High Lift Aerodynamics

School of Aeronautics and Astronautics
Purdue University

John Sullivan
Steve Schneider

Graduate Student

- Bryan Campbell

UnderGraduate Students

- Greg Bucci
- Rod Boone (Shaw University)
- Shad Torgerson
- Rick Erausquin
- Chad Knauer

High Lift Aerodynamics

School of Aeronautics and Astronautics

Purdue University

John Sullivan

Steve Schneider

Graduate Student

- Bryan Campbell

UnderGraduate Students

- Greg Bucci
- Rod Boone (Shaw University)
- Shad Torgerson
- Rick Erausquin
- Chad Knauer

- **Sponsored by NASA AMES**
  - Project Monitor - Larry Erickson
  - $30,000

High Lift Aerodynamics

School of Aeronautics and Astronautics

Purdue University

John Sullivan

Steve Schneider

Graduate Student

- Bryan Campbell

UnderGraduate Students

- Greg Bucci
- Rod Boone (Shaw University)
- Shad Torgerson
- Rick Erausquin
- Chad Knauer

Impact of High Lift on Aircraft Performance

- For a 150 Passenger Transport Aircraft
  - A 5% increase in Take-off L/D
    - » 15% increase in Payload , or,
    - » 11% increase in Range
  - A 5% increase in Max. Lift at Landing
    - » 20% increase in Range
    - » 3 Knot Decrease in Approach Speed
- Goal
  - Design of Optimum High Lift Systems with Minimum Complexity

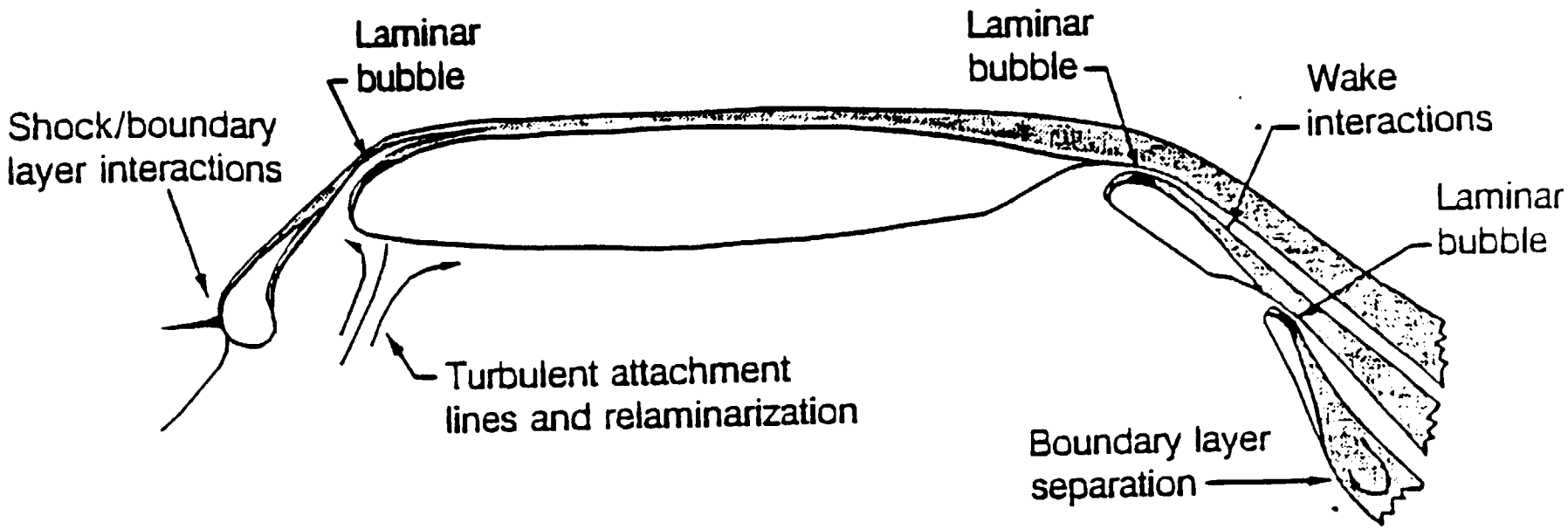


Figure 1. Flow on a Two-Dimensional High Lift Airfoil System

Objective of Current Program

- Experimental Program Aimed at Providing a Physical Picture of the Flow Physics and Quantitative Turbulence Data of the Interaction of a High Reynolds Number Wake with a Flap Element

- Coordinate with Researchers Developing Computational Procedures
  - Stuart Rogers - NASA Ames
  - Kyle Anderson/Russ Rausch - NASA Langley
  - Mark Drela - MIT
- Coordinate with NASA Ames Experiments
  - Joe Marvin/George Meteer

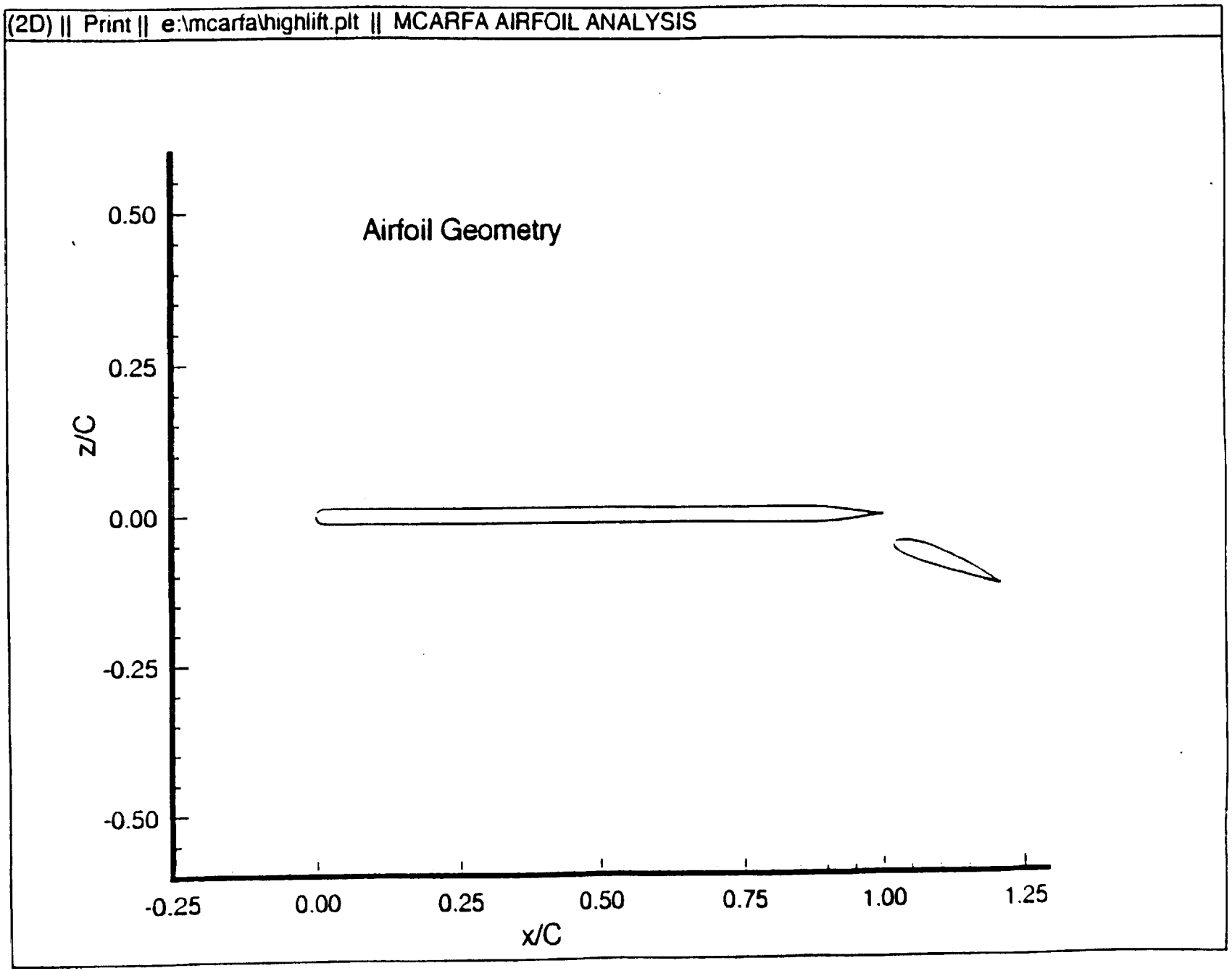


Figure 4. Two-Dimensional Model of Test Configuration

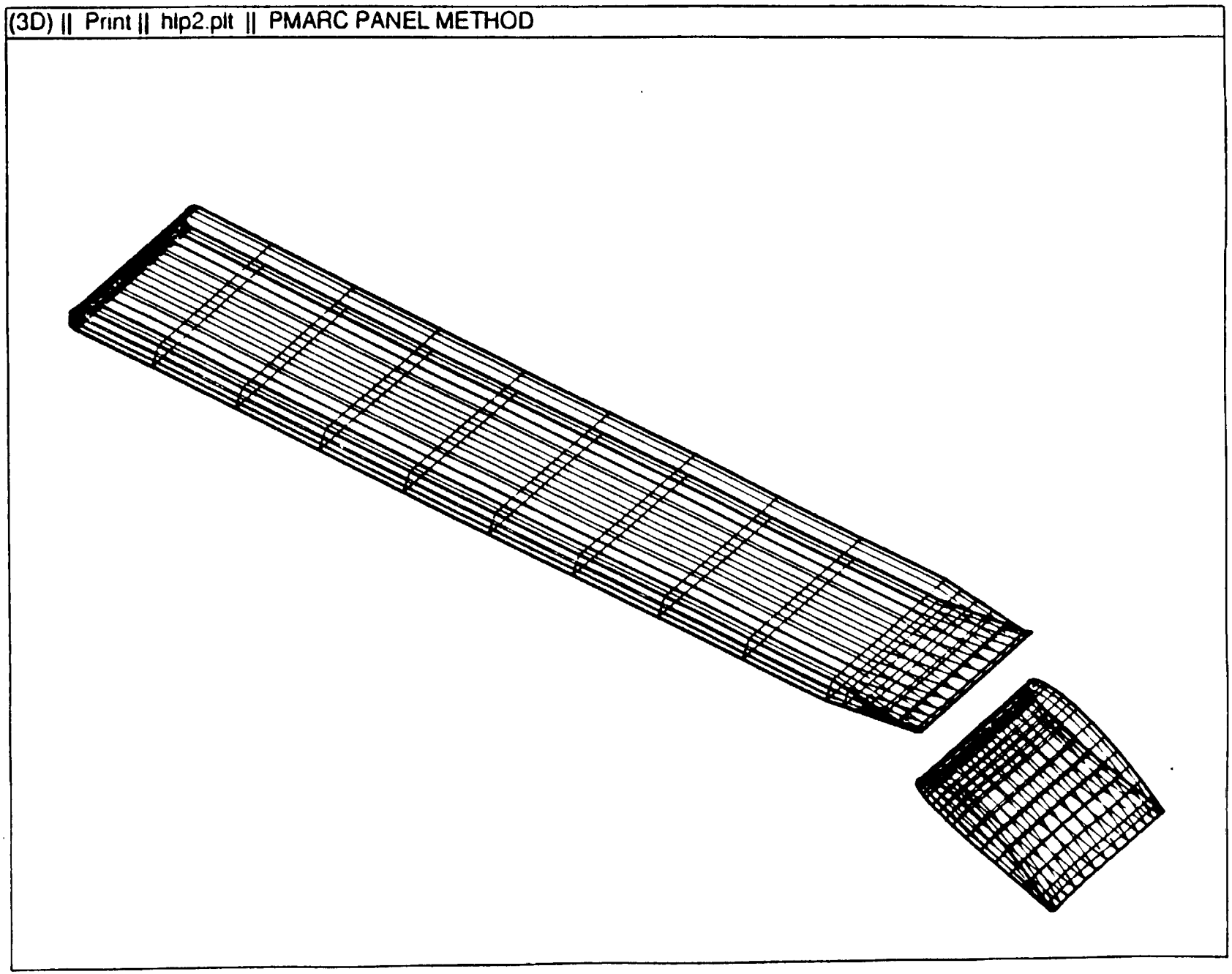


Figure 3. Panel Method Model of the Proposed Test Configuration

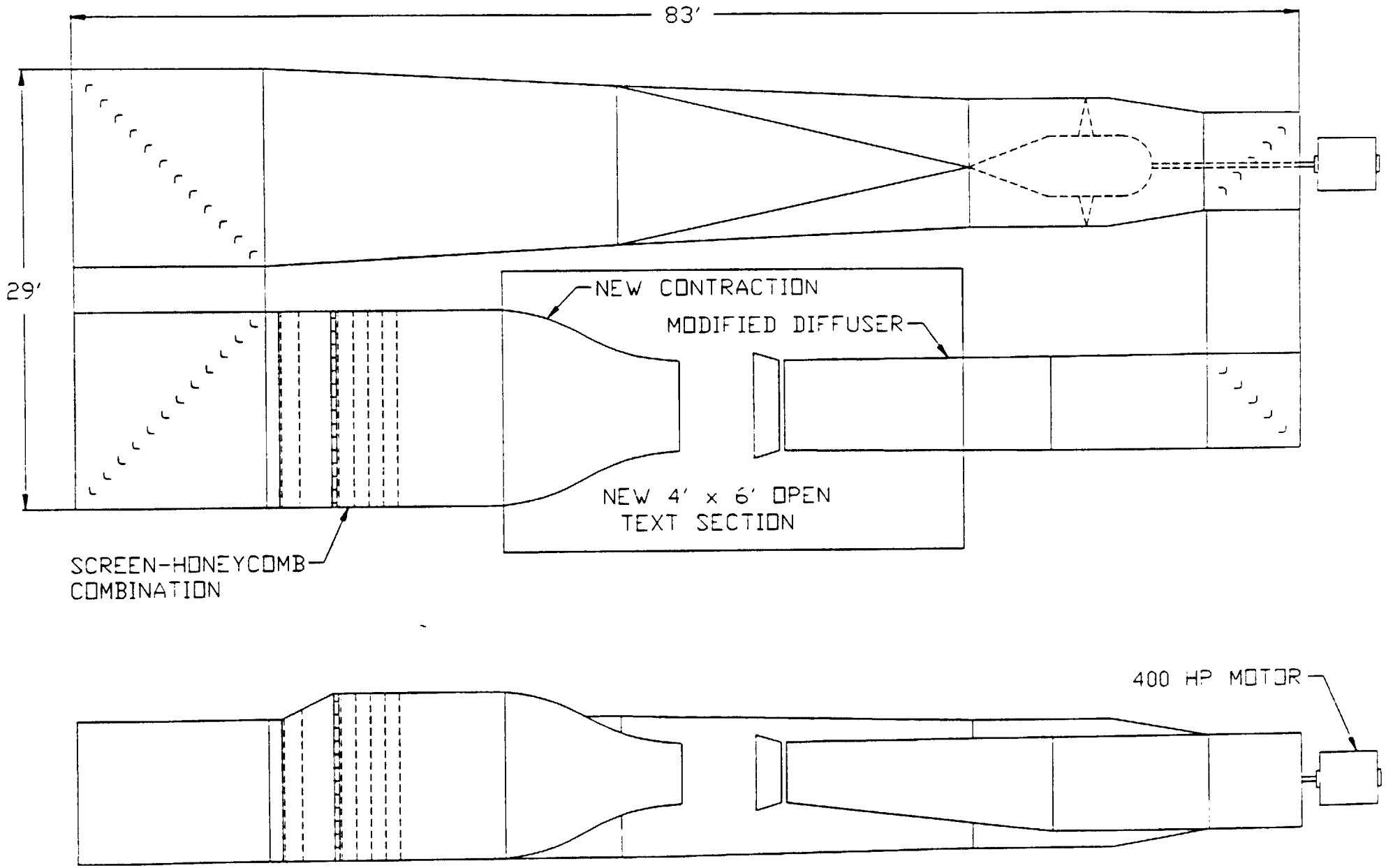
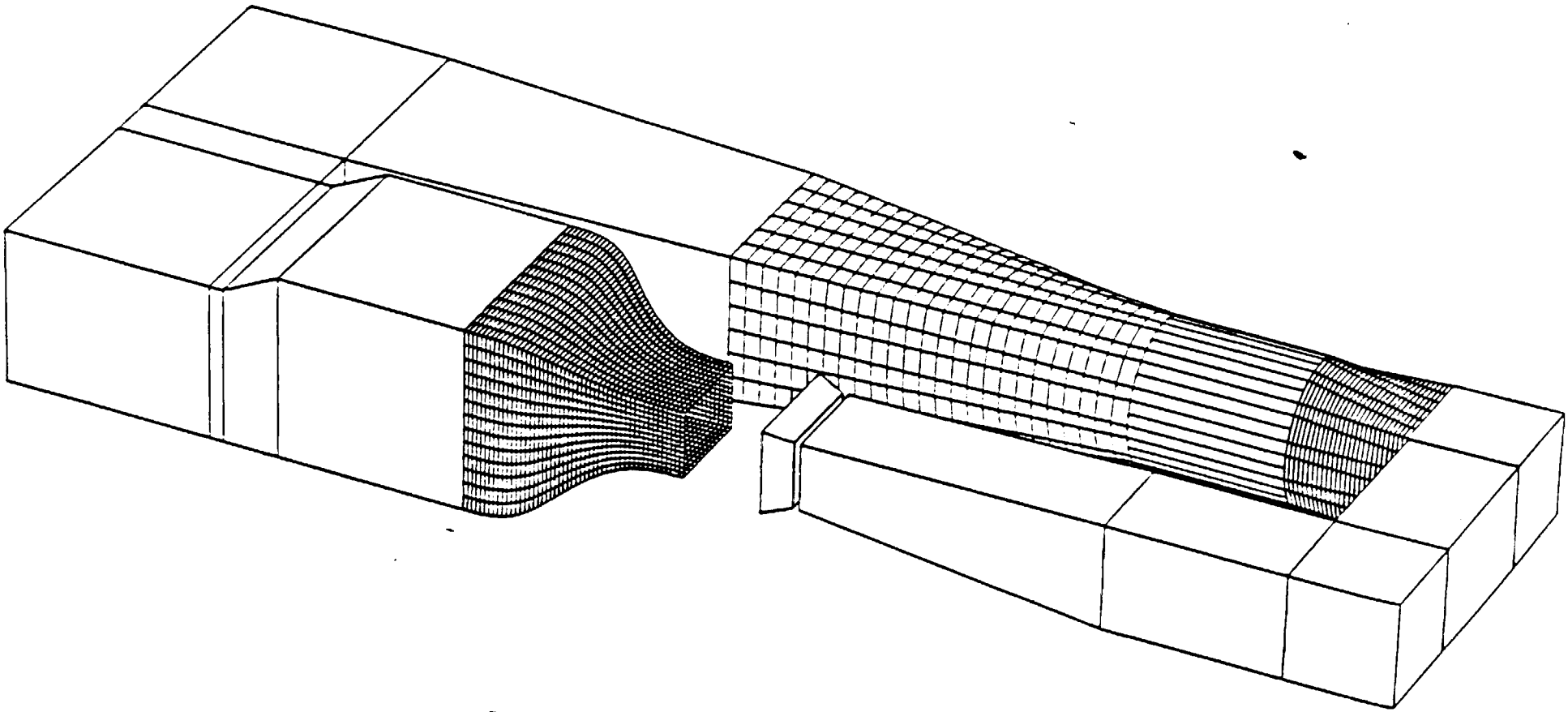


