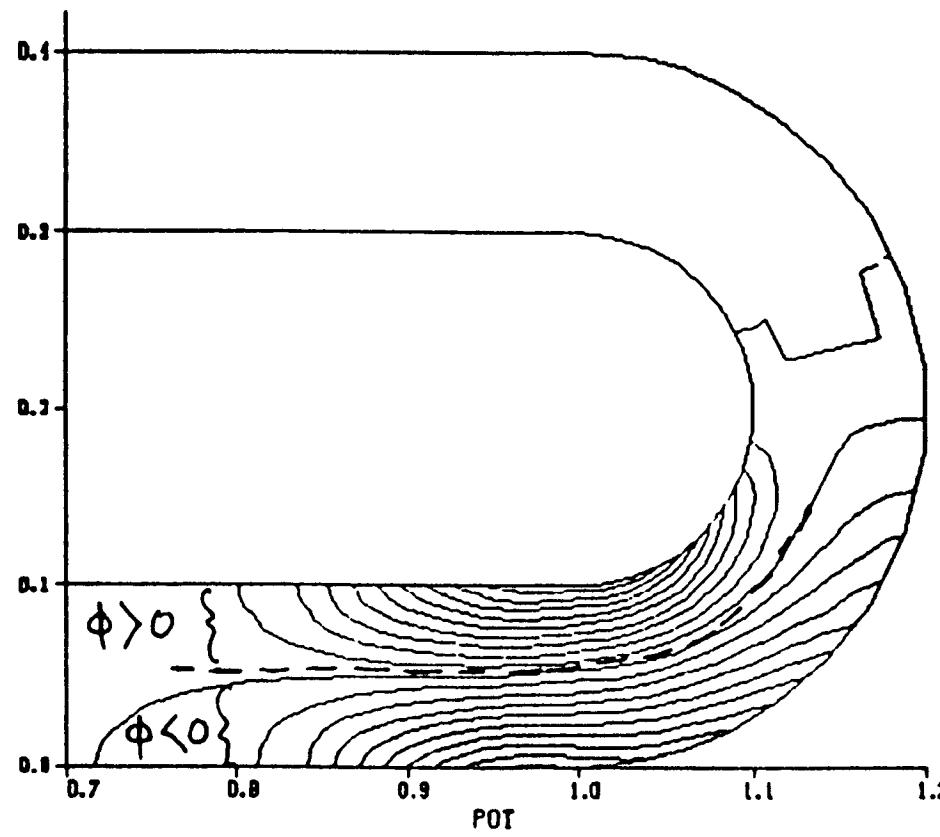


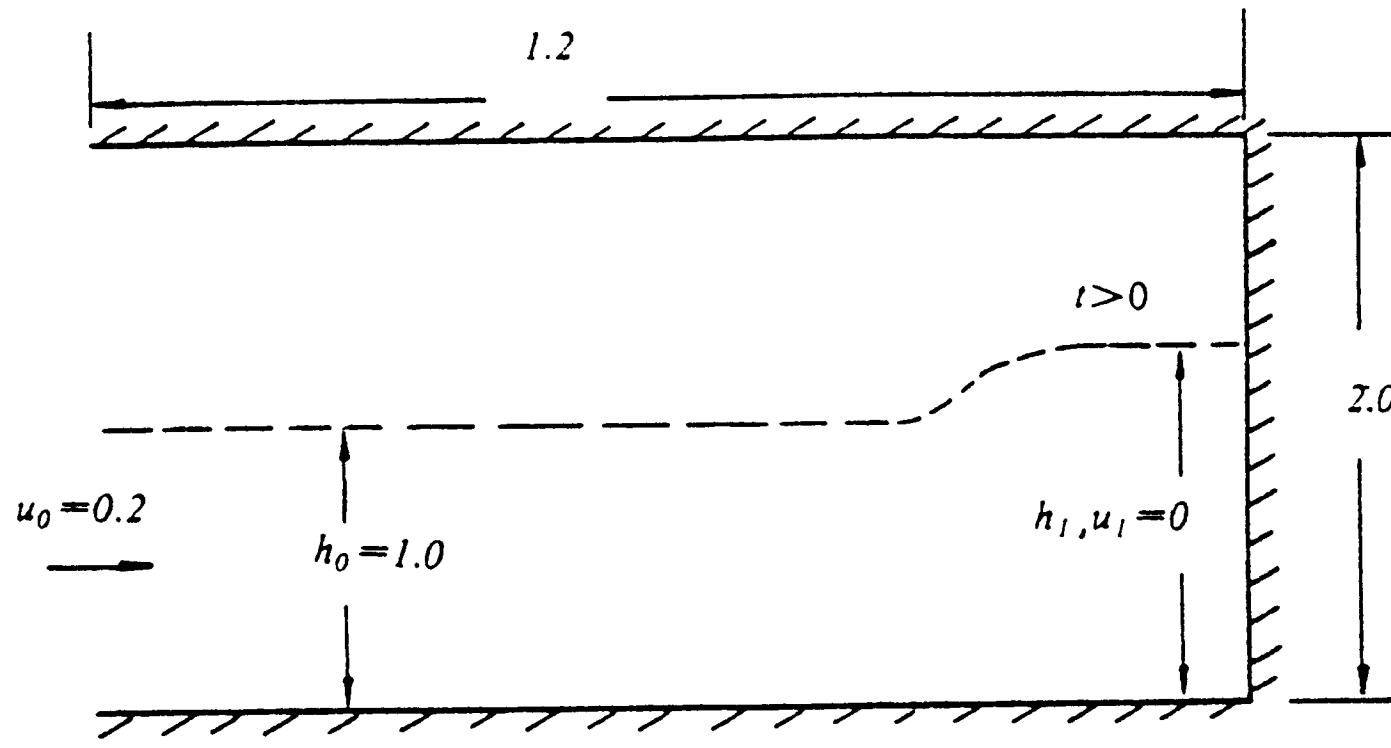
CFD Development for Free Surface Liquid Flows in APEX

