CFD MODELING OF TURBULENT DUCT FLOWS FOR COOLANT CHANNEL ANALYSIS

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ABSTRACT

The design of modern liquid rocket engines requires the analysis of chamber coolant channels to maximize the heat transfer while minimizing the coolant flow. Coolant channels often do not remain at a constant cross section or at uniform curvature. New designs require higher aspect ratio coolant channels than previously used. To broaden the analysis capability and to complement standard analysis tools an investigation on the accuracy of CFD predictions for coolant channel flow has been initiated. Validation of CFD capabilities for coolant channel analysis will enhance the capabilities for optimizing design parameters without resorting to extensive experimental testing. The eventual goal is to use CFD to determine the flow fields of unique coolant channel designs and therefore determine critical heat transfer coefficients.

In this presentation the accuracy of a particular CFD code is evaluated for turbulent flows. The first part of the presentation is a comparison of numerical results to existing cold flow data for square curved ducts (NASA CR-3367, "Measurements of Laminar and Turbulent Flow in a Curved Duct with Thin Inlet Boundary Layers"). The results of this comparison show good agreement with the relatively coarse experimental data. The second part of the presentation compares two cases of higher aspect ratio channels (AR=2.5,10) to show changes in axial and secondary flow strength. These cases match experimental work presently in progress and will be used for future validation. The comparison shows increased secondary flow strength of the higher aspect ratio case due to the change in radius of curvature. The presentation includes a test case with a heated wall to demonstrate the program's capability. The presentation concludes with an outline of the procedure used to validate the CFD code for future design analysis.

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BY

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TOPICS

- INTRODUCTION
- TURBULENT VALIDATION: 90° CURVED SQUARE DUCT, Re=40000
- ASPECT RATIO EFFECTS: 60° CURVED RECTANGULAR DUCT, ASPECT RATIOS 2.5 & 10,
- CONSTANT TEMPERATURE WALL: Tw-Tin=200°C
- FUTURE EFFORTS

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CFD MODELING OF TURBULENT DUCT FLOWS FOR COOLANT CHANNEL ANALYSIS

BACKGROUND: LOCAL COOLANT CHANNEL HEAT FLUX IS DIFFICULT AND EXPENSIVE TO MEASURE BUT CAN BE CRITICAL TO COMBUSTION CHAMBER LIFE. IMPROVED ANALYTICAL CAPABILITIES ARE DESIRED FOR EVALUATING NEW COOLANT CHANNEL DESIGNS.

OBJECTIVE: DEMONSTRATE THE EXISTING CAPABILITIES OF CFD FOR MODELING TURBULENT SQUARE DUCT FLOWS FOR COOLANT CHANNEL ANALYSIS

APPROACH: COMPARE REACT3D CODE RESULTS OF CURVED CHANNEL CALCULATIONS TO EXPERIMENTAL DATA

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TURBULENT VALIDATION

- TURBULENT CURVED DUCT DATA FROM NASA CR-3367, Taylor, et. al.
- REACT3D PERFORMED WELL

  INCOMPRESSIBLE FNS
  TWO EQUATION TURBULENCE MODEL (WALL FUNCTIONS,)
  43 SPARC 10 CPU HOURS, 113,000 NODE GRID

- GOOD QUALITATIVE COMPARISONS OF AXIAL VELOCITY TO RELATIVELY COARSE EXPERIMENTAL DATA
- PRESSURE PREDICTIONS ALSO SHOW GOOD AGREEMENT

