19951?1475

TURBULENCE MODELING NEEDS OF COMMERCIAL CFD CODES: COMPLEX FLOWS IN THE AEROSPACE AND AUTOMOTIVE INDUSTRIES

N95- 27896

Bizhan A. Befrui
adapco
Melville, New York

CONTENT OF PRESENTATION

- STAR-CD: COMPUTATIONAL FEATURES
- STAR-CD: TURBULENCE MODELS
- COMMON FEATURES OF INDUSTRIAL COMPLEX FLOWS
- INDUSTRY-SPECIFIC CFD DEVELOPMENT REQUIREMENTS
- INDUSTRIAL COMPLEX FLOWS: APPLICATIONS & EXPERIENCES
    - FLOW IN ROTATING DISC CAVITIES
    - DIFFUSION HOLE FILM COOLING
    - INTERNAL BLADE COOLING
    - EXTERNAL CAR AERODYNAMICS
- CONCLUSION: TURBULENCE MODELING NEEDS

STAR-CD: COMPUTATIONAL FEATURES

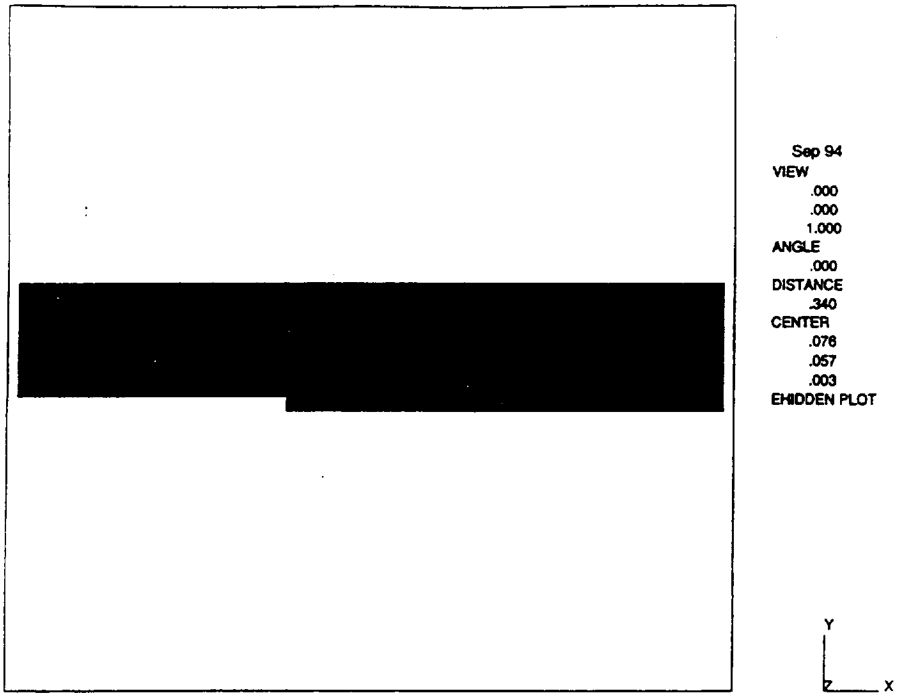
- BODY-FITTED NON-ORTHOGONAL COORDINATE SYSTEM
- UNSTRUCTURED COMPUTATIONAL MESH, DIFFERENT CELL TOPOLOGIES, IMBEDDED MESH REFINEMENT, DISCONTINUOUS MESH INTERFACE, MOVING BOUNDARY AND INTERNAL INTERFACES
- PRIMITIVE VARIABLE, SELF-ADAPTIVE ELLIPTIC-HYPERBOLIC PRESSURE CORRECTION METHOD
- COLLOCATED-VARIABLE ARRANGEMENT
- EULER-IMPLICIT TEMPORAL INTEGRATION
- UD, CD, LUD, SFCD SPATIAL DISCRETIZATION, WITH BLENDING CAPABILITY

STAR-CD: TURBULENCE MODELS

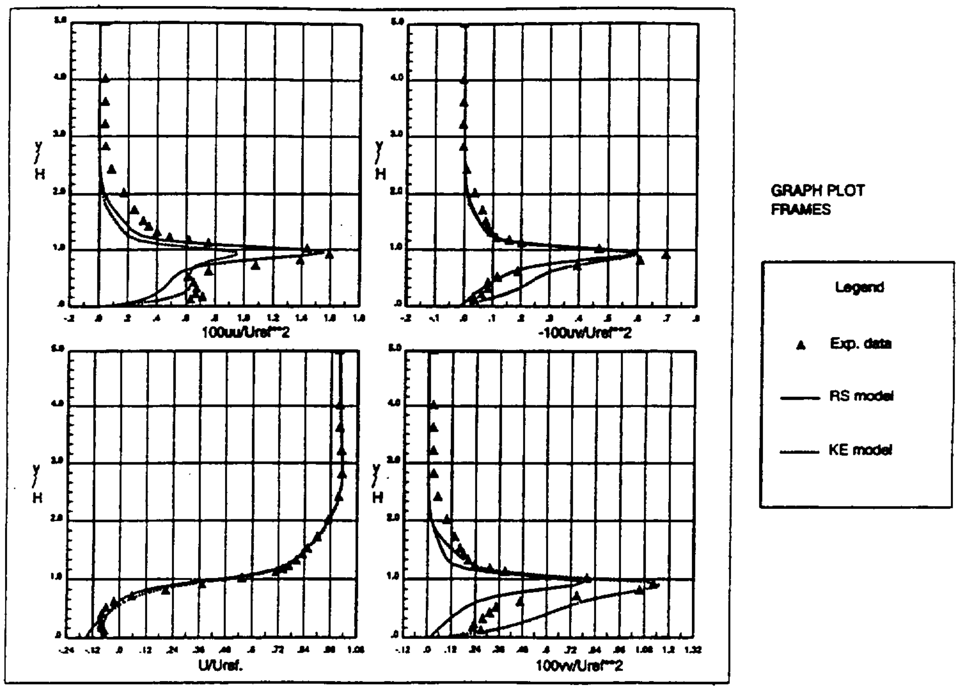
- TWO-EQUATION MODEL
  - STANDARD k-ε WITH CORRECTIONS FOR BULK DILATATION AND BUOYANCY
  - HIGH REYNOLDS NO. RNG BASED k-ε MODEL
- TWO-ZONE (TWO-LAYER) MODEL
  - HIGH REYNOLDS NO.: k-ε VARIANTS
  - LOW REYNOLDS NO.: k-ℓ VARIANTS, PRANDTL MIXING LENGTH MODEL

STAR-CD: TURBULENCE MODELS

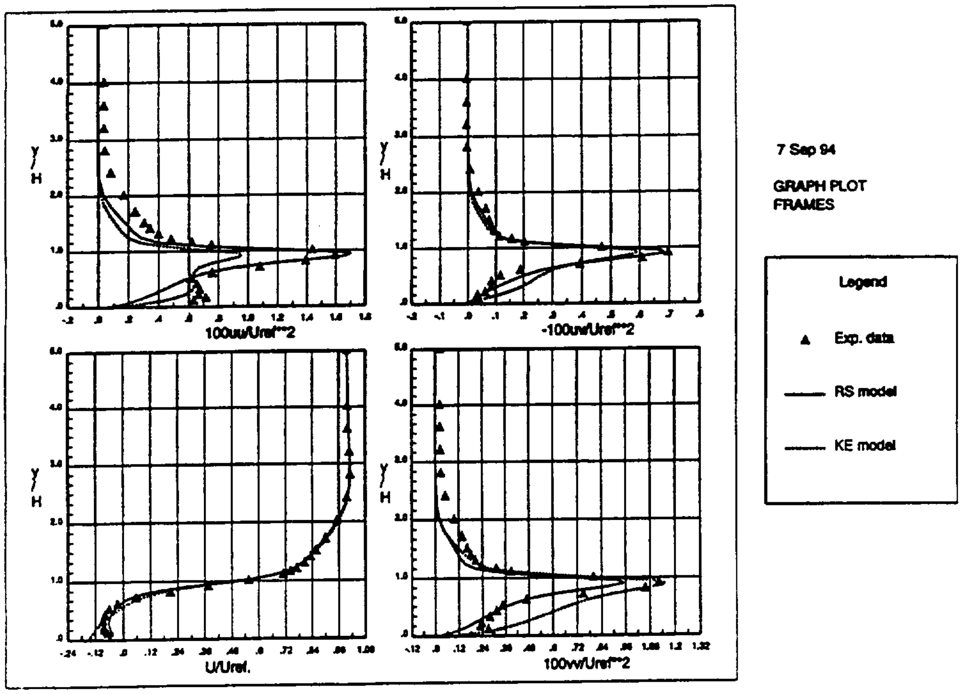
- REYNOLDS STRESS TRANSPORT MODEL
  - TRANSPORT EQUATIONS FOR CARTESIAN STRESS TENSOR IN NON-ORTHOGONAL COORDINATE SYSTEM, ON NON-STRUCTURED MESH
  - LAUNDER, RODI, REECE (1975) FORMULATION WITH LAUNDER (1989) MODEL CONSTANTS
  - GIBSON & LAUNDER (1978) WALL REFLECTION MODEL