**ALI H. HADID
Boeing/Rocketdyne
CFD Technology Center**

May 6, 1998

ELECTRIC POTENTIAL CONTOURS





(a) Flow Geometry

Plane Channel with One End Closed

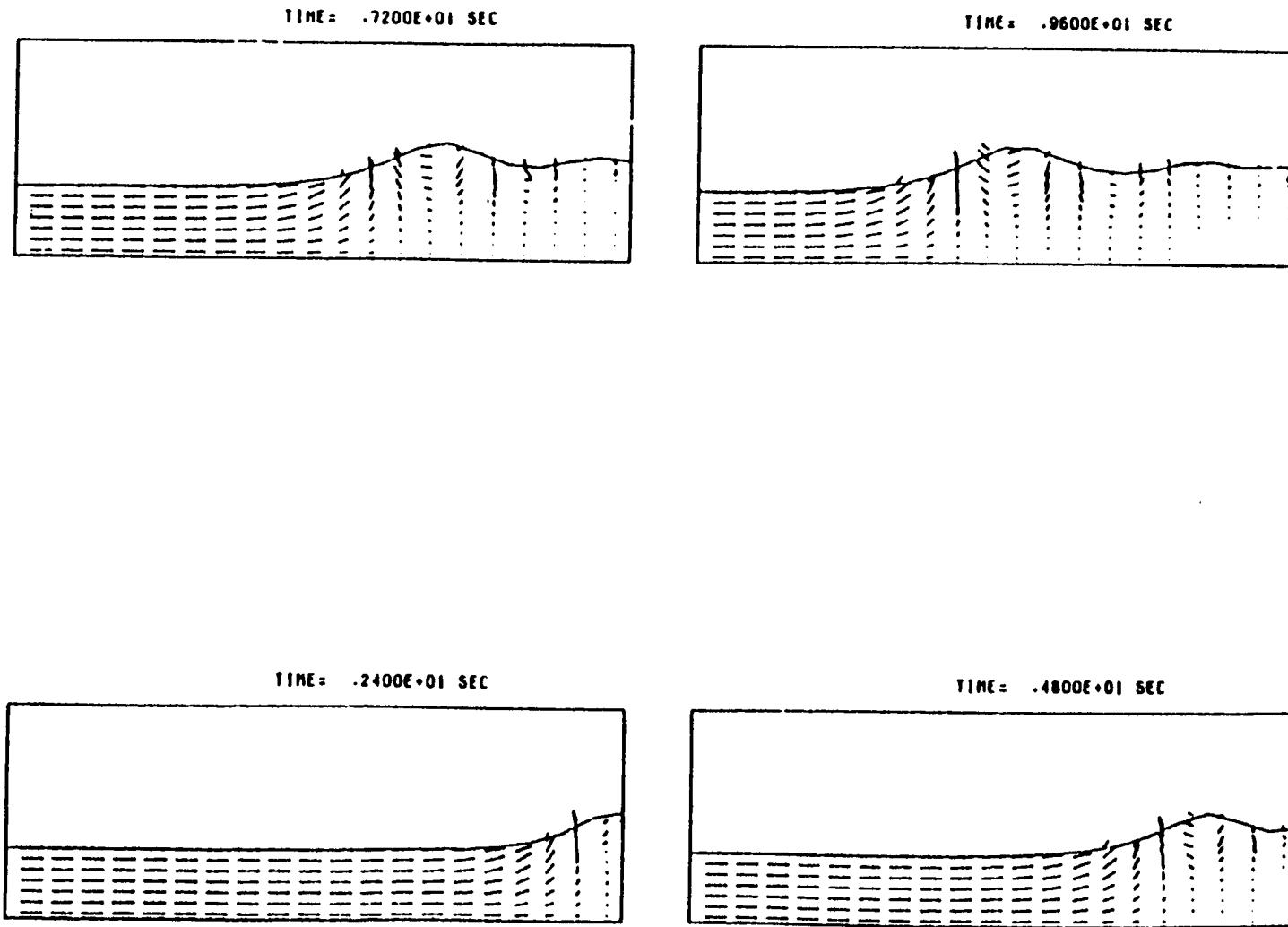
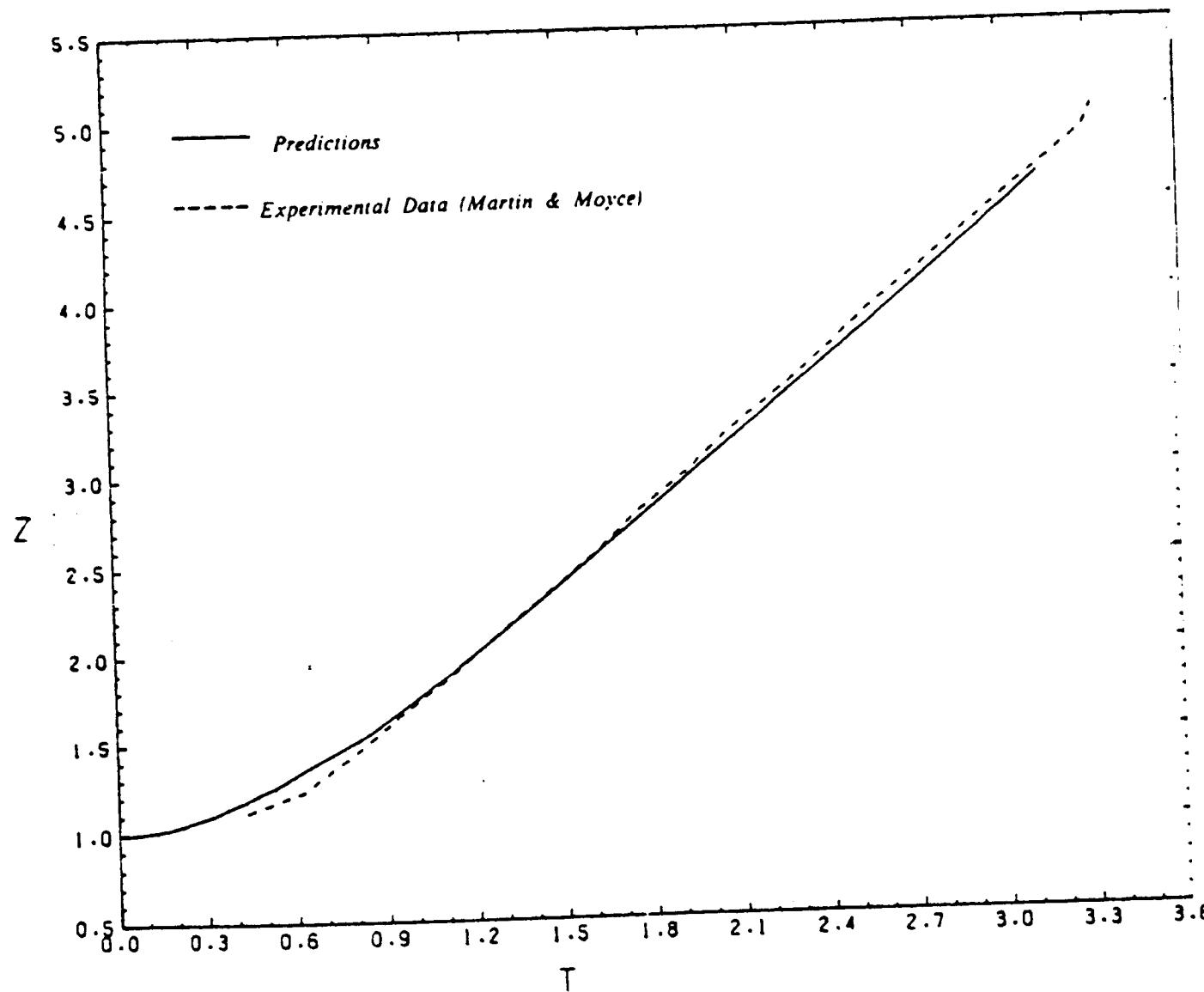
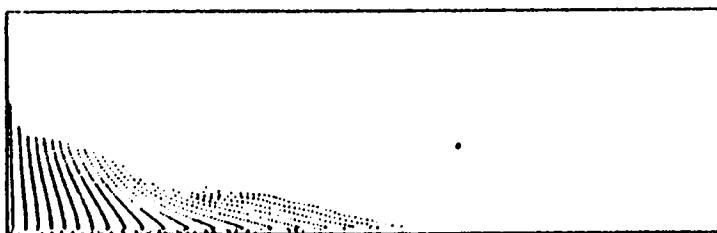


