2ND AIAA ICE PREDICTION WORKSHOP

IPW

ESTABLISHED 2019

AIAA 2nd Ice Prediction Workshop

Boeing LEWICE3D Summaries

June 22-23, 2023

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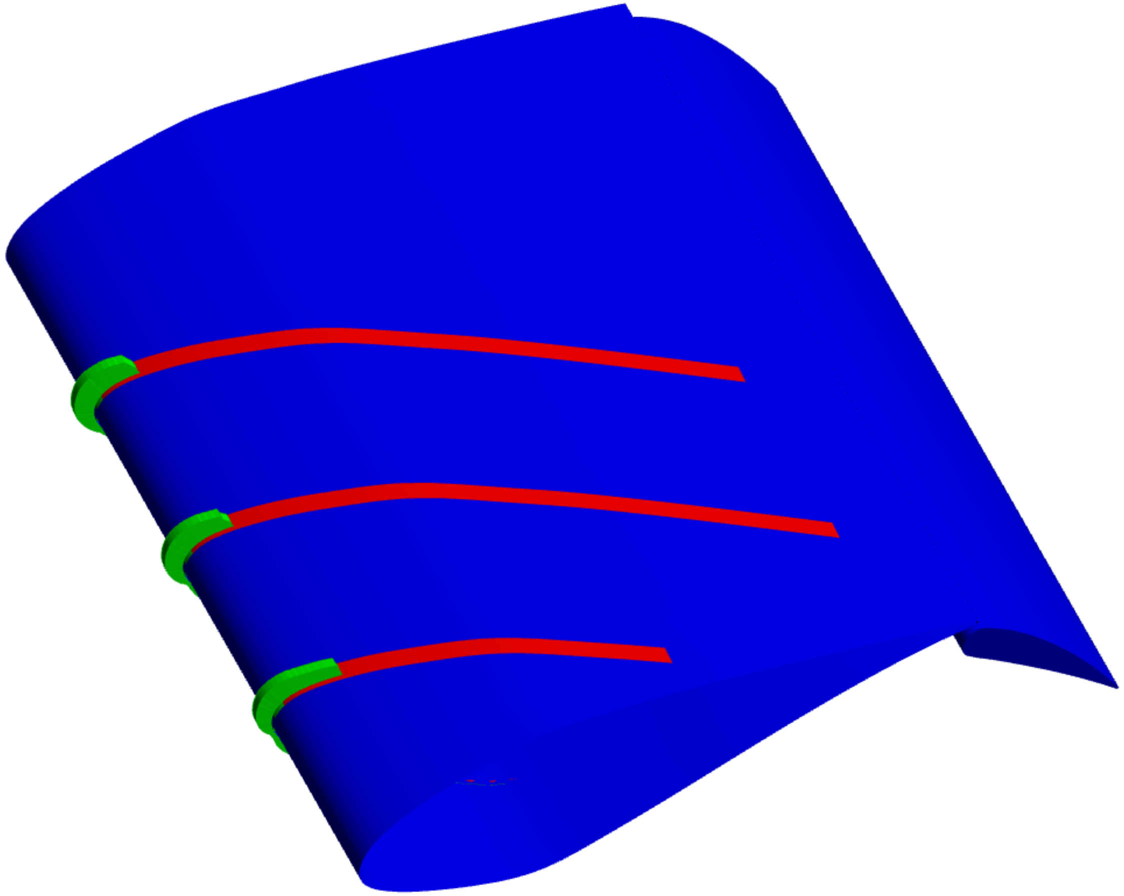
LEWICE3D (MPI)

- Single time step
  - Assumes constant collection efficiency, heat transfer and icing rates with time
  - Langrangian method with auto collection efficiency convergence
- Strip based method
  - 1-D Messinger model for heat and mass balance
  - Strips/cuts made normal to the LE to approximate streamlines
  - Roughness model correlated to LWC, Vamb, Tamb
  - Ice density constant 450 kg/m^3

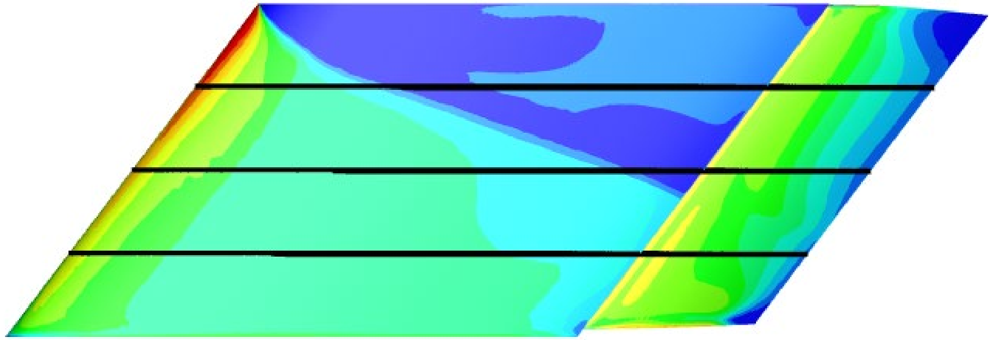
CFD++ (Version 17.1)

- RANS - steady
- SA + Rotation/Curvature Correction (SARC) turbulence model
- No Slip (Viscous) Walls in the tunnel section
- Slip (Inviscid) Walls at the inlet and outlet extensions
- Committee provided grids used
  - However, during aero calibration, committee surface grids preserved and new volume grid created with Boeing version of AFLR3 after surface grid rotation

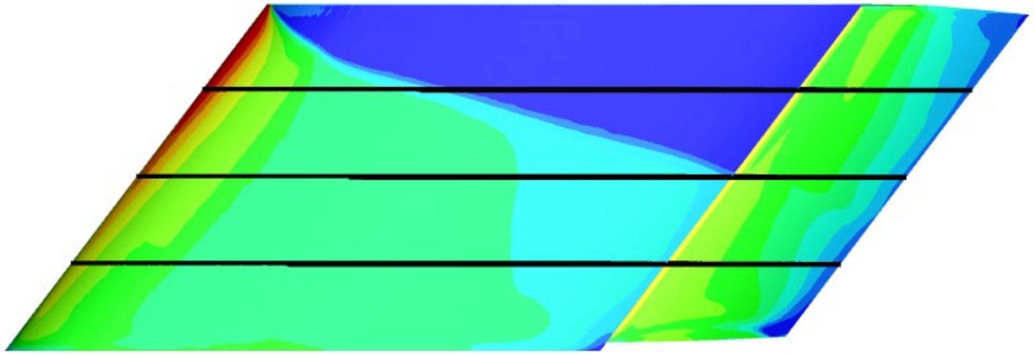


Inboard Gap vs No Gap – Skin Friction

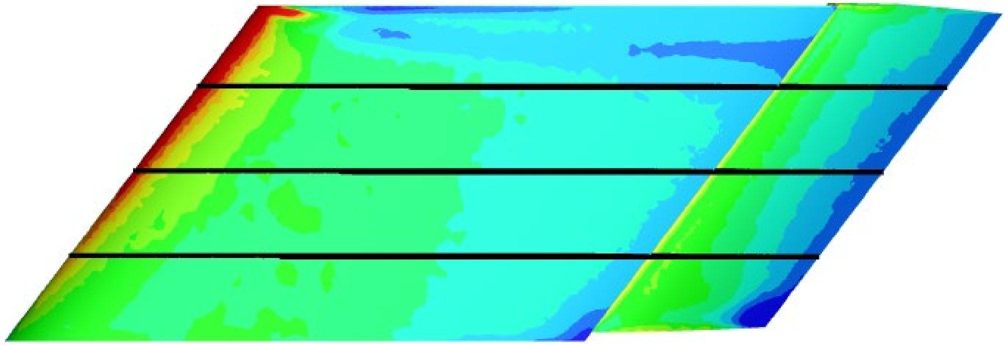
No Gap



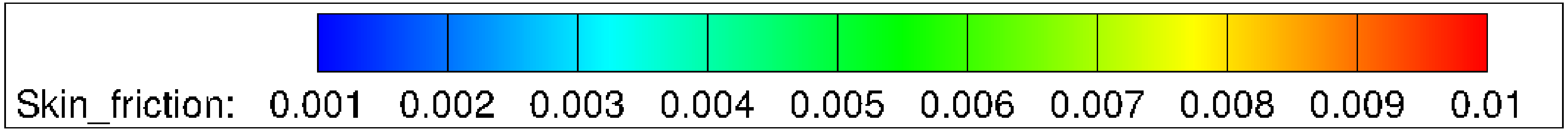
Gap (0.5” – Provided)



Increased Gap (0.75”)

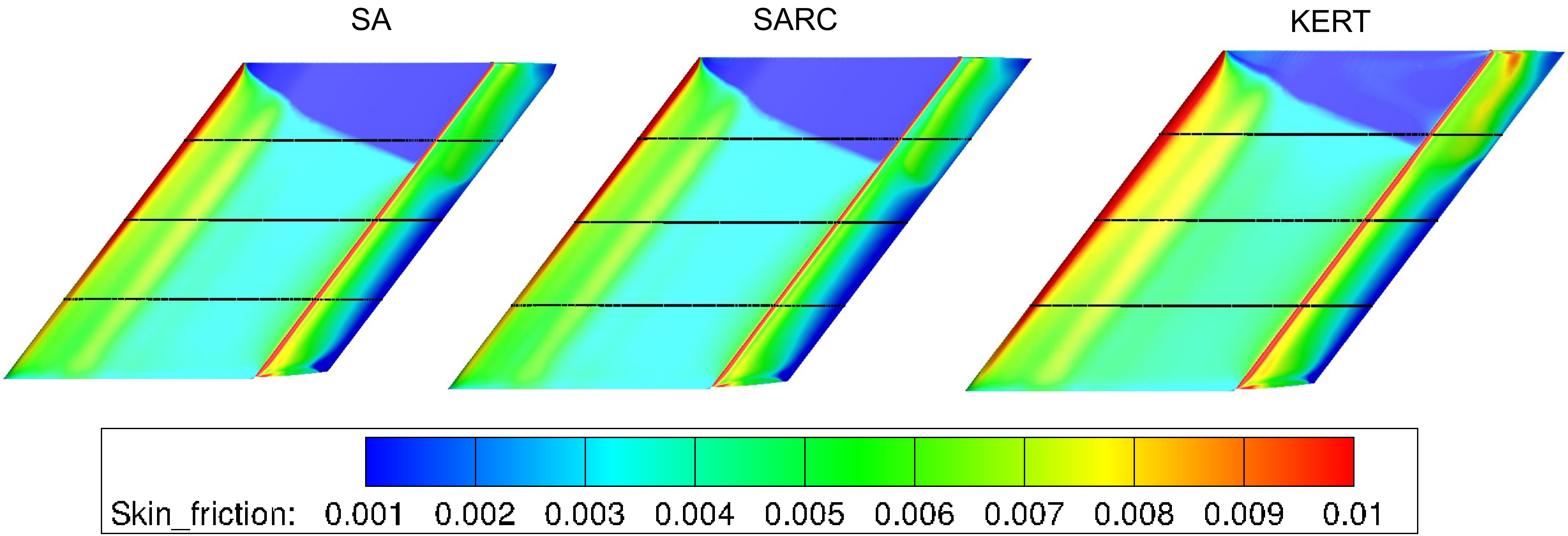


Increased Gap (0.75”):
- IPW2 surface mesh preserved
- New volume mesh created with Boeing version of AFLR3 using the provided IPW2 boundary conditions