Driver & Seegmiller Backward Facing Step
Flow Domain = -20*H to 32*H
Mesh = 105 (Axial) x 45 (Radial)



Driver & Seegmiller Backward Facing Step
Data Inlet B.C.
Location X/H = 1.5



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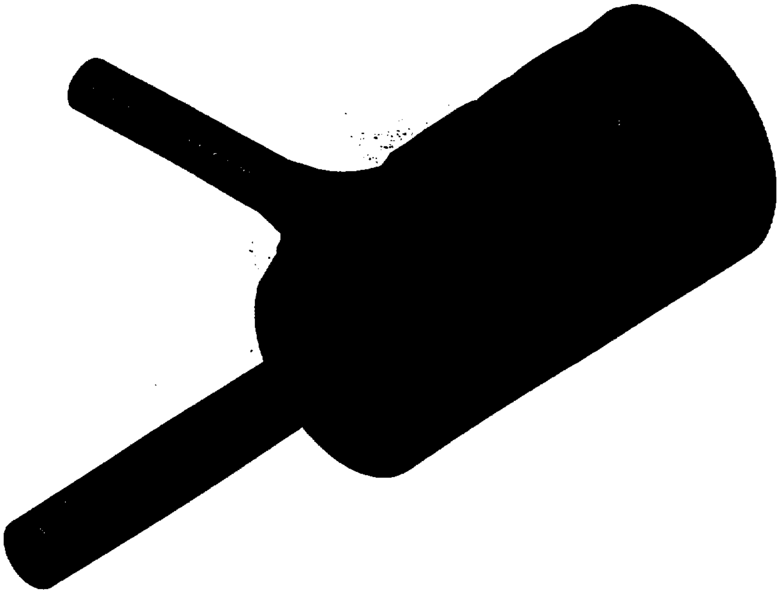
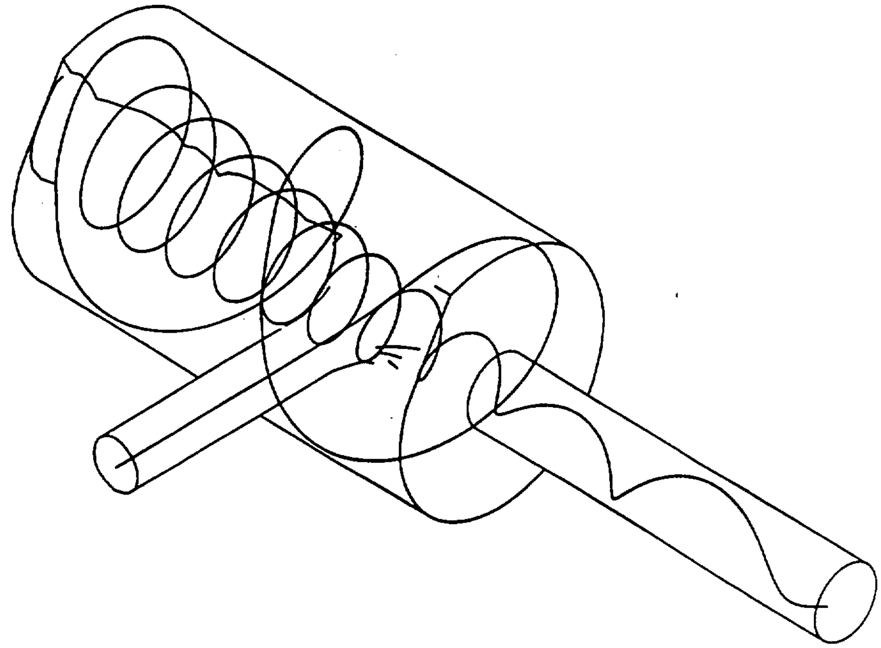
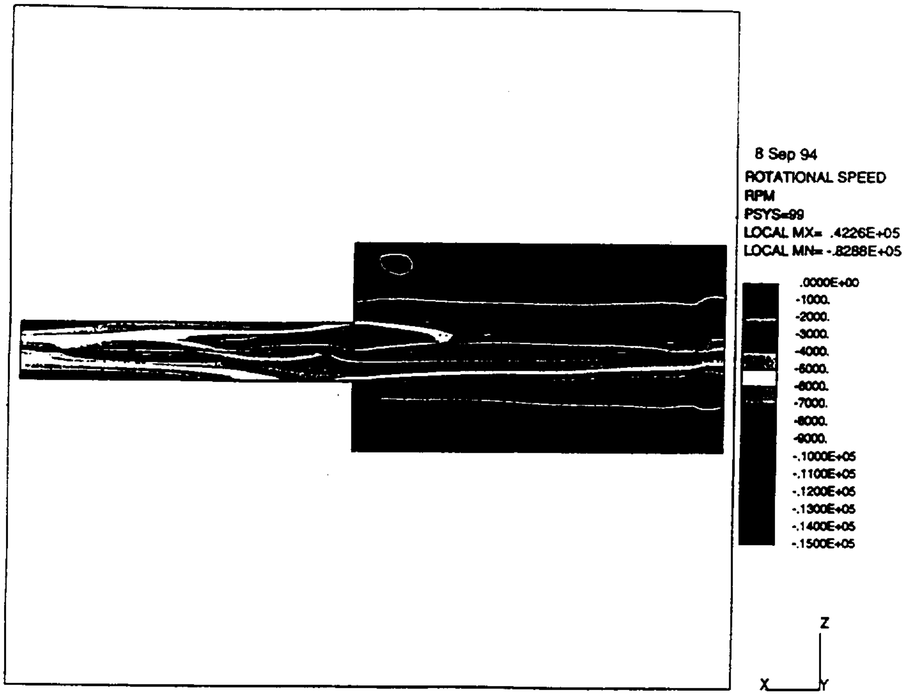
GRAPH PLOT FRAMES

Driver & Seegmiller Backward Facing Step
Data Inlet B.C.; No Wall Damping Funct.
Location X/H = 1.5






8 Sep 94
ROTATIONAL SPEED
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LOCAL MX= .4226E+05
LOCAL MN= -.8288E+05
.0000E+00
-1000.
-2000.
-3000.
-4000.
-5000.
-6000.
-7000.
-8000.
-9000.
-.1000E+05
-.1100E+05
-.1200E+05
-.1300E+05
-.1400E+05
-.1500E+05
Z
X
Y

0.5 LUD DIFFERENCING
TURBULENCE MODEL KE - UPPER, RSM - LOWER

COMMON FEATURES OF INDUSTRIAL COMPLEX FLOWS

- THREE DIMENSIONAL WITH MULTIPLE FLOW "COMPLEXITIES"
  - BODY-FORCE FIELDS
  - STREAM SURFACE CURVATURE
  - STRONG PRESSURE GRADIENTS
  - COMPRESSIBILITY EFFECTS
  - LAMINAR-TURBULENT TRANSITION
  - COMBUSTION, SHOCK, MULTIPHASE, NON-NEWTONIAN
- LARGE SCALE DOMAIN AND COMPLEX GEOMETRIC CONFIGURATION
- IRREGULAR, UNSTRUCTURED COMPUTATIONAL MESH
- SPATIAL RESOLUTION DIFFICULT TO ACHIEVE ON O(10^5 - 10^6) MESH CELLS
- INSUFFICIENT AND UNCERTAIN EXPERIMENTAL DATA FOR TURBULENCE MODEL VALIDATION/IDENTIFICATION OF DEFICIENCIES

INDUSTRY-SPECIFIC CFD DEVELOPMENT REQUIREMENTS

- AUTOMOTIVE INDUSTRY
  - EFFICIENT COMPLEX-GEOMETRY, MOVING-BOUNDARY CAPABILITIES
  - MEMORY/SOLUTION PERFORMANCE FOR LARGE SCALE DOMAIN CFD SIMULATION
  - DIAGNOSTIC/COMPARATIVE EVALUATION OBJECTIVES
  - GEOMETRIC FIDELITY AND SPATIAL RESOLUTION ARE PRIMARY ACCURACY FACTORS
- AEROSPACE INDUSTRY
  - REGULAR AND SMALL-SCALE FLOW DOMAIN (BENCHMARK EXPERIMENTAL MODELS)
  - DESIGN/PERFORMANCE OPTIMIZATION OBJECTIVES
  - NUMERICAL AND TURBULENCE MODEL ACCURACY IMPORTANT
  - REQUIREMENTS
    - HEAT TRANSFER
    - LOW REYNOLDS NO. FLOW
    - BODY FORCE FIELDS