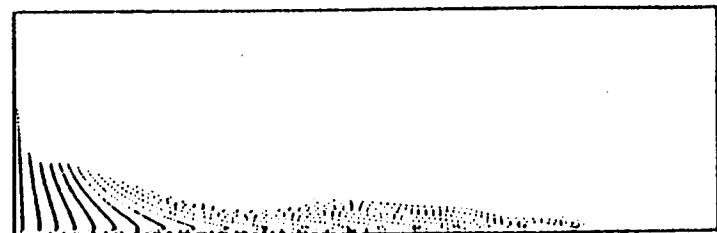
FIGURE (B-4) *Velocity Vector Plot at Different Instants of Time*



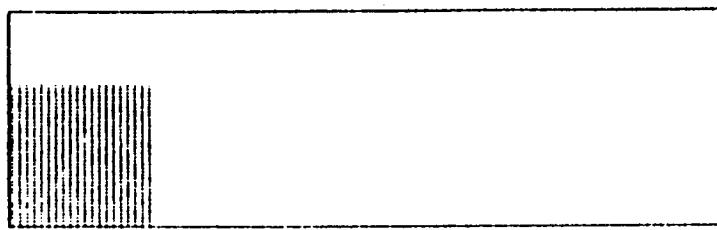
Broken Dam Problem



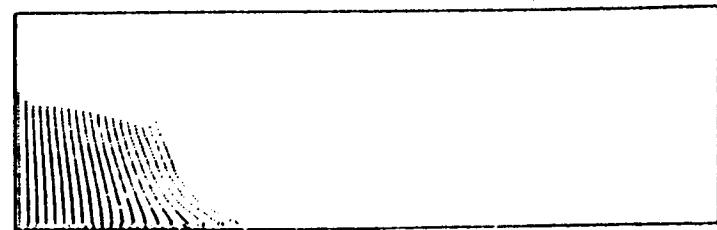
TIME=1.2E-1 SEC



TIME=1.8E-1 SEC



TIME=0.000 SEC



TIME=6.0E-2 SEC

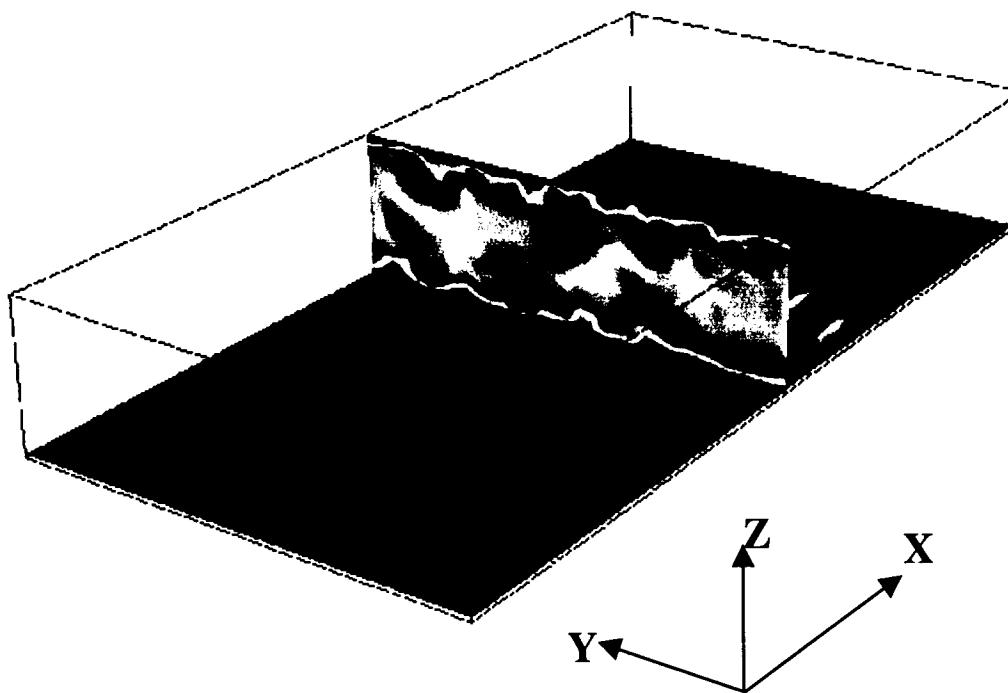
SUMMARY

- Experience base in film cooling heat transfer, e.g. nozzles and combustion chambers
- Technology effort underway to develop conjugate heat transfer capability using structured and unstructured grid methodology for wide range of Mach numbers
- Variety of turbulence models, e.g.
 - Reynolds averaged phenomenological models
 - Standard $k-\epsilon$ model, low RE $k-\epsilon$ models and multi-scale $k-\epsilon$
 - Algebraic and full Reynolds stress models
 - LES models
 - Smagorinsky
 - RNG

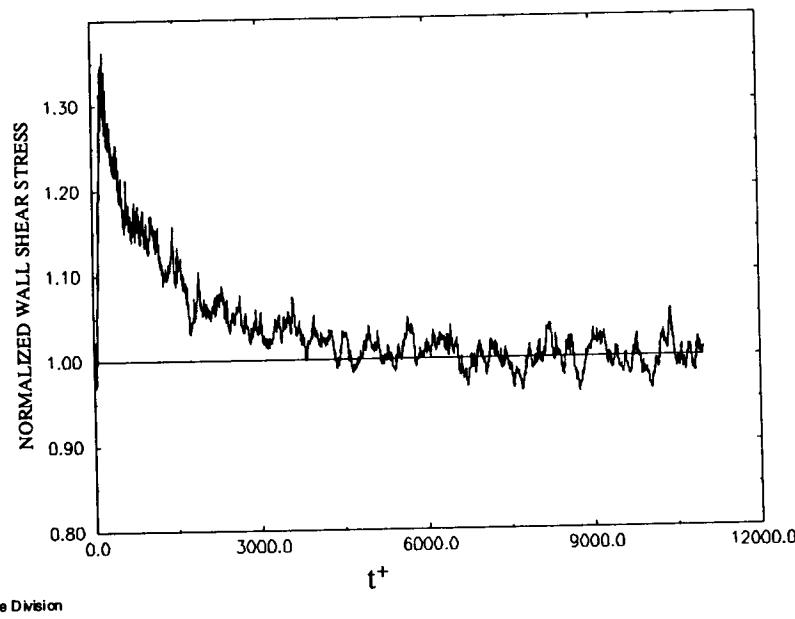
Turbulent Channel Flow, 32x32x65 grid

Smagorinsky Model, $Re_\tau = 180$.