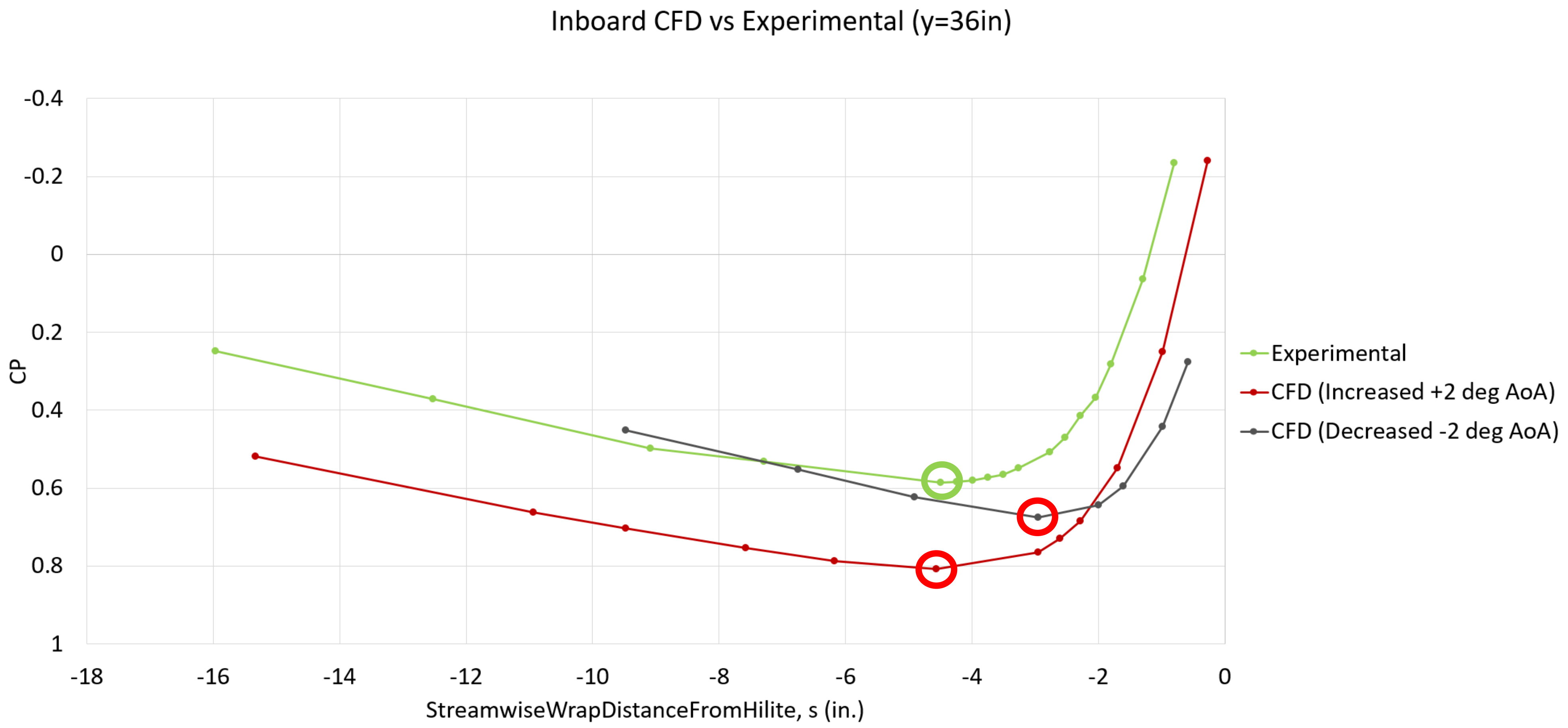
Midspan - Turbulence Model Comparisons

- Separation is too large for available CFD++ turbulence models to make a difference
- Inboard model showed similar results
- SARC selected due to matching the experiment attachment line the closest



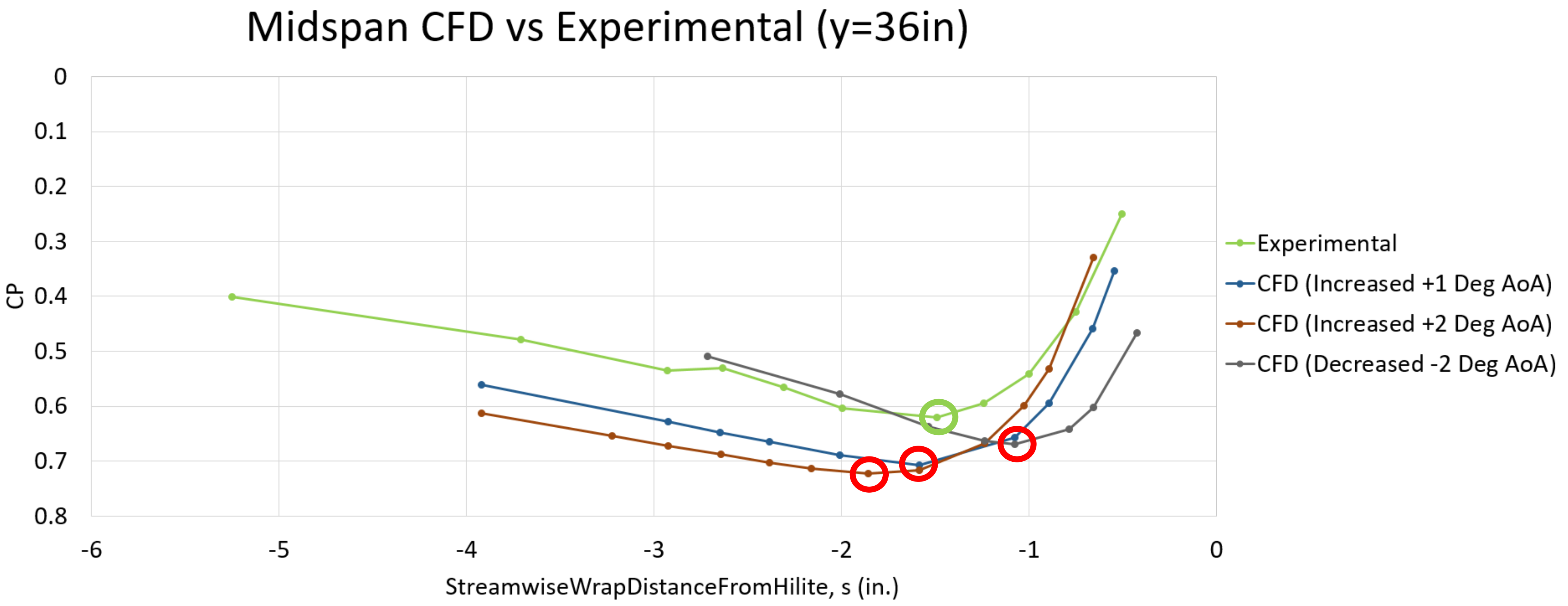
Aero Calibration - Inboard

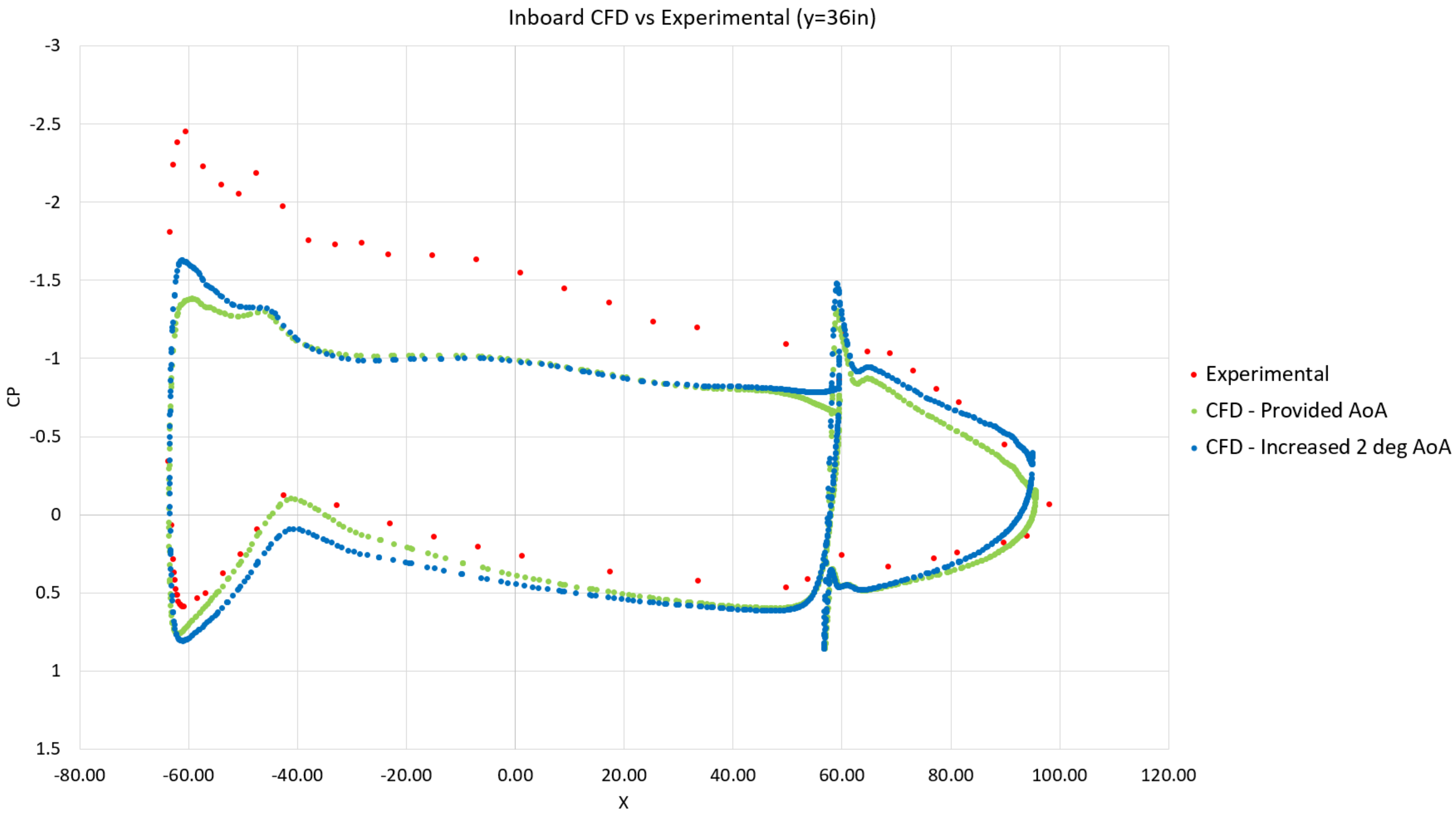
- AoA swept from -8 to 8 deg in 2deg increments
- +2 Deg AoA is closest with s=-4.56 in. (Experiment s=-4.49 in.)