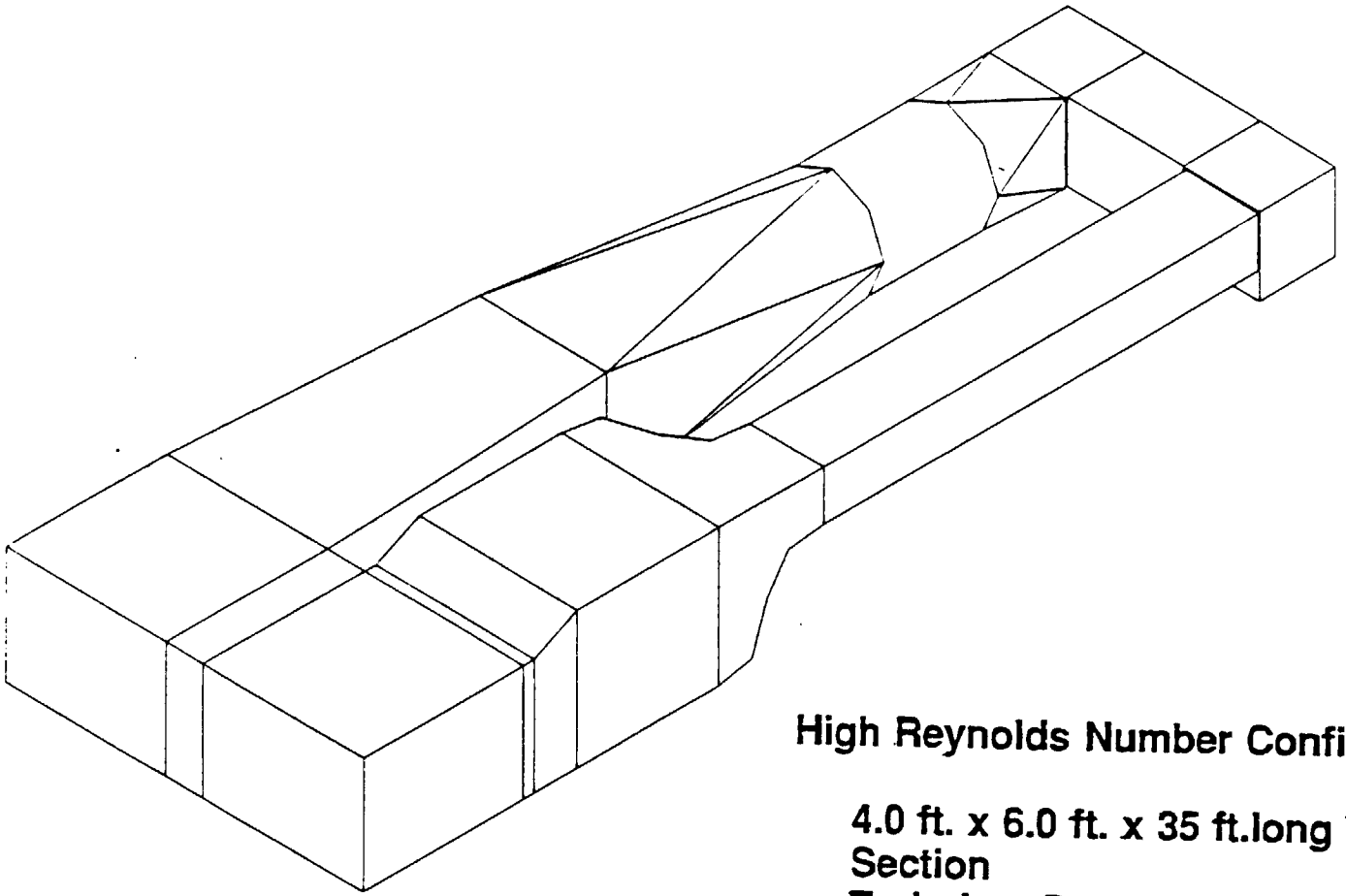
FIGURE #1: BOEING SUBSONIC WIND TUNNEL



Standard Configuration

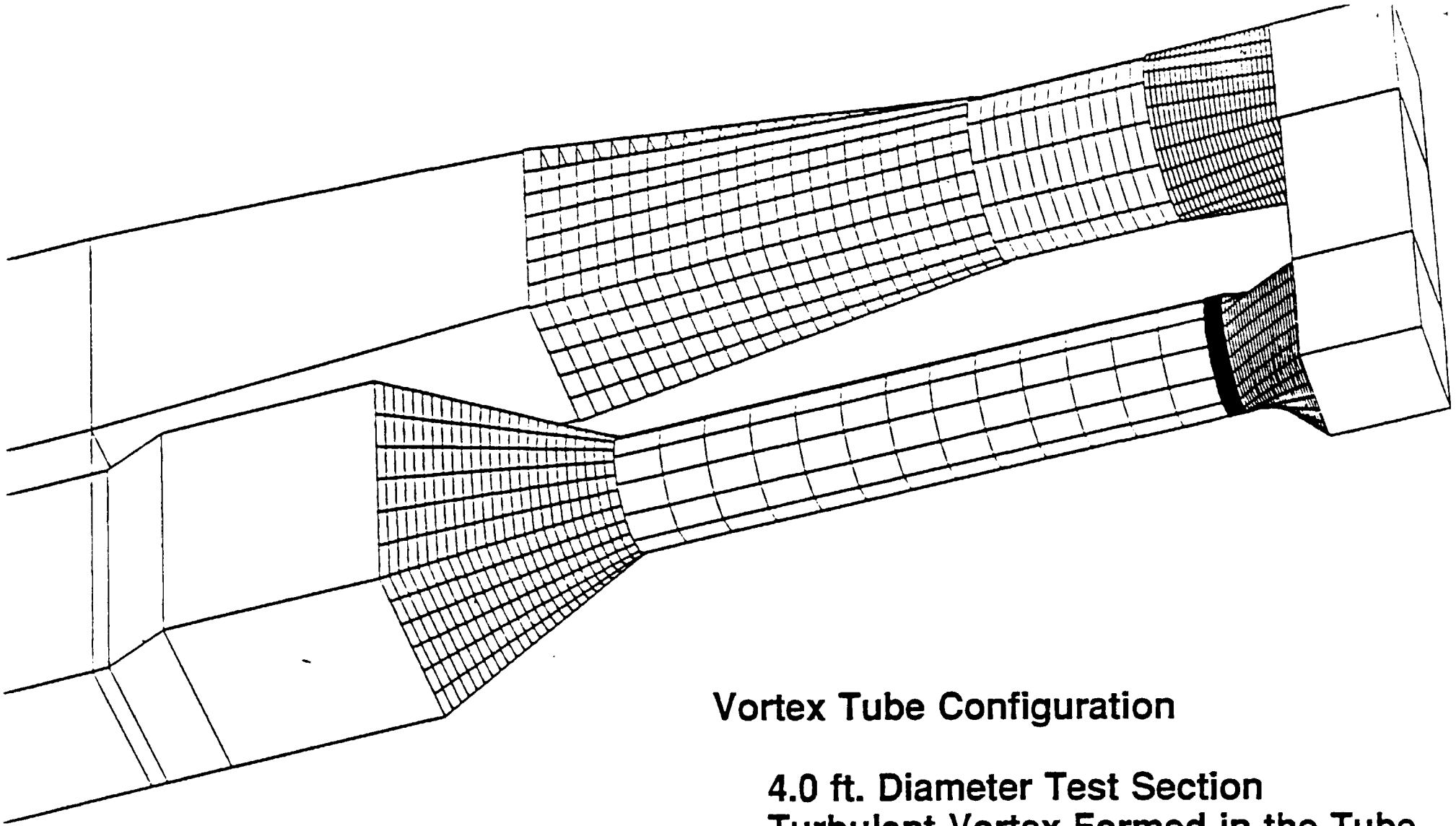
4.0 ft.x 6.0 ft. Test Section
- Open Test Section (as shown)
- Closed Test Section

Velocity - 200 mph.



High Reynolds Number Configuration

4.0 ft. x 6.0 ft. x 35 ft.long Test Section
Turbulent Boundary Layer on Walls
Reynolds Number = 40 million
This is equivalent to the boundary layer on the wing of a medium size commercial aircraft (ie. 737)



Vortex Tube Configuration

4.0 ft. Diameter Test Section
Turbulent Vortex Formed in the Tube
Vortex Reynolds Number =
1.0 million
This is equivalent to the wing tip vortex of a medium size commercial aircraft (ie. Boeing 737)

Instrumentation

- Pitot Probe, 5 Hole Probe
- Hot Wire Anemometry
  - 1, 2, 3 Component
- LDV
  - 1, 2 Component
- PIV
- Flow Visualization
  - Laser Sheet, Strobe Light

Design of the High Lift Experiment

- 2 - D
  - X-Foil
  - MCARFA
- 3 - D
  - PMARC

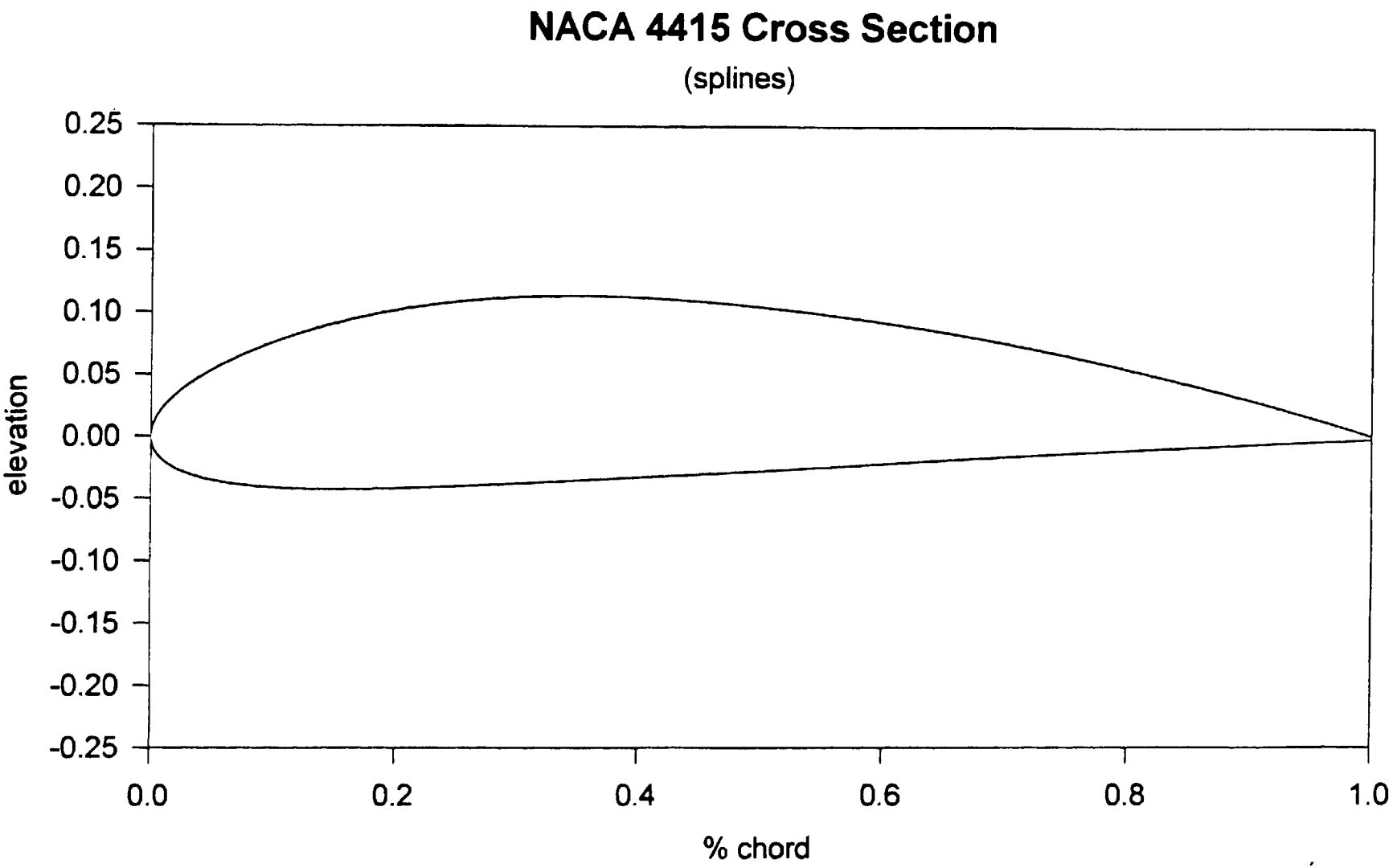
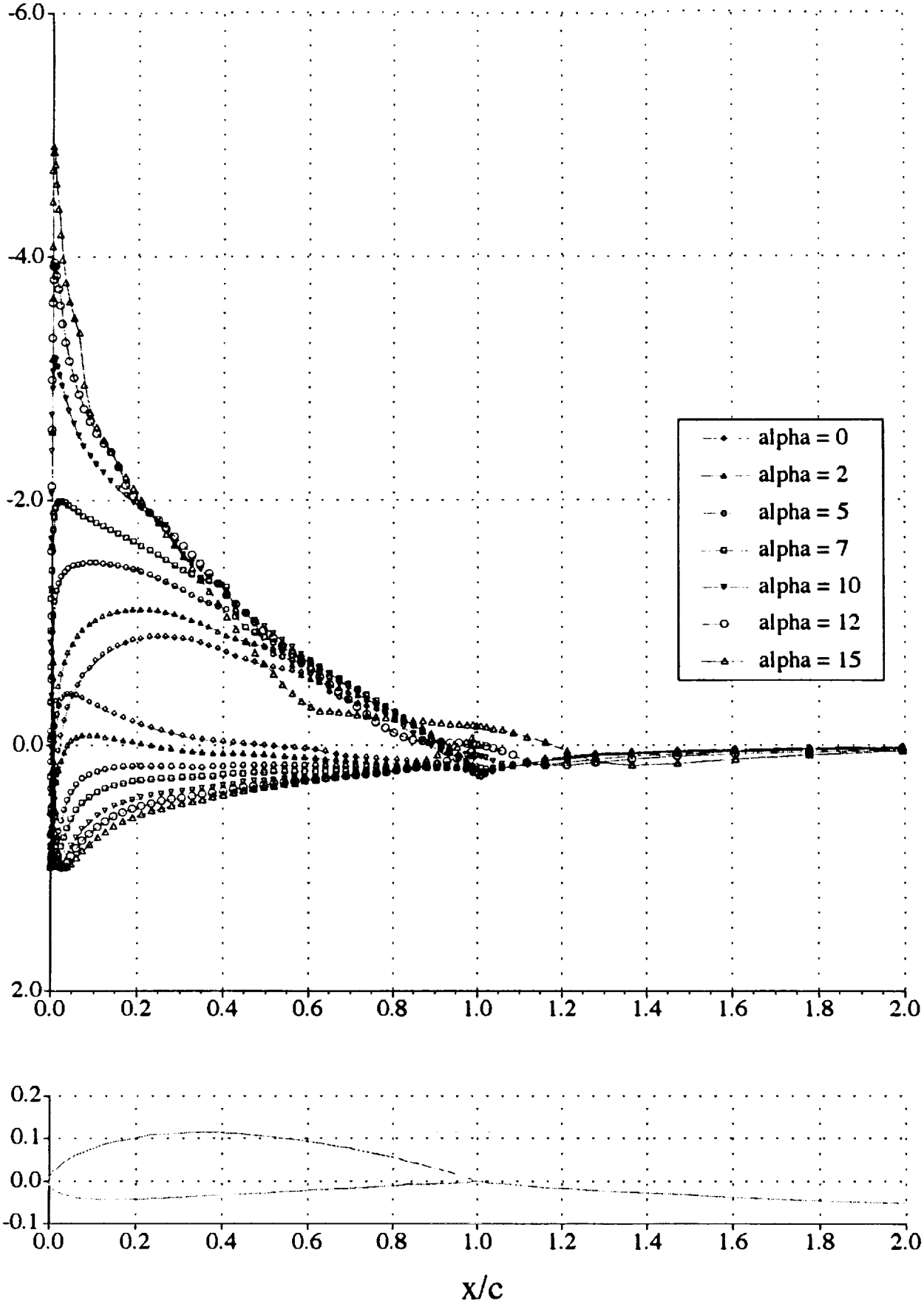

NACA 4415 Cross Section
(splines)
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
elevation
0.0
0.2
0.4
0.6
0.8
1.0
% chord