Contours of Streamwise Velocity Showing
“Streaky” Structure



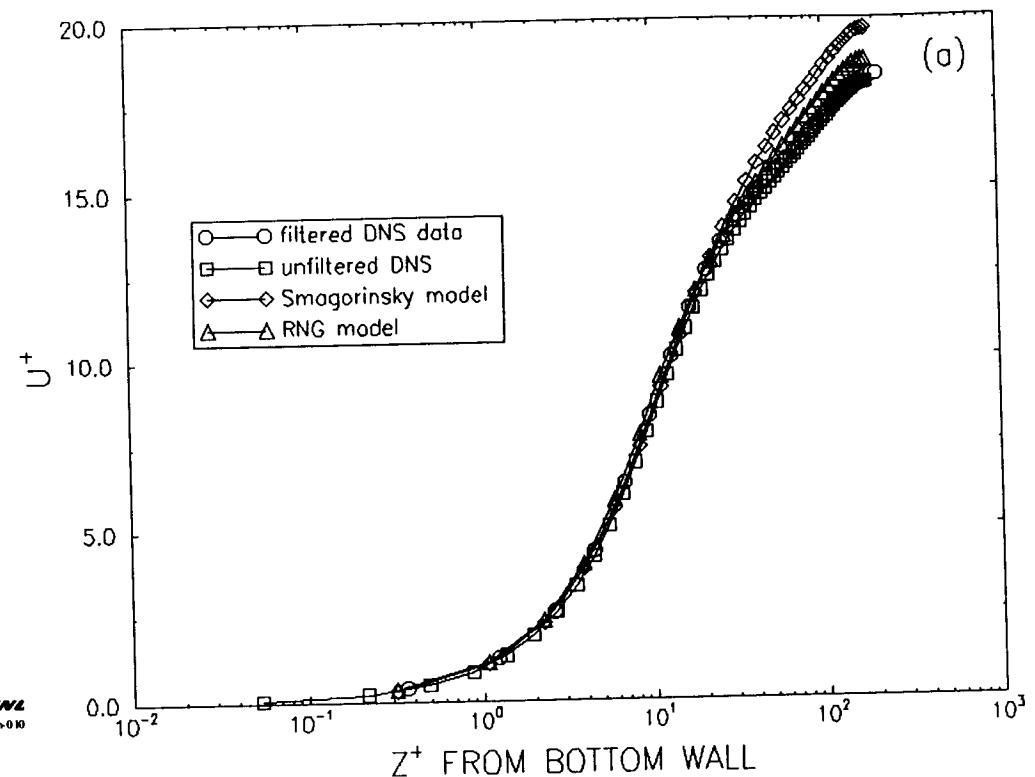
Time Variation of the Horizontal Averaged Wall Shear Stress



Rocketdyne Division

BOEING
CFDytron-010

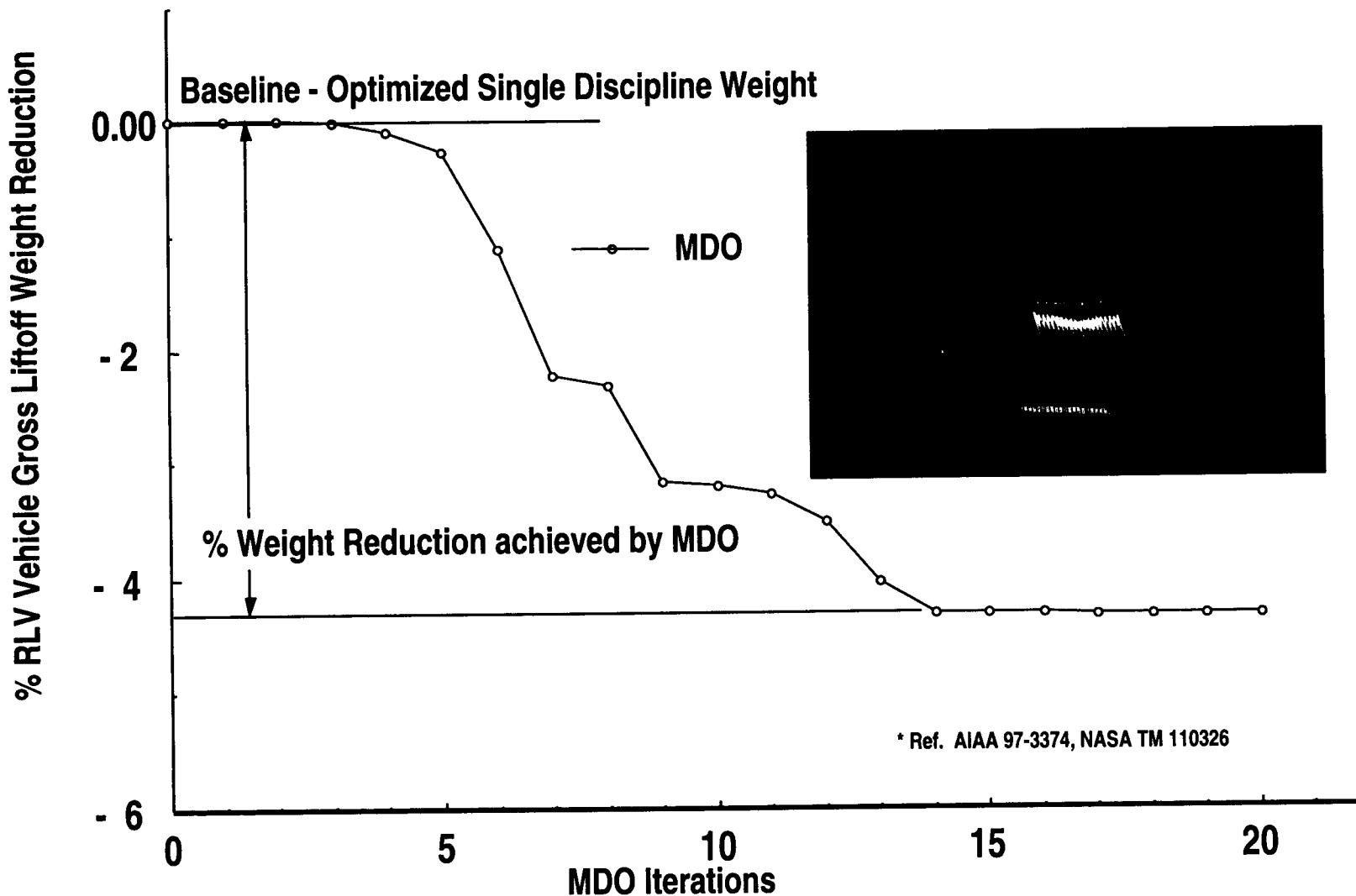
Mean Streamwise Velocity in Wall Units at $Re_\tau=180$
Using Different SGS models ($\Delta t^+=0.18$)



SUMMARY (CONTD.)