ORIGINAL PAGE IS OF POOR QUALITY

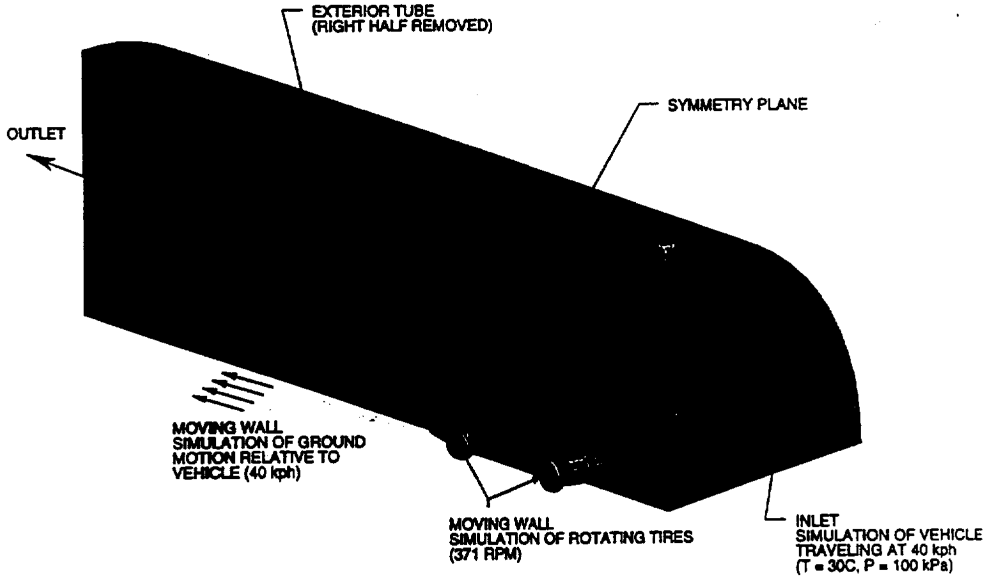
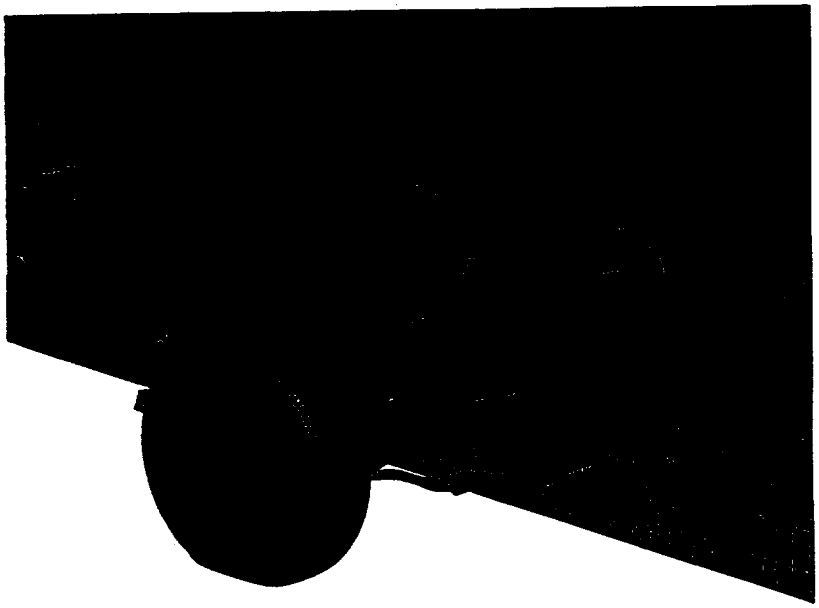
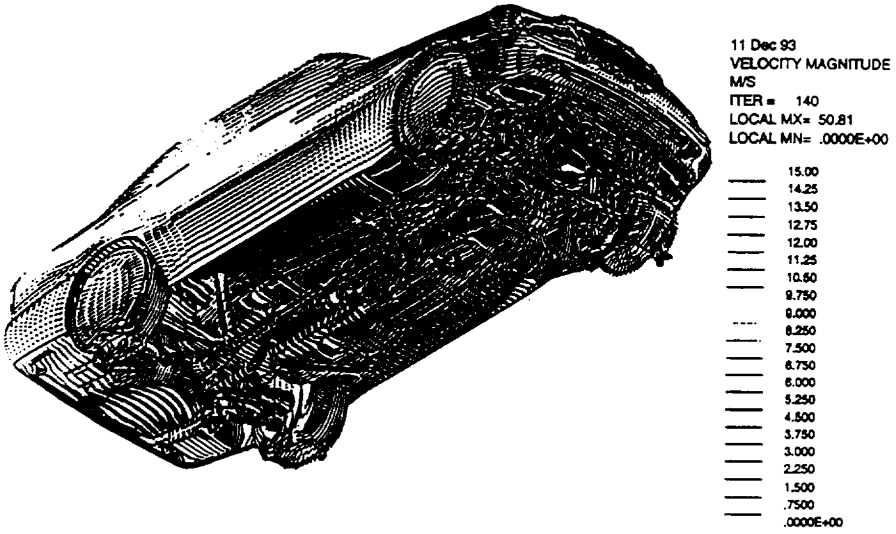
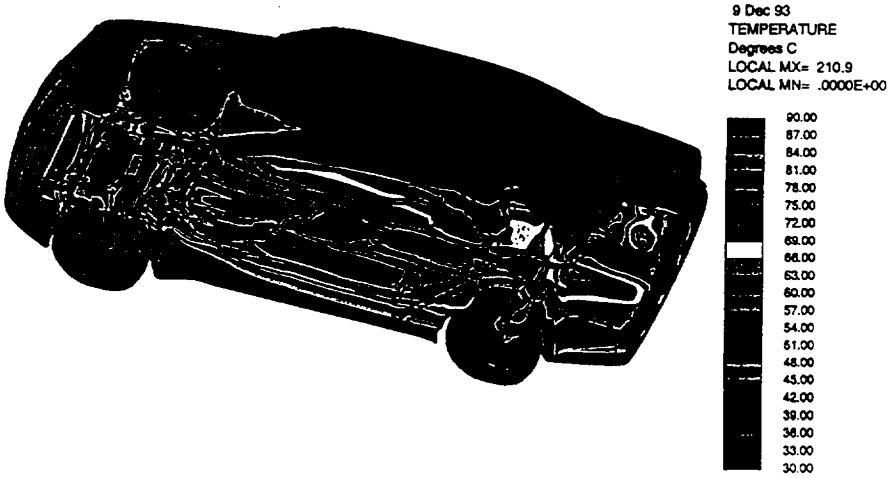


FIGURE 1: EXTERIOR BOUNDARY CONDITIONS FOR W202 40 kph ANALYSIS





W202 UNDERHOOD FLOW ANALYSIS
CASE 3: 40 kph SIMULATION
Velocity near the surface of the vehicle.