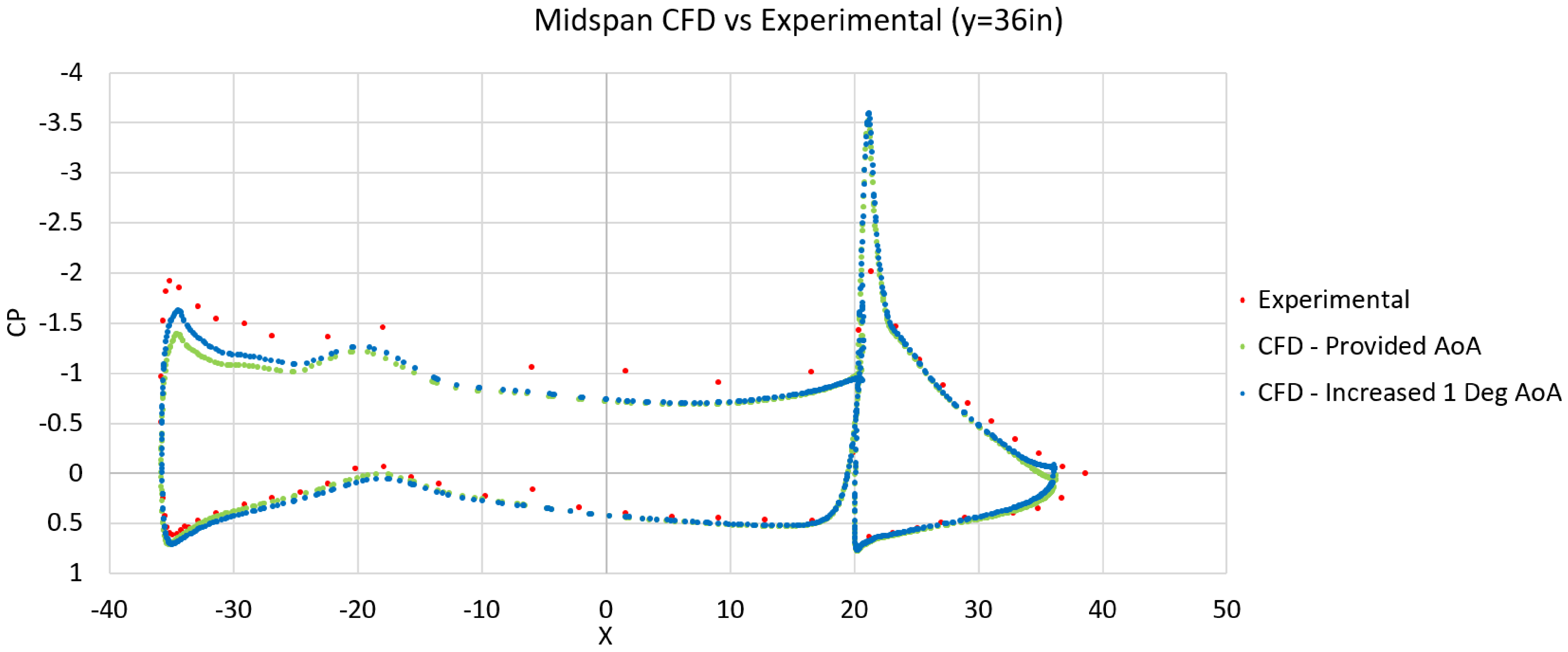
Aero Calibration - Midspan

- Full configuration AoA adjusted to match experiment attachment line
  - AoA swept from -8 to 8 deg in 2deg increments (further refined)
- +1 Deg AoA is closest with s=-1.58 in. (Experiment s=-1.49 in.)





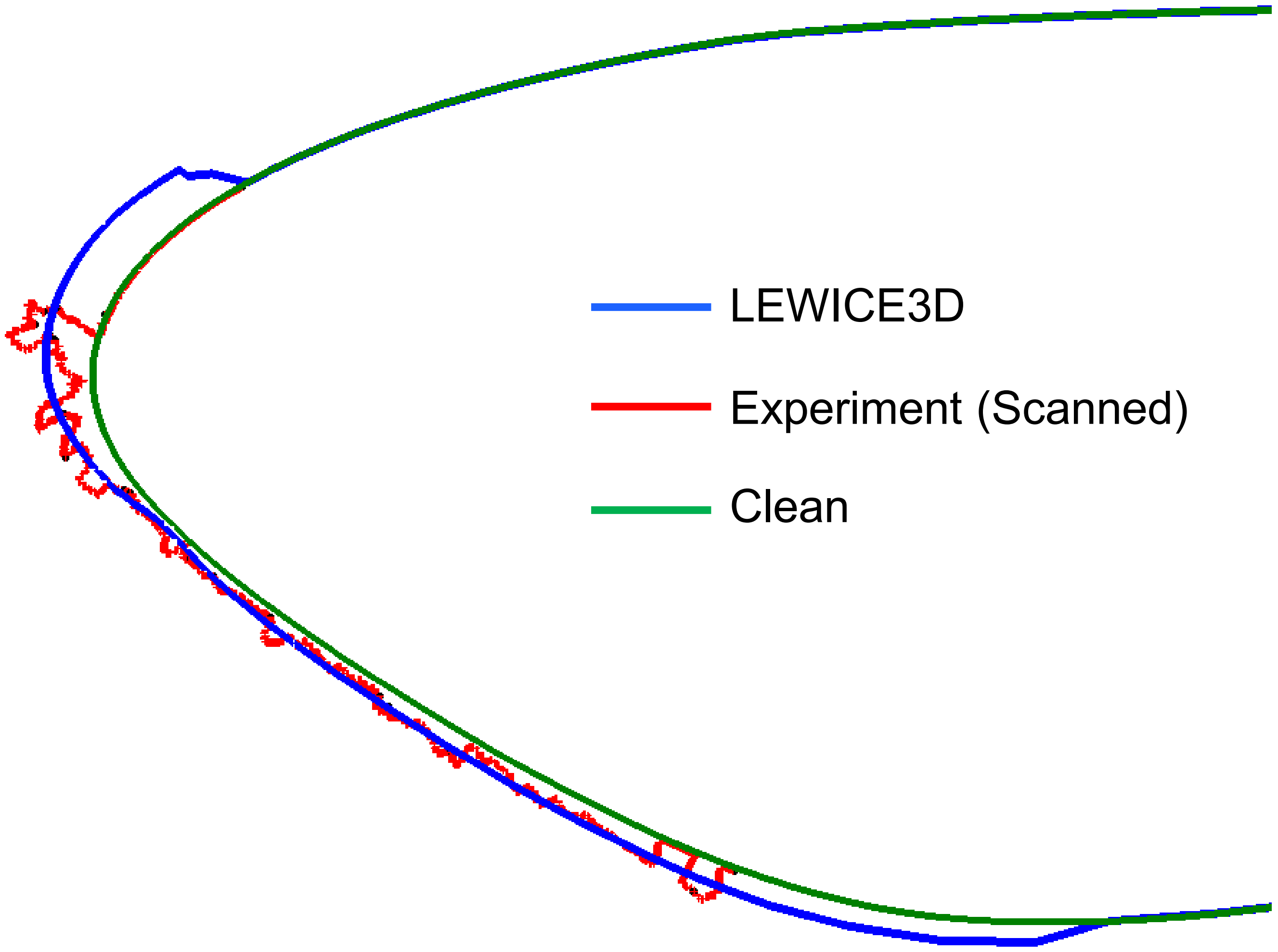
Inboard CFD vs Experimental (y=36in)
CP
X
-3
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
-80.00
-60.00
-40.00
-20.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
Experimental
CFD - Provided AoA
CFD - Increased 2 deg AoA



Midspan CFD vs Experimental (y=36in)
CP
-4
-3.5
-3
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
-40
-30
-20
-10
0
10
20
30
40
50
X
Experimental
CFD - Provided AoA
CFD - Increased 1 Deg AoA

Inboard Case 2.1

- Cut taken at y=36 in



Experiment: Ice Mass (kg/m): 4.92
LEWICE3D: Ice Mass (kg/m): 4.82

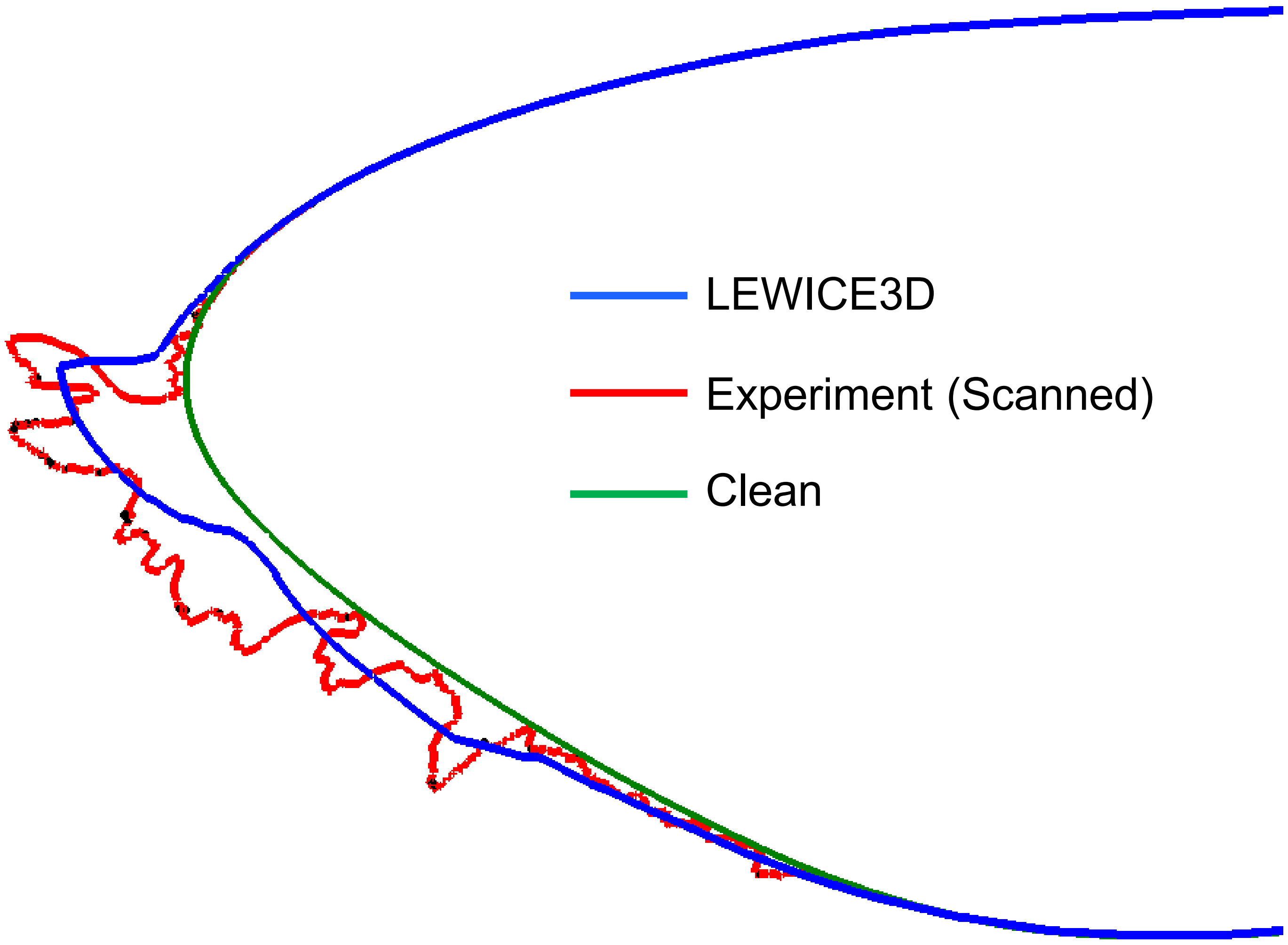
LEWICE3D:

Lower Horn Height (m): 0.025
Lower Horn Angle (deg): 539.29

Upper Horn Height (m): 0.028
Upper Horn Angle (deg): 93.91

Inboard Case 2.2

- Cut taken at y=36 in



Experiment: Ice Mass (kg/m): 8.22
LEWICE3D: Ice Mass (kg/m): 4.81

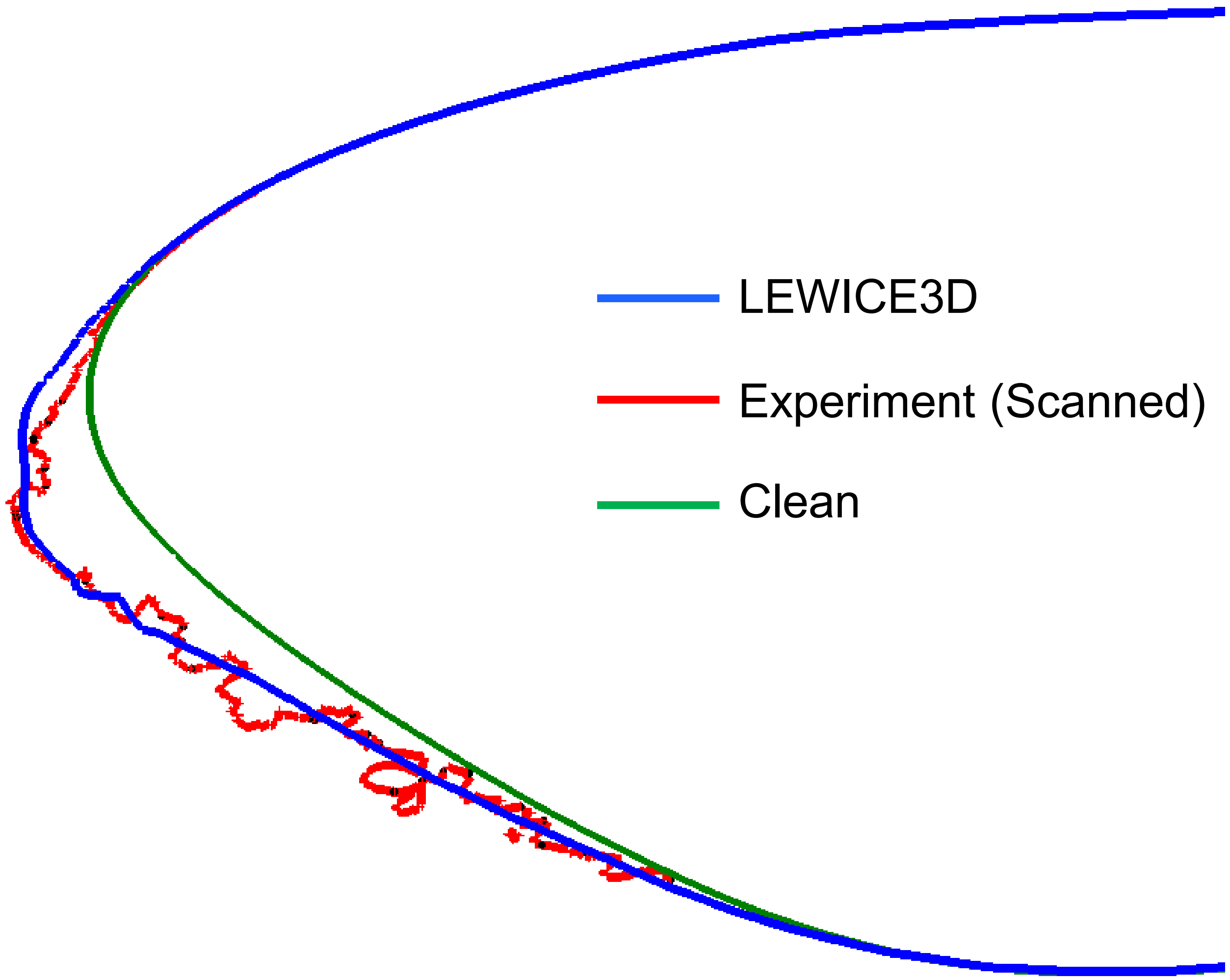
LEWICE3D:

Lower Horn Height (m): 0.066
Lower Horn Angle (deg): 181.76

Upper Horn Height (m): 0.029
Upper Horn Angle (deg): 175.15

Inboard Case 2.3

- Cut taken at y=36 in



Experiment: Ice Mass (kg/m): 7.90
LEWICE3D: Ice Mass (kg/m): 5.08

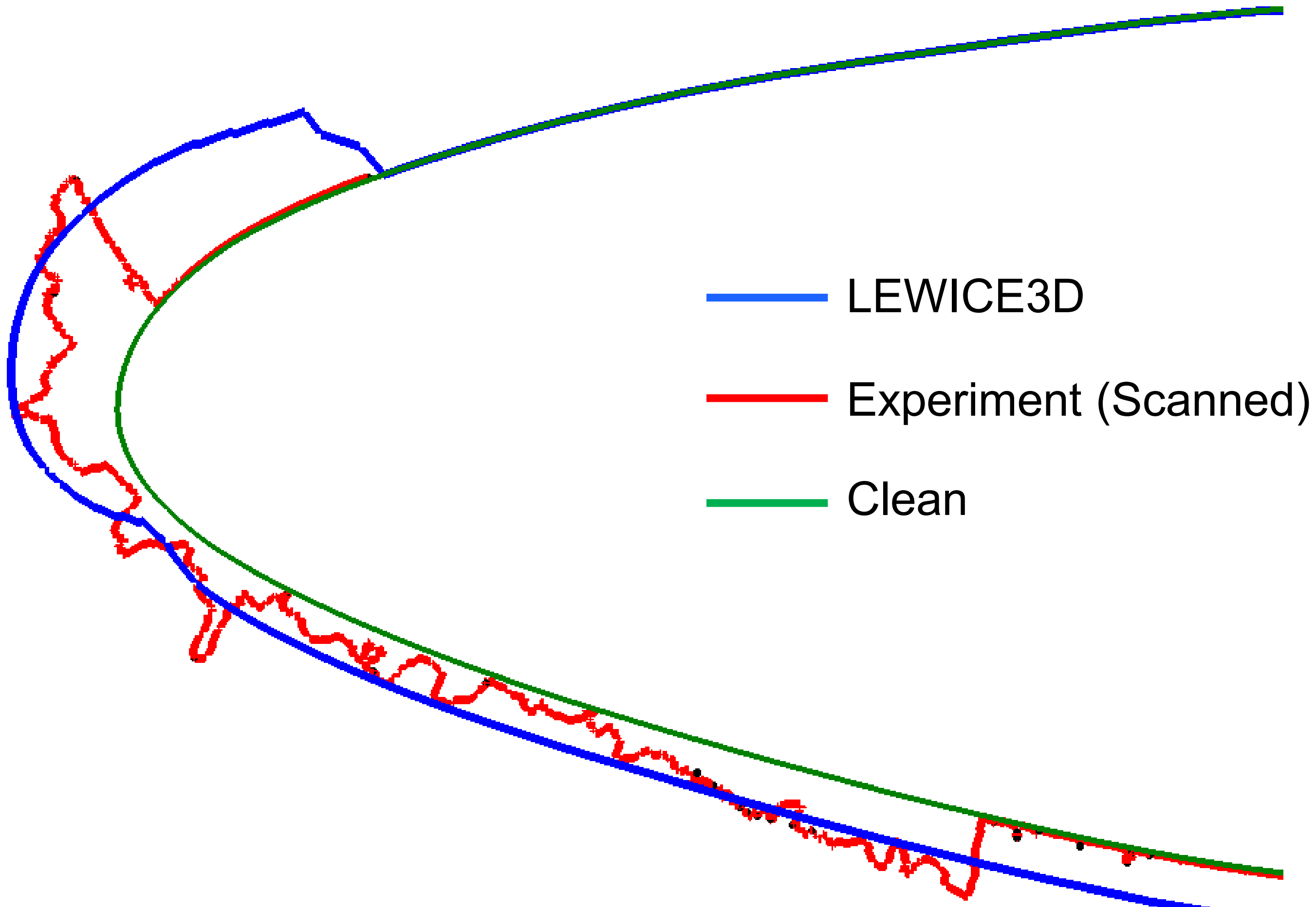
LEWICE3D:

Lower Horn Height (m): 0.050
Lower Horn Angle (deg): 250.84

Upper Horn Height (m): 0.021
Upper Horn Angle (deg): 174.64

Midspan Case 1.1

- Cut taken at y=36 in



Experiment: Ice Mass (kg/m): 3.70
LEWICE3D: Ice Mass (kg/m): 3.87

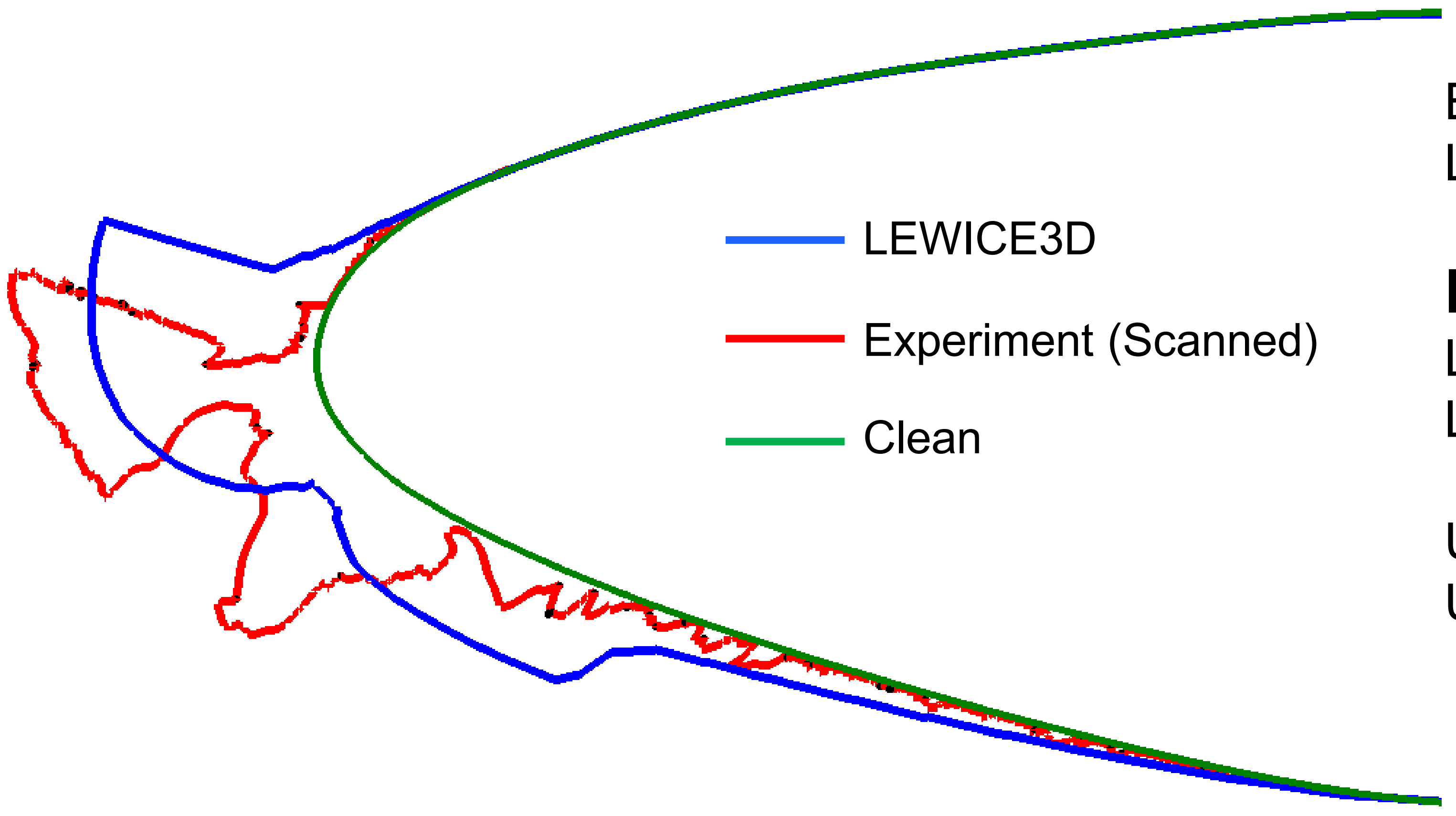
LEWICE3D:

Lower Horn Height (m): 0.027
Lower Horn Angle (deg): 184.17

Upper Horn Height (m): 0.032
Upper Horn Angle (deg): 122.48

Midspan Case 1.2

- Cut taken at y=36 in



Experiment: Ice Mass (kg/m): 5.93
LEWICE3D: Ice Mass (kg/m): 3.96

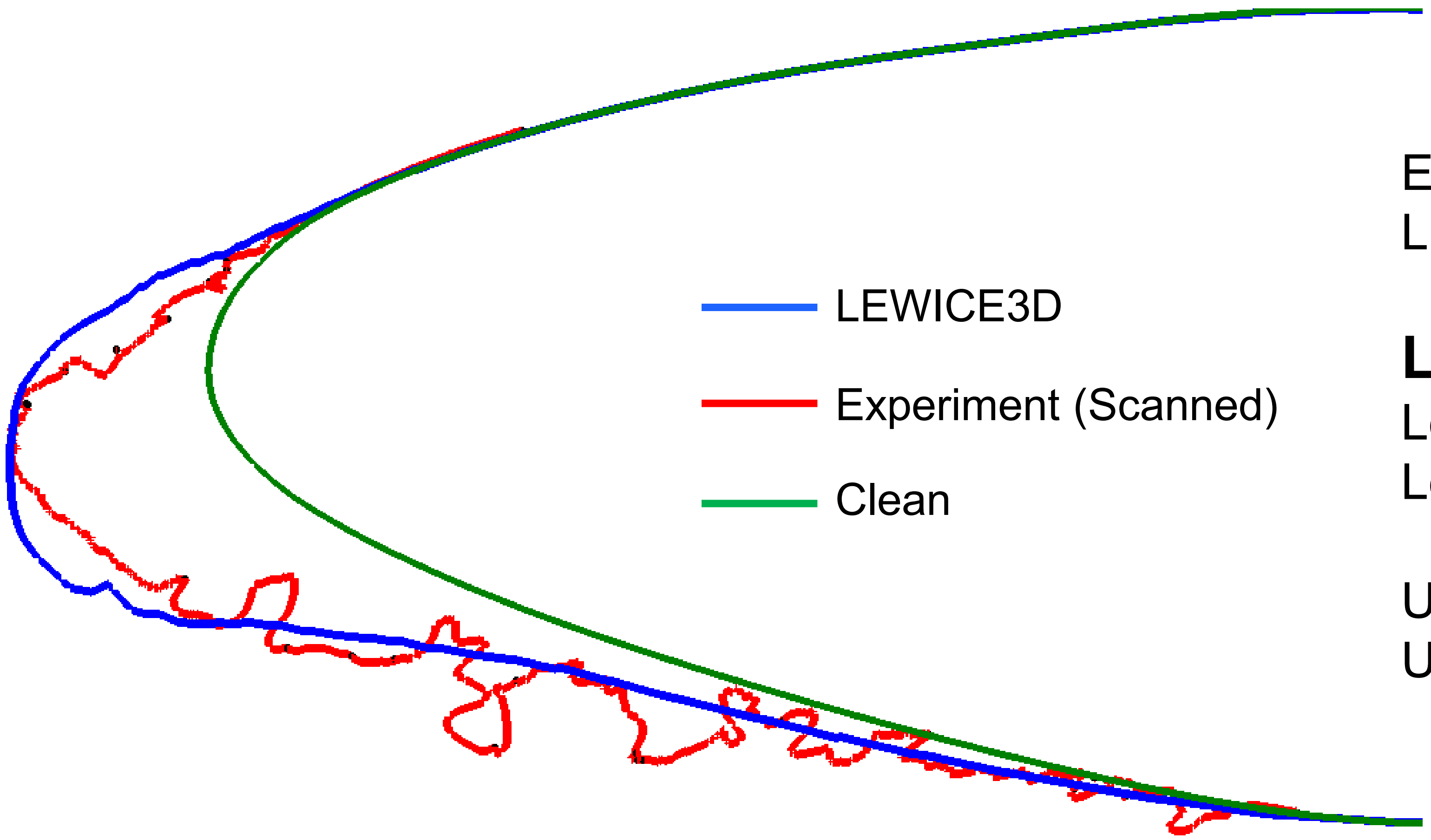
LEWICE3D:

Lower Horn Height (m): 0.065
Lower Horn Angle (deg): 188.59

Upper Horn Height (m): 0.071
Upper Horn Angle (deg): 154.07

Midspan Case 1.3

- Cut taken at y=36 in



Experiment: Ice Mass (kg/m): 5.93
LEWICE3D: Ice Mass (kg/m): 4.09

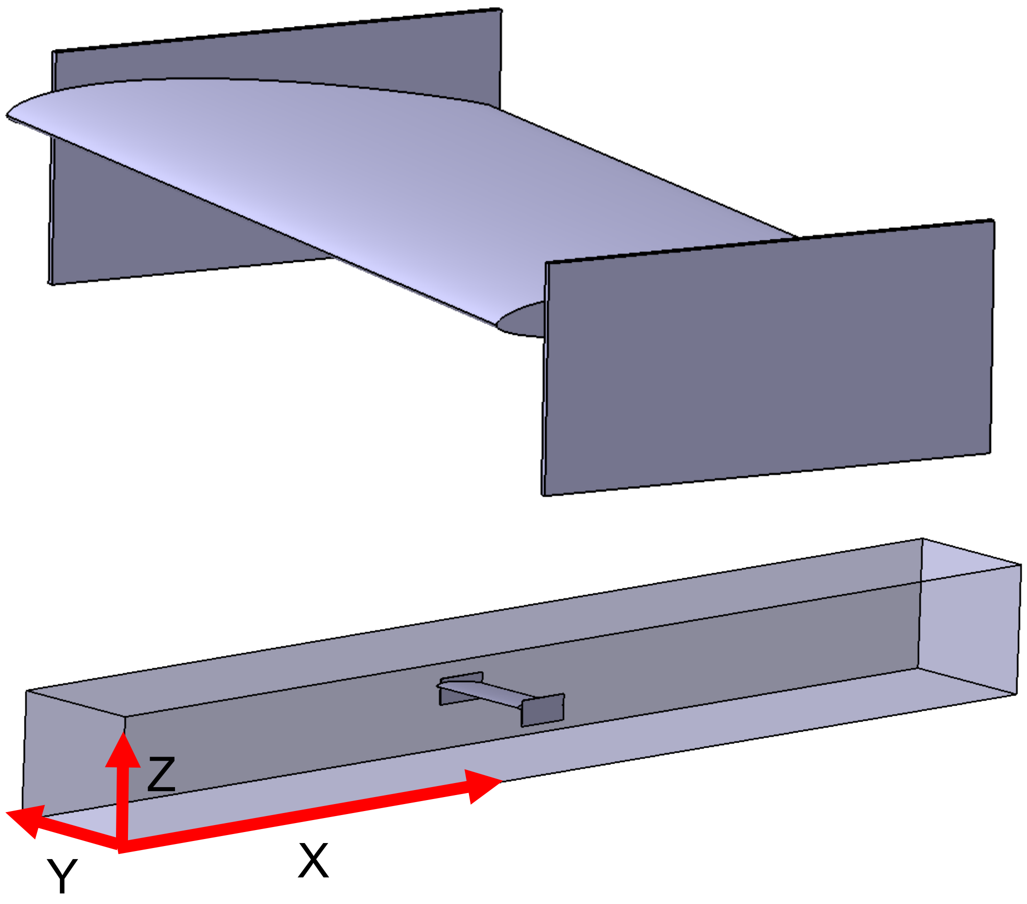
LEWICE3D:

Lower Horn Height (m): 0.066
Lower Horn Angle (deg): 229.03

Upper Horn Height (m): 0.048
Upper Horn Angle (deg): -175.60

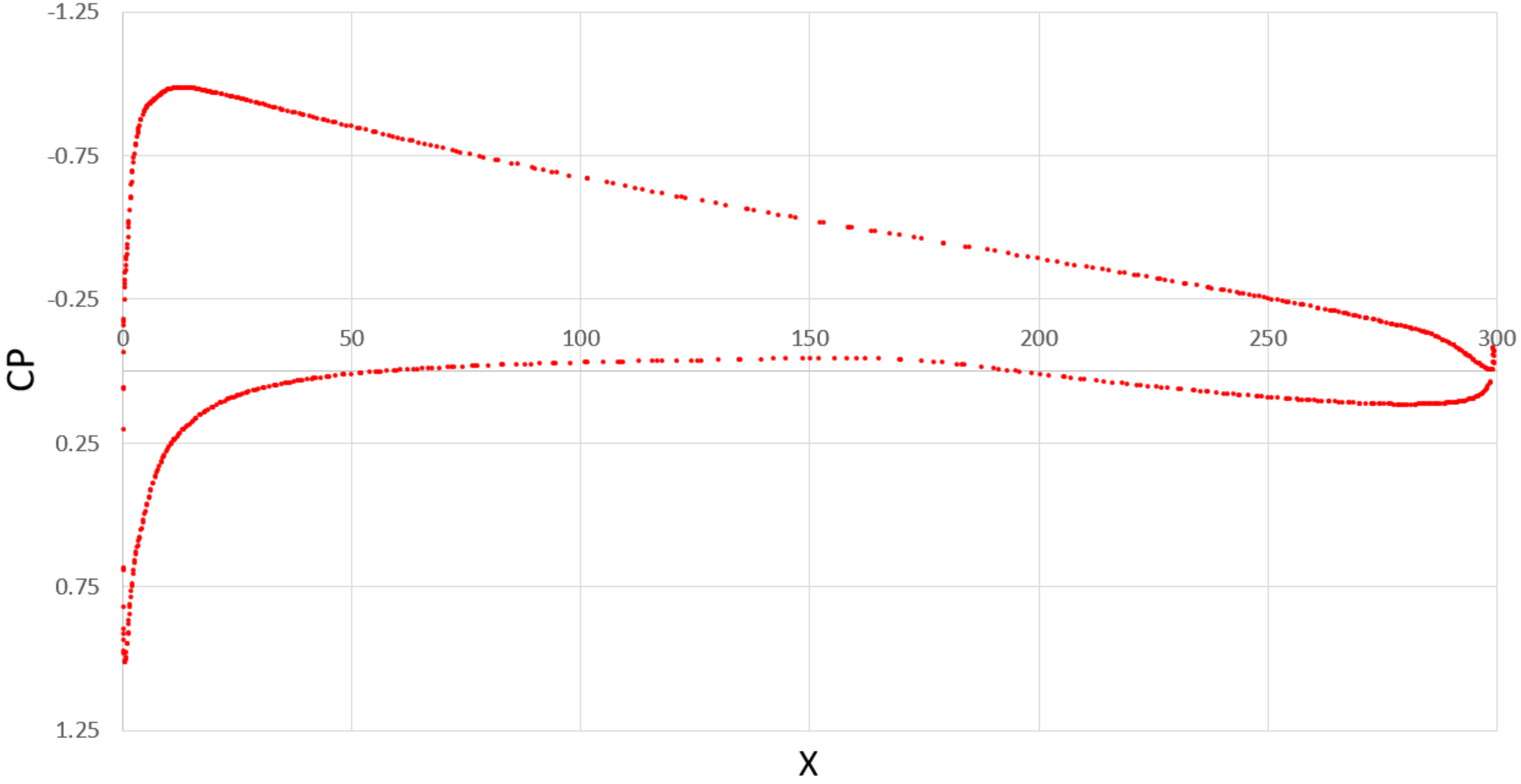
RG15 3D Boundary Conditions

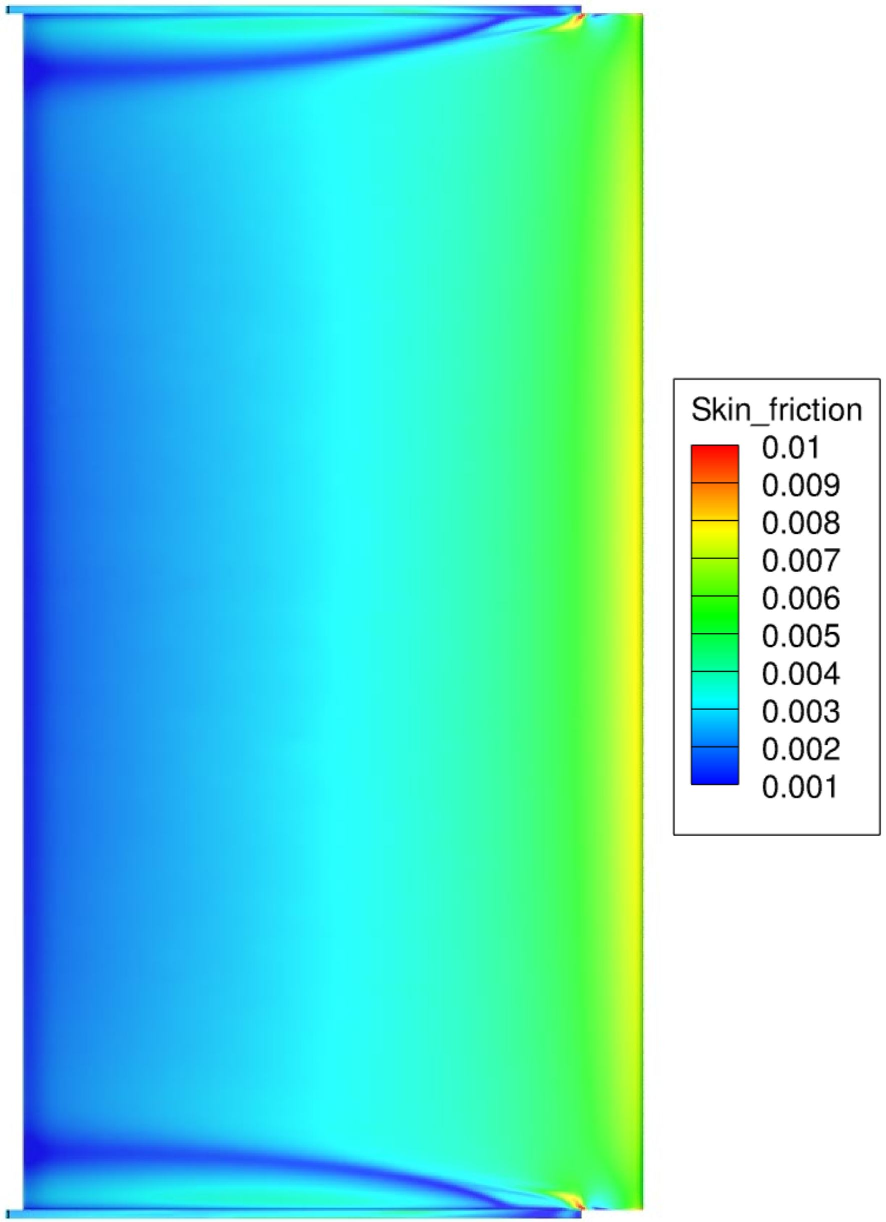
- Airfoil modeled in 3D with tunnel walls and airfoil endplates (committee provided dimensions)
- Tunnel Y and Z dimensions provided
- To match tunnel boundary layer thickness, X dimension swept from Airfoil Chord * 10 through 50 in 10 increments
  - Airfoil Chord * 40 chosen for best convergence
- Surface mesh created using internal meshing tools
- Volume mesh created using Boeing version of AFLR3