- Multidisciplinary analysis and optimization effort for effective vehicle aero, structure and weight performance

Potential to Reduce RLV Vehicle Dry Weight Demonstrated through Multidisciplinary Optimization*
(MDO)



* Ref. AIAA 97-3374, NASA TM 110326

OBJECTIVES

- Develop analytical and numerical predictive capabilities to analyze the convective thin liquid metal film cooling of first wall
- Stability of thin-film under large heat fluxes and magnetic fields to determine critical values to keep the unbroken film thickness well above critical minimum for rupture
- Numerical methods to analyze free-surface flows under intense heat fluxes and magnetic fields

Numerical Methods for Free Surface Flows

- Lagrangian Techniques

Grid is modified in a Lagrangian manner to match the distortion of the interface. Method ensures a smear-free interface but requires continuous remeshing of grid and can result in highly distorted grids.

- Eulerian Techniques

Best suited within a fixed grid framework

- Particle Method

Massless particles that either fill the whole fluid region or track only the fluid interface

- Height Function Method

Height of a free surface (h) along a reference line, e.g. $h(x,t)$ in 2D
Limitations when surface slope dh/dx exceeds cell aspect ratio

Numerical Methods for Free Surface Flows

Evolution equation for h ,

$$\frac{\partial h}{\partial t} + u \frac{\partial h}{\partial x} = v$$

- VOF Method

Fluid is defined by a step function $\Phi=1$ in a fluid or zero otherwise
 $0 < \Phi < 1$ contain a free surface. Φ moves with the fluid according to

$$\frac{\partial \Phi}{\partial t} + u \frac{\partial \Phi}{\partial x} + v \frac{\partial \Phi}{\partial y} = 0$$

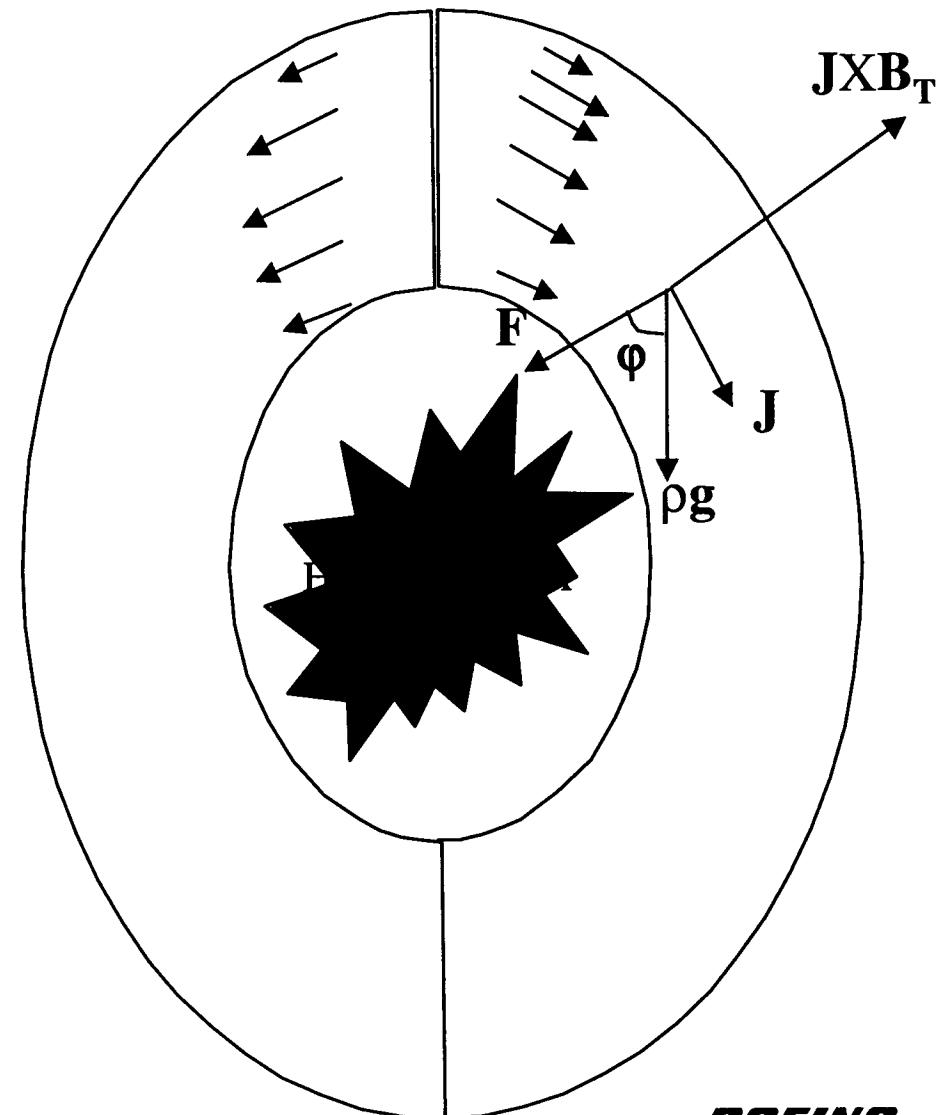
High order numerical scheme is required to minimize
numerical diffusion