W202 UNDERHOOD FLOW ANALYSIS
CASE 3: 40 kph SIMULATION

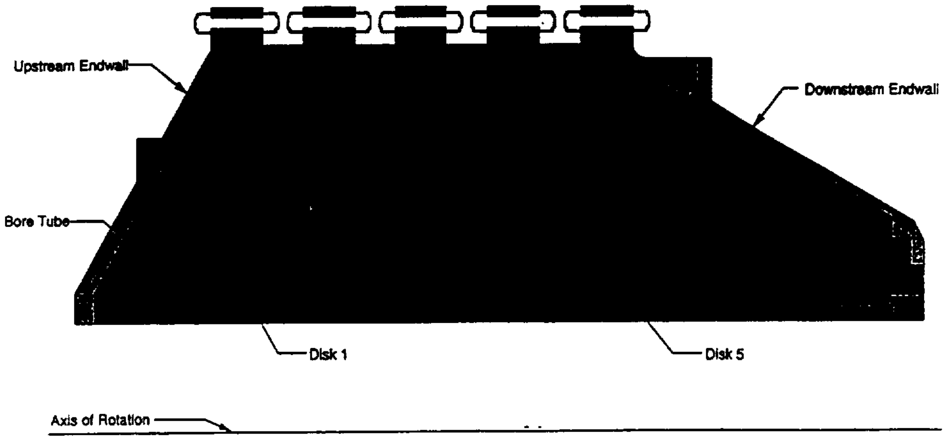
APPLICATIONS & EXPERIENCES

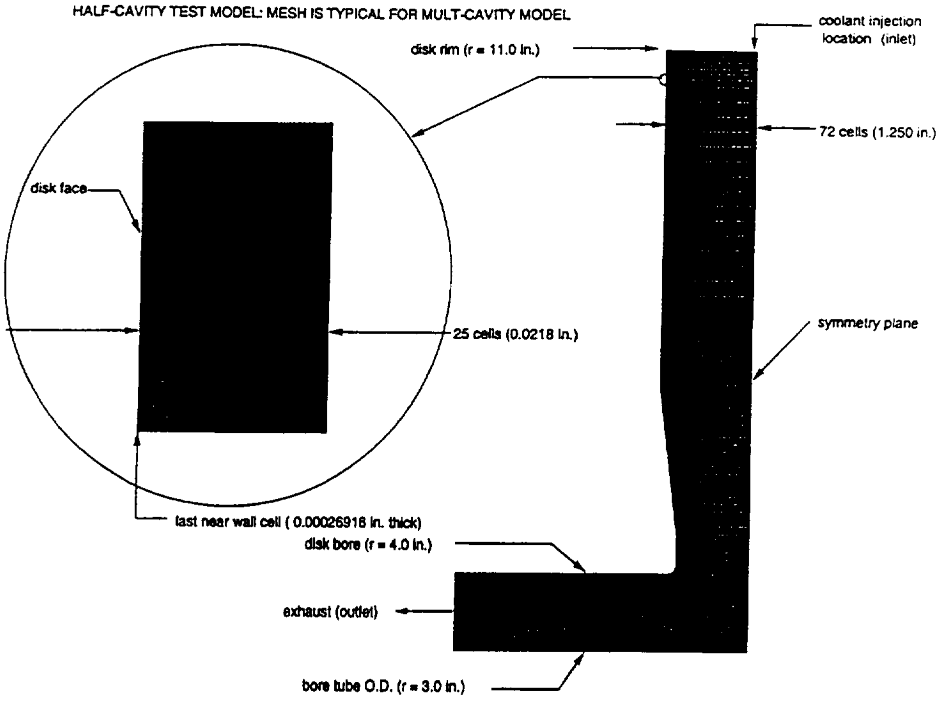
APPLICATION (DATA)	FLOW COMPLEXITY	TURBULENCE MODEL	FINDINGS	T.M. NEEDS
ROTATING DISC CAVITY[1]	• FORCE FIELD • WALL EFFECT	• k-ε • 2 LAYER k-ℓ	• EKMAN LAYER RESOLVED • FAIR PRESSURE DROP • EXCESSIVE E.V.	• RSTM + SUITABLE 2 LAYER • LOW Re RSTM
DIFFUSION HOLE FILM COOLING[2]	• JET-CROSS FLOW • WALL ANISOTROPY	• k-ε • RNG, k-ε • 2 LAYER k-ℓ	• JET SEPARATION SENSITIVE TO MESH TOPOLOGY/ RESOLUTION • POOR SPANWISE SPREAD	• RSTM + SUITABLE 2 LAYER • LOW Re RSTM

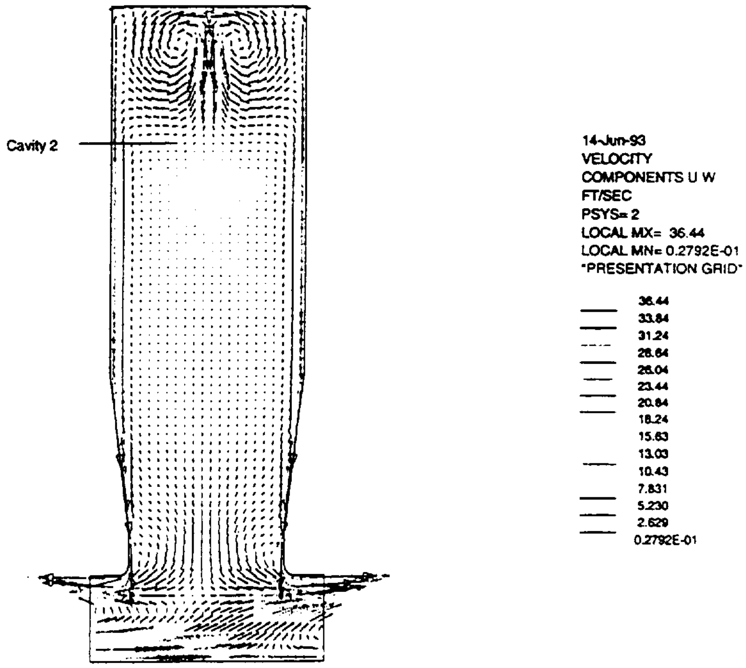
[1] GRABER et al (1987)

[2] GOLDSTEIN et al (1968), LIGRANI et al (1992)