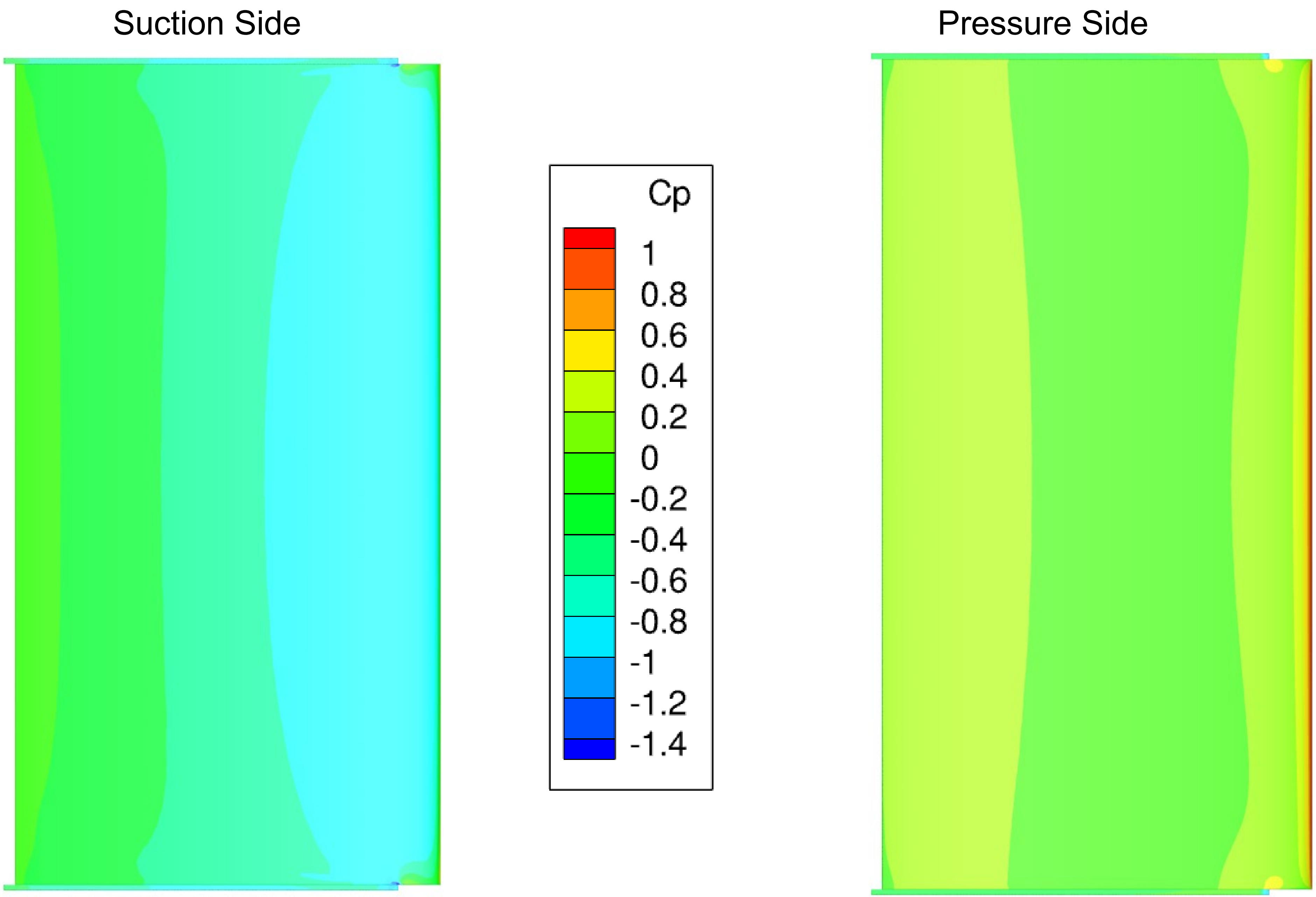
RG15

- Cut taken at center span of airfoil
- Attachment line: s = -1.26 mm



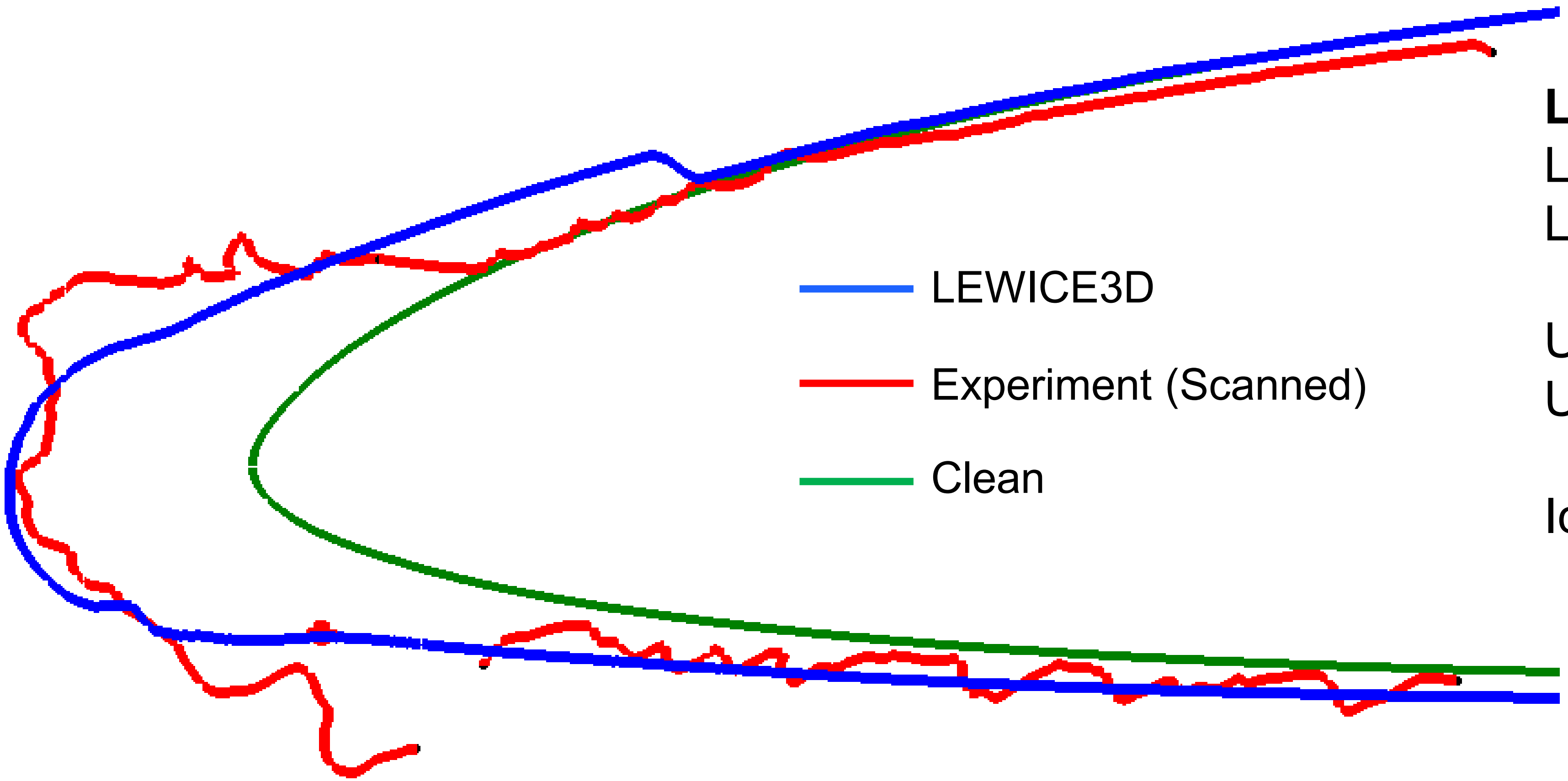


RG15



RG15 Case 3.1

- Cut taken at center span of airfoil



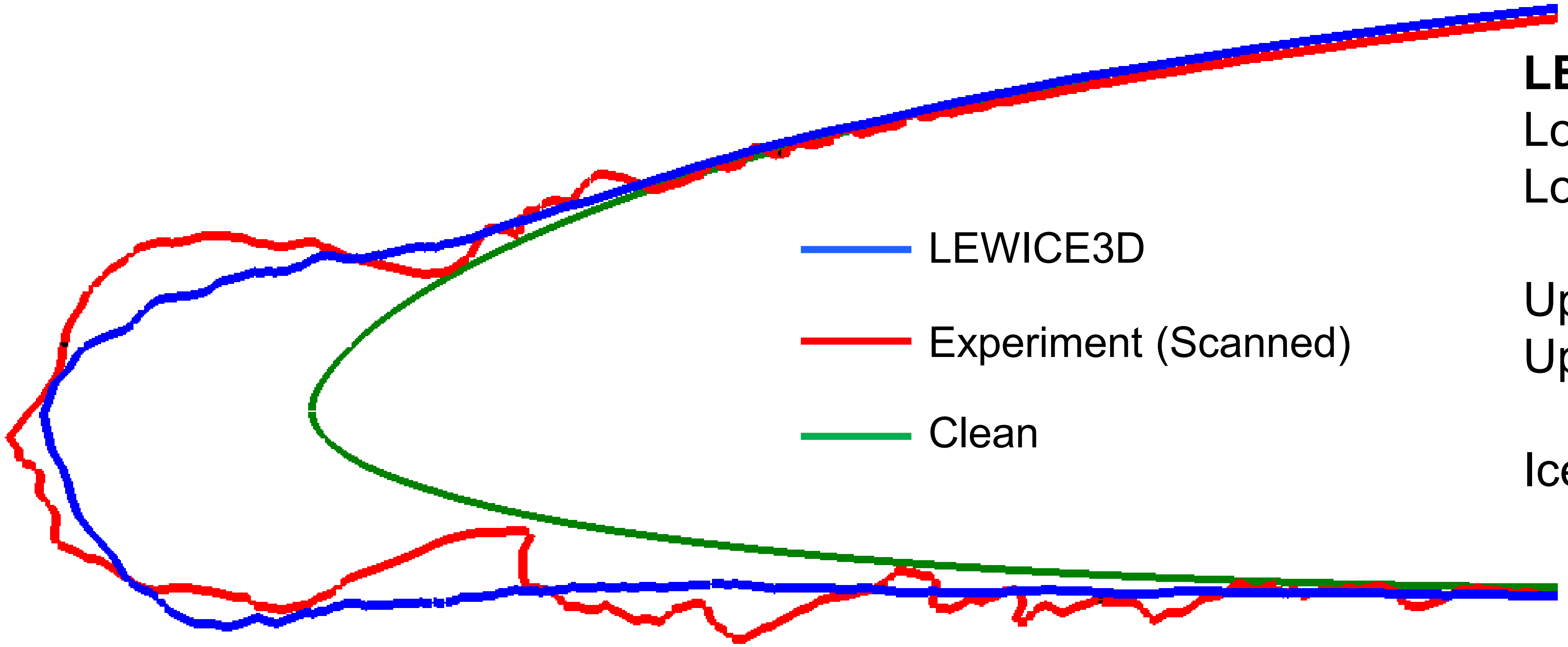
LEWICE3D:
Lower Horn Height (m): 0.009
Lower Horn Angle (deg): 192.96

Upper Horn Height (m): 0.0086
Upper Horn Angle (deg): 173.01

Ice Mass (kg/m): 0.135

RG15 Case 3.2

- Cut taken at center span of airfoil



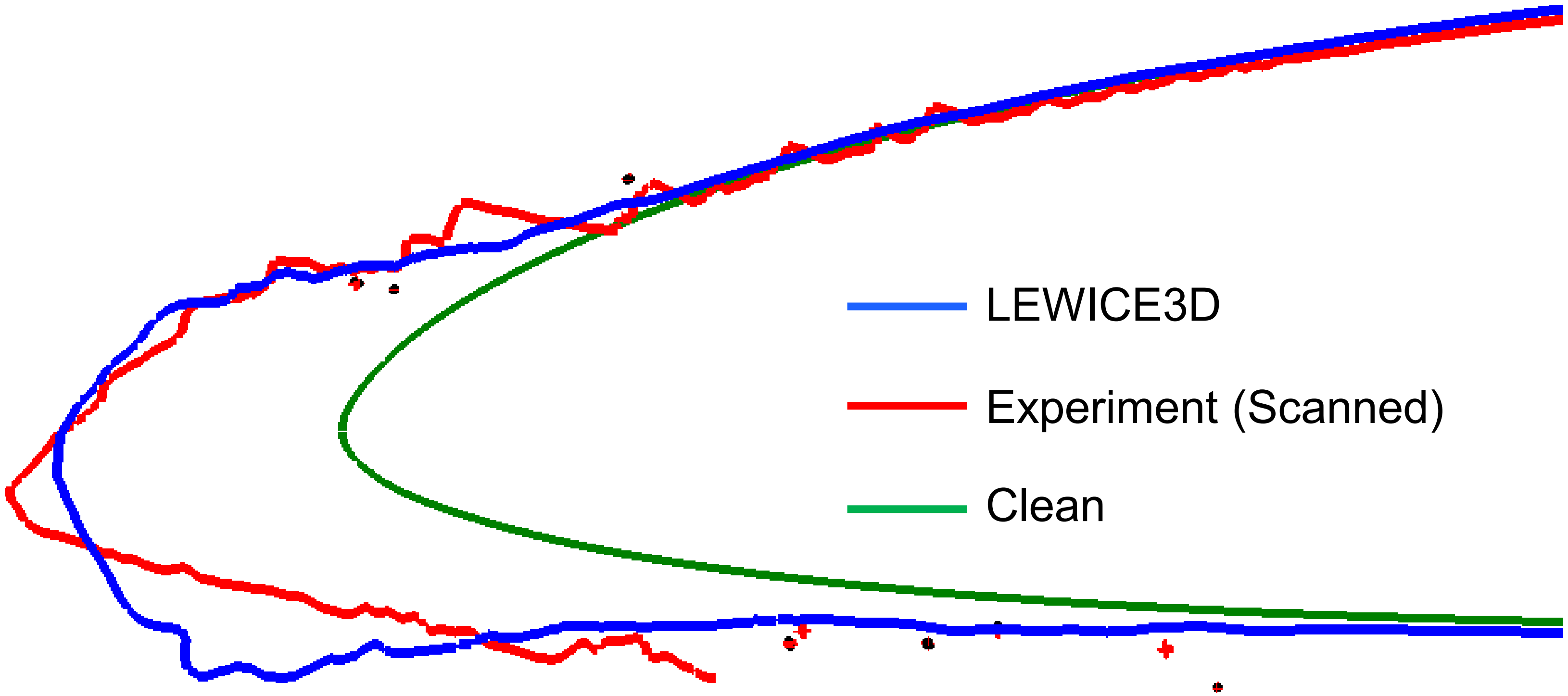
LEWICE3D:
Lower Horn Height (m): 0.012
Lower Horn Angle (deg): 180.27

Upper Horn Height (m): 0.011
Upper Horn Angle (deg): 173.23

Ice Mass (kg/m): 0.135

RG15 Case 3.3

- Cut taken at center span of airfoil



LEWICE3D:

Lower Horn Height (m): 0.011
Lower Horn Angle (deg): 188.01

Upper Horn Height (m): 0.010
Upper Horn Angle (deg): 173.18

Ice Mass (kg/m): 0.135

Summary

Midspan/Inboard CRM

- CFD aerodynamic calibration vs. experiment called for small AoA corrections to match the attachment line locations due to increased separation from CFD solutions.
- Ice mass agreement better for glaze cases, but too conservative for rime cases.
- Good ice thickness agreement and adequate horn location agreement (for aerodynamic impact purposes) for all cases.