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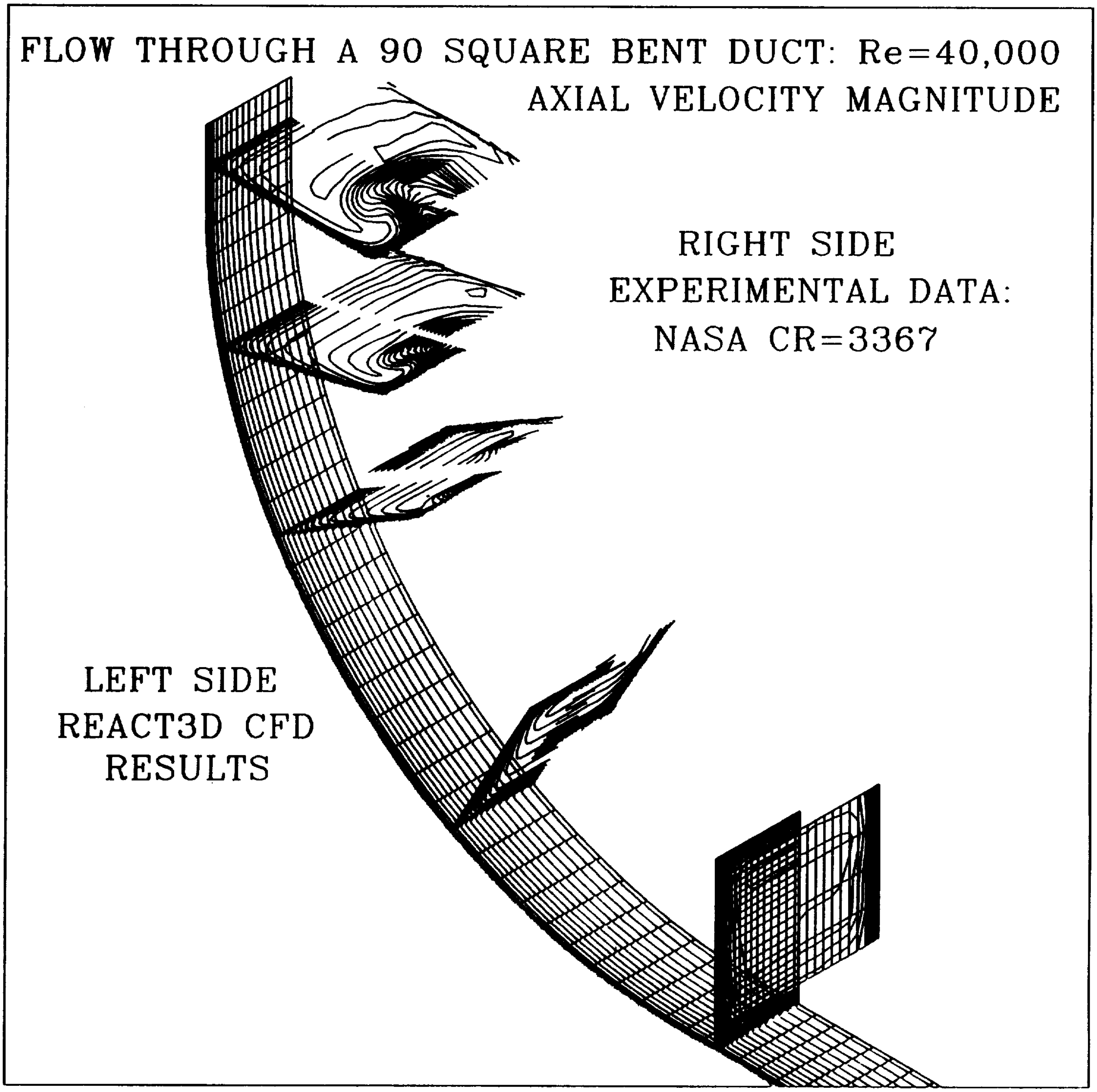
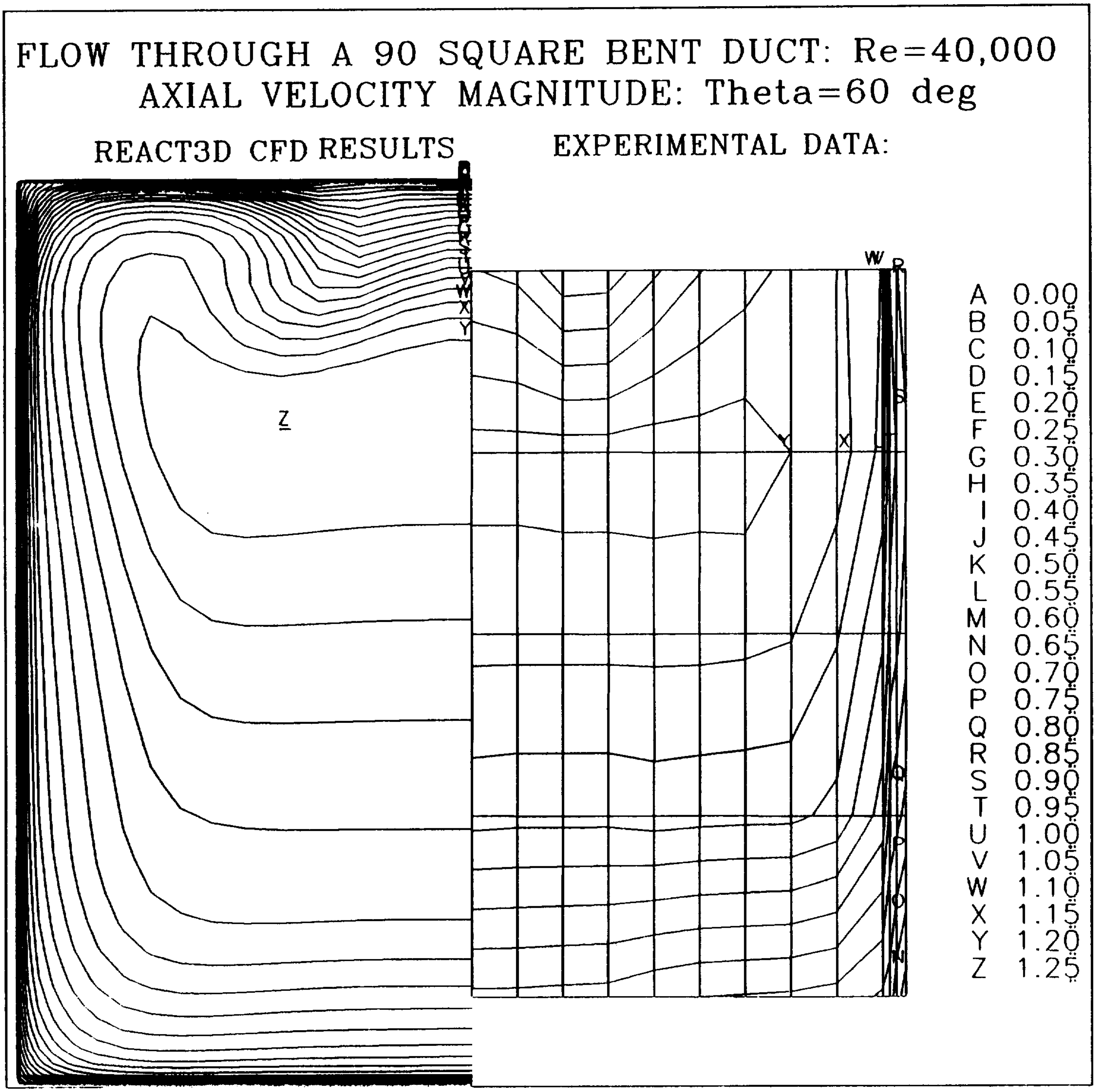
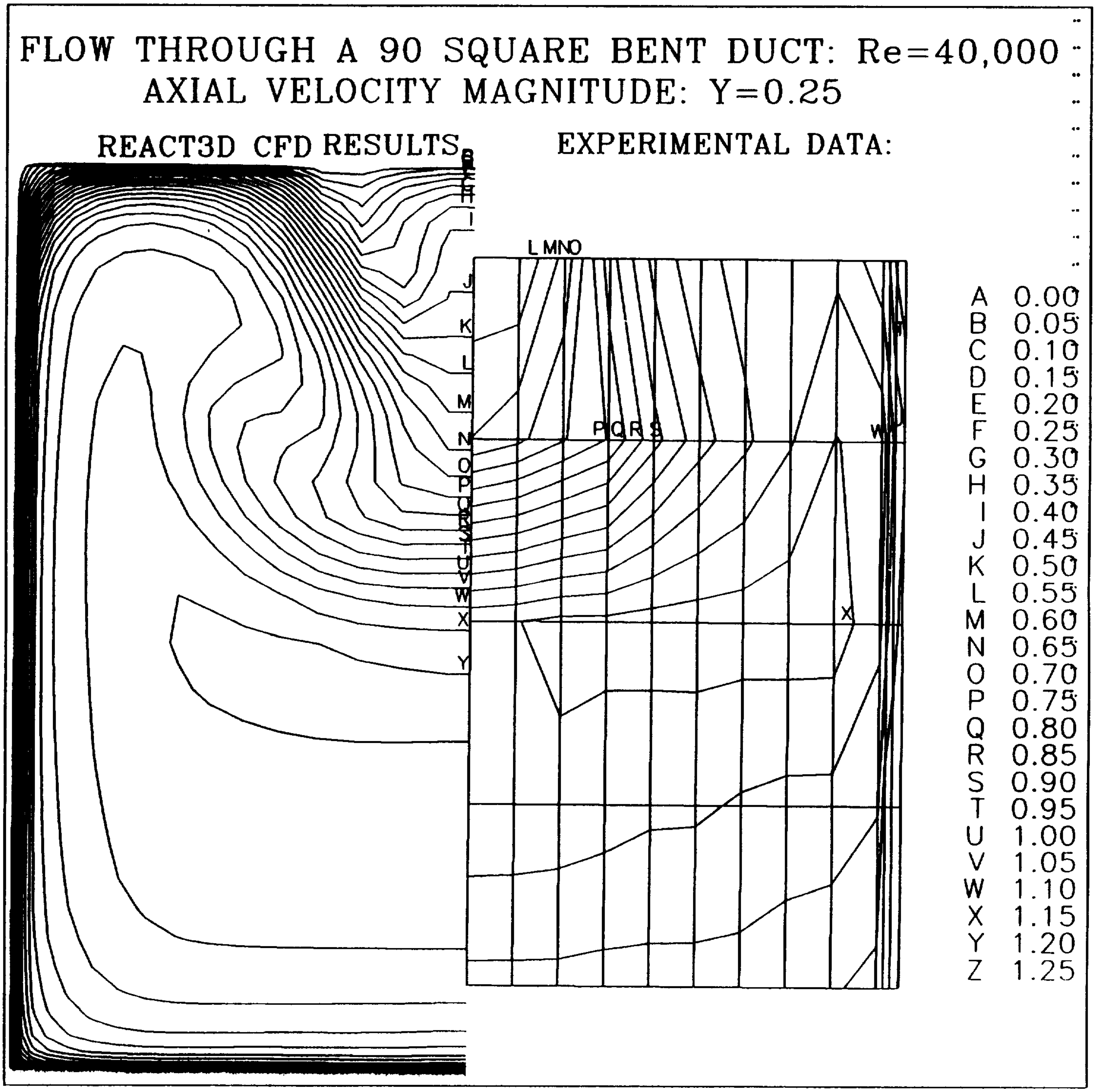