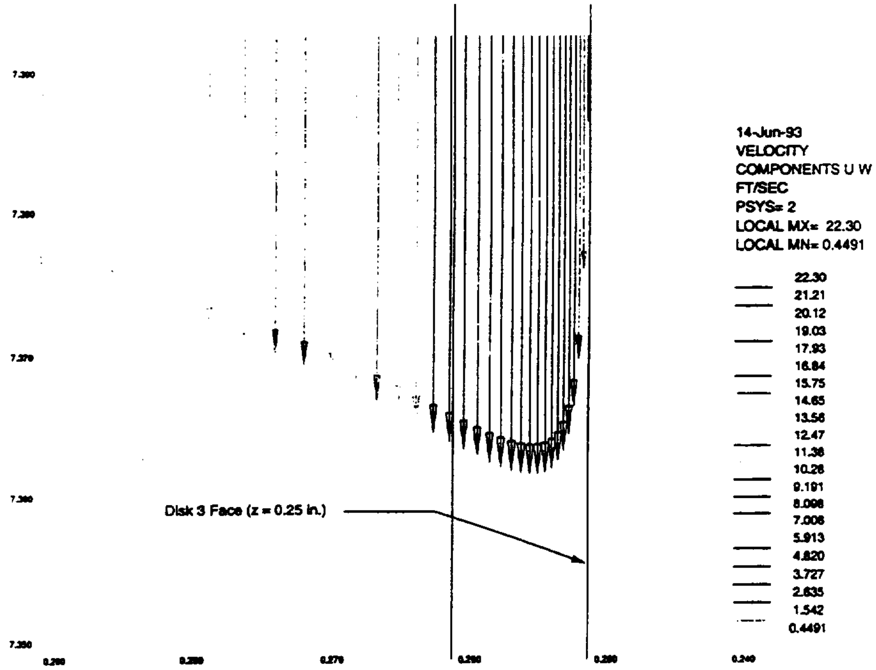
COMPRESSOR DRUM TEST RIG STAR-CD CONJUGATE HEAT TRANSFER MODEL



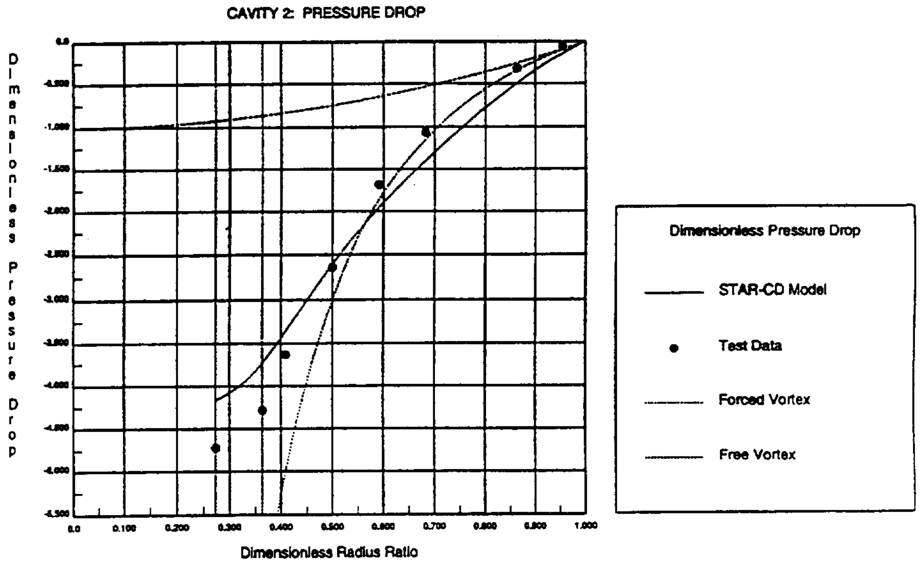


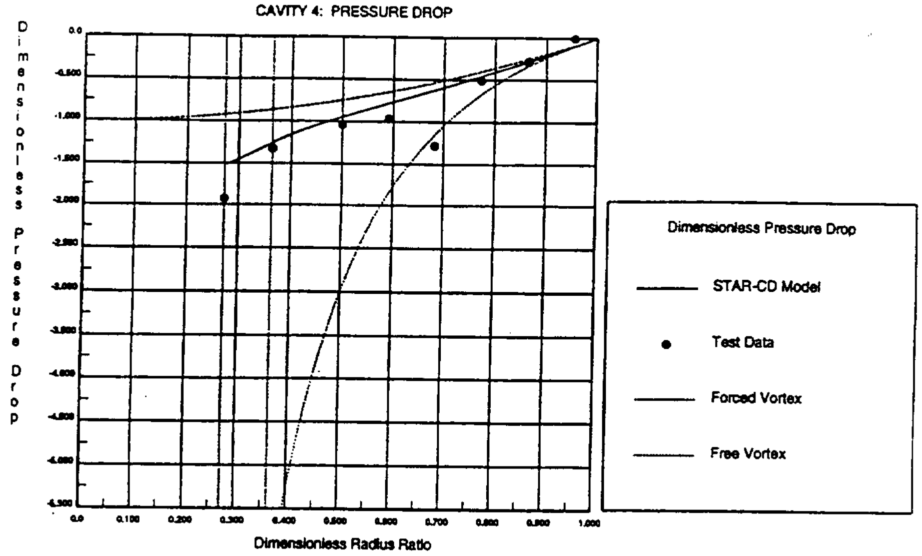


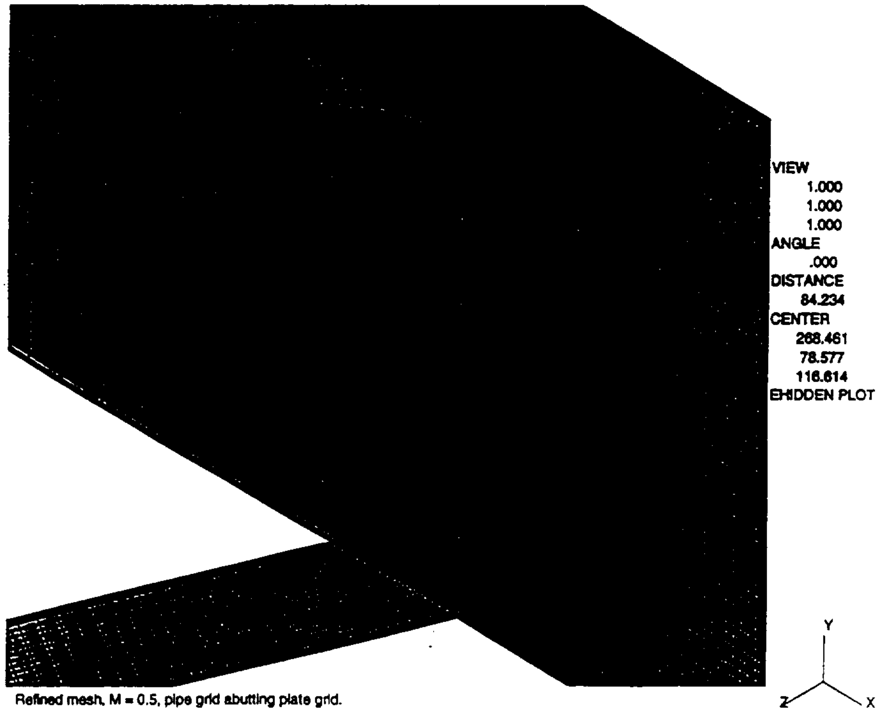
Compressor Drum Test Rig Cold Flow Benchmark Analysis
Secondary Flow



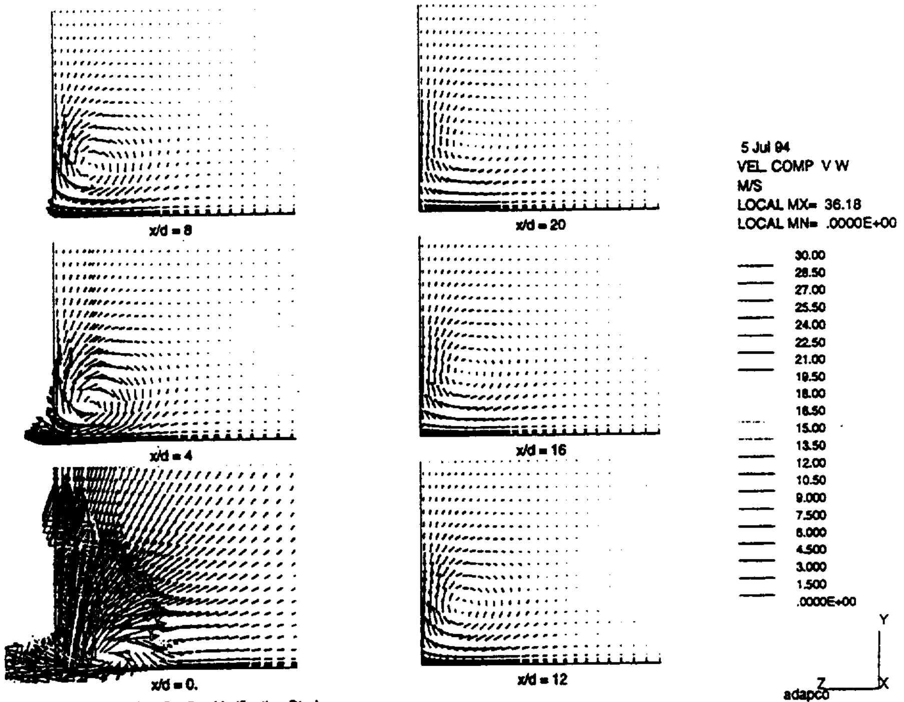
Compressor Drum Test Rig Cold Flow Benchmark Analysis
Secondary Flow in Cavity 2
Velocity Vectors at r = 7.40 inches



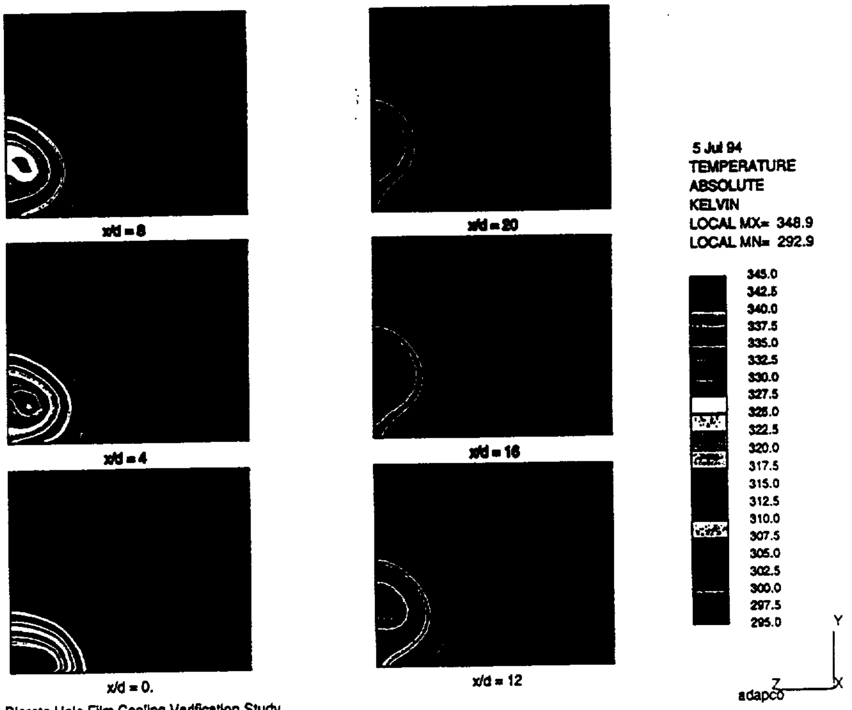




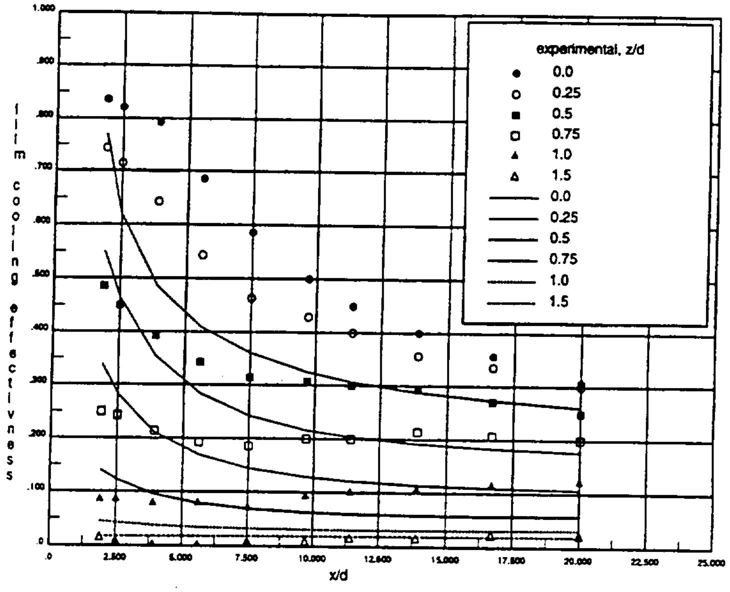
Refined mesh, M = 0.5, pipe grid abutting plate grid.
Mesh = 330000 fluid cells
Two-Layer mesh