Figure 2(b): NACA 4415 - XFOIL pressure distributions

Re = 0.5 x 10^6



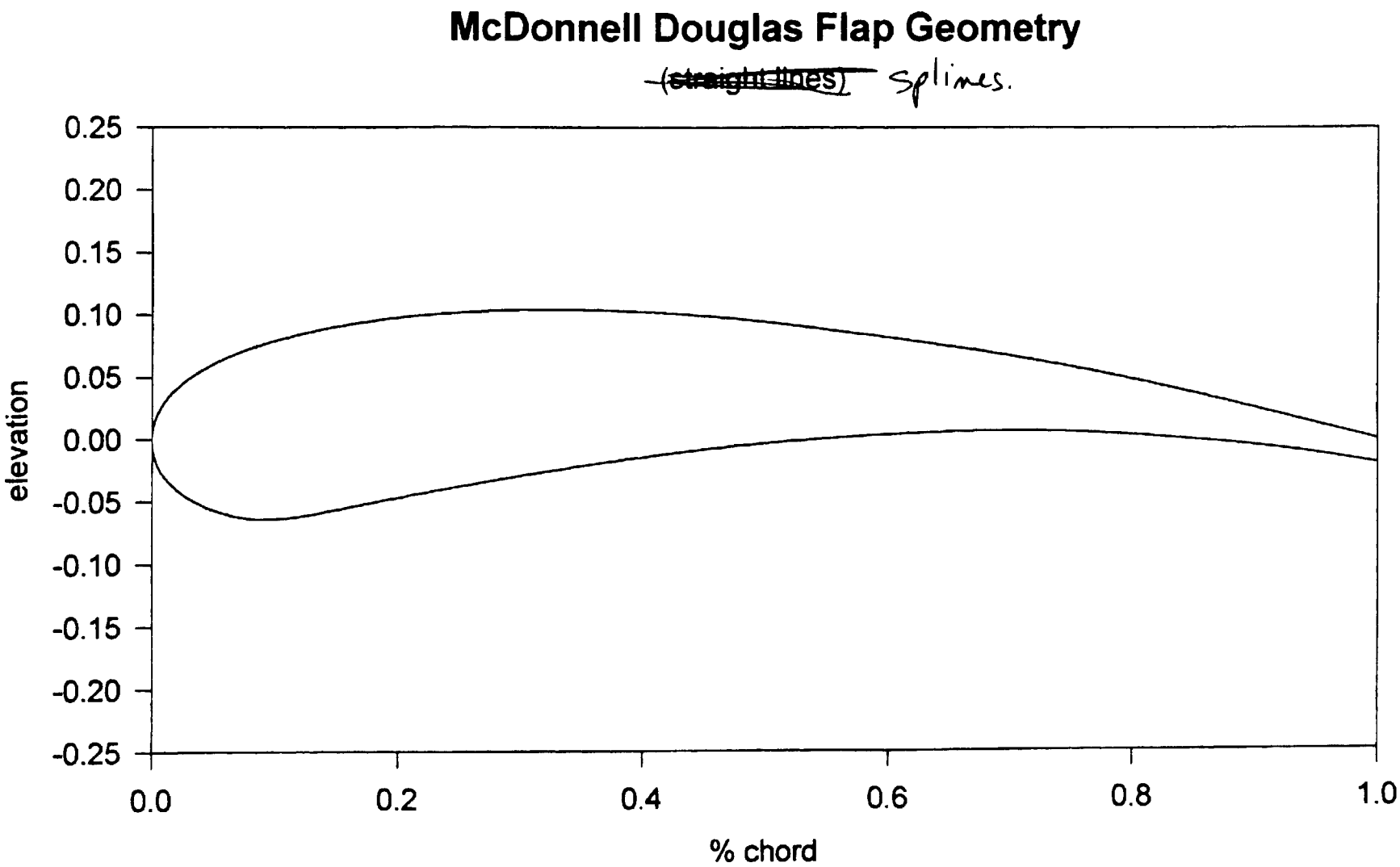
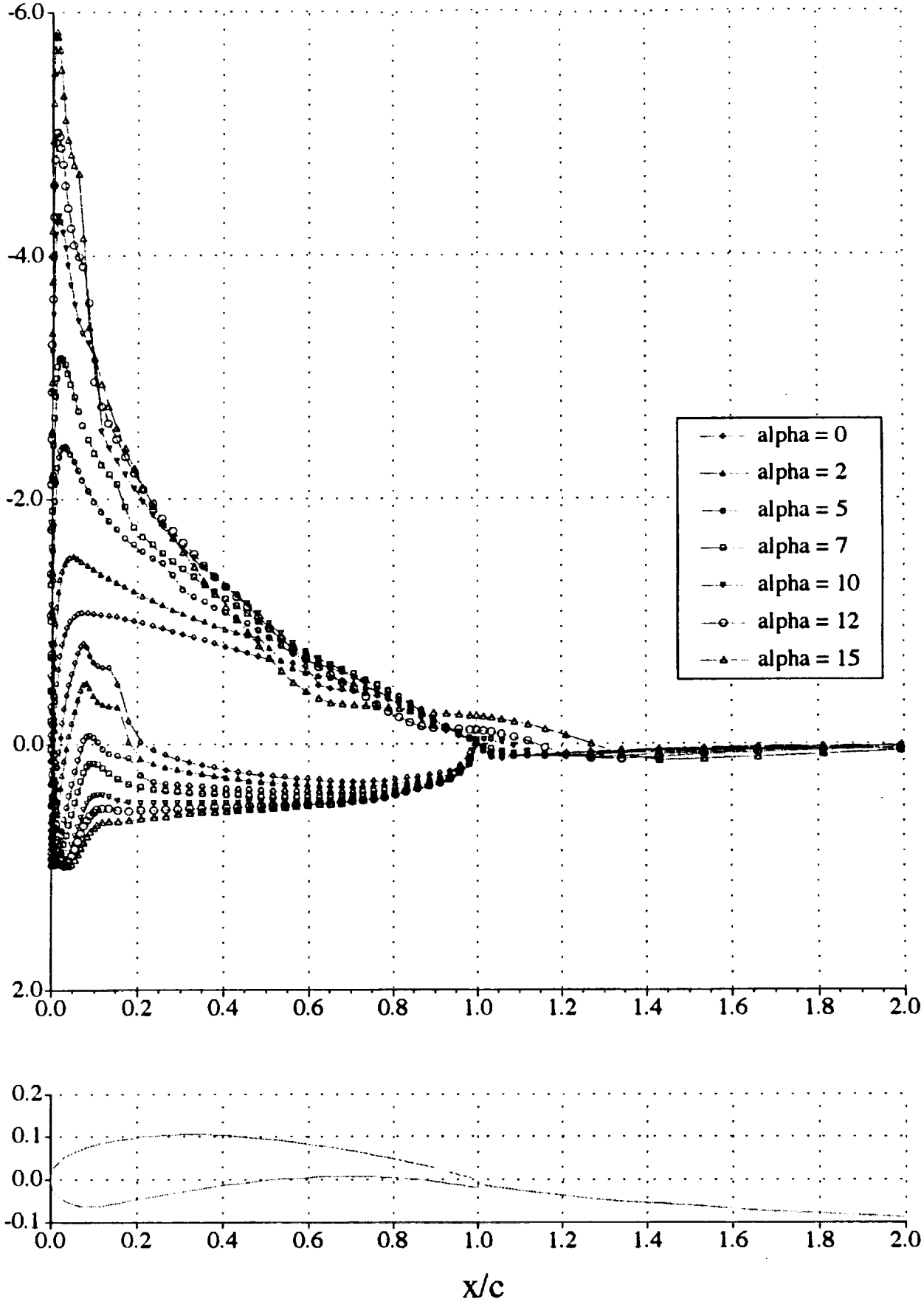
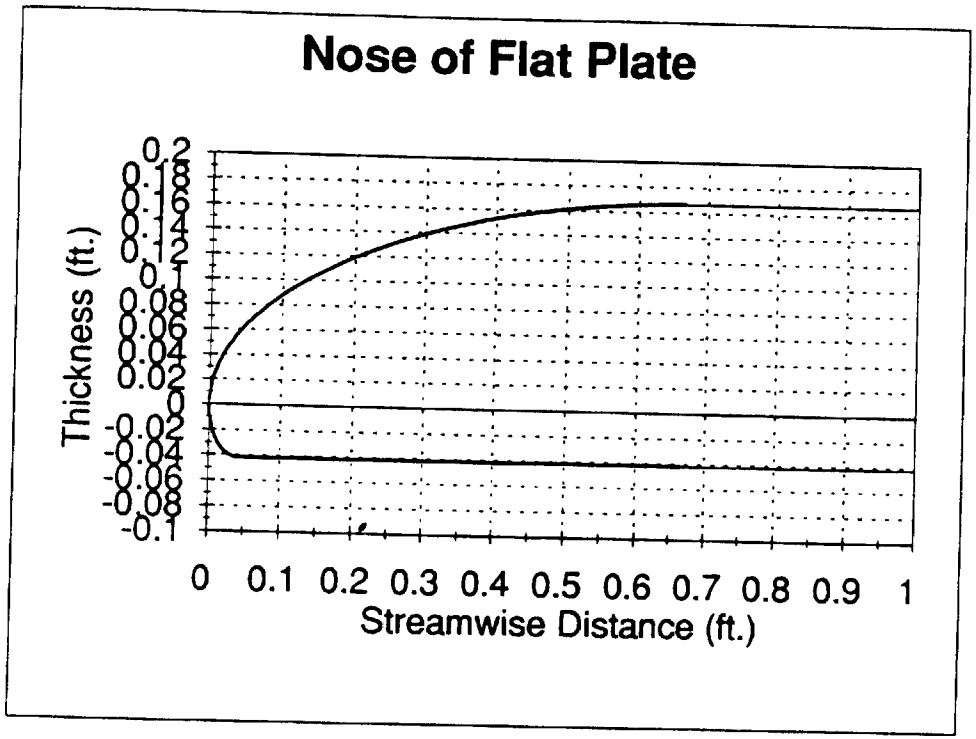

McDonnell Douglas Flap Geometry
~~(straight lines)~~ splines.
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
elevation
0.0
0.2
0.4
0.6
0.8
1.0
% chord

Figure 2(c): MD flap - XFOIL pressure distributions

Re = 0.5 x 10^6




Nose of Flat Plate
Thickness (ft.)
0.2
0.16
0.12
0
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Streamwise Distance (ft.)

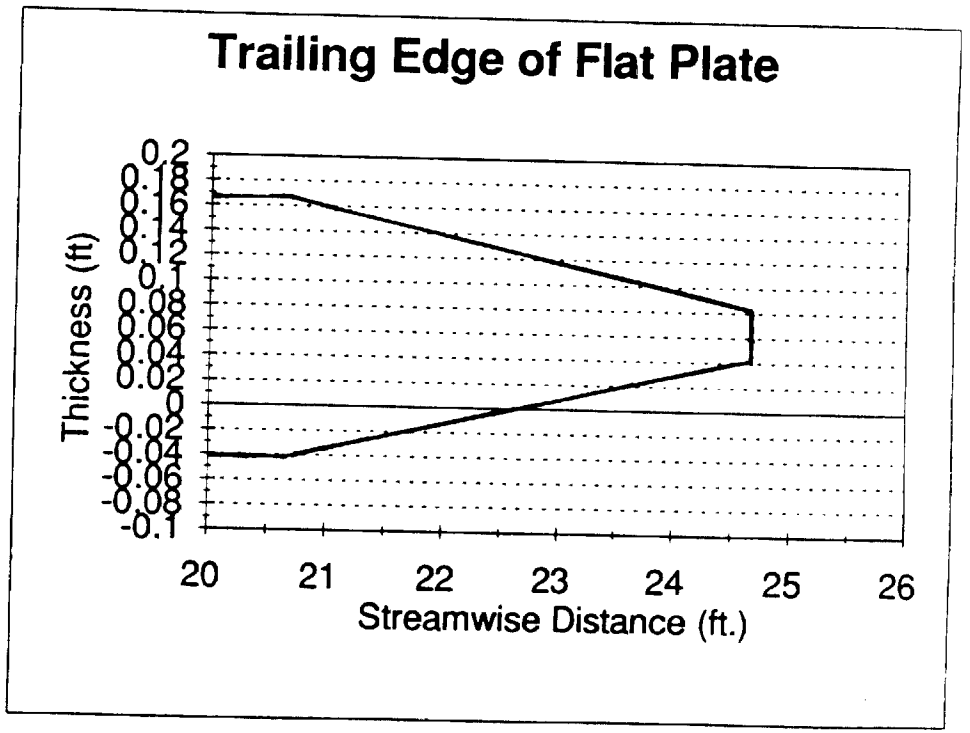

Trailing Edge of Flat Plate
Thickness (ft)
0.2
0.16
0.12
0
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
20 21 22 23 24 25 26
Streamwise Distance (ft.)