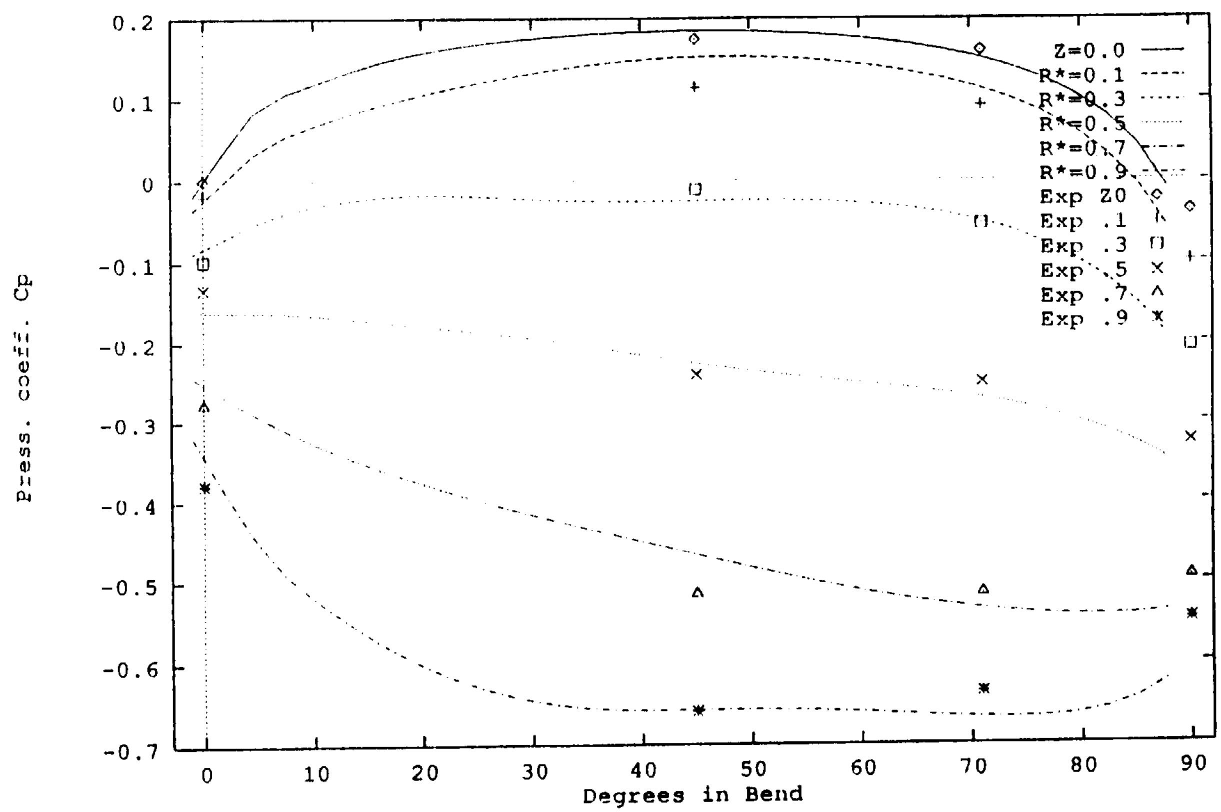
FLOW THROUGH A 90 SQUARE BENT DUCT: Re=40,000
AXIAL VELOCITY MAGNITUDE
RIGHT SIDE
EXPERIMENTAL DATA:
NASA CR=3367
LEFT SIDE
REACT3D CFD
RESULTS


FLOW THROUGH A 90 SQUARE BENT DUCT: Re=40,000
AXIAL VELOCITY MAGNITUDE: Theta=60 deg
REACT3D CFD RESULTS
EXPERIMENTAL DATA:
A 0.00
B 0.05
C 0.10
D 0.15
E 0.20
F 0.25
G 0.30
H 0.35
I 0.40
J 0.45
K 0.50
L 0.55
M 0.60
N 0.65
O 0.70
P 0.75
Q 0.80
R 0.85
S 0.90
T 0.95
U 1.00
V 1.05
W 1.10
X 1.15
Y 1.20
Z 1.25


FLOW THROUGH A 90 SQUARE BENT DUCT: Re=40,000
AXIAL VELOCITY MAGNITUDE: Y=0.25
REACT3D CFD RESULTS
EXPERIMENTAL DATA:
A 0.00
B 0.05
C 0.10
D 0.15
E 0.20
F 0.25
G 0.30
H 0.35
I 0.40
J 0.45
K 0.50
L 0.55
M 0.60
N 0.65
O 0.70
P 0.75
Q 0.80
R 0.85
S 0.90
T 0.95
U 1.00
V 1.05
W 1.10
X 1.15
Y 1.20
Z 1.25

C-6.