Liquid Lithium Electromagnetic Confinement

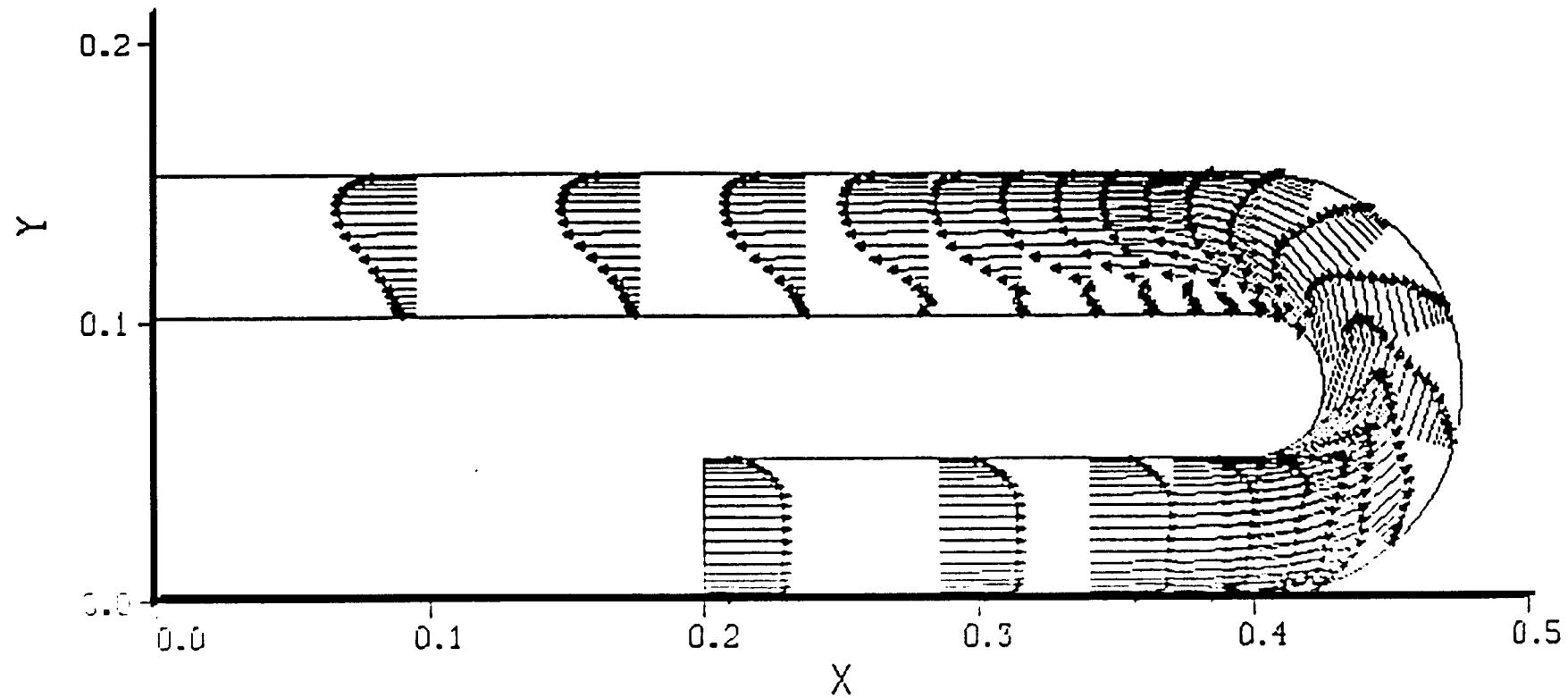
Confine a thin layer of flowing liquid Lithium by electromagnetic force ($h \sim 2 \text{ cm}$)