Figure 3(b): MCARFA pressure distributions for flat plate w/ NACA 4415 flap

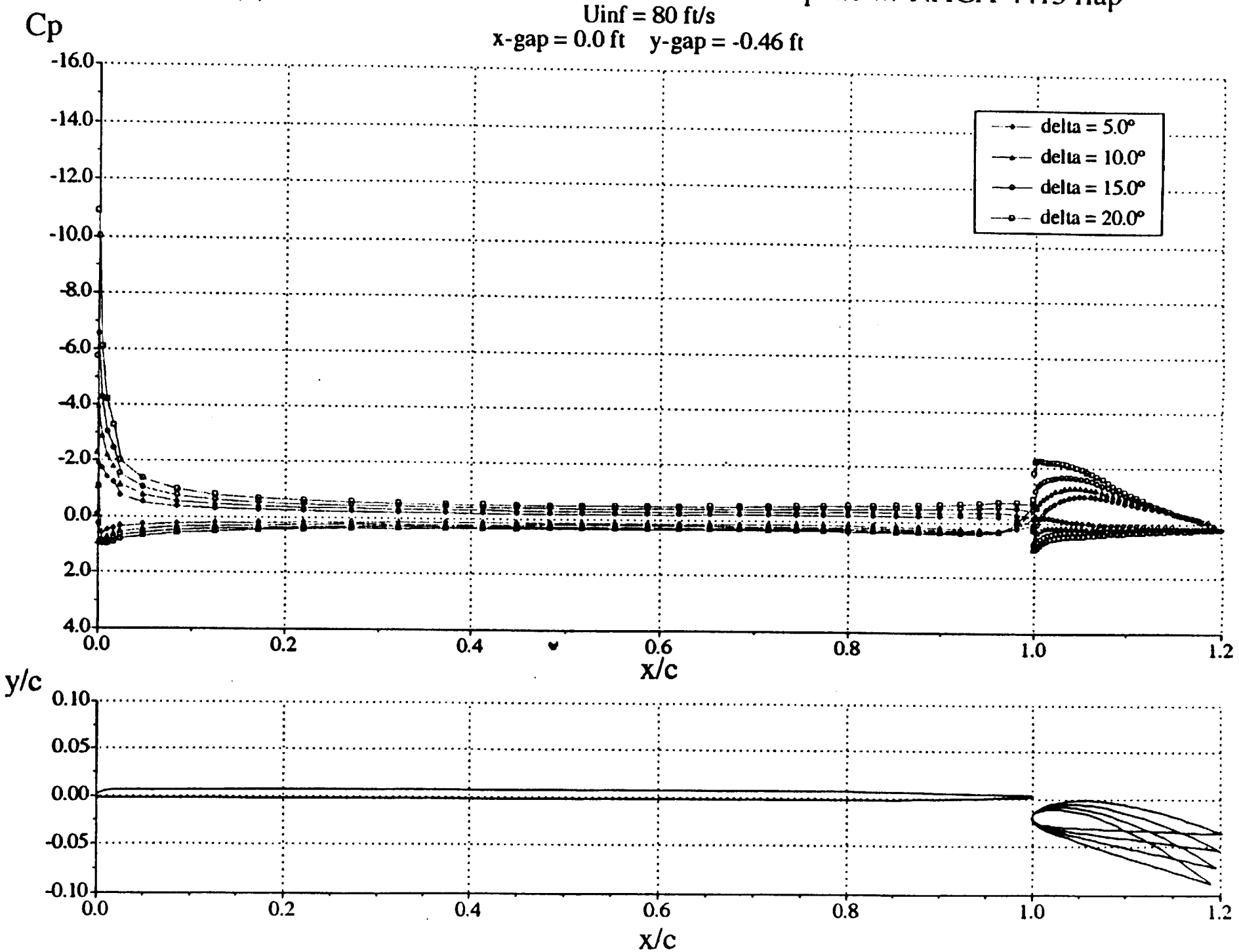


Figure 3(c): MCARFA pressure distributions for flat plate w/ NACA 4415 flap

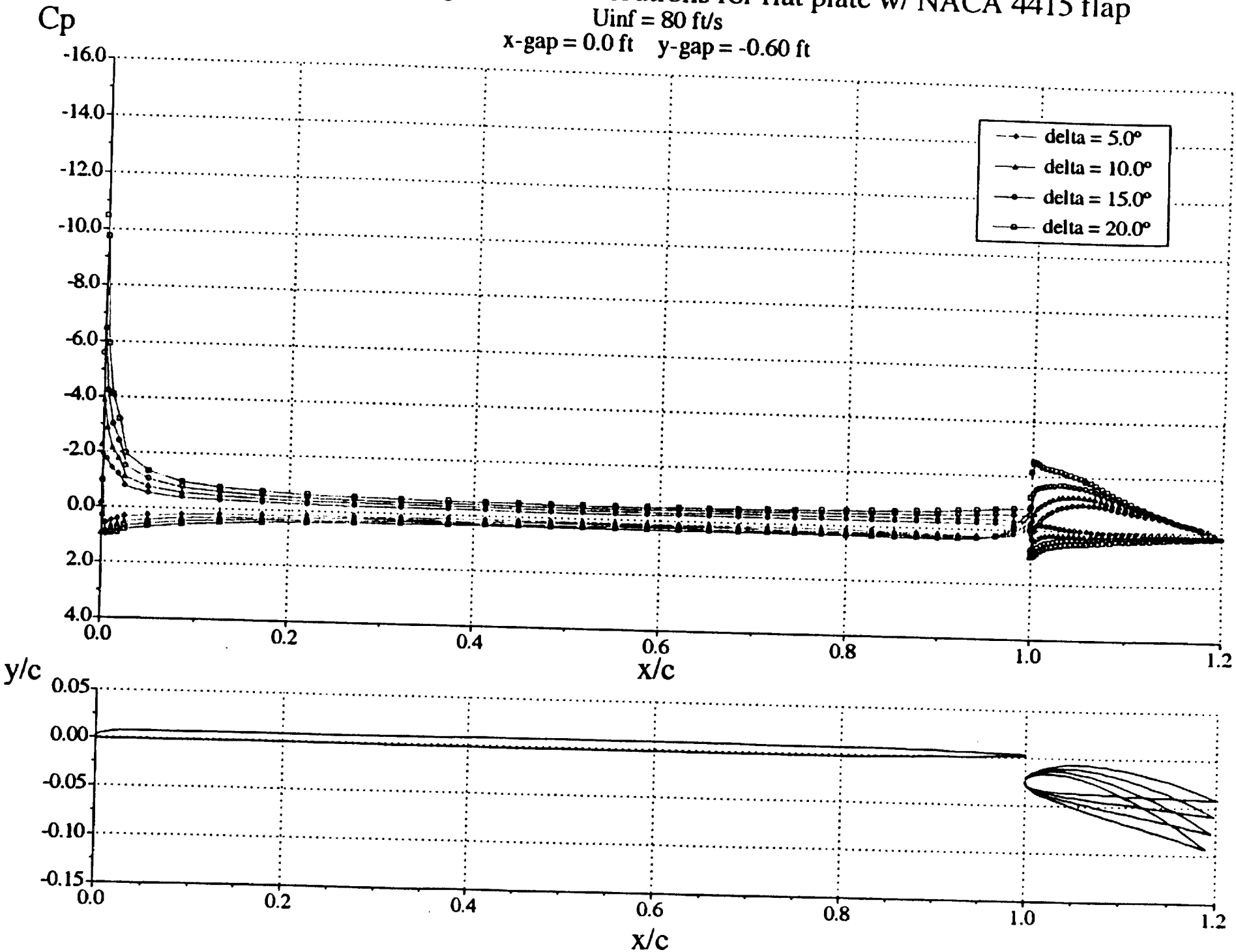


Figure 3(d): MCARFA pressure distributions for flat plate w/ NACA 4415 flap

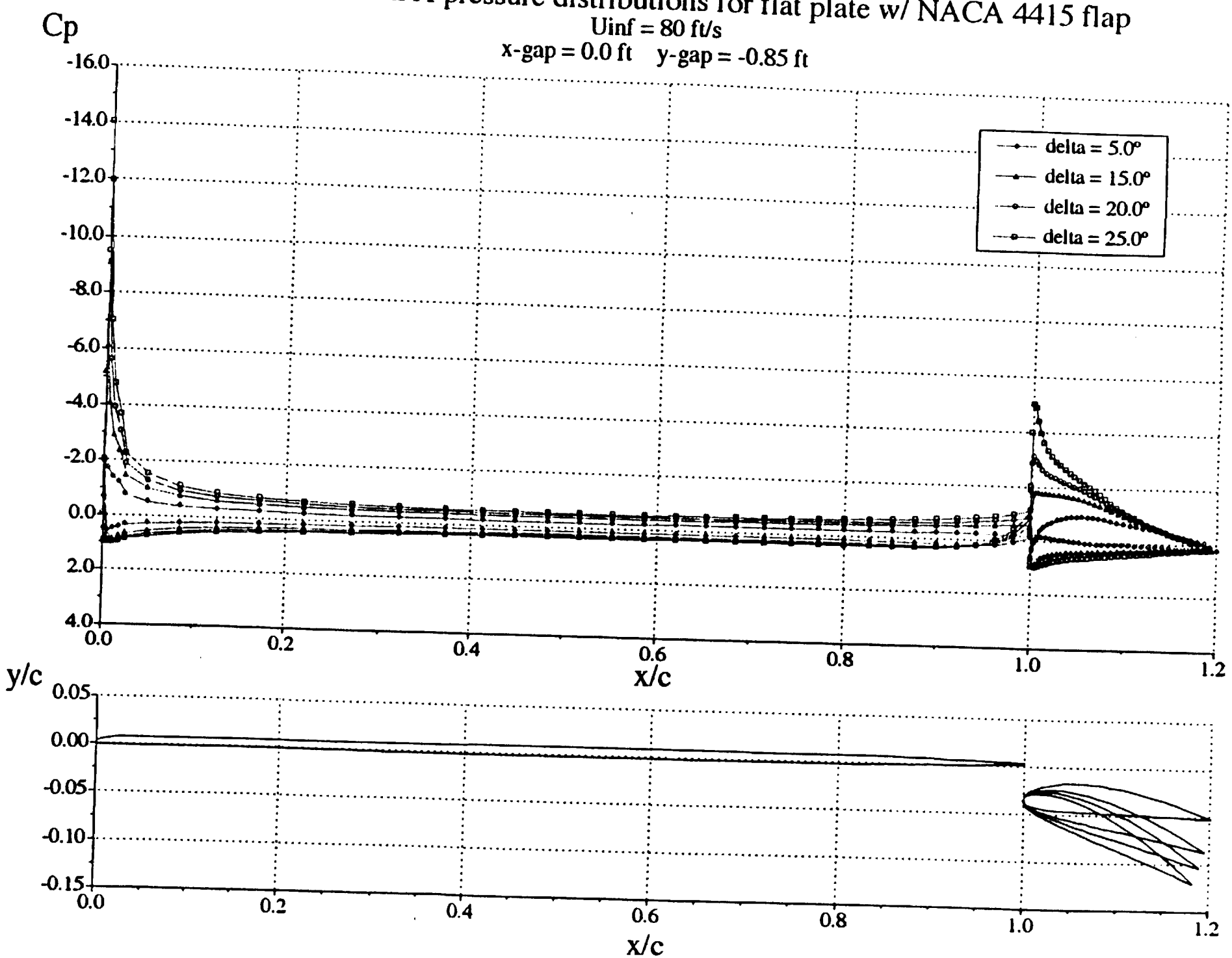


Figure 3(e): MCARFA pressure distributions for flat plate w/ M-D flap

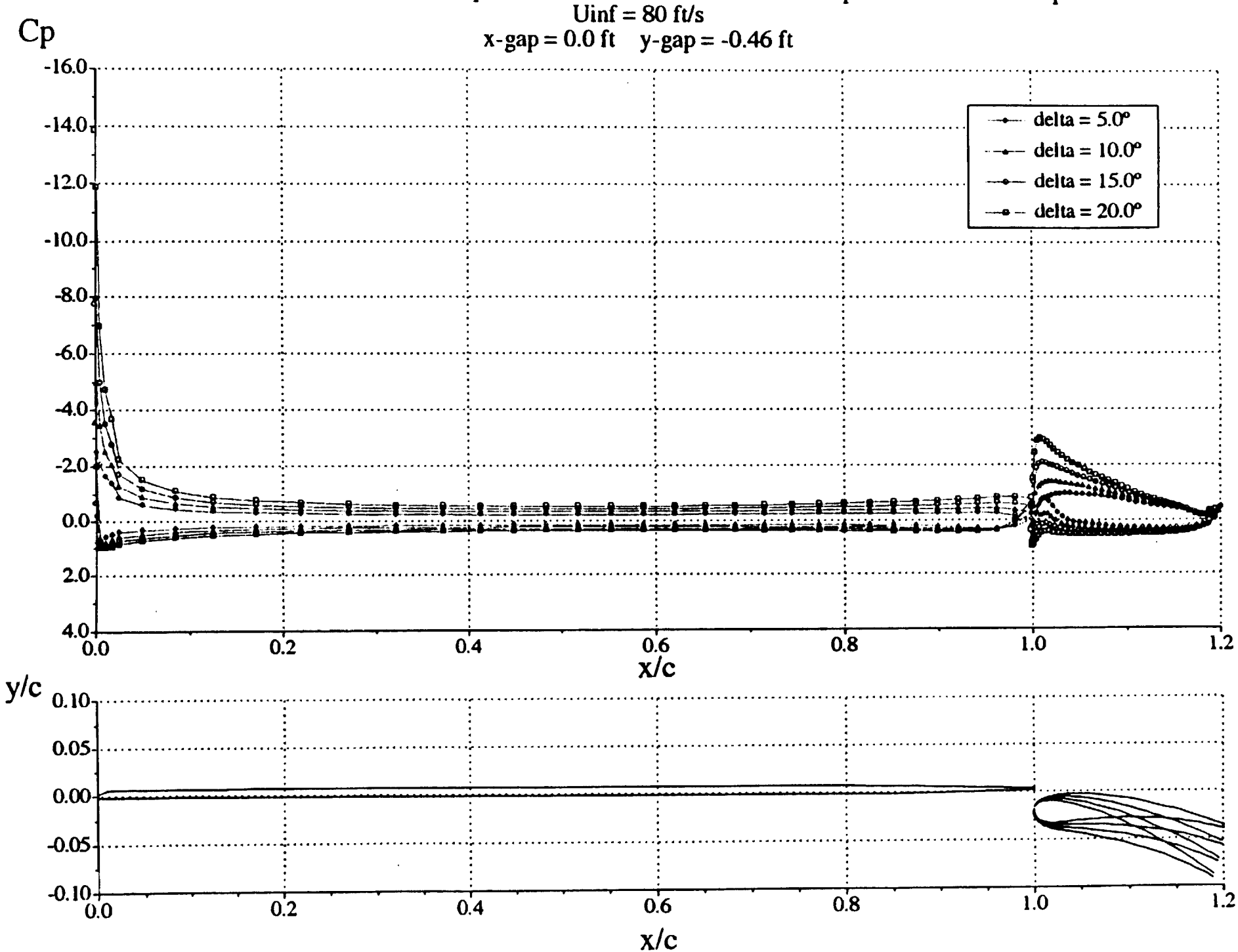


Figure 3(f): MCARFA pressure distributions for flat plate w/ M-D flap

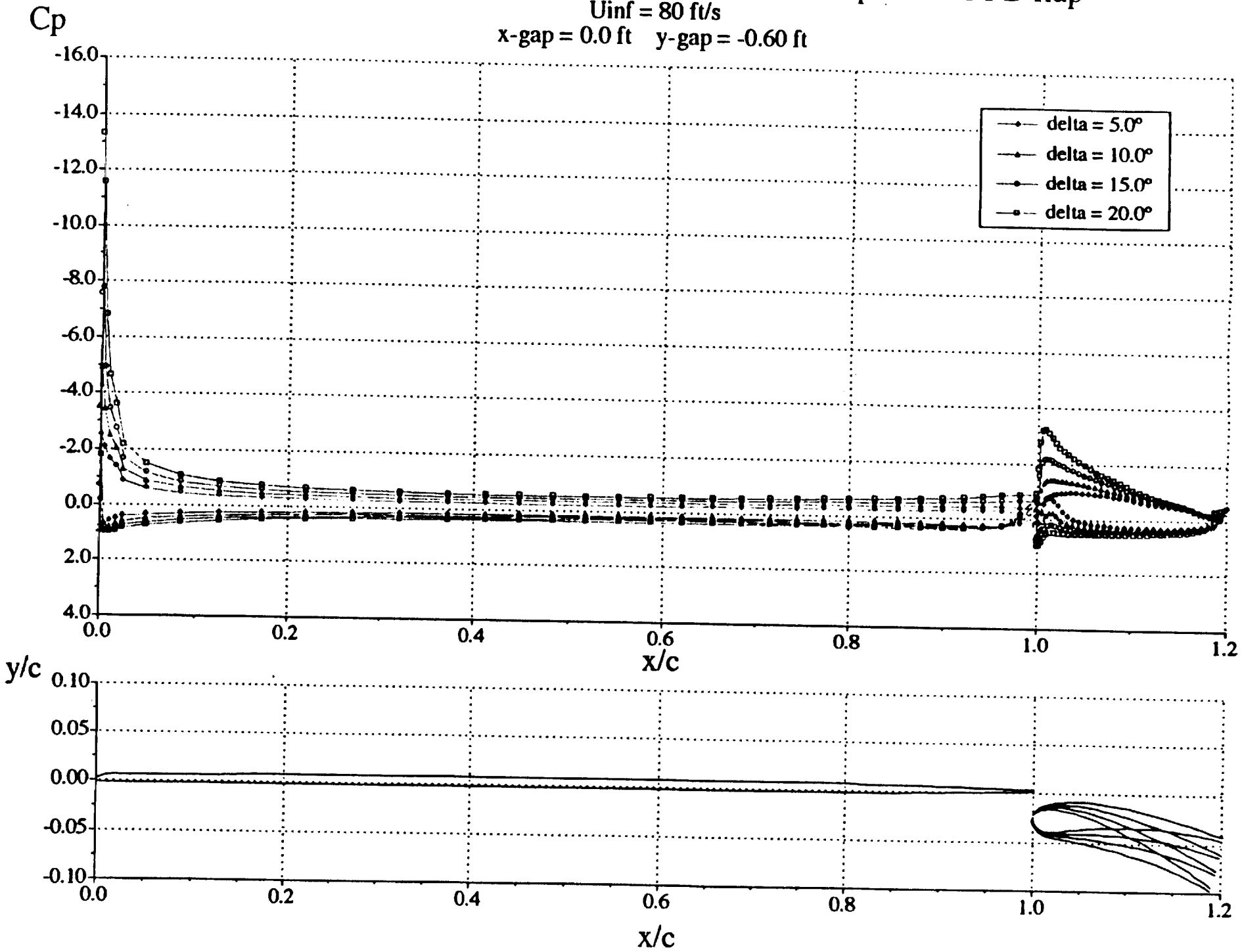
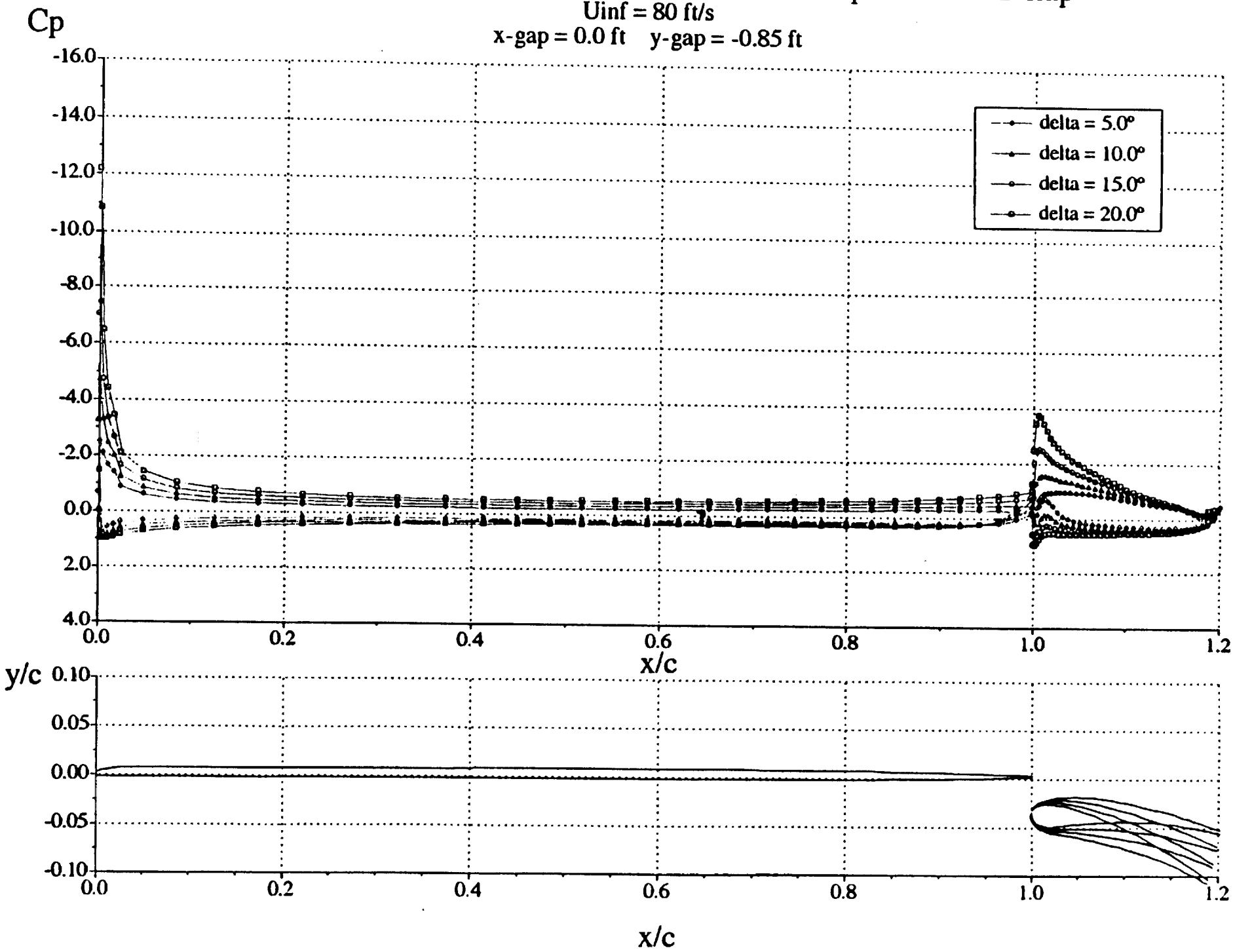


Figure 3(g): MCARFA pressure distributions for flat plate w/ M-D flap



Facilities

- 1/4 Scale (To Investigate 3-D effects)
  - Tunnel Cross-Section (1 ft. x 1.5 ft.)
  - Flat Plate - L= 8 ft.
  - Flap Chord - c= 1.2 ft.
  - Reynolds Number Range (based on L)
    - » Re = .5 to 6.0 Million
- Full Scale
  - Tunnel Cross-Section (4 ft. x 6 ft.)
  - Flat Plate - L = 24 ft.
  - Flap Chord - c = 5 ft.
  - Reynolds Number Range(based on L)
    - » Re = 2.0 to 45.0 Million

1/4 Scale Facility Results

- Pitot Probe Surveys
- PIV

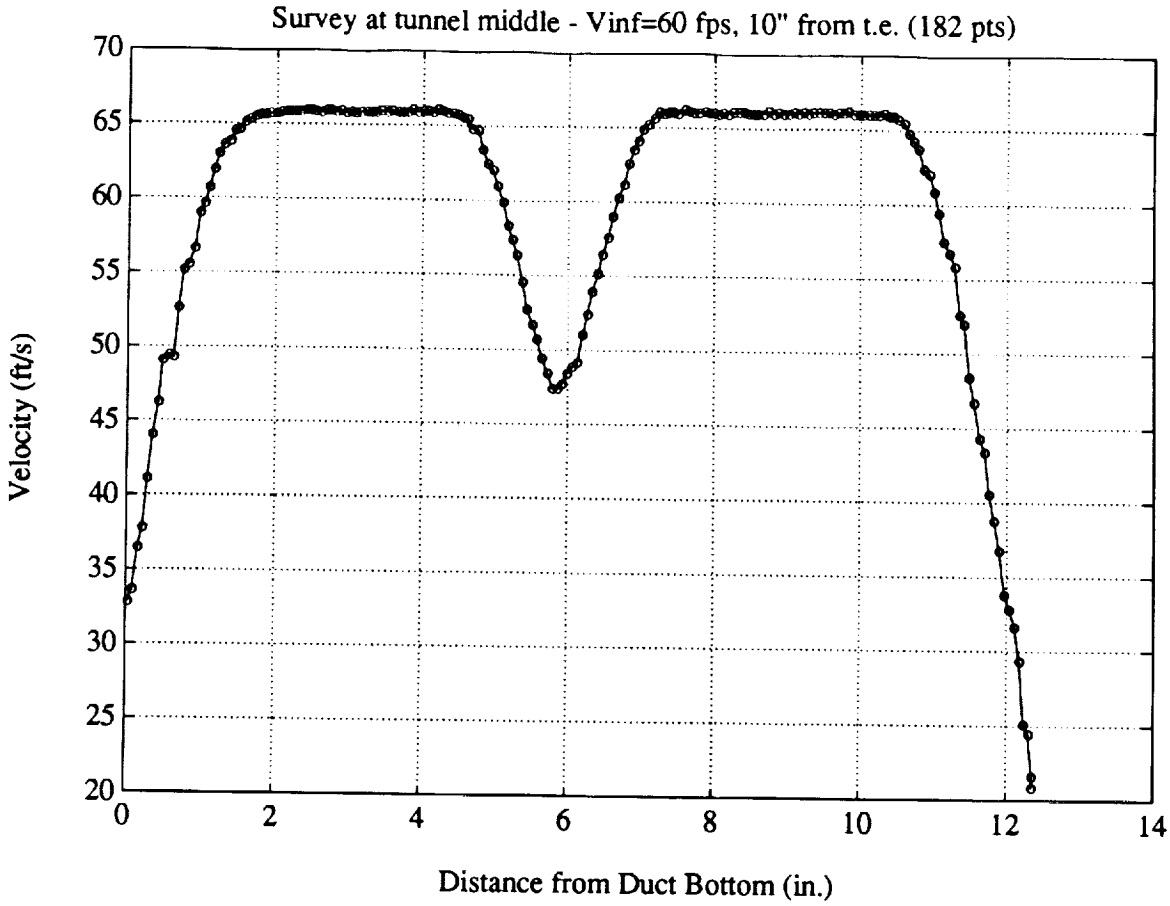


Fig. 4: Wake Survey (No Flap)

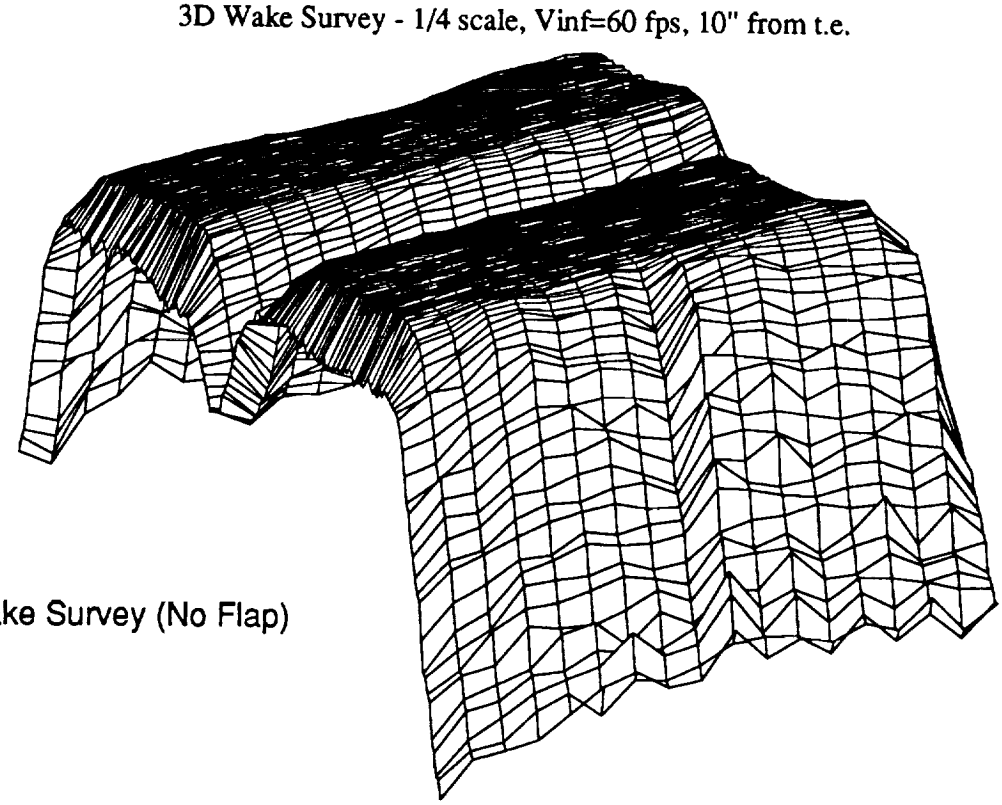
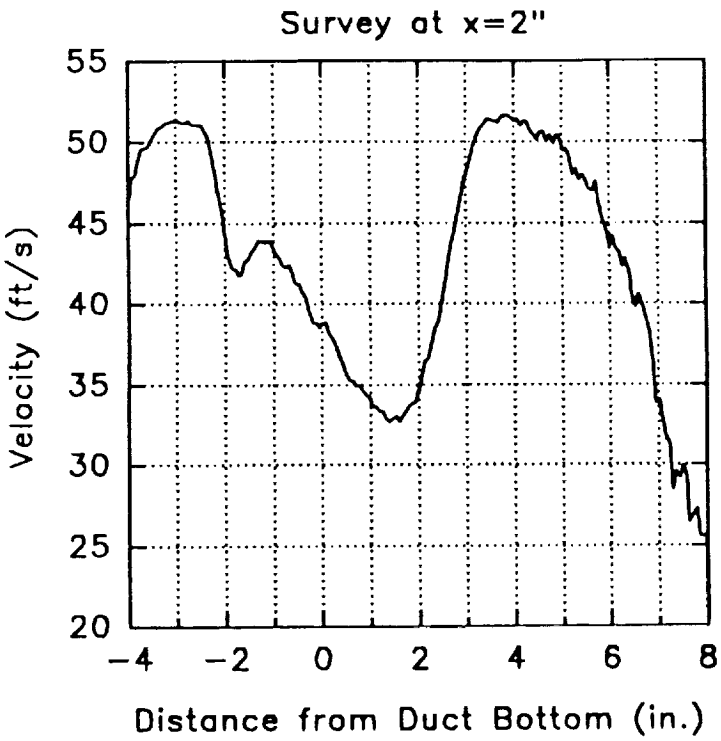
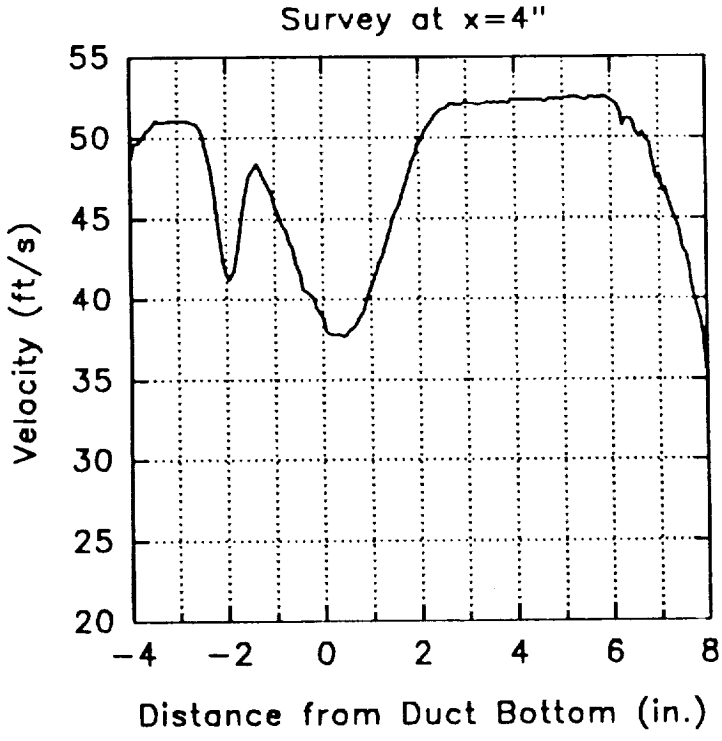