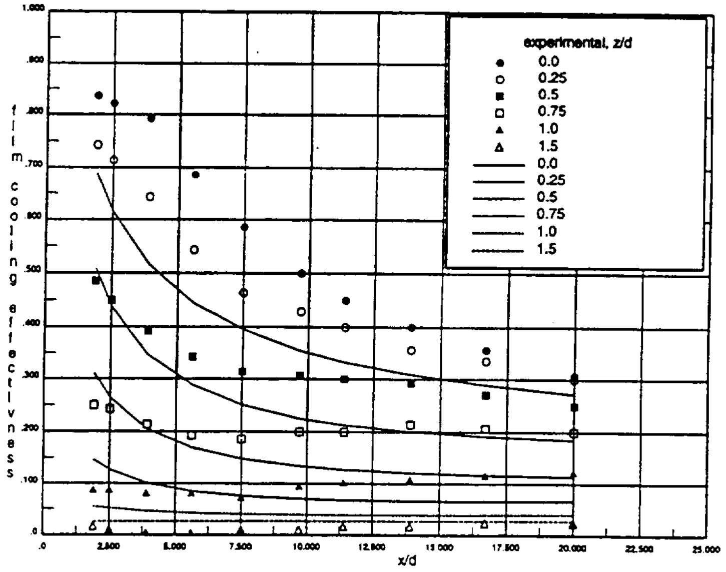
CFD Dicrete Hole Film Cooling Verification Study
Simulation of experiment of Goldstein, et. al. [1968] ; Blowing ratio M =0.5
Velocity vectors on spanwise planes ; 2-layer model.



CFD Dicrete Hole Film Cooling Verification Study
Simulation of experiment of Goldstein, et. al. [1968] ; Blowing ratio M =0.5
Temperature contours on spanwise planes ; 2-layer model.



EXPERIMENTS OF GOLDSTEIN ET AL.,1968
COMPARISON OF FILM COOLING EFFECTIVENESS
M = 0.5 : Mesh II.



EXPERIMENTS OF GOLDSTEIN ET AL.,1968
COMPARISON OF FILM COOLING EFFECTIVENESS
M = 0.5 : 2 Layer mesh.

APPLICATIONS & EXPERIENCES (cont'd)

APPLICATION (DATA)	FLOW COMPLEXITY	TURBULENCE MODEL	FINDINGS	T.M. NEEDS
INTERNAL BLADE COOLING[3]	• FORCE FIELD • B.L. DISRUPTION	• k-ε	• DEPENDENCE ON MESH RESOLUTION • GOOD ΔP, h	
EXTERNAL CAR AERO-DYNAMICS[4]	• B.L. STRUCTURE INTERACTION • COMPLEX WAKE	• k-ε • RNG k-ε • 2 LAYER k-ℓ	• DEPENDENCE ON MESH RESOLUTION • GOOD C_D • POOR LIFT	• RSTM • LOW Re RSTM

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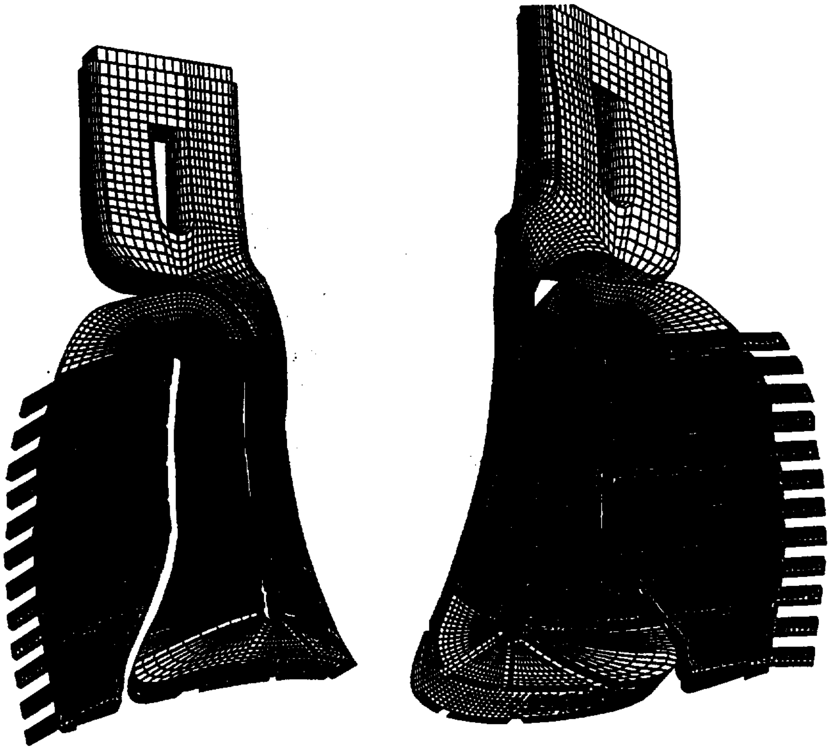
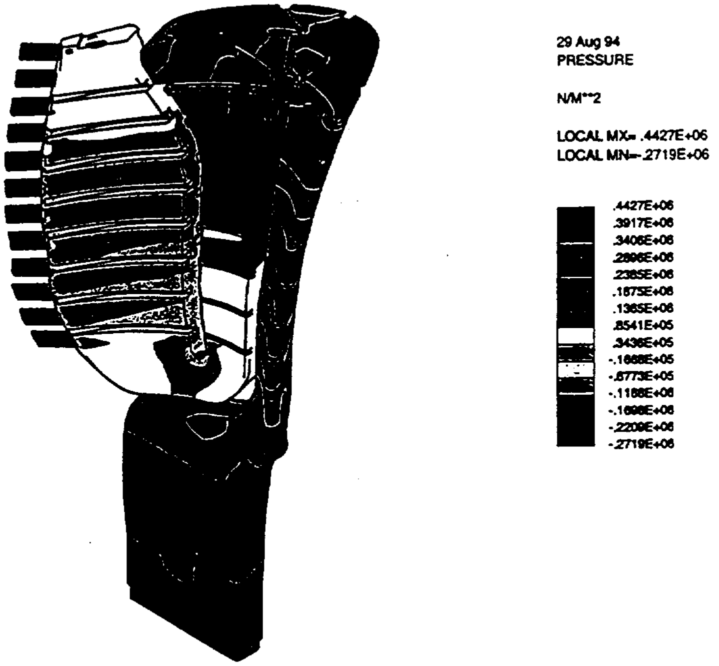
[3] GE AIRCRAFT ENGINES [ABUAF & KERCHER (1991)]
[4] 10 FORD 1/4 SCALE MODELS IN WIND TUNNEL TEST [WILLIAMS et al (1994)]




29 Aug 94
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LOCAL MN=-.2719E+06
.4427E+06
.3917E+06
.3406E+06
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.1875E+06
.1365E+06
.8541E+05
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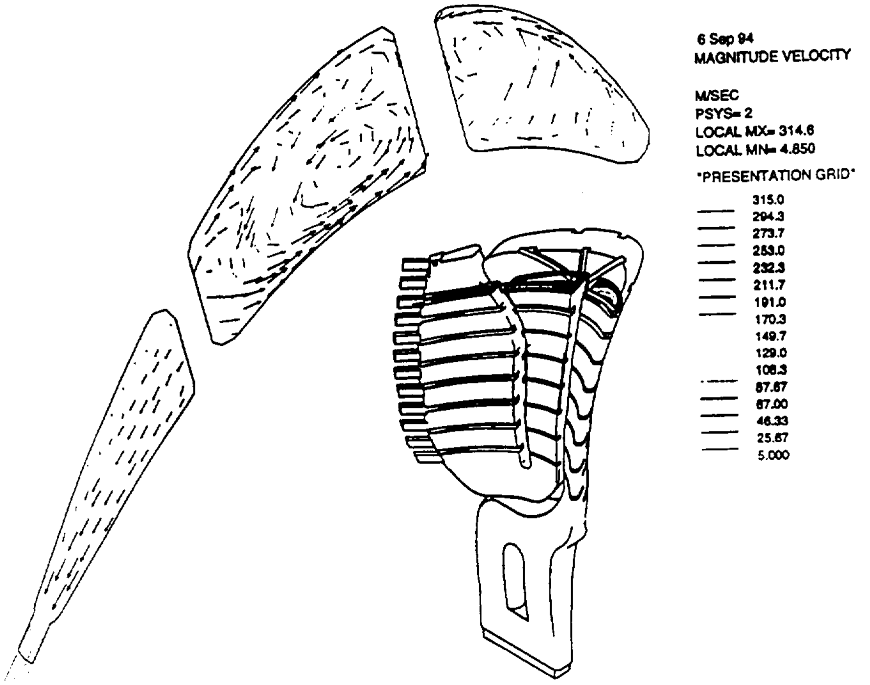
-.2209E+06
-.2719E+06