RG15

- Good ice thickness agreement for all cases.
- Good horn location agreement for all cases.
- Location of ice horns suggests that the attachment line was close, although unable to compare CFD prediction due to lack of experimental data.

Questions?

Backup

Inboard – Slip vs No Slip

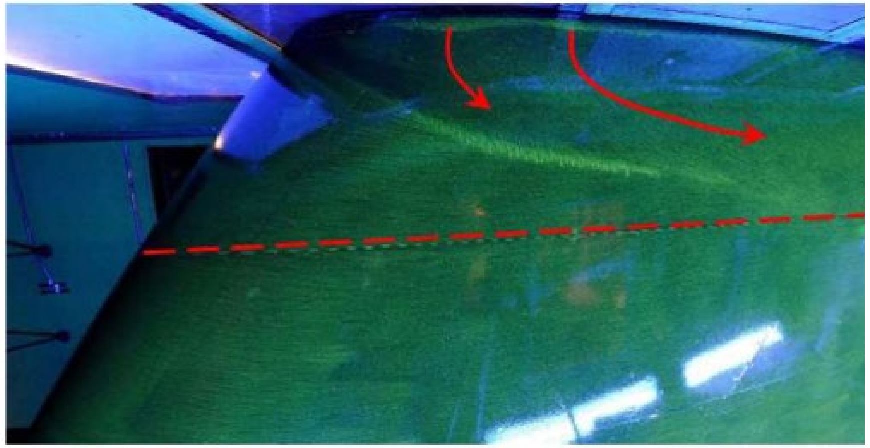
No Slip:

- No Slip (Viscous) Walls in the tunnel section and Slip Walls at the inlet and outlet extensions

Slip:

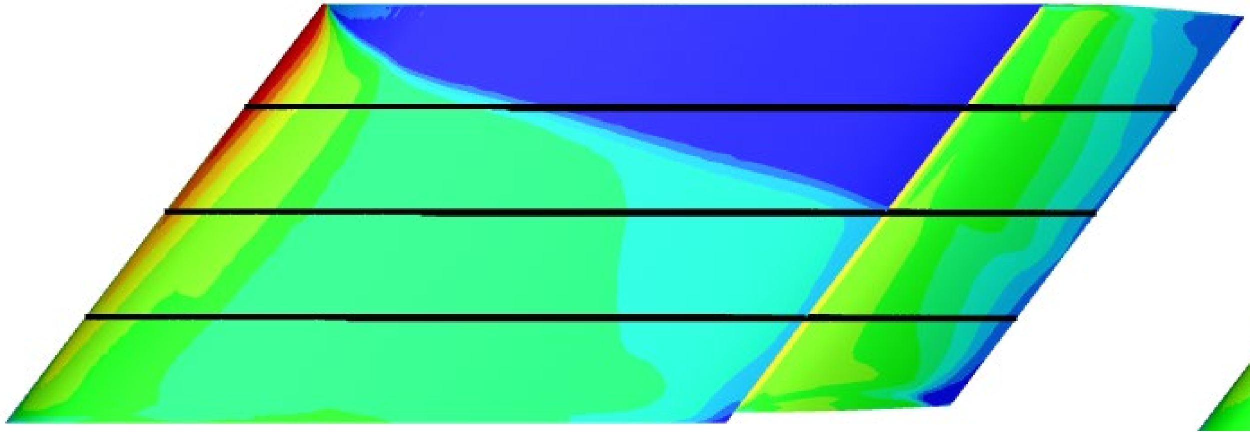
- Slip (Inviscid) Walls on each domain wall

Experiment:

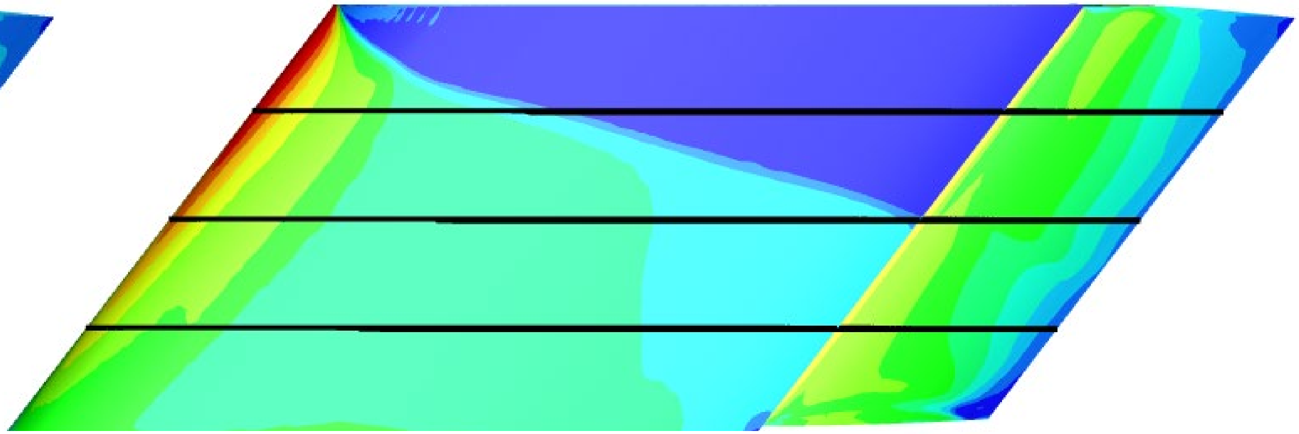


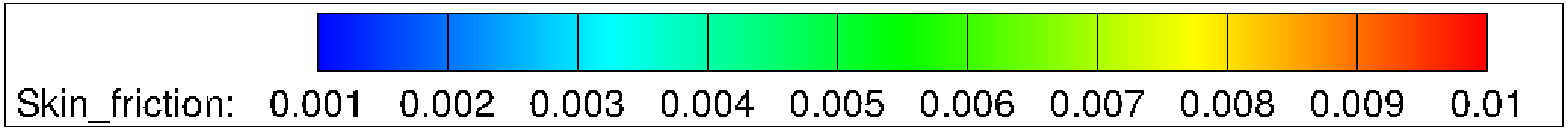
Y=54 in

No Slip

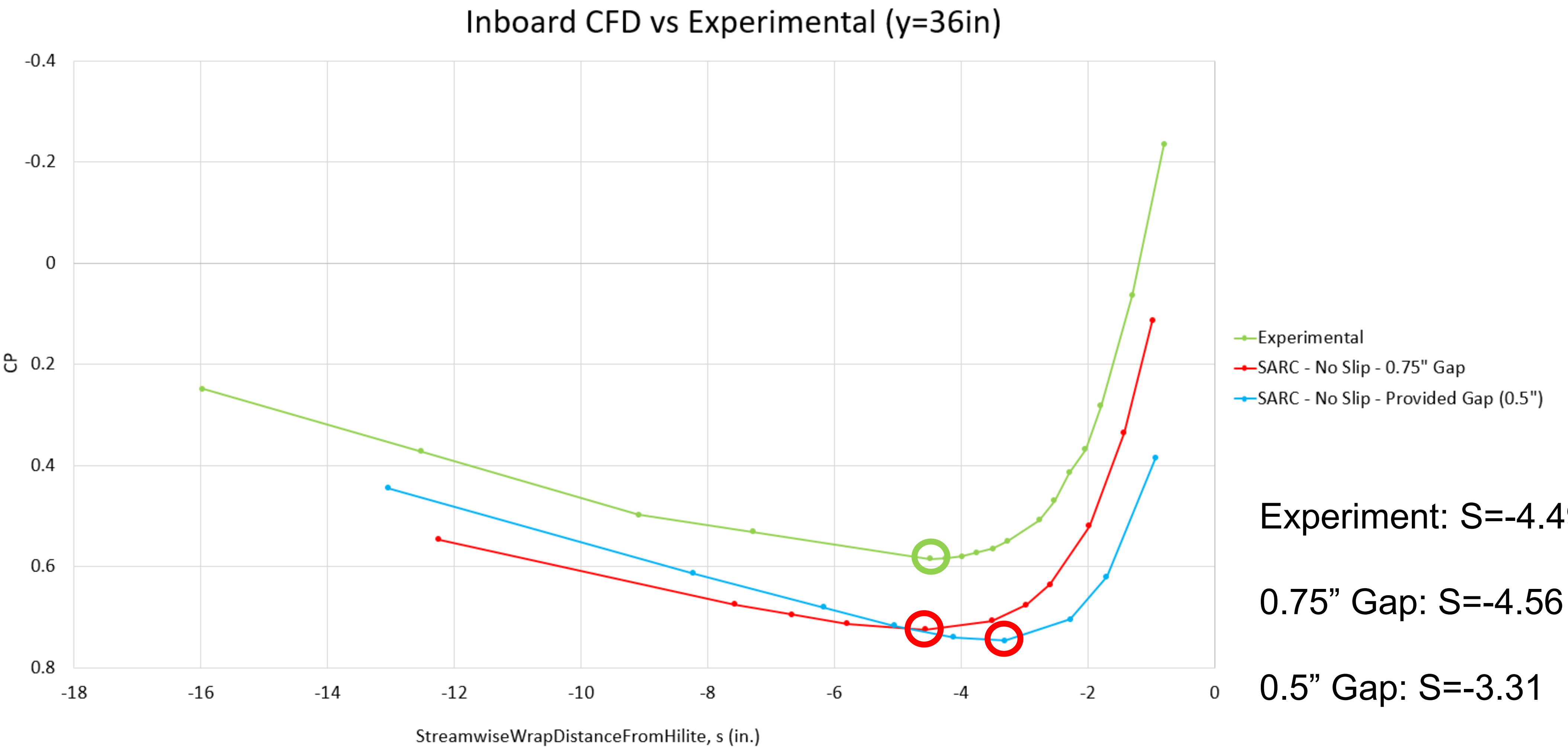


Slip





Inboard Gap vs No Gap – Attachment Line



Experiment: S=-4.49

0.75” Gap: S=-4.56

0.5” Gap: S=-3.31

Increased Gap not used