Confinement possible if
 $| \mathbf{J} \times \mathbf{B}_T | > \rho g \cos \phi$

\mathbf{V} parallel \mathbf{B}_P
 \mathbf{J} normal to \mathbf{B}_T

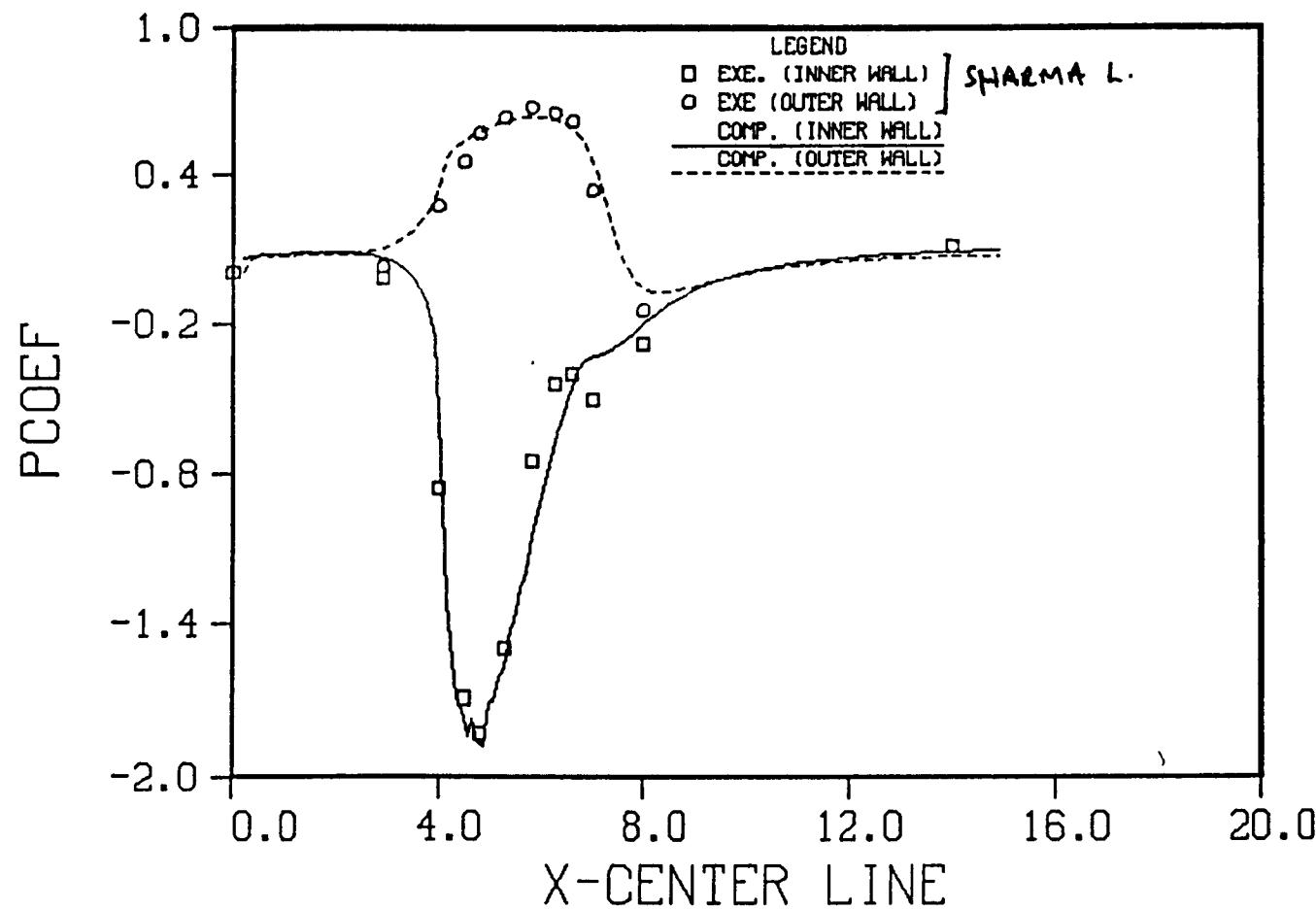


Flow In a 180° Turn Around Duct



Flow In a 180° Turn Around Duct

Pressure Coefficient Comparison with Experiment



MHD Flow in a 180° U-Bend Flow (magnetic field aligned with flow)

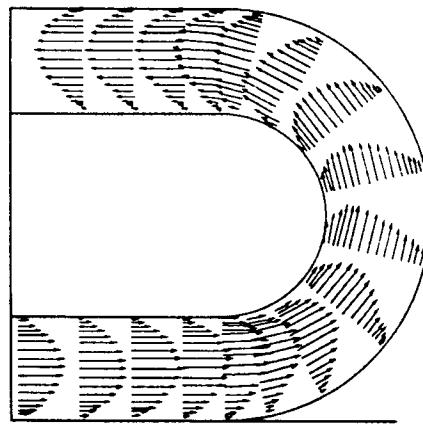


Figure 11a Flow Field in U-Bend at Zero Magnetic Field

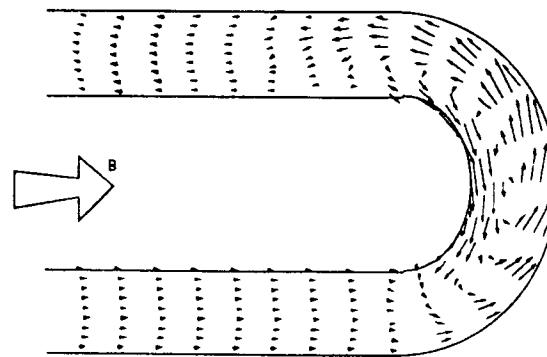
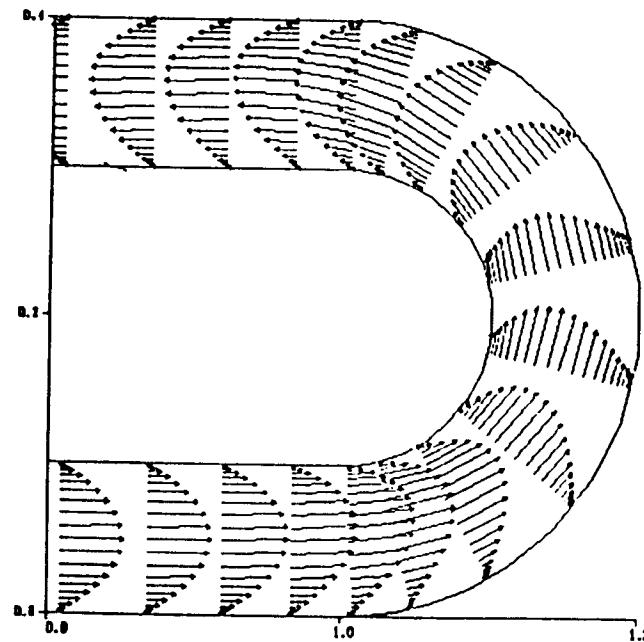


Figure 11b MHD Flow in U-Bend With Applied Magnetic Field

MHD Flow in a 180° U-Bend Magnetic Field Perpendicular to the Plane of Flow

FLOW FIELD IN A 180° U-BEND AT RE=500

ZERO MAGNETIC FIELD



APPLIED MAGNETIC FIELD