6 Sep 94
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LOCAL MN= 4.850
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67.00
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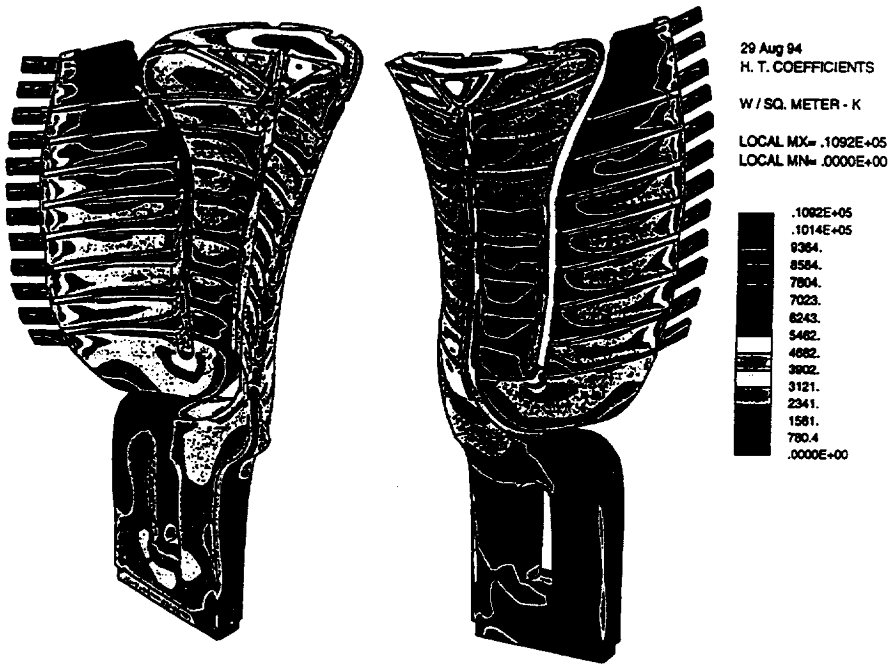
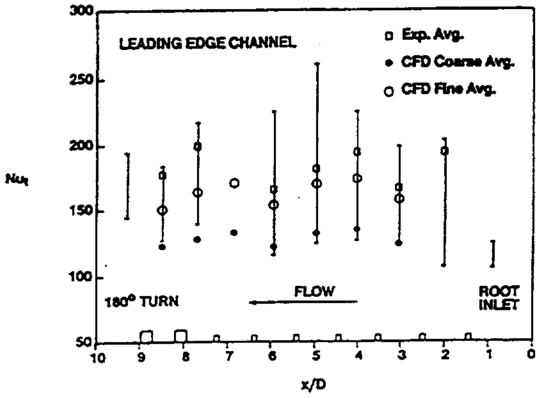
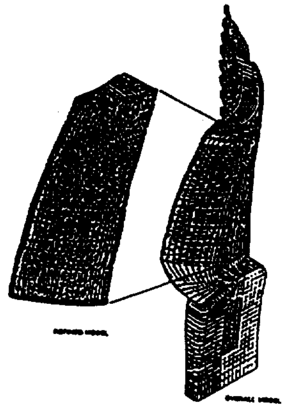
5.000

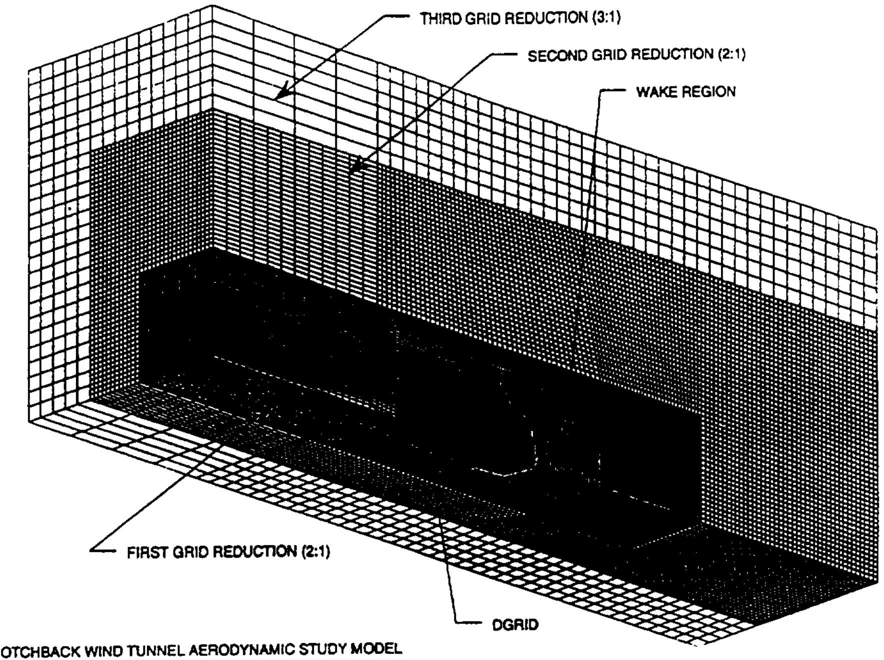




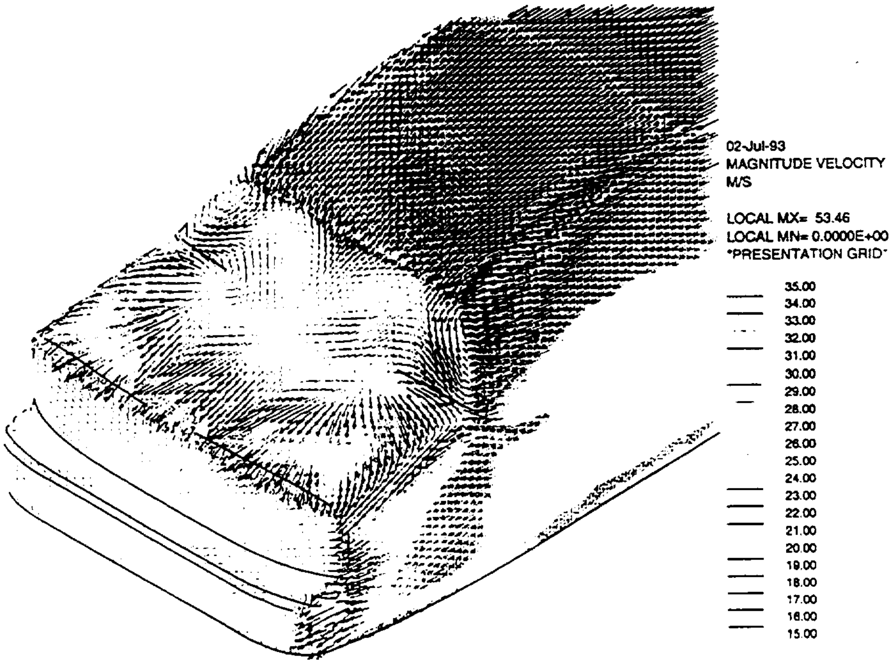


CFD BLADE AND LEADING EDGE MODELS
Marinaccio (1989,1990a,1991)

Figure 4 a Leading edge channel heat transfer distribution with distance from the inlet. Comparison of model turbulated convex surface maximum, minimum and average measurements with blade CFD average predictions.



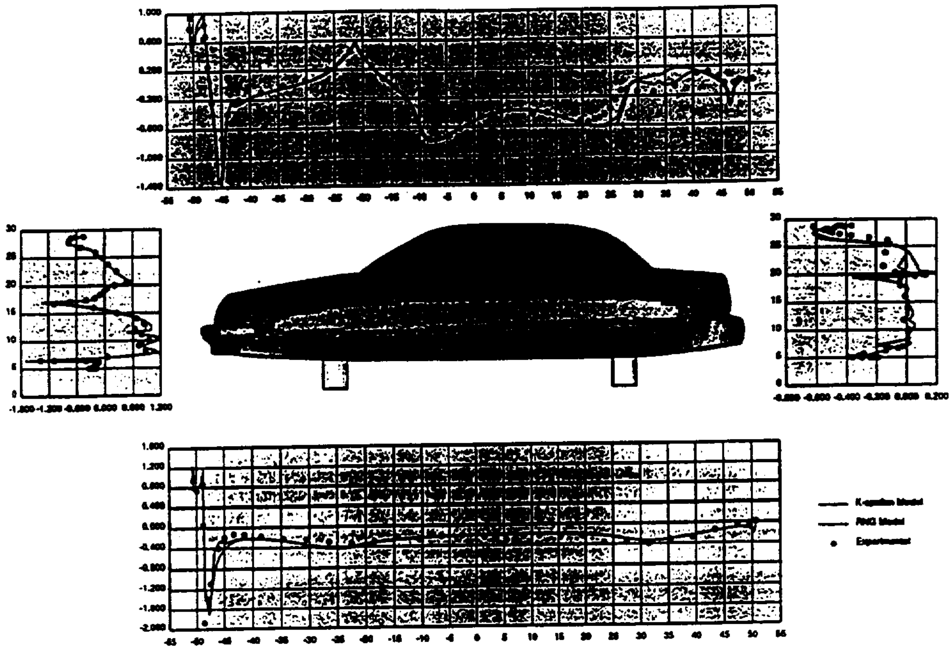
NOTCHBACK WIND TUNNEL AERODYNAMIC STUDY MODEL
COMPLETE MODEL DOMAIN



WIND TUNNEL AERODYNAMICS STUDY OF NOTCHBACK TEST SHAPE
KE RESULTS - KE TURBULENCE MODEL WITH LUD
VELOCITY MAGNITUDE NEAR THE VEHICLE