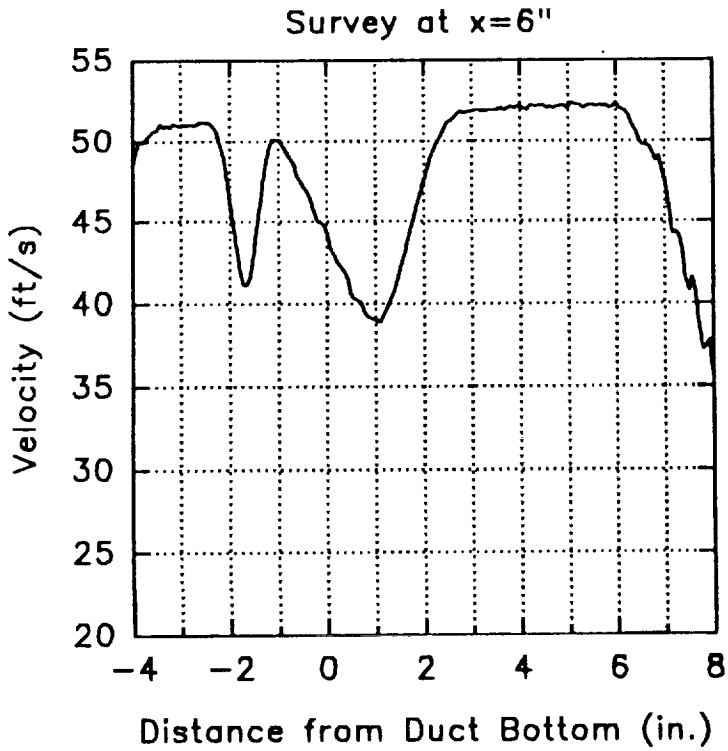
Fig. 5: Wake Survey (No Flap)

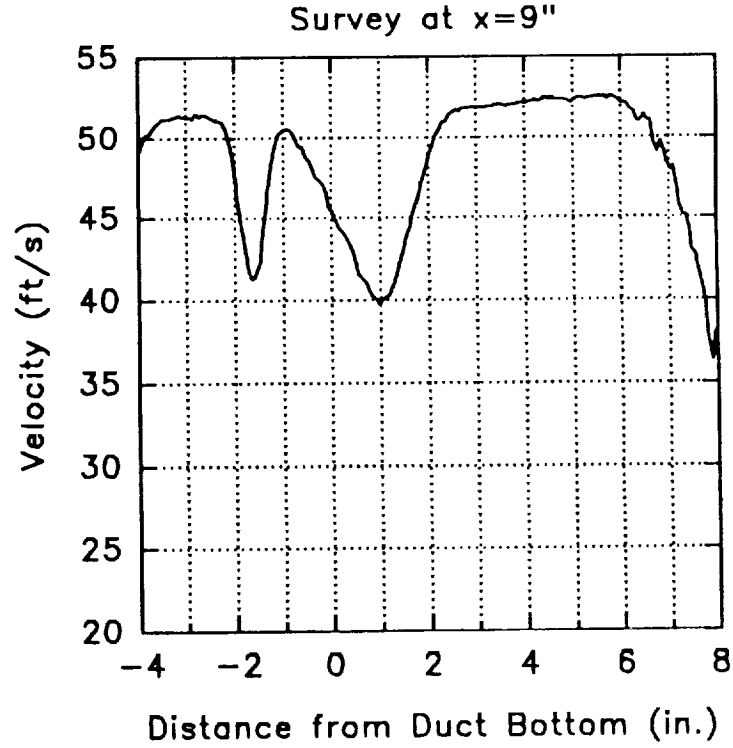
Wake Survey with Flap Deflected 25 deg (10/26/93)

(probe aligned with freestream dirsction)



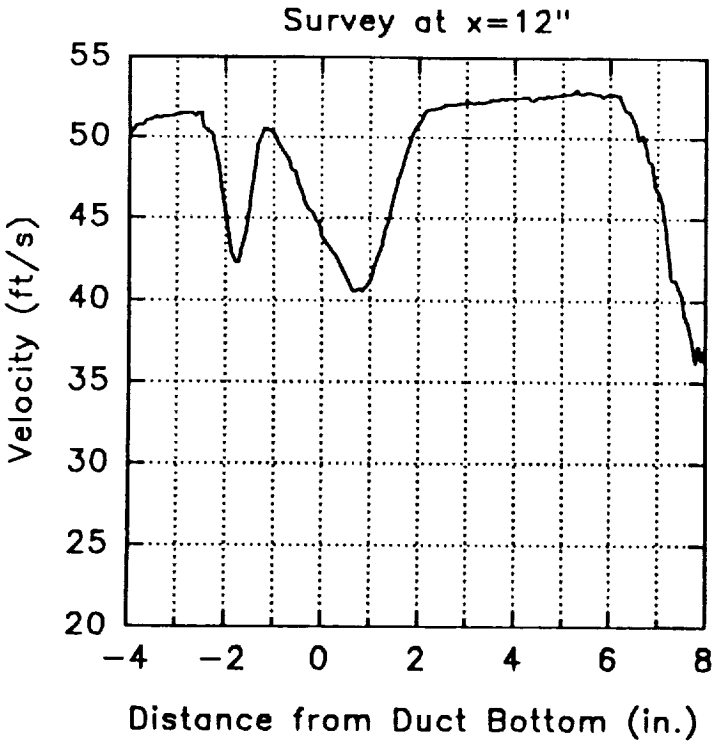


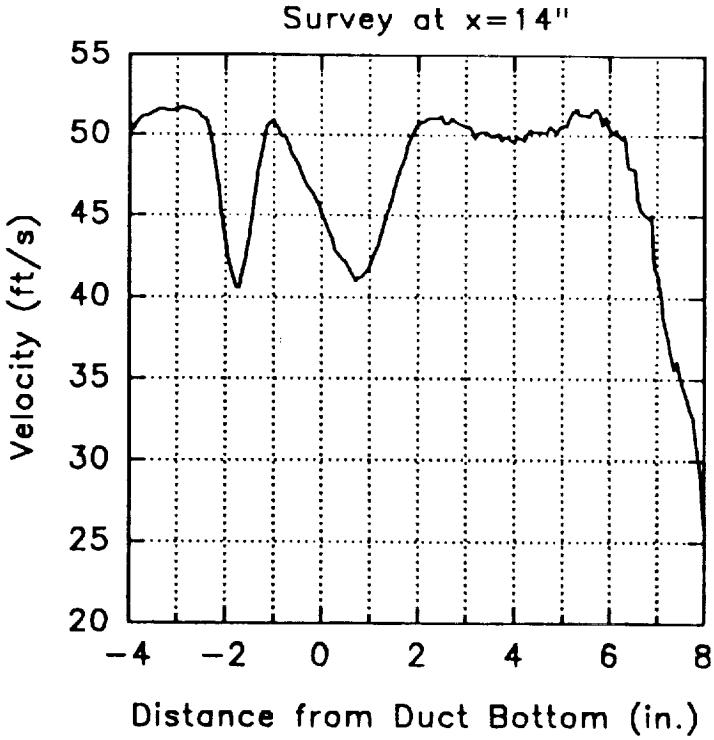


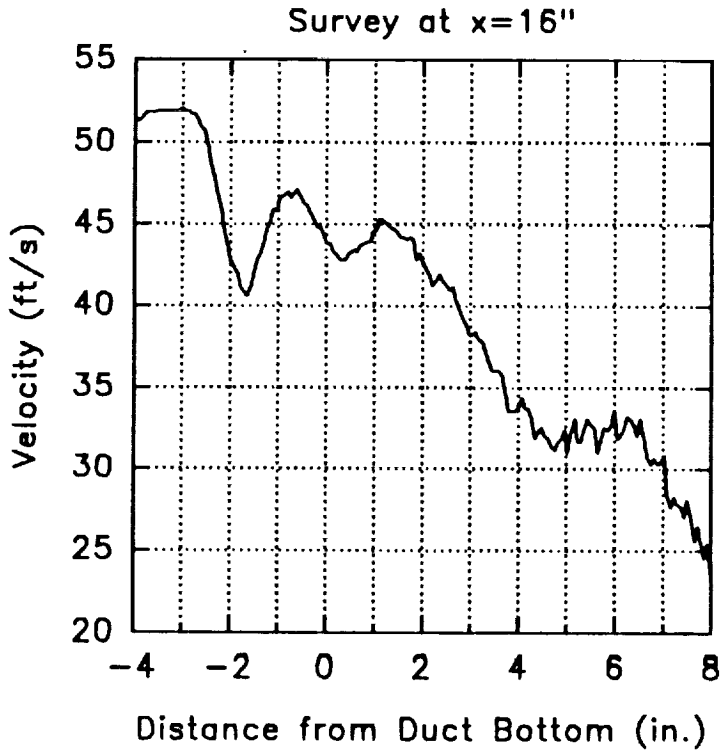


Wake Survey with Flap Deflected 25 deg (10/26/93)

(probe aligned with freestream dirsction)







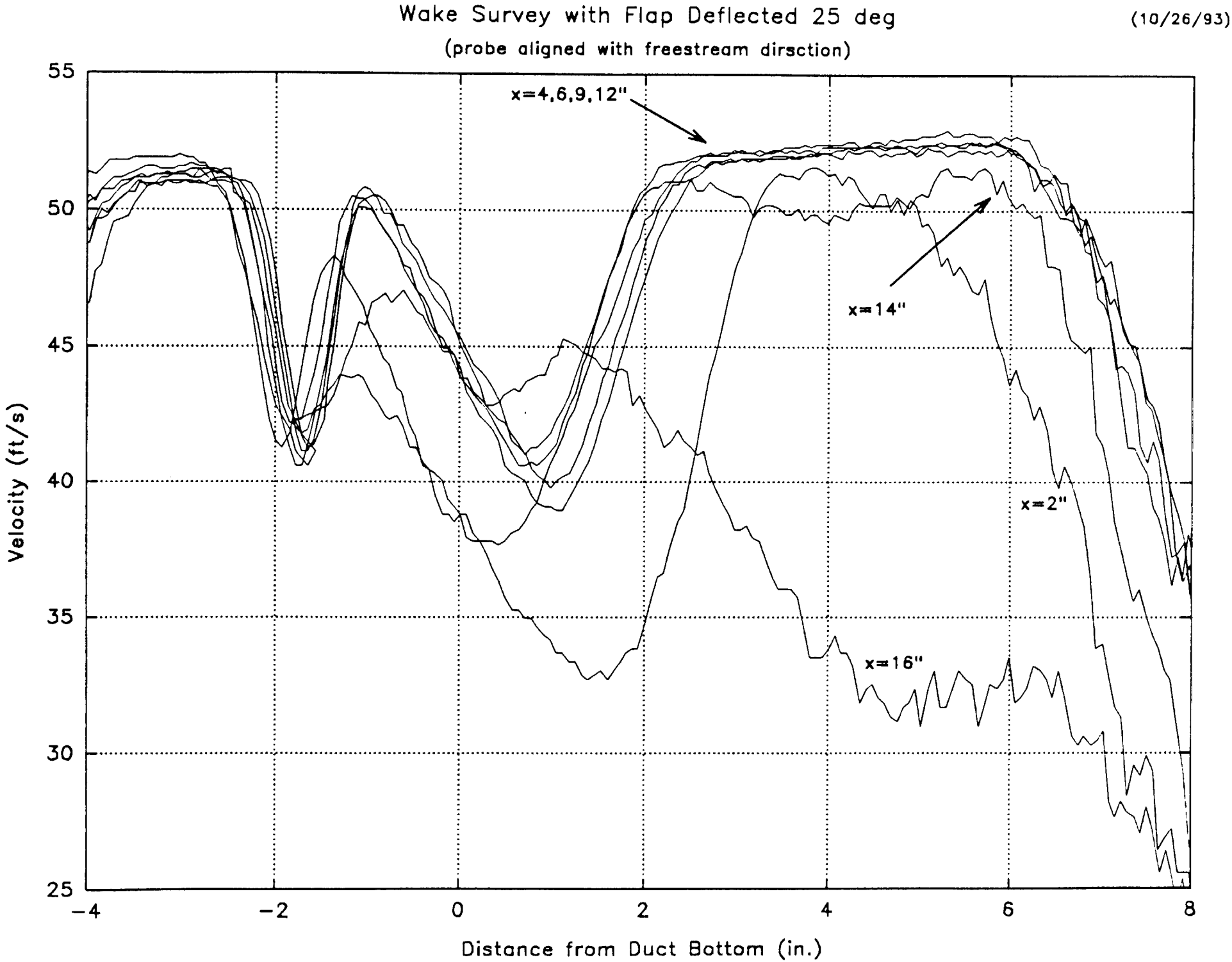

Wake Survey with Flap Deflected 25 deg
(10/26/93)
(probe aligned with freestream dirsction)
x=4,6,9,12"
x=14"
x=2"
x=16"
Velocity (ft/s)
55
50
45
40
35
30
25
−4
−2
0
2
4
6
8
Distance from Duct Bottom (in.)

Figure 4(a)

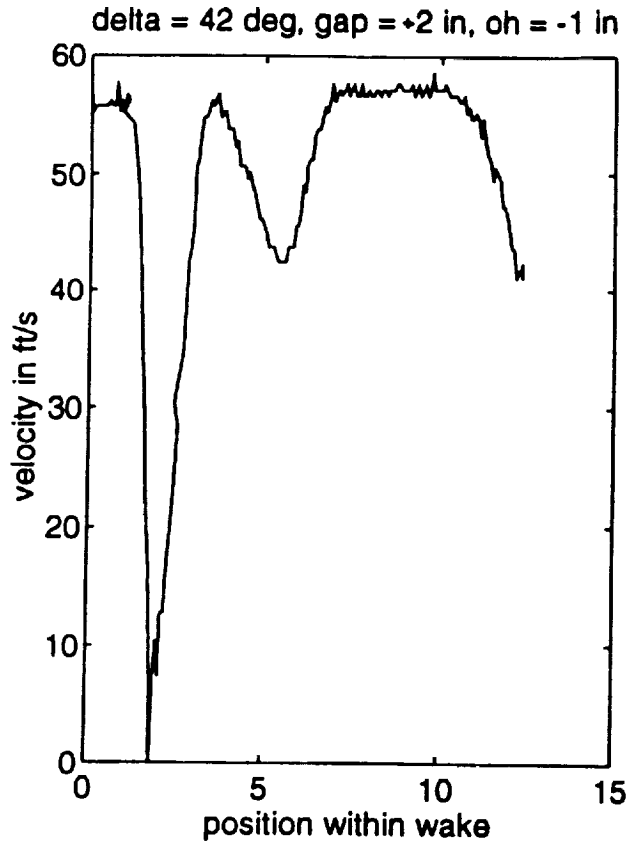


Figure 4(b)

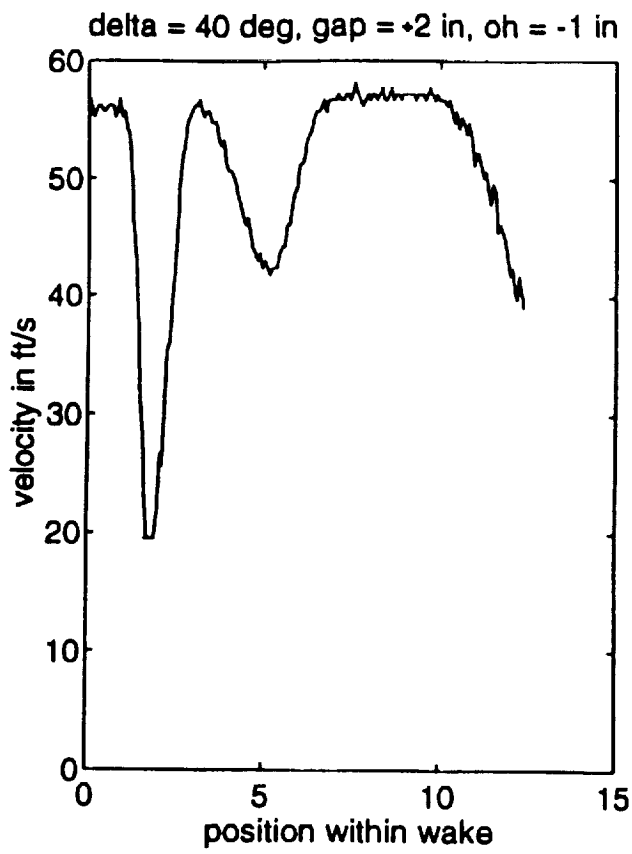


Figure 4(c)

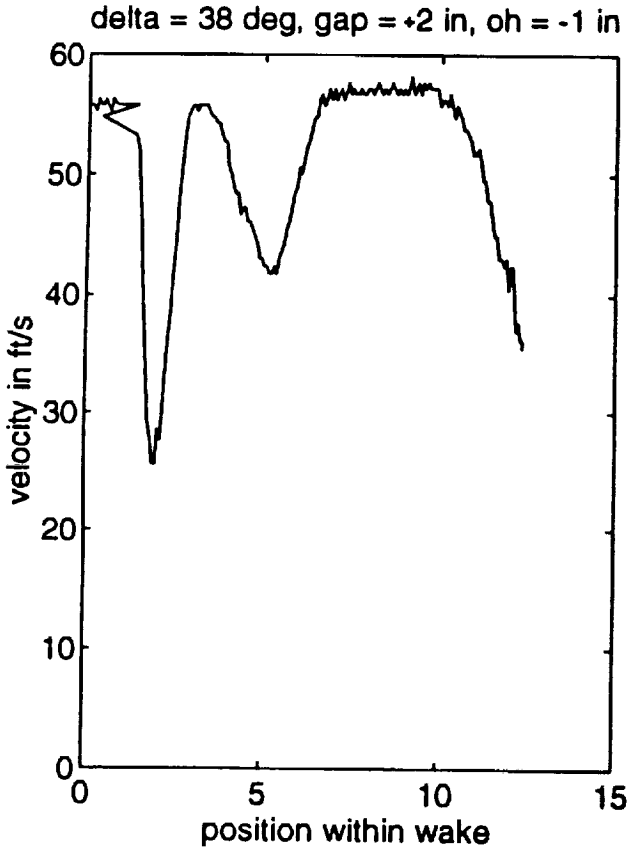


Figure 4(d)

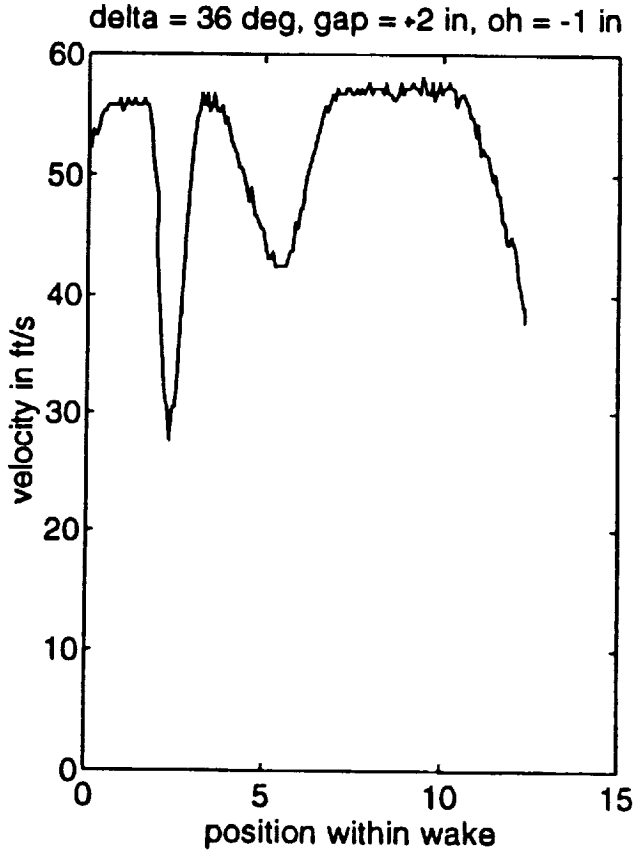


Figure 4(e)