TURBULENT VALIDATION



SOLID LINE; NUMERICAL

POINTS; EXPERIMENTAL

- **PRESSURE VALUES ARE ALONG THE OUTSIDE WALL, Z=0.0, AND SIDE WALLS, R*=0.1, 0.3,.05, 0.7, 0.9**

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ASPECT RATIO EFFECTS

- GEOMETRY MATCHES EXPERIMENTAL WORK IN PROGRESS
- 60° CURVED RECTANGULAR DUCTS, OUTSIDE RADIUS CONSTANT (RADIUS IS SCALED FROM SSME DESIGN)

ASPECT RATIO	Dh	RADIUS CURVATURE	REYNOLDS #	DEAN #
2.5	1.57"	37.3"	100,000	20500
10	2.0"	33.2"	127,000	31200

- TWO STEP SOLUTION PROCESS

  1) CALCULATE STRAIGHT DUCT SOLUTION (INLET CONDITION)
  2) CALCULATE CURVED DUCT SOLUTION

- NO SIGNIFICANT COMPUTATIONAL PROBLEMS WITH HIGH ASPECT RATIO COMPUTATIONAL CELLS
- SECONDARY FLOW MAGNITUDE GREATER FOR ASPECT RATIO OF 10

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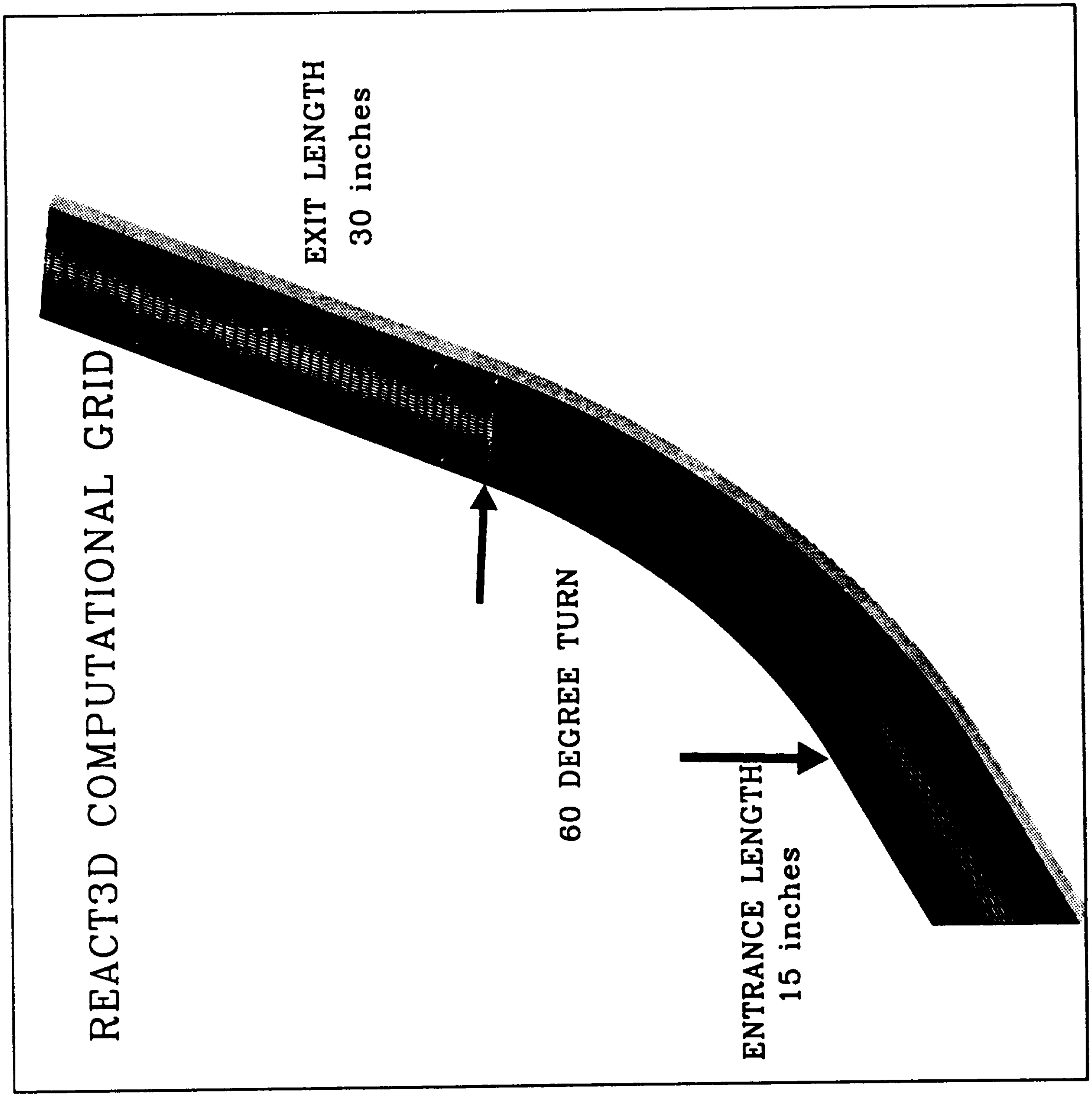
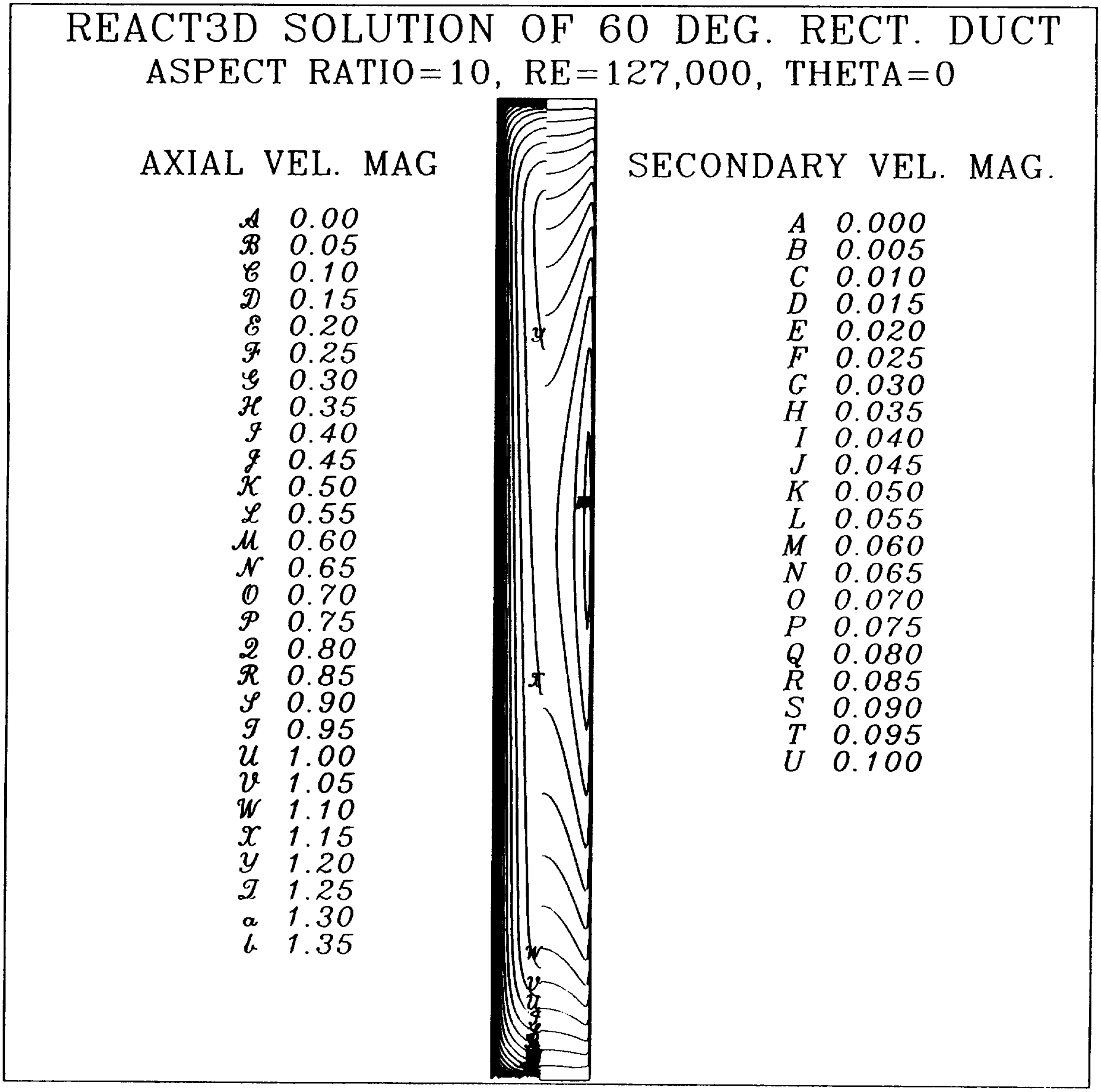
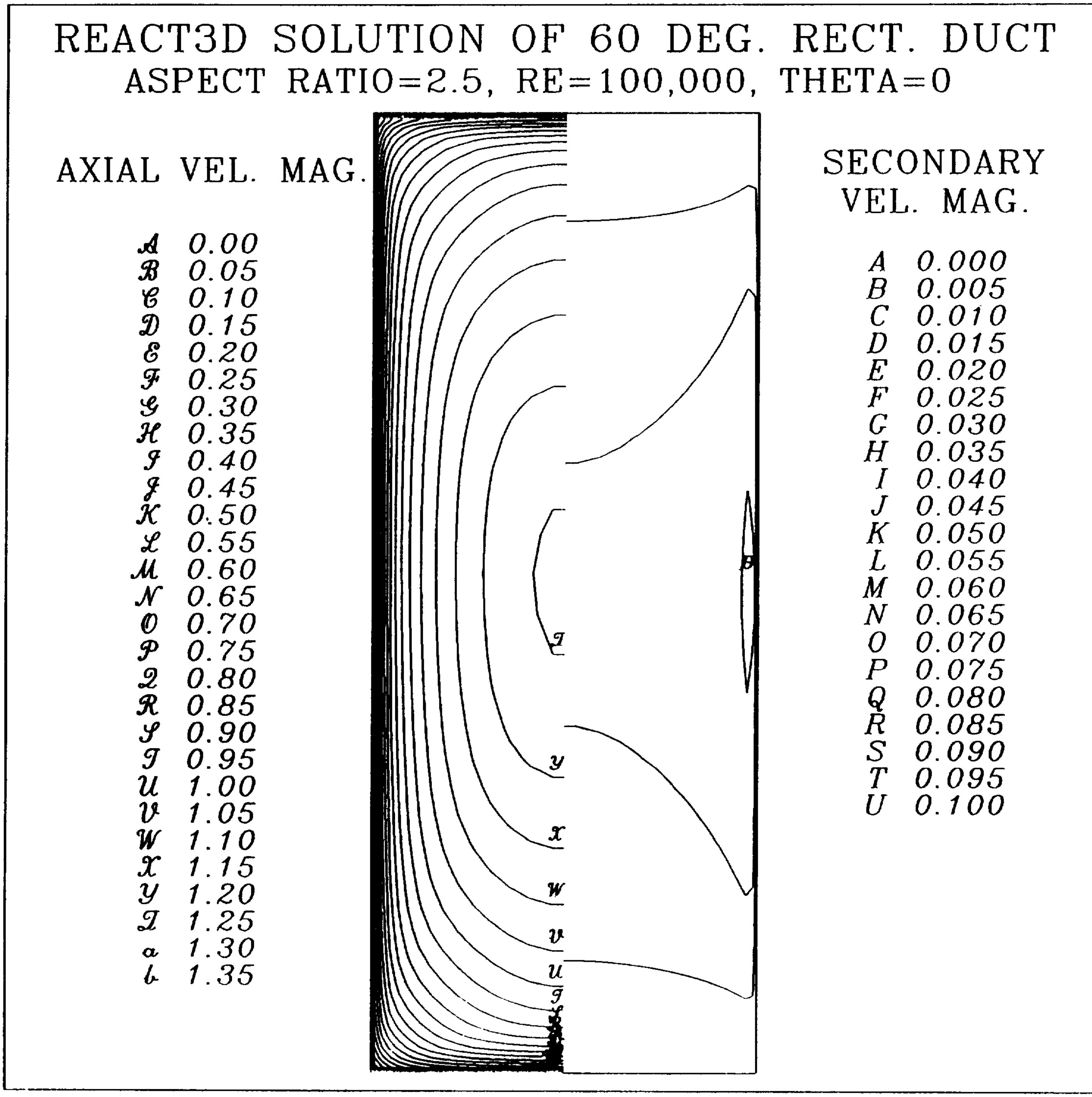