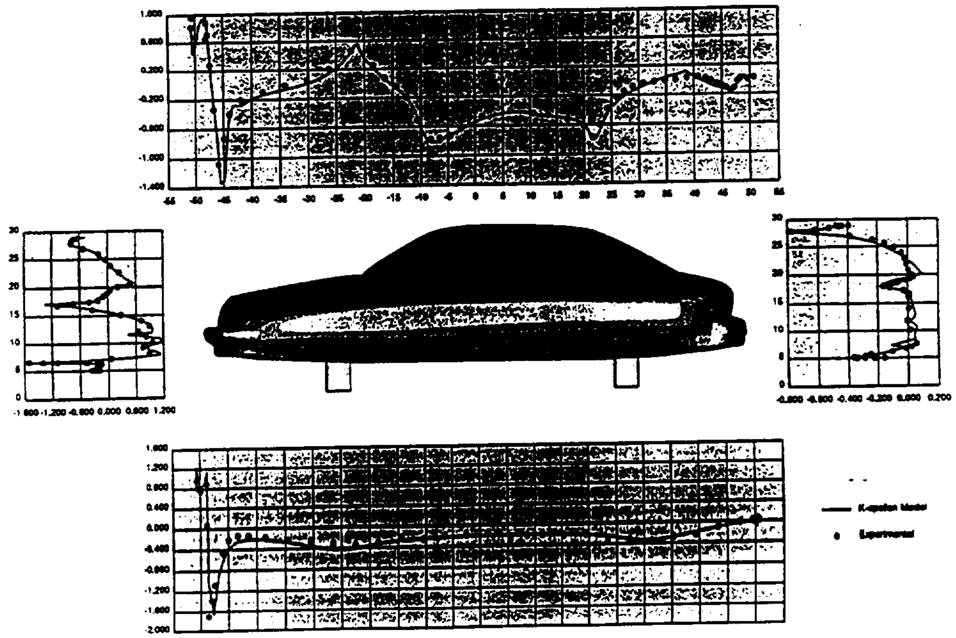
VIEW FROM REAR

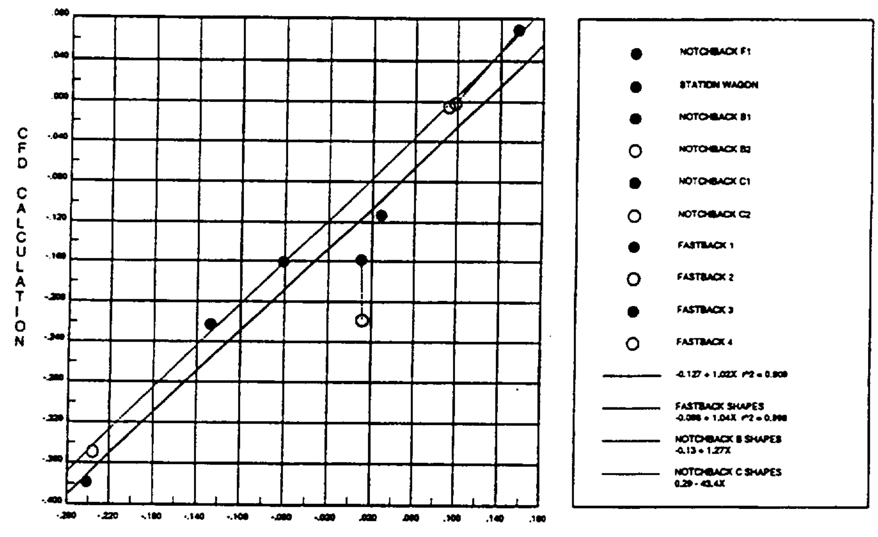
PRESSURE COEFFICIENTS AT THE CENTERLINE OF VEHICLE



NOTCHBACK 1 BODY STYLE

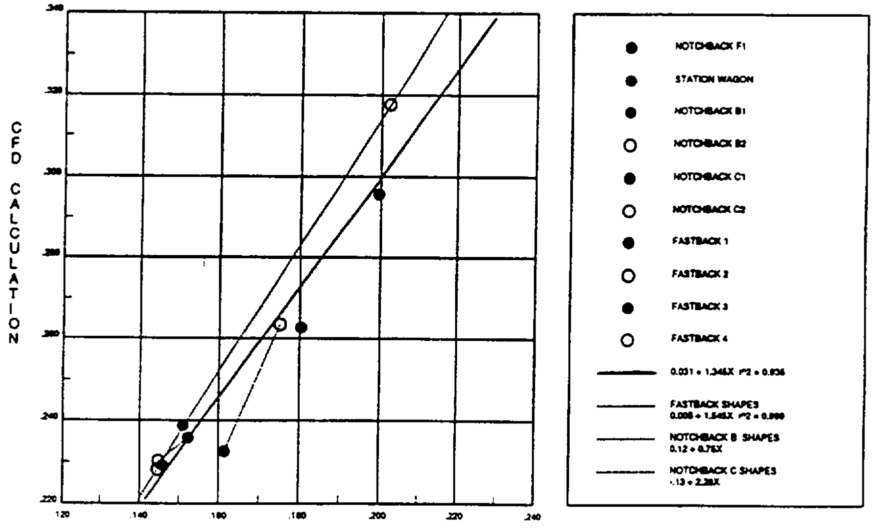
PRESSURE COEFFICIENTS AT THE CENTERLINE OF VEHICLE





EXPERIMENT RESULTS

COMPARISON OF EXPERIMENTAL AND COMPUTIONAL LIFT COEFFICIENTS
K EPSILON TURBULENCE MODEL - *** INITIAL RESULTS ***



EXPERIMENTAL RESULTS

COMPARISON OF EXPERIMENTAL AND COMPUTIONAL DRAG COEFFICIENTS
K EPSILON TURBULENCE MODEL - *** INITIAL RESULTS ***

CONCLUSIONS: TURBULENCE MODELING IMMEDIATE NEEDS

- NEAR-WALL TURBULENCE
  - ECONOMICAL, ROBUST LOW REYNOLDS NUMBER 2 EQ. EVM's AND RSTM
  - A GENERAL AND VERSATILE NEAR-WALL TREATMENT FOR RSTM
- RSTM MODEL
  - ALTERNATIVE CLOSURE OF THE WALL REFLECTION COMPONENT, WITHOUT NEED OF WALL TOPOGRAPHY PARAMETERS
- EDDY-VISCOSITY MODELS
  - EXTENSION OF THE NON-LINEAR k-ϵ TO INCORPORATE FORCE-FIELD EFFECTS
- BENCHMARKING
  - A RELIABLE DATABASE OF BENCHMARK SET OF REPRESENTATIVE COMPLEX FLOWS
  - BENCHMARK PERFORMANCE CLASSIFICATION OF VARIOUS EVM's (k-ϵ, k-ω, RNG AND NON-LINEAR k-ϵ, MULTISCALE EVM's) AND RSTM CLOSURE VARIANTS

CONCLUSIONS: TURBULENCE MODELING PROGRAM NEEDS

- A LARGER VIEW OF THE RSTM DEVELOPMENT TOWARDS IMPLEMENTATION IN GENERAL COORDINATE, COMPLEX GEOMETRY DOMAIN, UNSTRUCTURED CFD METHOD

- A BROADER APPLICATION OF DNS TO COMPLEX FLOWS TO ASSIST TURBULENCE MODEL DEVELOPMENT/OPTIMIZATION

- WELL-POSED EXPERIMENTAL DATA, OBTAINED IN THE ORIGINAL OR REDUCED SCALE MODEL OF THE INDUSTRIAL COMPONENT FOR CFD VALIDATION

- COLLABORATIVE INDUSTRY-CFD RESEARCH/DEVELOPMENT PROGRAMS FOR EXPERIMENTATION - CFD VALIDATION (CALIBRATION) FOR SPECIFIC INDUSTRIAL APPLICATIONS