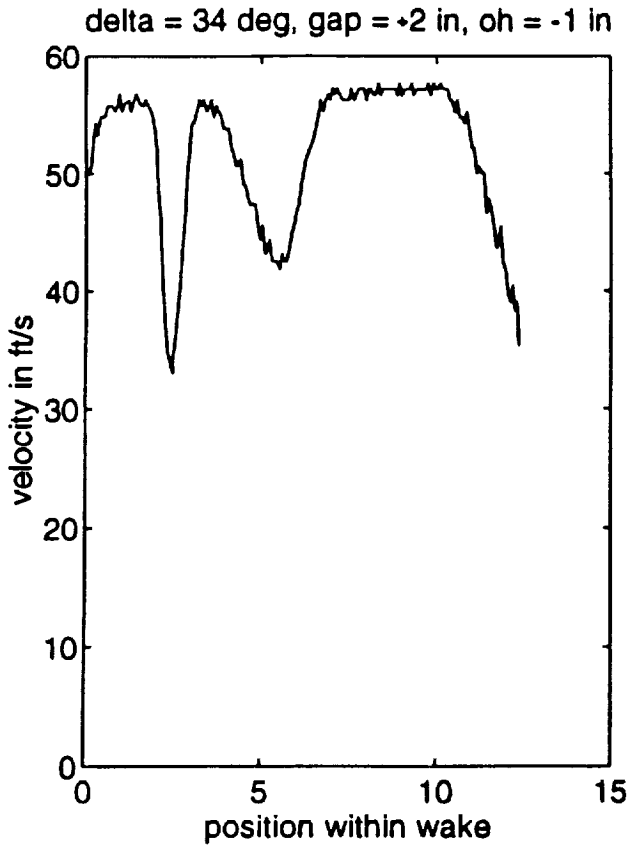


Figure 4(f)

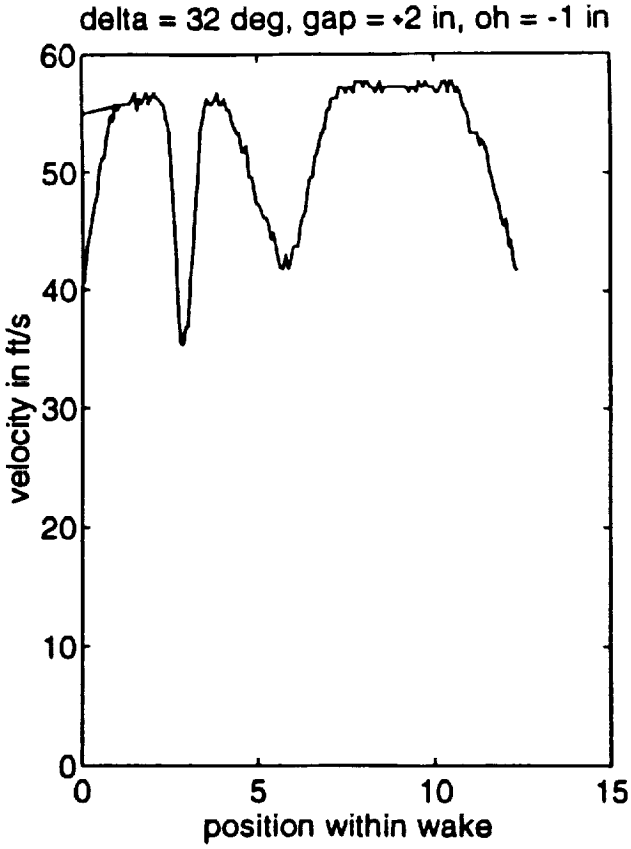


Figure 4(g)

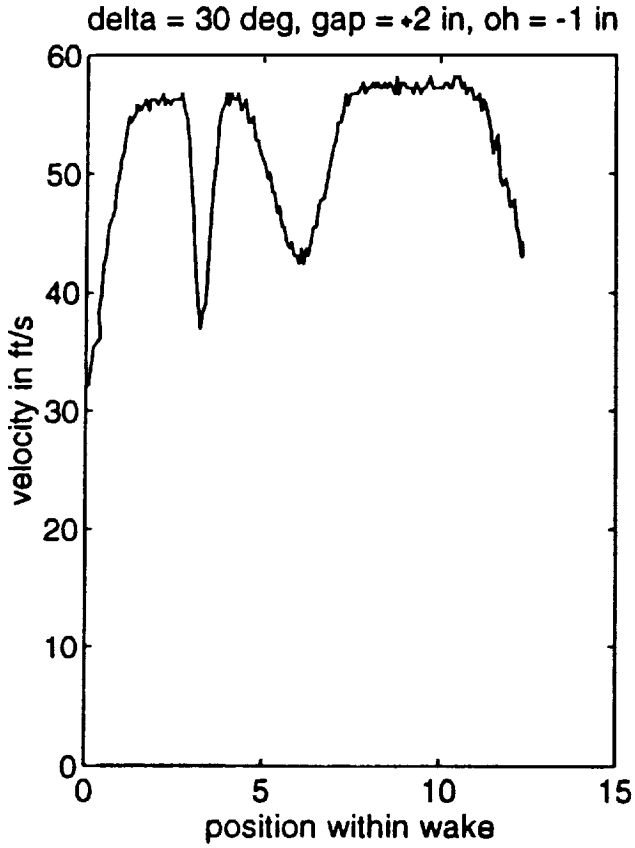
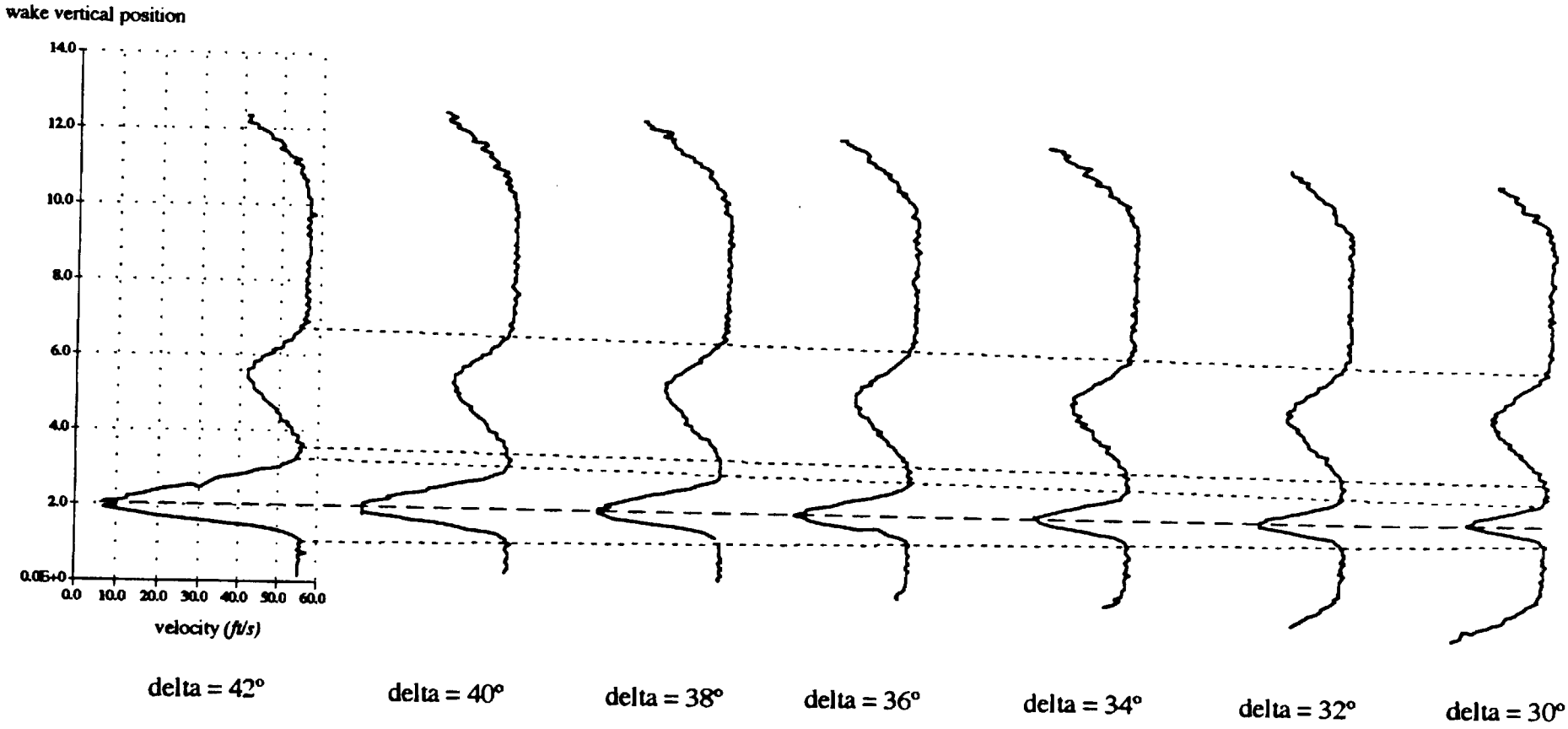
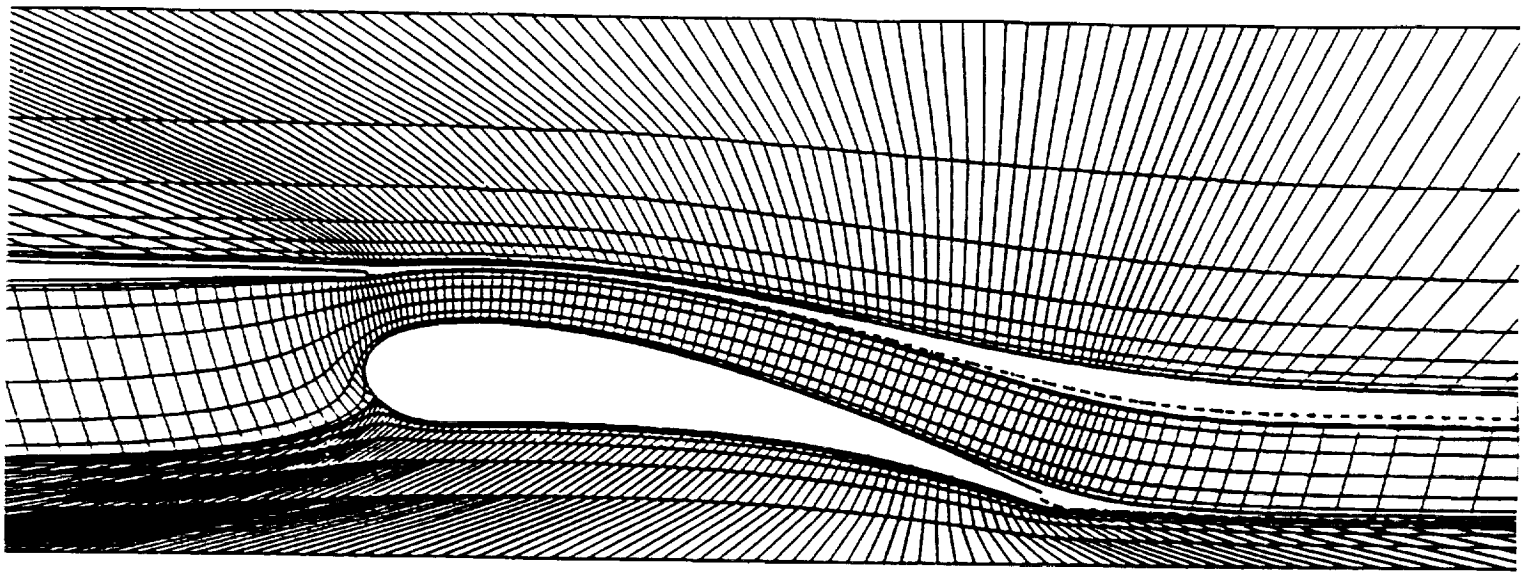


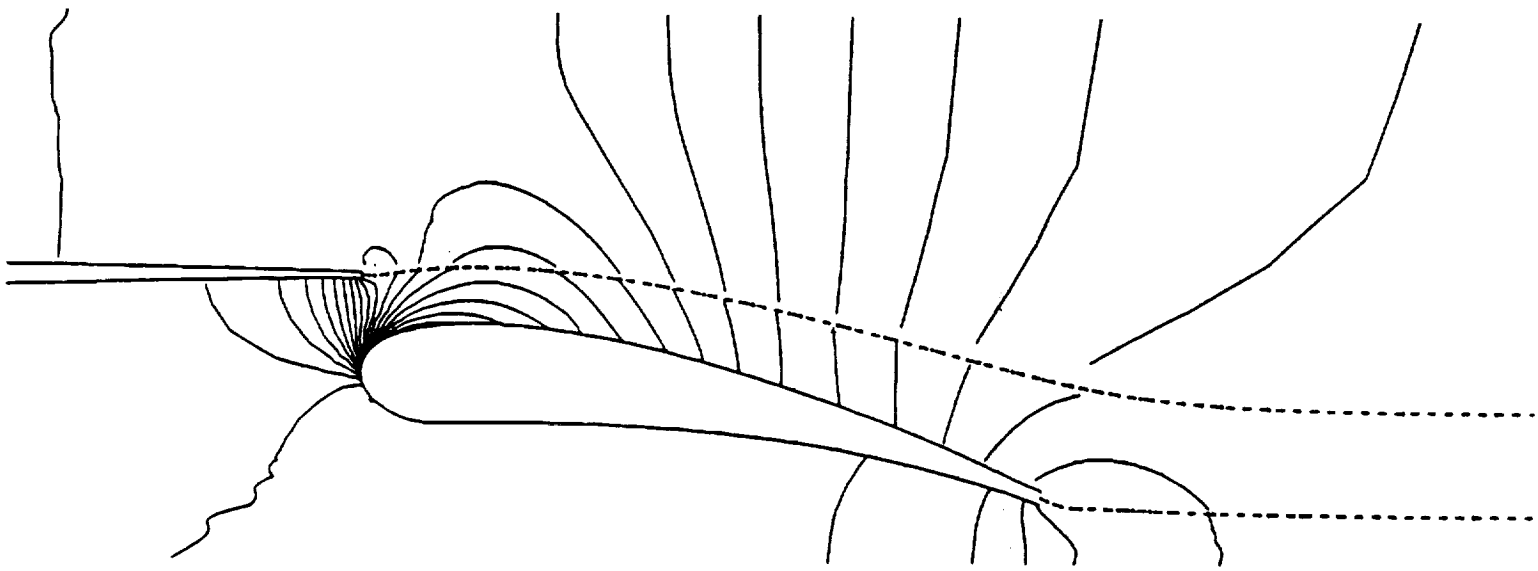
Figure 4(h): Comparison of wake profiles

V = 50 ft/s, gap = 2.0 inches, overhang = -1.0 inches, wake station = +3.0 inches aft of flap trailing edge