REACT3D COMPUTATIONAL GRID
EXIT LENGTH
30 inches
60 DEGREE TURN
ENTRANCE LENGTH
15 inches


REACT3D SOLUTION OF 60 DEG. RECT. DUCT
ASPECT RATIO=10, RE=127,000, THETA=0
AXIAL VEL. MAG
A 0.00
B 0.05
C 0.10
D 0.15
E 0.20
F 0.25
G 0.30
H 0.35
I 0.40
J 0.45
K 0.50
L 0.55
M 0.60
N 0.65
O 0.70
P 0.75
Q 0.80
R 0.85
S 0.90
T 0.95
U 1.00
V 1.05
W 1.10
X 1.15
Y 1.20
Z 1.25
a 1.30
b 1.35
SECONDARY VEL. MAG.
A 0.000
B 0.005
C 0.010
D 0.015
E 0.020
F 0.025
G 0.030
H 0.035
I 0.040
J 0.045
K 0.050
L 0.055
M 0.060
N 0.065
O 0.070
P 0.075
Q 0.080
R 0.085
S 0.090
T 0.095
U 0.100


REACT3D SOLUTION OF 60 DEG. RECT. DUCT
ASPECT RATIO=2.5, RE=100,000, THETA=0
AXIAL VEL. MAG.
A 0.00
B 0.05
C 0.10
D 0.15
E 0.20
F 0.25
G 0.30
H 0.35
I 0.40
J 0.45
K 0.50
L 0.55
M 0.60
N 0.65
O 0.70
P 0.75
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U 1.00
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SECONDARY
VEL. MAG.
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N 0.065
O 0.070
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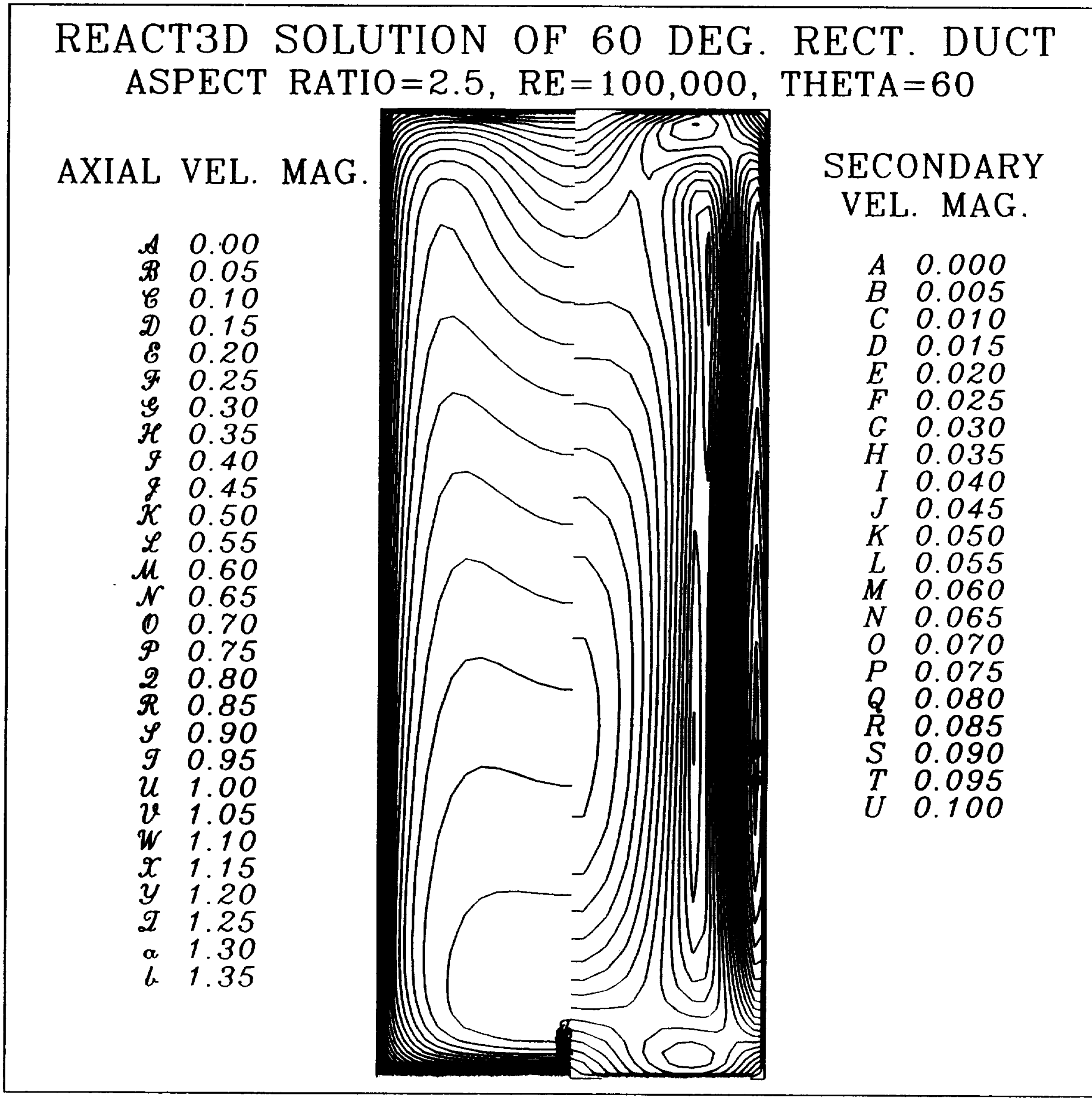
Q 0.080
R 0.085
S 0.090
T 0.095
U 0.100


REACT3D SOLUTION OF 60 DEG. RECT. DUCT
ASPECT RATIO=2.5, RE=100,000, THETA=60
AXIAL VEL. MAG.
A 0.00
B 0.05
C 0.10
D 0.15
E 0.20
F 0.25
G 0.30
H 0.35
I 0.40
J 0.45
K 0.50
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U 1.00
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X 1.15
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Z 1.25
a 1.30
b 1.35
SECONDARY VEL. MAG.
A 0.000
B 0.005
C 0.010
D 0.015
E 0.020
F 0.025
G 0.030
H 0.035
I 0.040
J 0.045
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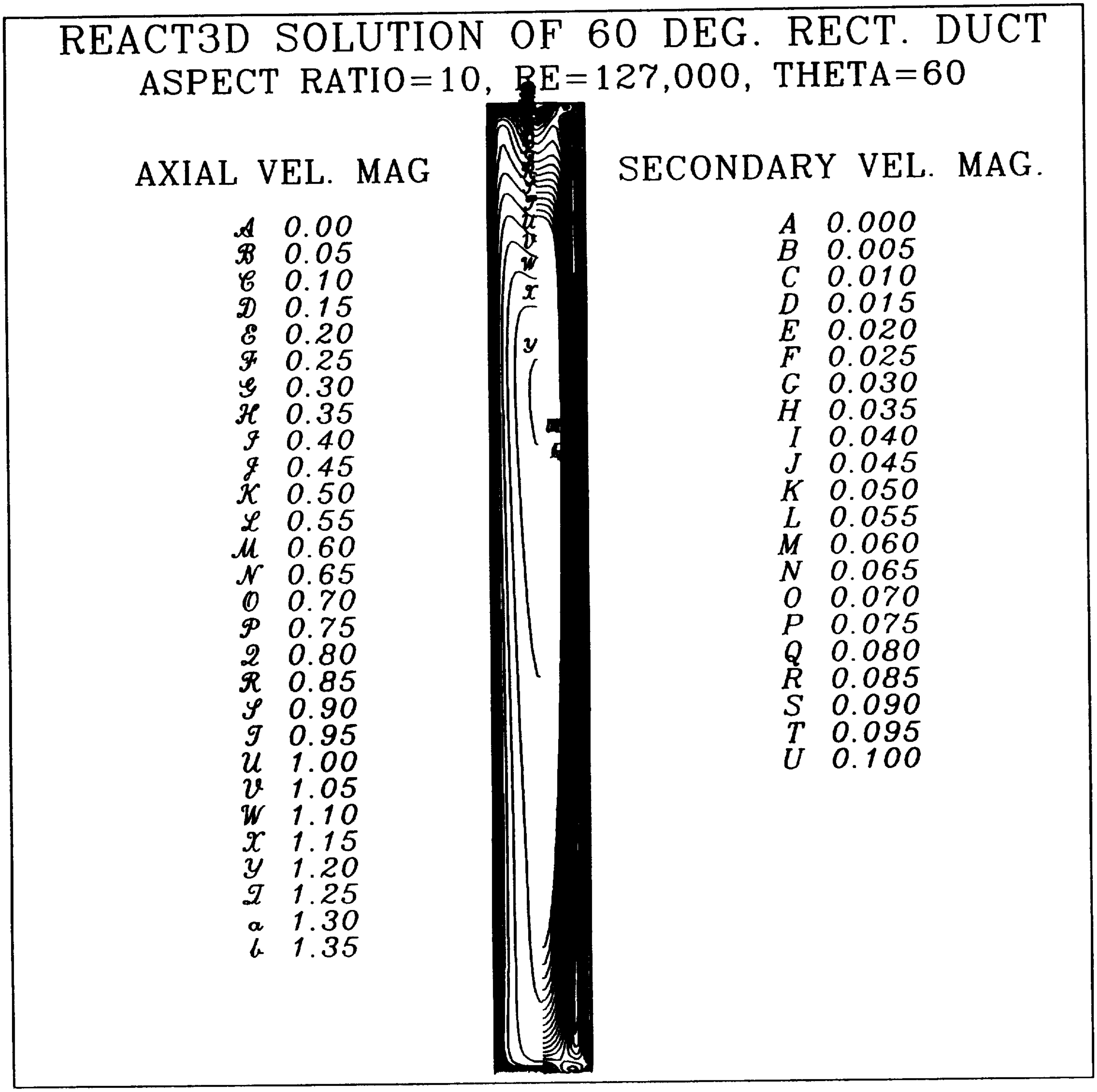
L 0.055
M 0.060
N 0.065
O 0.070
P 0.075
Q 0.080
R 0.085
S 0.090
T 0.095
U 0.100


REACT3D SOLUTION OF 60 DEG. RECT. DUCT
ASPECT RATIO=10, RE=127,000, THETA=60
AXIAL VEL. MAG
A 0.00
B 0.05
C 0.10
D 0.15
E 0.20
F 0.25
G 0.30
H 0.35
I 0.40
J 0.45
K 0.50
L 0.55
M 0.60
N 0.65
O 0.70
P 0.75
Q 0.80
R 0.85
S 0.90
T 0.95
U 1.00
V 1.05
W 1.10
X 1.15
Y 1.20
Z 1.25
a 1.30
b 1.35
SECONDARY VEL. MAG.
A 0.000
B 0.005
C 0.010
D 0.015
E 0.020
F 0.025
G 0.030
H 0.035
I 0.040
J 0.045
K 0.050
L 0.055
M 0.060
N 0.065
O 0.070
P 0.075
Q 0.080
R 0.085
S 0.090
T 0.095
U 0.100

ASPECT RATIO EFFECTS

- HEATED WALL CALCULATIONS PERFORMED TO DEMONSTRATE CODE CAPABILITIES
- INITIAL ASSESSMENT OF HEAT TRANSFER EFFECTS OF HIGH ASPECT RATIO CHANNELS
- Tin-Tw=200 CASE SHOWS LIMITED IMPROVEMENT OF HEAT TRANSFER WITH INCREASED ASPECT RATIO