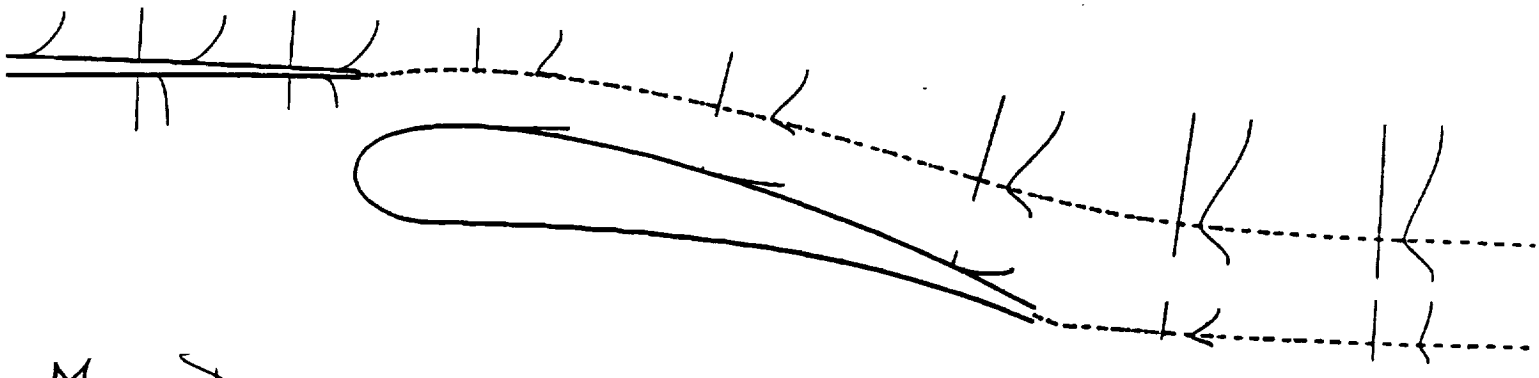




STREAMLINE GRID

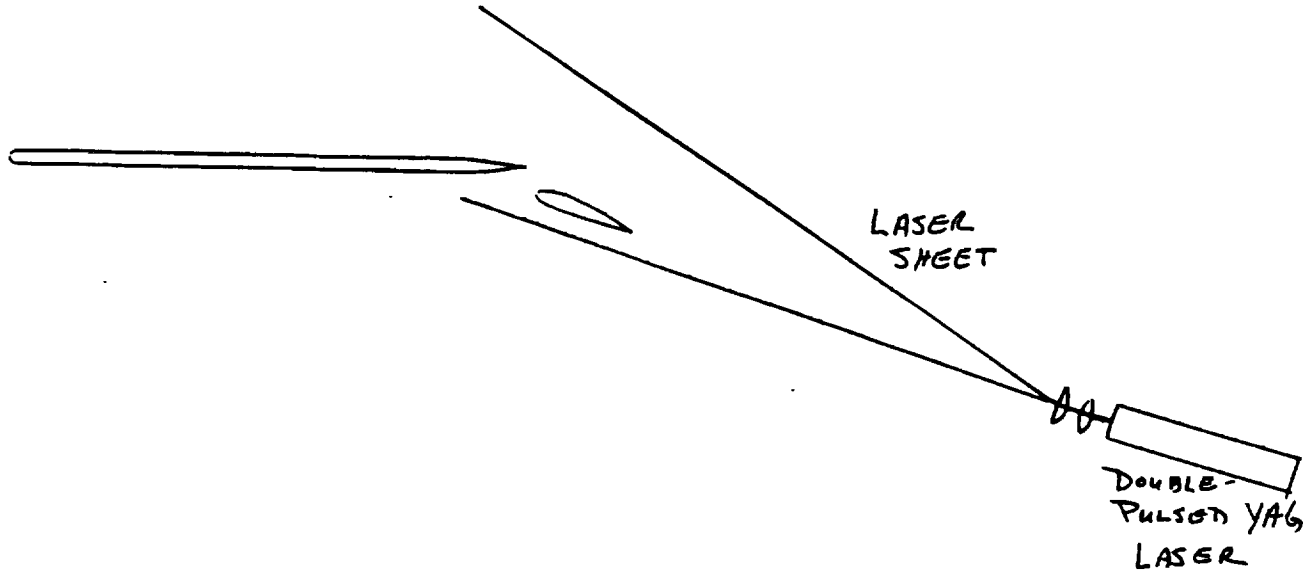


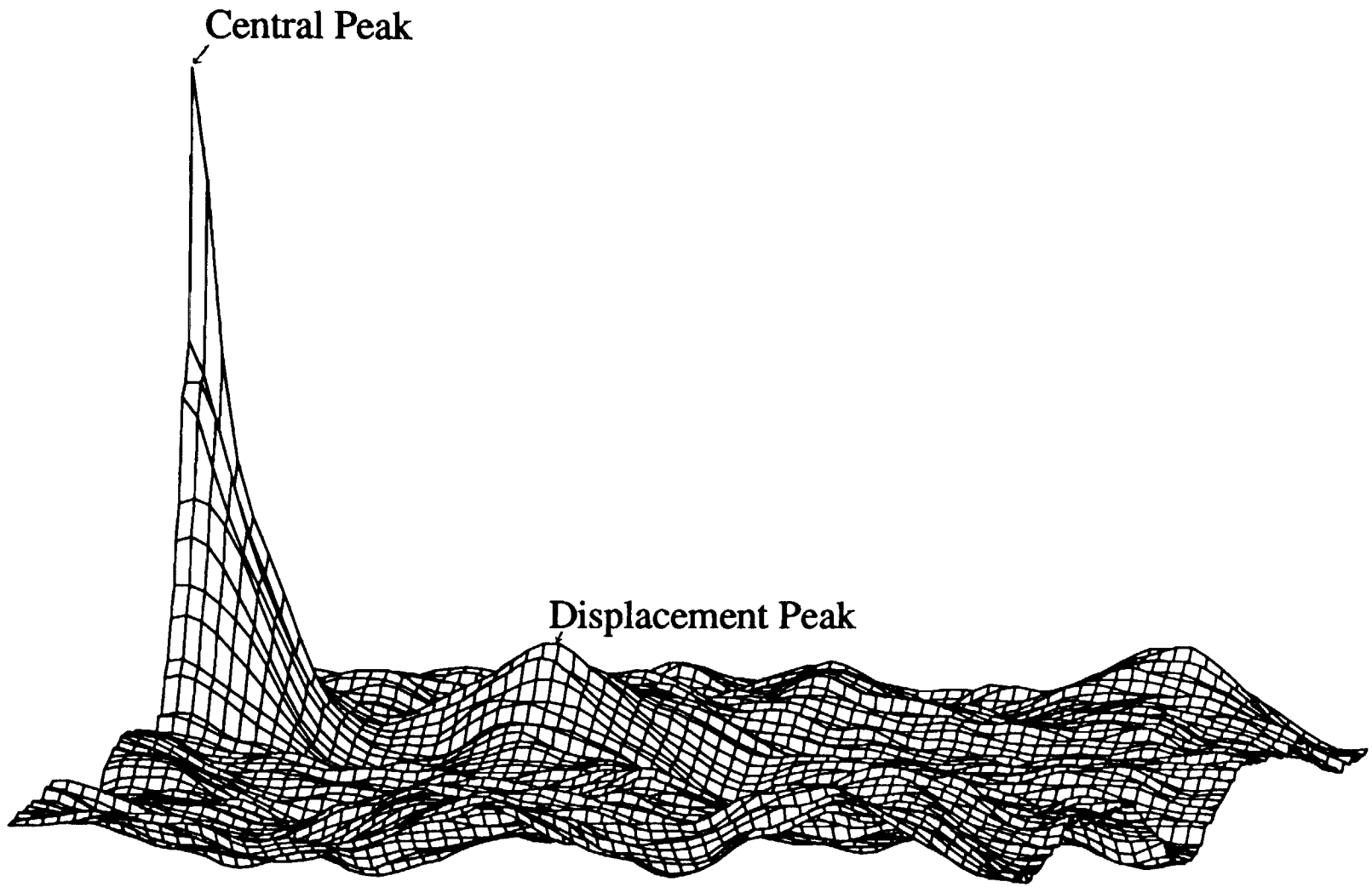
CONTOURS OF CP



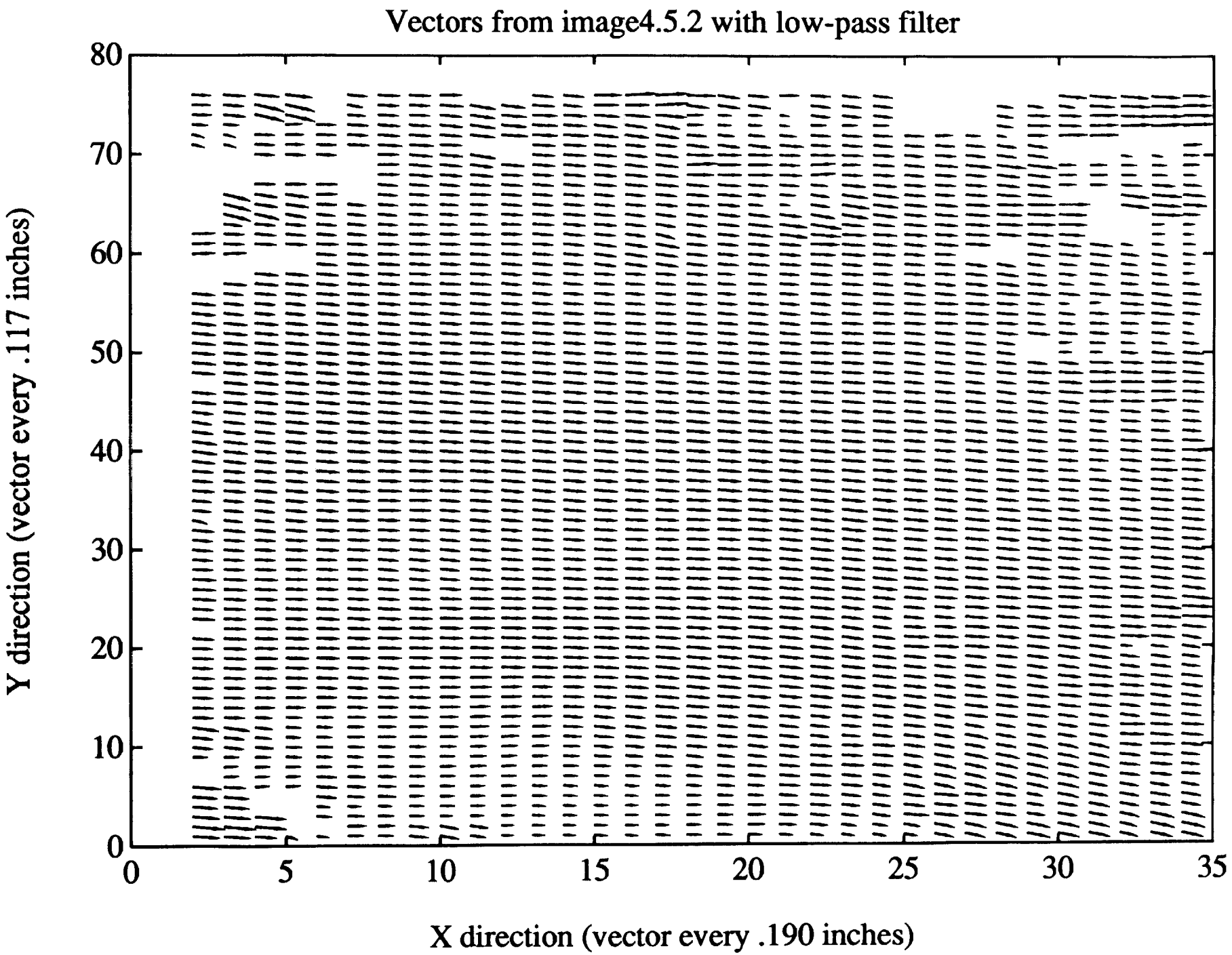
MARK DRELA - MIT
MSES

PIV
1/4 Scale Facility





Sample Autocorrelation Output


Vectors from image4.5.2 with low-pass filter
Y direction (vector every .117 inches)
X direction (vector every .190 inches)
0
10
20
30
40
50
60
70
80
0
5
10
15
20
25
30
35

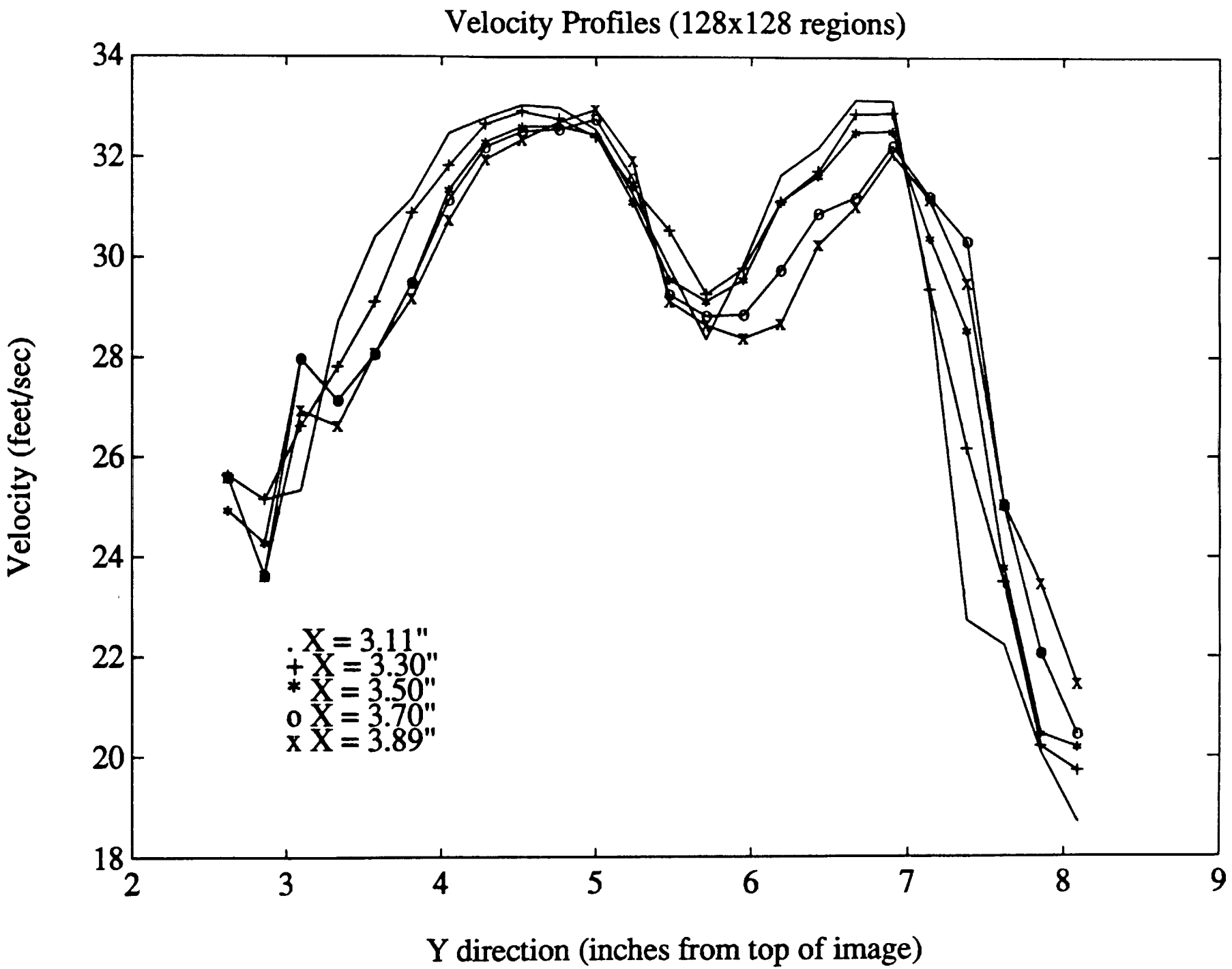
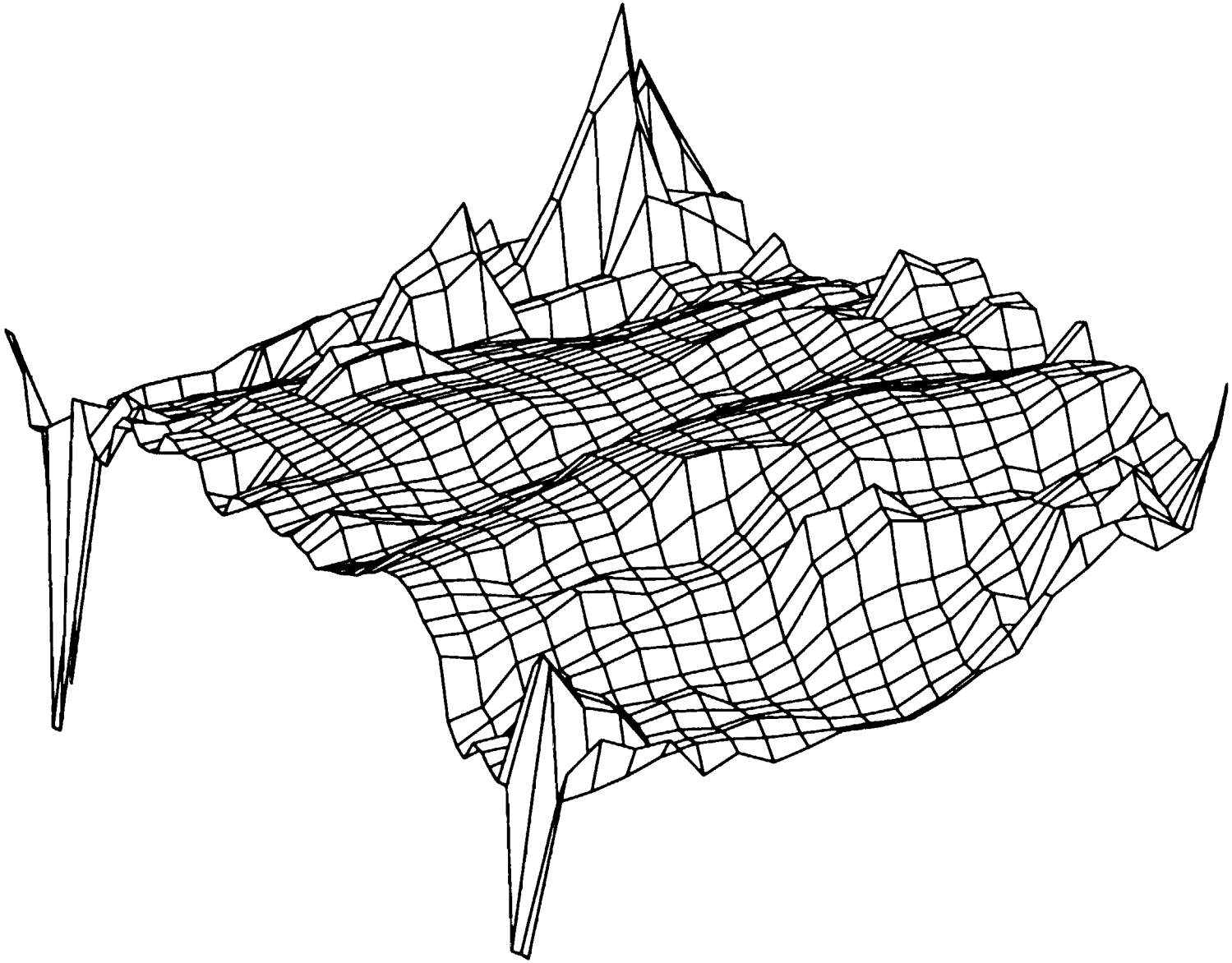

Velocity Profiles (128x128 regions)
Velocity (feet/sec)
Y direction (inches from top of image)
34
32
30
28
26
24
22
20
18
2
3
4
5
6
7
8
9
. X = 3.11"
+ X = 3.30"
* X = 3.50"
o X = 3.70"
x X = 3.89"