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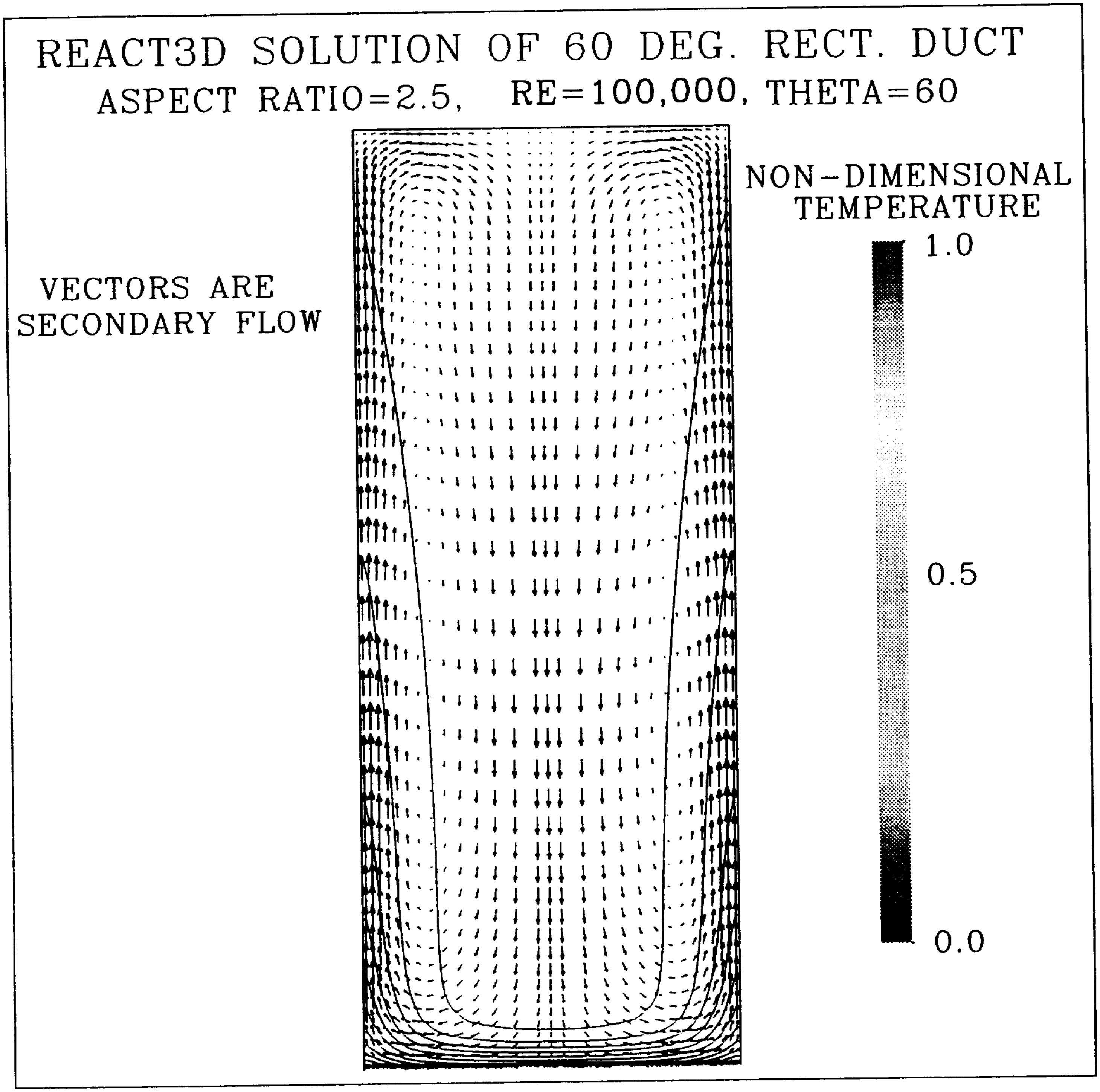
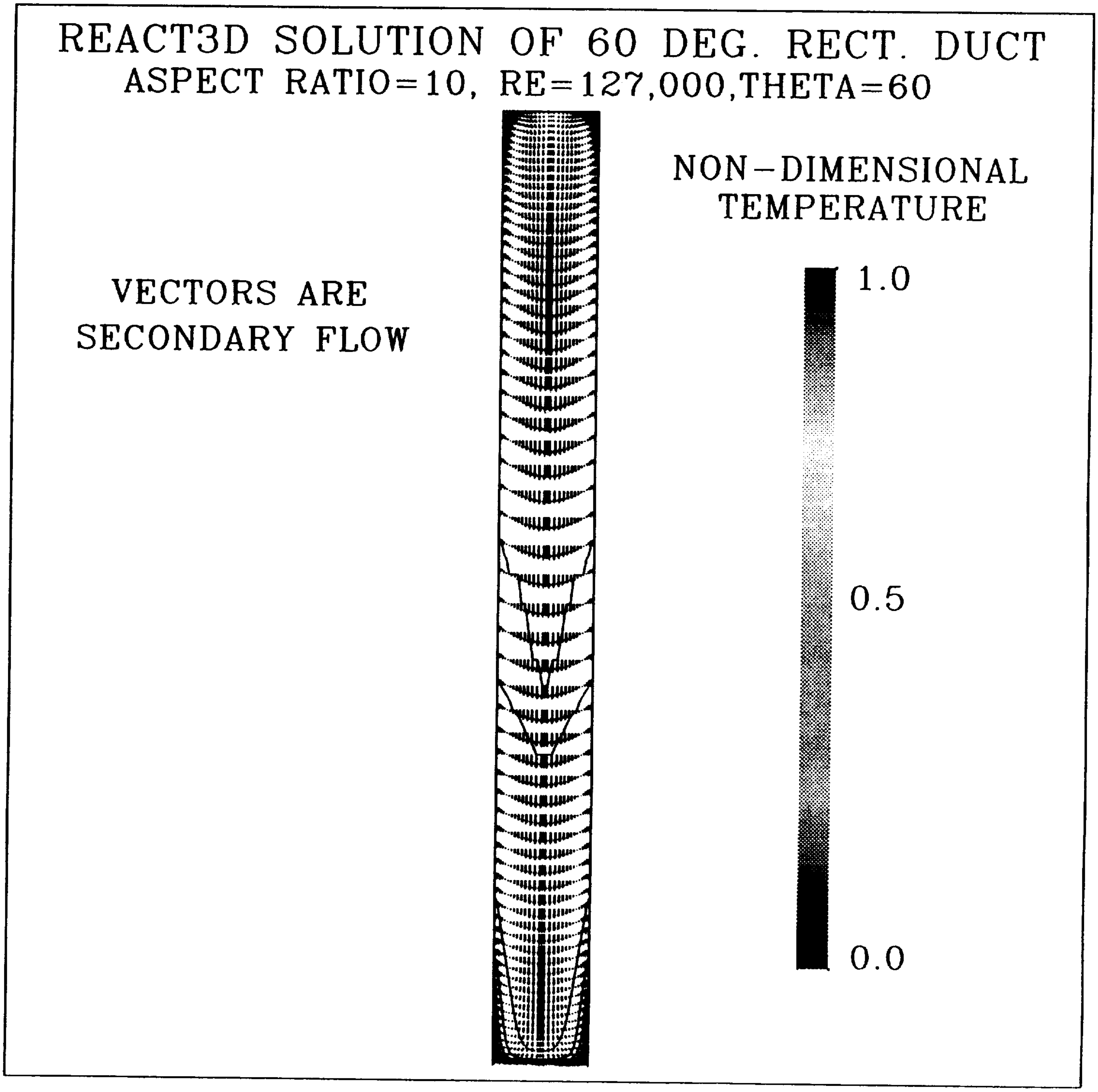


REACT3D SOLUTION OF 60 DEG. RECT. DUCT
ASPECT RATIO=2.5, RE=100,000, THETA=60
VECTORS ARE
SECONDARY FLOW
NON-DIMENSIONAL
TEMPERATURE
1.0
0.5
0.0


REACT3D SOLUTION OF 60 DEG. RECT. DUCT
ASPECT RATIO=10, RE=127,000,THETA=60
NON-DIMENSIONAL TEMPERATURE
VECTORS ARE SECONDARY FLOW
1.0
0.5
0.0

FUTURE PLANS

- COLLECT LDV DATA ON 60° CURVED DUCT FLOWS
- VALIDATE CFD SOLUTIONS TO DATA
- UPGRADE THERMOPHYSICAL PROPERTIES OF FLUIDS
- COLLECT HEAT TRANSFER DATA ON HIGH ASPECT RATIO CHANNELS
- VALIDATE CFD CODE ON HEAT TRANSFER DATA
- PERFORM PARAMETRIC STUDIES FOR COOLANT CHANNEL DESIGNS

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