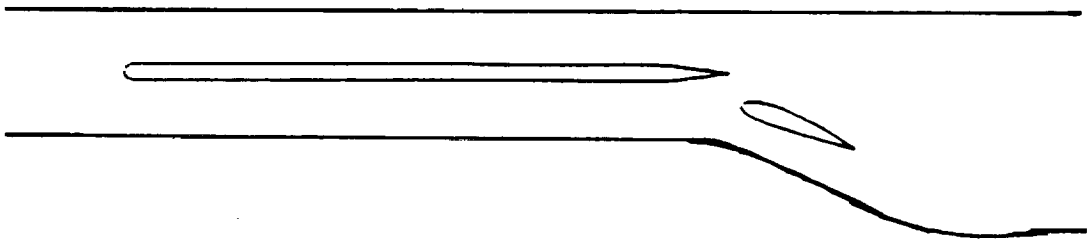
Image4.5.2

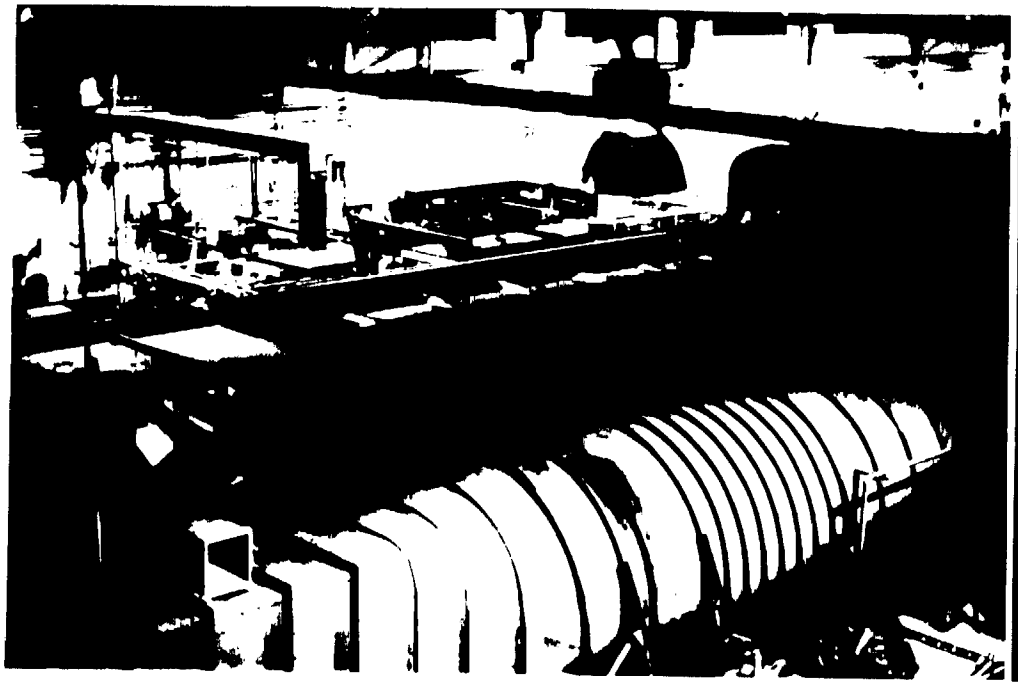


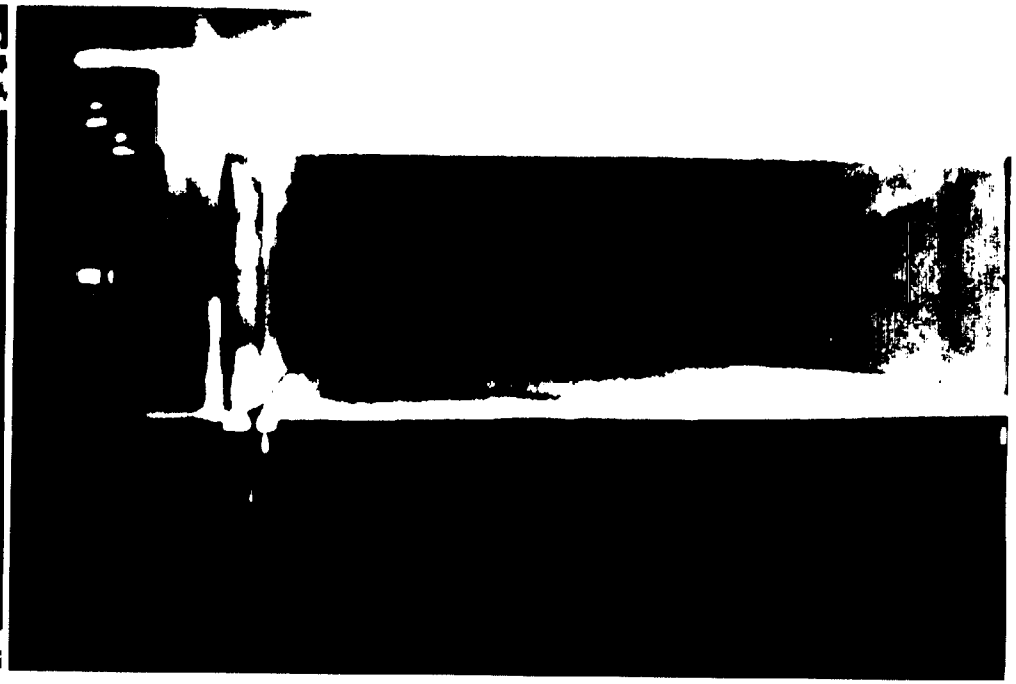
Mesh of velocity profile

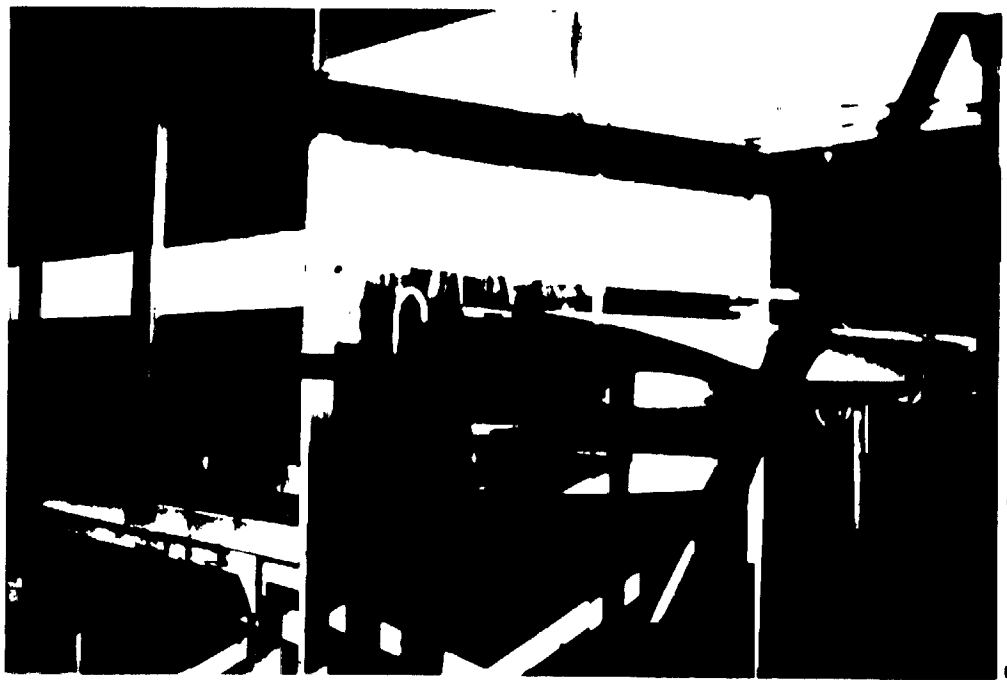
Full Scale Facility

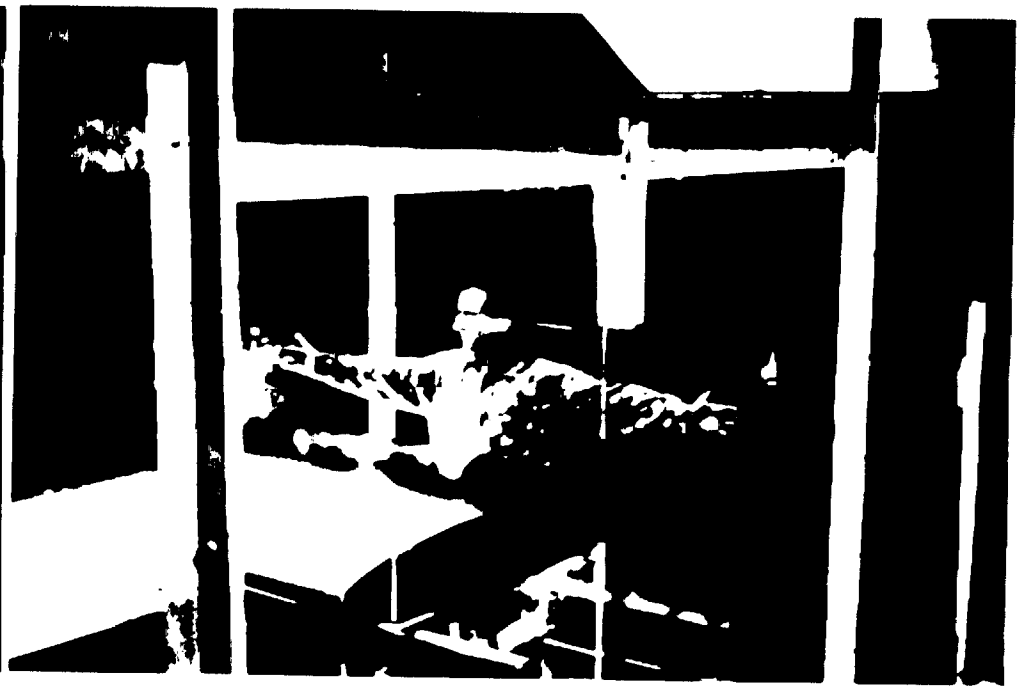
- Status
  - Construction Complete
    - » Foam-Fiberglass with Smooth Gel-Coat
  - Pitot Probe Surveys
  - Flow Visualization





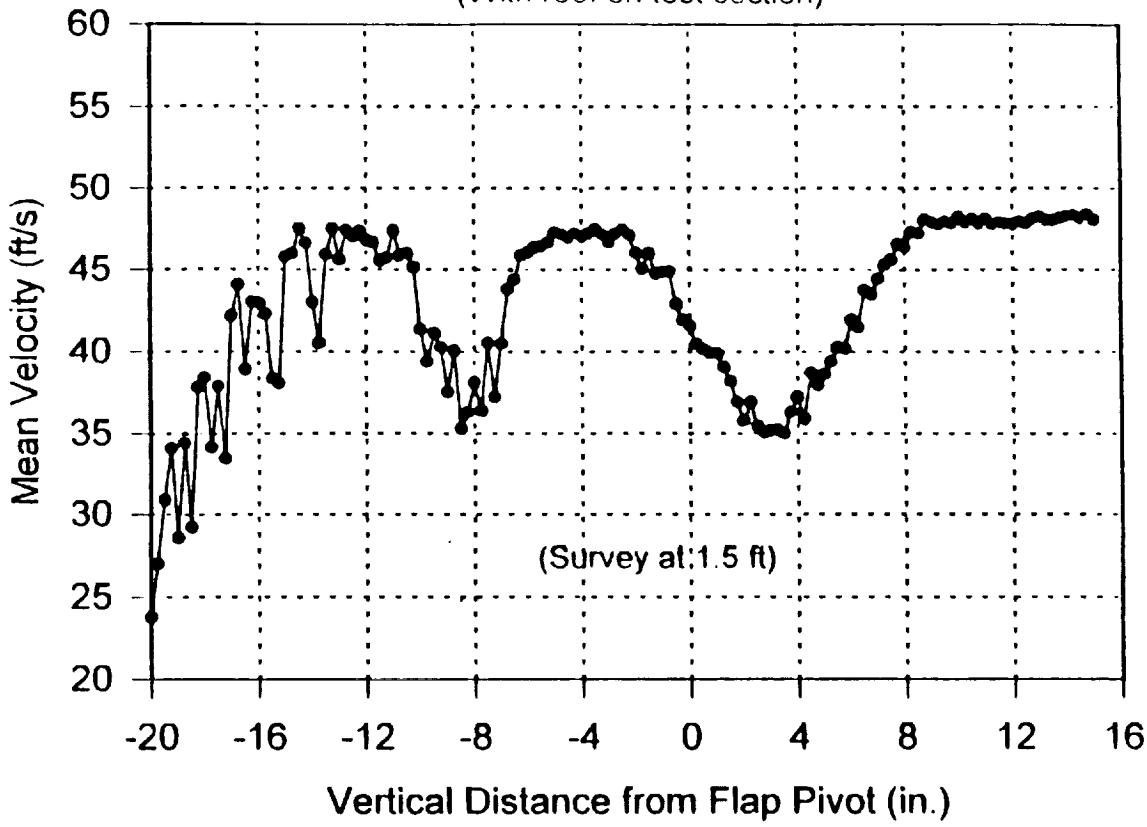






Mean Velocity Profile in Wake

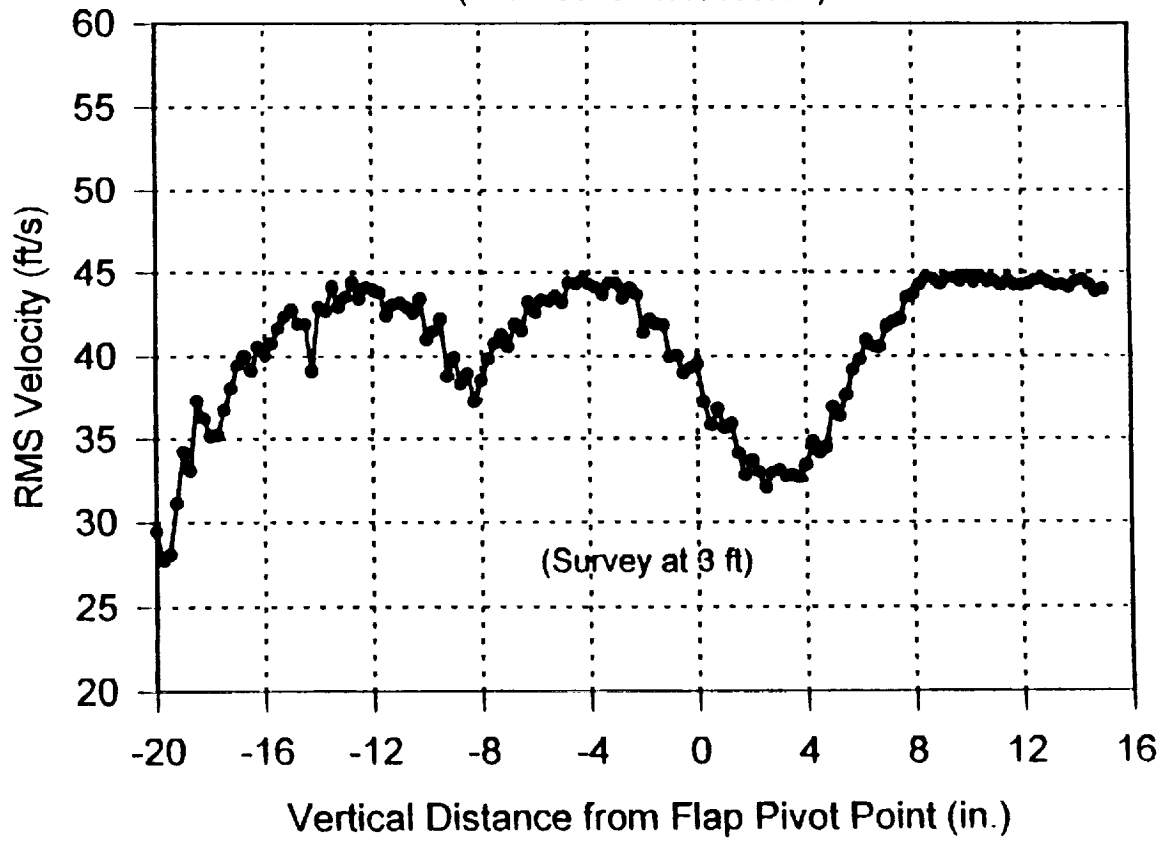
(With roof on test section)



(0.25" between data points)

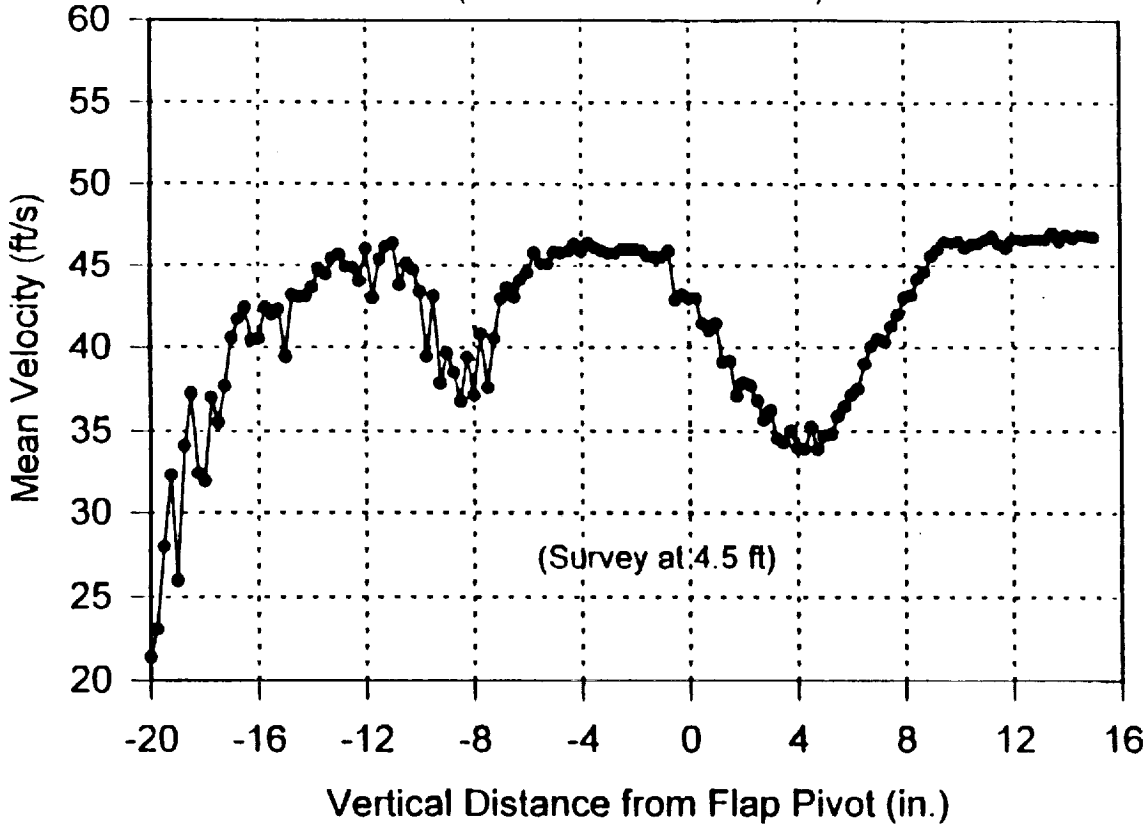
Mean Velocity Profile in Wake

(With roof on test section)



Mean Velocity Profile in Wake

(With roof on test section)

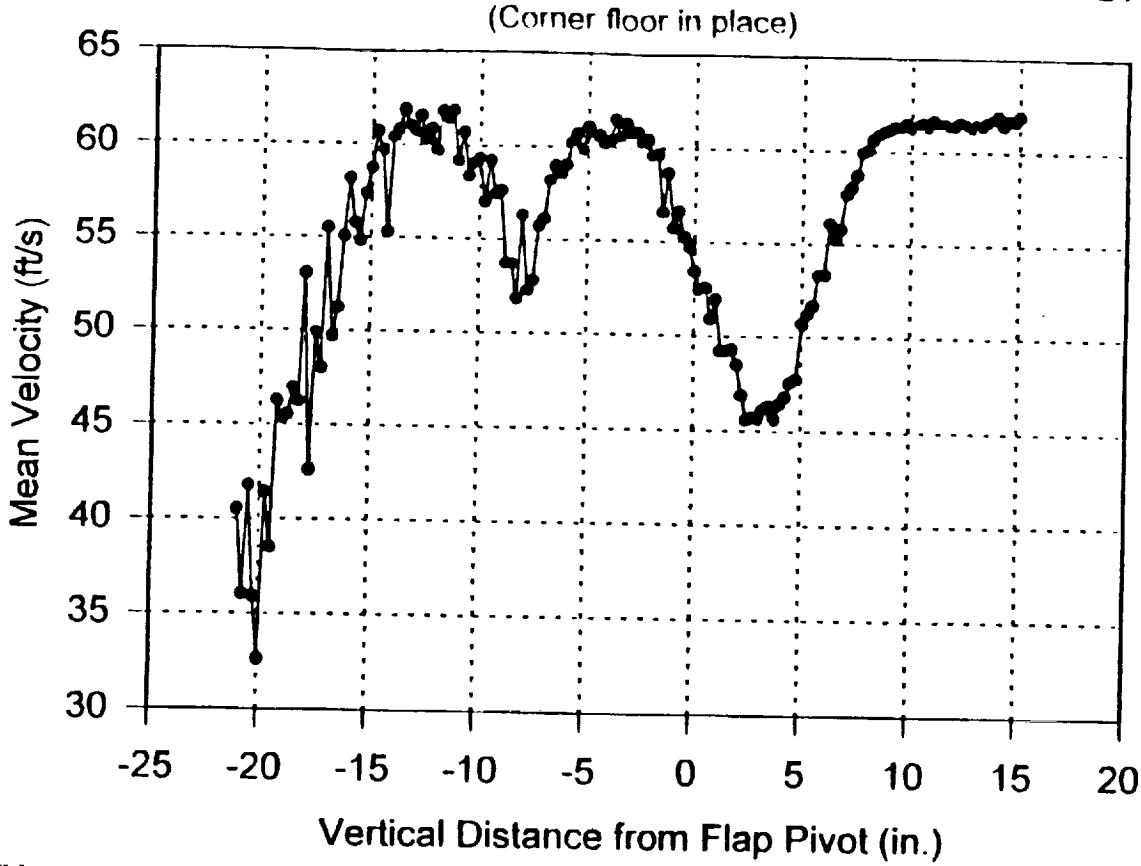


(0.25" between data points)

12/19/9

Mean Velocity Profile in Wake (AOA=0 deg)

(Corner floor in place)

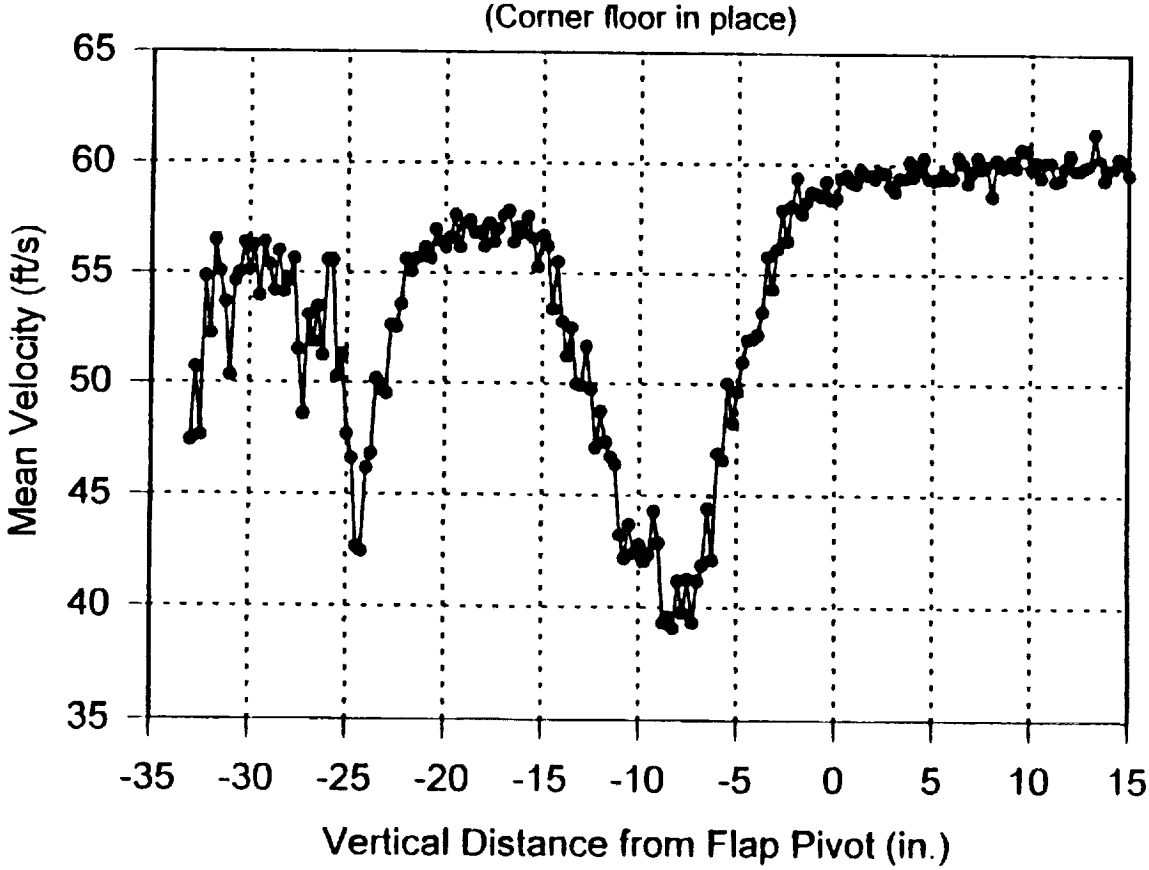


(0.25" between data points)

12/19/93

Mean Velocity Profile in Wake (AOA=10 deg)

(Corner floor in place)



(0.25" between data points)

Conclusions

- 1/4 Scale Facility
  - Pitot Probe and PIV Data
  - Small 3-D Effects Up to Flap Stall
- Full Scale Facility
  - Operational
  - Preliminary Pitot Probe Data

Recommendations

- **Experiments in Full Scale Facility**
  - Work with Turbulence Modelers and CFD People to Develop Design Capability of High Lift Systems of High Reynolds Numbers
- **Issues**
  - Wake Structure
  - Wake Bursting
  - Coves
  - Trailing Edge Treatment
- **Facility Improvements**
  - Blowing in Flap/Side Wall Corner
    - » Higher Lift on Flap with 2-D Flow
  - Suction of Side Wall Boundary Layers